Materials & Mechanisms of Superconductivity

July, 29 – August, 3, 2012

Washington

M2S 2012 Technical Program

Monday, July 30, 2012

Plenary 1 - Theoretical Perspectives on Unconventional Superconductivity
S. Kivelson (Stanford University)
Regency, 9:15 AM to 10:00 AM
Session Chair: Rick Greene

Unconventional superconductivity occurs in materials that exhibit a host of other interesting behaviors that distinguish them from simple metals. Specifically, they often have: 1) complex phase diagrams with multiple "competing ordered phases" including "electronic liquid crystalline" phases and magnetism with ordered moments of order 1 Bohr magneton, 2) "bad metal" behavior at elevated temperatures in the "normal" state, 3) broad fluctuational "pseudo-gap" regimes in which some form (or multiple forms) of local order exists. Looking at the problem in a theoretical context, I will define the "weak" and "strong" coupling perspectives, and examine what of the phenomenology can and cannot be explained straightforwardly from each perspective. In all theoretically controlled cases, optimal superconductivity occurs as a crossover phenomenon, so it is, perhaps, unsurprising that high temperature superconductors exhibit "intermediate" coupling characteristics, where the interactions and the band-width are nearly equal. I will argue that "competing orders" are not a side-show, but are an integral part of the problem – better thought of as "intertwined orders," and will present empirical evidence of this using the cuprates as an example.

This work was carried out in collaboration with many others, but most especially with E.Fradkin, S.Raghu, D.J,. Scalapino, E.Berg, A.Kapitulnik, L.Li, H.Yao, S.White, D-H. Lee, G. Karakonstantakis, A.Chubukov, and J.Tranquada. It was supported, in part, by DOE grant #DE-FG02-06ER46287 and NSF grant #DMR-0531196.

Plenary 2 - Organizing Principles of Cuprate Superconductivity
L. Taillefer (University of Sherbrooke & Canadian Institute for Advanced Research)
Regency, 10:30 AM to 11:15 AM
Session Chair: Piers Coleman

An antiferromagnetic quantum critical point (QCP) is the central organizing principle of quasi-1D organic and electron-doped cuprate superconductors, as well as several iron-pnictide and heavy-fermion superconductors. It accounts for the superconducting T_c dome, the linear-T resistivity at the QCP, and the Fermi-surface reconstruction below the QCP. Linear-T scattering and pairing are found to decrease in parallel as the system moves away from the QCP [1, 2].

We propose that a similar scenario is also a fundamental organizing principle of hole-doped cuprate superconductors, where the QCP in this case is the doping at which stripe order ends [3]. We review the properties that are naturally explained within this scenario – including Fermi-surface reconstruction [4], the linear-T resistivity [5] scaling with T_c [6], and the nematic character of the pseudogap phase [7] – and those that are not.

[1] N. Doiron-Leyraud *et al*., *Phys. Rev. B* **80**, 214531 (2009).
[2] K. Jin *et al*., *Nature* **476**, 73 (2011).
[3] L. Taillefer, *Annu. Rev. Condens. Matter Phys.* **1**, 51 (2010).
[4] F. Laliberté *et al*., *Nature Commun.* **2**, 432 (2011).
[5] R. Daou *et al*., *Nature Phys.* **5**, 31 (2009).
[6] R. A. Cooper *et al*., *Science* **323**, 603 (2009).
[7] R. Daou *et al*., *Nature* **463**, 519 (2010).

Plenary 3 - Theory Overview for Iron-based Superconductors
P. Hirschfeld (University of Florida)
Regency, 11:15 AM to 12:00 PM
Session Chair: Piers Coleman

In contrast to cuprate superconductors, which manifest low-temperature properties with a common (dx2-y2) form, the gap structure in Fe-based superconductors appears to be far from universal[1]. I argue that, while aesthetically unappealing from a traditional theoretical perspective, such a situation affords a novel opportunity to develop a quantitative theory of unconventional superconductivity. I will review approaches to this problem which focus on pairing from spin and orbital fluctuations in the Fe d states, and discuss how well they allow us to understand current experiments on the superconducting state of various Fe-based systems. I will particularly focus on calculations which describe the evolution of superconductivity with doping or pressure, and emphasize recent work on the fascinating ``end-point” compounds AFe2Se2 and KFe2As2 of the 122 family.
"Gap symmetry and structure of Fe-based superconductors", P.J. Hirschfeld, M.M. Korshunov, and I.I. Mazin, Rep. Prog. Phys. 74, 124508 (2011).

Poster Session - Hotel Exhibit Hall, 1:30 PM to 3:30 PM

P1 - Copper Oxide, Heavy Fermion, Organic and Other Superconductors

P1-01 From rapid to slow quench: The trajectory from normal to superconducting state of cuprate superconductors in real time. - ***D. Mihailovic, P. Kusar, T. Mertelj, M. Lu-Dac, V. Kabanov, L. Stojchevska (Jozef Stefan Institute)***
The formation of the superconducting condensate after a laser-induced quench is studied in real time using femtosecond spectroscopy. The use of a 3-pulse sequence enables us to distinguish the dynamics of the order parameter ψ from the quasiparticle (QP) dynamics for the first time. Time-dependent Ginzburg-Landau (GL) theory and thermal diffusion processes are used to model the trajectory of the ψ(t). Under fast quench conditions where the quench time is comparable or shorter than the GL time, vortices according to the Kibble-Zurek scenario are predicted to appear on a time-scale of 3-5 ps, just before the crossover from non-thermal to thermal dynamics. Experimentally, we can tune the quench rate, allowing us to investigate the crossover from fast to slow quench and the appearance of vortices on femtosecond timescales.

P1-02 A magnetic analog of the isotope effect in cuprates - ***A. Keren (Technion-Israel Institute of Technology)***
A proper understanding of the mechanism for cuprate superconductivity can emerge only by comparing materials in which physical parameters vary one at a time. We performed transport, resonance, and scattering measurements on the $(Ca_xLa_{1-x})(Ba_{1.75-x}La_{0.25+x})Cu_3O_y$ high temperature superconductors, in which this can be done. We determined the superconducting, Néel, glass, and pseudogap critical temperatures, and the critical doping in which phase transitions occur. We clarify which measured physical parameter varies, and, equally important, which does not, with each chemical modification. This allows us to demonstrate that a single energy scale, set by the superexchange interaction J(x), controls all the critical temperatures of the system. J(x), in-turn, is determined by the in plane Cu-O-Cu buckling angle [1].
1) A. Kanigel et al. Phys Rev. Lett. **88,** 137003 (2002); R.Ofer *et al.* Phys. Rev. B **74**, 220508 (2006); Y. Lubashevsky et al. Phys. Rev. B **78**, 020505(R) (2008); A. Keren New Journal of Physics **11**, 065006 (2009); E. Amit et al. Phys. Rev. B 82, 172509 (2010).

P1-03 Evolution of the temperature dependence of the upper critical field in electron-doped Nd2-xCexCuO(4+delta) with a change of the doping level and the degree of disorder. - ***T. Charikova, N. Shelushinina, G. Harus, O. Petukhova, D. Petukhov (Institute of Metal Physics Ural Division RAS), A. Ivanov (Moscow Engineering Physics Institute)***
The resistively-determined upper critical field Hc2(T) of electron-doped superconductor Nd2-xCexCuO(4+delta) with x=0.14 - 0.18 and different degree of disorder has been investigated in the temperature range 0.4 – 40 K.
After the synthesis by pulsed laser deposition the series of Nd2-xCexCuO(4+delta)/SrTiO3 epitaxial films (x = 0.14; 0.15; 0.17; 0.18) with standard (001) orientation were subjected to heat treatment (annealing) under various conditions to obtain samples with various oxygen content delta (different degree of disorder).
The study of the dependences of the upper critical field slope on the degree of disorder makes it possible to distinguish experimentally between the superconducting states with d-wave paring or anisotropic s-wave paring. We have found that there are differences in the behavior of the dependences of the slope of the upper critical field on the disorder parameter for the optimally doped (x=0.15) and underdoped (x-0.14) and overdoped (x=0.17, 0.18) samples: this behavior is in keeping with d-

wave paring for x=0.15, is rather close to anisotropic s-wave type for x=0.18. We have found also that an evolution of the shape and curvature (positive or negative) of Hc2(T) with doping level and disordering takes place. The concave and convex forms of Hc2(T) can occur depending on the degree of disorder and such complex dependences were considered in the frame of two-band model.
This work was done within RAS Program (project N12-P-2-1018), with partial support by the RFBR (grant N12-02-00202).

P1-04 Two gaps with one energy scale in cuprate superconductors - *S. Feng, H. Zhao, Z. Huang (Department of Physics, Beijing Normal University)*

The interplay between the superconducting gap and normal-state pseudogap in cuprate superconductors [1] is studied based on the kinetic energy driven superconducting mechanism [2]. It is shown that the interaction between charge carriers and spins directly from the kinetic energy by exchanging spin excitations induces the normal-state pseudogap state in the particle-hole channel and superconducting-state in the particle-particle channel, therefore there is a coexistence of the superconducting gap and normal-state pseudogap in the whole superconducting dome [3]. This normal-state pseudogap is closely related to the quasiparticle coherent weight, and is a necessary ingredient for superconductivity in cuprate superconductors. In particular, both the normal-state pseudogap and superconducting gap are dominated by one energy scale, and they are the result of the strong electron correlation. Within this framework, the doping dependence of the specific-heat in cuprate superconductors is also discussed, and the results show that the humplike anomaly of the specific-heat near superconducting transition temperature in the underdoped regime can be attributed to the emergence of the normal-state pseudogap [3].

[1] S. Hufner et al., Rep. Prog. Phys. 71, 062501 (2008); M. R. Norman et al., Adv. Phys. 54, 715 (2005).
[2] Shiping Feng, Phys. Rev. B 68, 184501 (2003); Shiping Feng, Tianxing Ma, and Huaiming Guo, Physica C 436, 14 (2006).
[3] Shiping Feng, Huaisong Zhao, and Zheyu Huang, Phys. Rev. B, in the press [arXiv:1109.3973].

P1-06 Doping dependence of thermodynamic properties in cuprate superconductors - *H. Zhao, L. Kuang, S. Feng (Department of Physics, Beijing Normal University)*

Based on the t-J model, the doping and temperature dependence of the thermodynamic properties [1] in cuprate superconductors is studied. By considering the interplay between the superconducting gap and normal-state pseudogap within the framework of the kinetic energy driven superconducting mechanism [2], the main features of the doping and temperature dependence of the specific-heat, the condensation energy, and the upper critical field are well reproduced [3]. The specific-heat shows a humplike peak and remains as long tail in the underdoped regime, however, this long tail is absent in the heavily overdoped regime, and then the specific-heat shows a steplike BCS transition, while the condensation energy increases with increasing doping in the underdoped regime, and follows a pair gap type temperature dependence [3]. Moreover, in analogy to the domelike shape of the doping dependence of Tc, the maximal upper critical field occurs around the optimal doping, and then decreases in both underdoped and overdoped regimes [3]. The results also show that the striking behavior of the specific-heat humplike anomaly near Tc is closely related to the doping and temperature dependence of the normal-state pseudogap.

[1] H. H. Wen et al., Phys. Rev. Lett. 103, 067002 (2009); Y. Wang et al., Europhys. Lett. 81, 57007 (2008).
[2] S. Feng, Phys. Rev. B 68, 184501 (2003); S. Feng, T. Ma, and H. Guo, Physica C 436, 14 (2006); S. Feng, H. Zhao, and Z. Huang, Phys. Rev. B, in the press [arXiv:1109.3973].
[3] H. Zhao, L. Kuang, and S. Feng, arXiv: cond-mat/1111.6426.

P1-07 Temperature dependence of Fermi arc length in cuprate superconductors - *H. Zhao, L. Kuang, S. Feng (Department of Physics, Beijing Normal University)*

The pseudogap observed in the excitation spectrum as a suppression of spectral weight in the normal-state of cuprate superconductors is thought to be key to understanding the mechanism of superconductivity. Within the framework of the kinetic energy driven superconducting mechanism [1], we study the evolution of the Fermi arc with doping and temperature [2]. It is shown that the system in the underdoped regime is a nodal liquid, and the length of the Fermi arc increases with increasing temperatures, in qualitative agreement with the experimental observation on cuprate superconductors [3]. Our results also show that the unusual behavior of the quasiparticle dispersion and Fermi arc in cuprate superconductors is intriguingly related to the effect of the normal-state pseudogap.

[1] S. Feng, Phys. Rev. B 68, 184501 (2003); S. Feng, T. Ma, and H. Guo, Physica C 436, 14 (2006); S. Feng, H. Zhao, and Z. Huang, Phys. Rev. B, in the press [arXiv:1109.3973].
[2] Huaisong Zhao, Lulin Kuang, and Shiping Feng, unpublished.
[3] A. Kanigel et al., Nature Phys. 2, 447 (2006); U. Chatterjee et al., Nature Phys. 6, 99 (2010)

P1-08 Dynamical spin response in cuprate superconductors - *Z. Huang, S. Feng (Department of Physics, Beijing Normal University), J. Qin (Department of Physics, University of Science and Technology Beijing)*

Within the framework of the kinetic energy driven superconducting mechanism [1], the dynamical spin response of cuprate superconductors [2] is studied. By calculating the dynamical spin structure factor, some main features of inelastic neutron scattering and nuclear magnetic resonance experiments [2] are reproduced. The incommensurate magnetic scattering peaks appear at both low and high energies, then they converge to the commensurate magnetic resonance peak at intermediate energy [3]. This commensurate magnetic resonance energy increases with increasing doping in the underdoped regime, and reaches a maximum in the optimal doping, then decreases in the overdoped regime. In particular, the inverse of the spin-lattice relaxation time divided by temperature increases with increasing temperature at low temperature followed by a peak developed around the superconducting transition temperature, and then decrease with increasing temperature in the normal-state pseudogap state [3], in qualitative agreement with the experimental observation on cuprate superconductors [2].

[1] S. Feng, Phys. Rev. B 68, 184501 (2003); S. Feng, T. Ma, and H. Guo, Physica C 436, 14 (2006); Shiping Feng, Huaisong Zhao, and Zheyu Huang, Phys. Rev. B, in the press [arXiv:1109.3973].
[2] See, e.g., R. E. Walstedt, The NMR Probe of High-Tc Materials (Springer, Berlin Heidelberg, 2008).
[3] Zheyu Huang, Jihong Qin, and Shiping Feng, unpublished.

P1-09 Effect of normal-state pseudogap on the Fermi surface and quasiparticle dispersion of electron-doped cuprate superconductors - ***L. Kuang, H. Zhao (Department of Physics, Beijing Normal University), S. Feng (Department of Physics, Beijing Normal University)***

The electron-doped cuprate superconductors provides an important additional example of the result of introducing charge into the copper oxide planes, where the normal-state pseudogap is also observed experimentally [1]. A detailed study will give insight into how various phenomena depend on the normal-state pseudogap. Based on the charge-spin separation fermion-spin theory [2], we study the doping and temperature dependence of the electronic structure of the electron-doped cuprate superconductors in the normal-state state [3]. It is shown that the interaction between charge carriers and spins directly from the kinetic energy by exchanging spin excitations induces the normal-state pseudogap state in the particle-hole channel. The spectral weight in the excitation spectrum is suppressed due to the existence of normal-state pseudogap. Moreover, the quasiparticles have a unusual dispersion around the antinodal point with anomalously small changes of electron energy as a function of momentum. The striking behavior of the doping dependence of the Fermi surface is also discussed.
[1] H. Matsui et al., Phys. Rev. B75, 224514 (2007); M. Ikeda et al., Phys. Rev. B80, 014510 (2009).
[2] S. Feng et al., J. Phys.: Condens. Matter 16, 343 (2004); S. Feng et al., Phys. Rev. B 49, 2368 (1994).
[3] Lulin Kuang, Huaisong Zhao, and Shiping Feng, unpublished.

P1-10 Enhancement of critical current density of liquid infiltration processed Y-Ba-Cu-O bulk superconductors using milled Y2BaCuO5 powder - ***A. Mahmood, Y. Alzeghayer (King Saud University (KSU)***

The size effects of a precursor Y_2BaCuO_5 (Y211) powder on the microstructure and critical current density (J_c) of liquid infiltration growth (LIG)-processed $YBa_2Cu_3O_{7-y}$ (Y123) bulk superconductors were investigated in terms of milling time (*t*). Y211 powders were attrition-milled for 0-10 h in 2 h increments at a fixed rotation speed of 400 rpm. Y211 pre-forms were made by pelletizing the milled Y211 powders followed by subsequent sintering, after which an LIG process with top seeding was applied to the Y211/$Ba_3Cu_5O_8$ (Y035) pre-forms. Spherical pores were observed in all LIG-processed Y123 samples, and the pore density gradually decreased as *t* increased from 0 h to 8 h. In addition to the reduced pore density, the Y211 particle size in the final Y123 products also decreased with increasing*t*. As *t* increased further to 10 h, unexpected Y211 coarsening and large pore evolutions were observed. The magnetic susceptibility-temperature curves showed that the onset superconducting transition temperature ($T_{c,\ onset}$) of all samples was the same (91.5 K), but the transition width became greater as *t* increased. The J_c of the Y123 bulk superconductors fabricated in this study was observed to correlate well with *t* of the Y211 precursor powder. The maximum J_c of 1.0×10^5 A cm^{-2} (at 77 K, 0 T) was achieved at *t* = 8 h, which is attributed to the reduction in pore density and Y211 particle size. The prolonged milling time of *t* = 10 h decreased the J_c of the LIG-processed Y123 superconductor owing to the evolution of large pores and exaggerated Y211 growth.
The authors extend to thank their appreciation to the Deanship of Scientific Research at King Saud University for funding the work through the research group project No RGP-VPP-106.

P1-11 The Critical Temperature and the Anisotropy in k-space of Cuprate Superconductors Calculated with an Array of Small Josephson Junctions - ***E. de Mello (Instituto de Física, Universidade Federal Fluminense, Niteroi, RJ 24210-340, Brazil)***

In this work we show that it is possible to find an unified explanation to different properties of cuprate superconductors.
The dichotomy of k-space and the Fermi arcs measured by ARPES[1], the varying local density of states measured by many STM experiments[2], the two energy scales measured by ARPES[1], Tunneling spectroscopy[3] and Raman scattering[4], just to cite the most well known ones. Our starting point is an electronic phase separation (EPS) forming small granular regions (grains) where isolated superconducting amplitudes may be formed. The origin of the EPS may be due to the lower free energy of the low density anti-ferromagnetic domains[5]. On such density disordered system we perform self-consistent calculations based on the Bogoliubov-deGennes approach that yields local varying d-wave amplitudes. These local d-wave gaps in isolated regions form an structure similar to a granular superconductor where intragrain superconductivity may occur without long range order. Consequently, the system is modeled by an array of multiple Josephson junctions[5]. We also use the idea that in a typical d-wave superconductors junction the direction dependence of the tunnel matrix elements that describe the barrier is relevant[6]. In the case of cuprates, all the domains or islands have d-wave pair wave functions with the same direction with respect to the a and b crystal axis. Phase fluctuation above Tc generates the gapless region that increases with temperatures at the nodal direction where the d-wave superconducting gap is smaller and accounts for the formation of the Fermi arcs and the dichotomy in k-space. Then the two-energy of cuprates are associated withthe superconducting gap amplitude and the Josephson coupling among the grains.
[1]-Lee W.S. et al, Nature (London) 450, 81 (2007).
[2]-McElroy K., et al, Phys. Rev. Lett. 94, 197005 (2005).
[3]-V.M. Krasnov et al, Phys. Rev. Lett. 86, 2657 (2001).
[4]-W. Guyard et al, Phys.Rev. Lett. 101, 097003 (2008).
[5]-E.V.L. de Mello, and Raphael B. Kasal, Physica C472, 60 (2012).
[6]-C. Bruder et al, Phys. Rev. {\bfB51 R12904 (1995).

P1-12 Spin fluctuations and Cooper pairing in electron-doped cuprate superconductors - ***K. Jin, N. Butch, K. Kirshenbaum, J. Paglione, R. Greene (Center for Nanophysics & Advanced Materials and Department of Physics,University of Maryland, College Park, MD 20742, USA)***

Although it is generally accepted that superconductivity is unconventional in the high-T_c cuprates, the relative importance of phenomena such as spin and charge (strip) order, superconductivity fluctuations, proximity to Mott insulator, a pseudogap phase and quantum criticality are still a matter of debate.

In electron-doped cuprates, the absence of "anomalous" pseudogap phase in the underdoped region of the phase diagram and weaker electron correlations suggest that Mott physics and other unidentified competing orders are less relevant and that antiferromagnetic (AFM) spin fluctuations are the dominant feature.

In this poster, we will show results of low temperature magnetotransport experiments in optimal to overdoped (non-superconducting) thin films of the electron-doped cuprate $La_{2-x}Ce_xCuO_4$ (LCCO). We find that a linear-in-T scattering rate is correlated with the superconductivity (T_c). Our results show that an envelope of such scattering surrounds the superconducting phase, surviving to 20 mK (the limit of our experiments) when superconductivity is suppressed by magnetic fields [1]. Comparison with similar behavior found in organic superconductors [2] strongly suggests that the linear-in-T resistivity in the electron-doped cuprates is caused by spin-fluctuation scattering. Because linear-in-T scattering has also been linked to T_c in some hole-doped cuprates [2], our results suggest a fundamental connection between AFM spin fluctuations and the pairing mechanism of high temperature superconductivity in all cuprates. In addition, we will show you how quantum criticality plays a significant role in shaping the anomalous properties of the electron-doped cuprate phase diagram [3].

This work was supported by the NSF.[1] K. Jin, N.P. Butch, K. Kirshenbaum, J. Paglione, and R.L. Greene, Nature 476, 73 (2011).[2] L. Taillefer, Annu. Rev. Cond. Matter Phys. 1, 51 (2010).[3] N.P. Butch, K. Jin, K. Kirshenbaum, R.L. Greene, and J. Paglione, arXiv: 1112.3950.

P1-13 Three Crossovers Associated With Pseudogap Phenomenology In A Gauge Approach To Cuprates - ***P. Marchetti (Dipartimento di Fisica, INFN, I-35131 Padova, Italy), L. Yu (Beijing National Laboratory for Condensed Matter Physics and Institute of Physics, Chinese Academy of Sciences,100190 Beijing, China and Institute of Theoretical Physics, Chinese Academy of Sciences, 100190 Beijing, China), F. Ye (Department of Physics, South University of Science and Technology of China, 518055 Shenzhen, China), M. Gambaccini (Dipartimento di Fisica, Università di Padova, Italy), Z. Su (Institute of Theoretical Physics, Chinese Academy of Sciences, 100190 Beijing, China)***

Most theories of pseudogap (PG) in cuprates fit in 2 schemes: in the doping-T phase-diagram either (1) the PG crossover crosses the superconducting (SC) dome, or (2) it joins Tc at low T in the overdoped side. Typically (1) is associated with competing orders while (2) is related to the phase fluctuation of the SC order parameter. We show that in our gauge approach to cuprates [1,2] in terms of the t-t'-J model [3] both crossovers appear. The hole is viewed as a bound-state of a spin carrier (spinon) and a charge carrier (holon), whose attraction is mediated by a gauge field emerging from the no-double occupation constraint. The crossover (1), T*, is due to a change in the holon dispersion, leading to a complete suppression of the spectral weight for holes in the antinodal region and to a broad peak in the specific heat coefficient [4]. Below T* the short-range antiferromagnetism becomes stronger and its interplay with the thermal diffusion induced by the gauge field produces the metal-insulator crossover [1]. The crossover (2) is related to the phase fluctuations of a incoherent holon-pair (not physical hole-pair) field, with charge attraction coming from spin vortices with core on holons in different Neel sublattices. Enhanced by the gauge field, the scattering of that phase against holons produces ARPES Fermi-arc phenomenology [3]. The reduction of the density of states[3], similar to the proposal in [5], induces a deviation from the T-linear resistivity. In addition there is a third crossover, also dome-shaped like Tc, where incoherent spinon RVB pairs appear as a consequence of gauge attraction acting on holon pairs, producing a gas of incoherent preformed physical hole pairs supporting magnetic vortices and a related Nernst signal agreeing with [6].

[1] P.A. Marchetti, Z.B. Su, L. Yu, J P Cond. Mat. 19 (2007) 125209 [2] P.A. Marchetti, F. Ye, Z.B. Su, L. Yu, EPL 93 (2011) 57008; PR B84 (2011) 214525 [3] P.A. Marchetti, M. Gambaccini, in prep.; F. Bovo, Thesis, Padua 2011. [4] P.A. Marchetti, A. Ambrosetti, PR B 78 (2008) 085119 [5] J. Hwang, PR B83 (2011) 014507 [6] Y. Wang, L. Li, N. P. Ong, PR B 73 (2006) 024510.

P1-14 Electron-like Fermi surface and in-plane anisotropy arising from the chain state in YBCO superconductors - ***T. Das (Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM)***

The evolution of the electronic states in the pseudogap phase of cuprates remains elusive. Important clues to this state have been achieved in 'YBCO' families through numerous bulk measurements: (1) an electron-like Fermi surface emerges in this phase, (2) the observables are associated with large in-plane anisotropy. Numerous proposals based on various broken symmetry origin of pseudogap, stipulating multiform Fermi pockets, essentially lead to contradiction when compared with the well-established results of extensive spectroscopic fingerprints. In this study, we introduce a fundamentally new perspective – we show that the emergence of the electron-like FS and associated in-plane anisotropy in the pseudogap state can be rationalized by realistically considering the contributions of the much ignored metallic CuO chain bands in YBCO. We present a tri-layer quantum lattice model for the CuO_2 bilayers and uniaxial CuO chain layer and computes the Hall-coefficient, Nernst effects as well as inelastic neutron spectra to quantify the observed results. We show that the chain state is electron-like which explains the negative Hall coefficient. Furthermore, by assuming a simple commensurate order in the common CuO_2 bilayers, without the presence of any complicated stripe or nematic order, we can quantify the enhanced Nernst effect. Finally, we show that the Neutron spectra and Nernst signal acquire in-plane anisotropy due to the uniaxial character of the chain state. Our results suggest that the seemingly different observables in YBCO family arise from the existence of an additional electronic structure, while the underlying pseudogap ground state in the common CuO_2 layer is generic to hole-doped cuprates.

P1-15 Effect of inter-layer pair hopping and single-electron hopping on superconductivity in multi-layered high-Tc cuprates - *K. Nishiguchi (Department of Physics, The University of Tokyo), R. Arita (Department of Applied Physics, The University of Tokyo), K. Kuroki (Department of Engineering Science, The University of Electro-Communications), T. Oka, H. Aoki (Department of Physics, The University of Tokyo)*

The high-Tc cuprates still harbor important open questions. Specifically, the multi-layered cuprates, as exemplified by the homologous series $HgBa_2Ca_{n-1}Cu_nO_{2+2n+\delta}$, have the highest Tc to date, but have not been fully understood, although there have been studies on phenomenological interlayer pair hopping[1] or on an effect of interlayer single-electron hopping[2]. One of the key questions is why Tc increases as we go from n =1 to n =3 (for which Tc = 135 K).

We have studied the superconductivity in multi-layered cuprates by first solving the Eliashberg equation for the multi-orbital Hubbard model with the random-phase approximation (RPA) and with the fluctuation-exchange approximation (FLEX). The hopping parameters are obtained with a downfolding from the first-principles electronic structure obtained with the density functional theory for the Hg-series (n = 1, 2, 3). The result indicates that the n-dependence of Tc cannot be understood simply by the electronic band structure.

We then explore possible factors that are not included in the simple Hubbard model but can affect Tc in multi-layered cuprates. Hence we have considered inter-layer single-electron hopping and inter-layer Cooper-pair hopping. First, inter-layer single-electron hoppings suppress the superconductivity due to the degraded nesting and the charge imbalance between layers. Inter-layer pair hoppings, on the other hand, exert two effects, i.e., suppress pairing due to the increase of self-energy and enhance pairing due to the increase of the pairing interaction. We have shown that the net effect depends on specific forms of the inter-layer pair hopping, where the d-wave pairing can be enhanced in a certain parameter regime.

[1] S. Chakravarty et al, Nature **428**, 53 (2004); Science **261**, 337 (1993).
[2] N. Bulut and D. J. Scalapino, Phys. Rev. B **45**, 5577 (1992).

P1-16 Low-frequency response of superconducting fluctuations in La2-xSrxCuO4 - *M. Grbic (Department of Physics, Faculty of Science, University of Zagreb, P.O. Box 331, HR-10002 Zagreb), D. Peligrad (2. Physikalisches Institut, Universität Stuttgart, 70550 Stuttgart), M. Požek, A. Dulcic (Department of Physics, Faculty of Science, University of Zagreb, P.O. Box 331, HR-10002 Zagreb), T. Sasagawa (Materials and Structures Laboratory, Tokyo Institute of Technology, Kanagawa 226-8503), M. Greven (School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455), N. Barišic (Service de Physique de l'Etat Condensé, CEA-DSM-IRAMIS, F 91198 Gif-sur-Yvette)*

The superconducting fluctuation regime in the pseudogap phase of cuprate superconductors has been under extensive investigation for many years. By measuring microwave conductivity (~ 15 GHz), we have shown that the fluctuation regime of compounds ($HgBa_2CuO_{4+\delta}$ and $YBa_2Cu_3O_{6+\delta}$) with high maximal transition temperatures at optimal doping ($T_c^{max} \approx$ 93-97 K) is confined to a narrow temperature range, extending just 10-15 K above T_c [1-2]. Recently, THz time-domain spectroscopy (0.2-1.5 THz) on thin films of the low-T_c^{max} compound $La_{2-x}Sr_xCuO_4$ ($T_c^{max} \approx$ 40 K) [3] indicated the presence of fast superconducting fluctuations in a similarly narrow temperature range (10-15 K above T_c). In order to clarify whether the observation of a narrow fluctuation regime is a universal property of the cuprates and not limited to specific compounds or probes, we have studied the microwave conductivity of high-quality, single crystals of $La_{2-x}Sr_xCuO_4$ and determined the ac conductivity parallel (σ_{ab}) and perpendicular (σ_c) to the CuO_2 planes. By applying an external magnetic field, we were able to extract the contribution due to superconducting fluctuations. Consistent with the aforementioned studies, the fluctuation regime in bulk single crystals of this low-T_c^{max} compound is narrow and tracks the superconducting dome.

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P1-17 Distinct magnetic states in the underdoped and overdoped regimes of La_{2-x}Sr_{x}Cu_{1-y}Fe_{y}O_{4} studied by muon spin relaxation - *K. Suzuki (Department of Applied Physics, Graduate School of Engineering, Tohoku University), R. Risdiana, Y. Ishii, T. Suzuki, I. Watanabe (Advanced Meson Science Laboratory, Nishina Center for Accelerator-Based Science, The Institute of Physical and Chemical Research (RIKEN)), Y. Koike (Department of Applied Physics, Graduate School of Engineering, Tohoku University), T. Adachi, Y. Tanabe, H. Sato (Department of Applied Physics, Graduate School of Engineering, Tohoku University)*

Recent neutron-scattering experimentsin $La_{2-x}Sr_xCu_{1-y}Fe_yO_4$ (LSCFO) have revealed that the 1%substitution of Fe forCu induces an incommensurate static magnetic order in a wide range of hole concentrationper Cu, p, where superconductivityappears and that the nature of the induced magnetic order changes at p ~ 1/8.[1,2] Therefore, in order to clarifythe detailed magnetic state, we have investigated the low-frequency magneticfluctuation of LSCFO with x = 0.06 - 0.235 and y = 0.005, 0.01 by zero-field muon-spin-relaxationmeasurements.[3]

It has been found that the magnetic transition temperature, T_N, is enhanced by the Fesubstitution in a wide range of p and that T_N appear seven in the over doped regime. The T_N of LSCFO with y = 0.01 exhibits a local maximum at p ~ 0.115. It is surprising that the decrease in T_N with increasing p is weak for p > 0.115, resulting in larger values of T_N than those for p < 0.115. This does not agree with the general understandingthat the magnetic correlation tends to markedly weaken with increasing p in the overdoped regime. Therefore, the character ofthe magnetic correlation induced by the Fe substitution at p > 0.115 is distinct from that at p ≦.

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P1-19 Intrinsic universal doping-dependence of the in-plane dc conductivity in the underdoped high-temperature cuprate superconductor - *T. Honma (Department of Physics, Asahikawa Medical University), P. Hor (Department of Physics and Texas Center for Superconductivity, University of Houston)*

We have studied the in-plane dc conductivity (s_{ab}) of the typical high-temperature cuprate superconductors (HTCSs), such as $La_{2-x}Sr_xCuO_4$ (SrD-La214), $YBa_2Cu_3O_{6+d}$ (OD-Y123) and $Bi_2Sr_2CaCu_2O_{8+d}$ (OD-Bi2212), as a function of doped-hole concentration (P_{pl}) based on our established intrinsic hole-scale [1,2]. We find that when the reduced conductivity (s_{ab}/s_{ab}^{opt}), where s_{ab} is normalized to the conductivity (s_{ab}^{opt}) at the optimally doped concentration (P_{pl}^{opt}), is plotted as a function of the unified doped-hole concentration (P_{pl}/P_{pl}^{opt}), s_{ab}/s_{ab}^{opt} collapses on a single universal curve in the range of $0.4 < P_{pl}/P_{pl}^{opt} < 1.1$ [3]. For a conventional metal, the dc conductivity can be represented as a product of the square Fermi velocity (v_F^2), relaxation time (t) and the density of states at the Fermi level ($N(E_F)$). Based on this simple picture, we find that the universal doping dependence of s_{ab}/s_{ab}^{opt} is also intrinsically consistent with the doping dependence of the change in the squared nodal Fermi velocity observed in OD-Bi2212 by high resolution laser ARPES [4,5]. This result suggests that the doping dependence of the s_{ab} in the underdoped HTCS is dictated by the squared nodal Fermi velocity and the product $t \times N(E_F)$ is independent of the doping. Furthermore, since the dc conductivity was measured at above superconducting critical temperature (T_c) and the ARPES was measured at below T_c, our result suggests that the nodal carriers at the vicinity of E_F experience the same underlying electronic structure going from the normal state to the superconducting state.

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P1-20 Pressure Dependence on Nernst effect for High-Tc Superconductor - *T. Fujii, A. Asamitsu (Cryogenic Research Center, the University of Tokyo), O. Cry-Choiniere, N. Doiron-Leyraud, L. Taillefer (Depertment of Physics, University of Sherbrooke)*

Since the discovery of Anomalous Nernst effect in high-Tc cuprates, it has been discussed as a clue to the mechanism of superconductivity. Up to now, there are two explanations for the enhancement of Nernst signal. One is that the large Nernst signal is attributed to the movement of vortices which survives far above Tc [1]. The other is that Nernst signal is enhanced by stripe order [2]. The former supports the scenario that the superconducting gap opens far above Tc, although the long-range phase coherence is destroyed by vortex excitation. While the latter implies that the superconductivity occurs near the quantum critical point where the competing orders, such as stripe order and/or charge order, cross in the phase diagram. Here, we controlled the strength (stability) of the stripe order, and measured the Nernst effect to investigate the effects of the charge (stripe) ordered state on Nernst signal. It is well known that Nd-doping in LSCO enhances the strength of stripe order [3]. And also, hydrostatic pressure is known to destroy the stripe order [4]. In the static pressure, we found the enhancement of the Nernst signal below superconducting fluctuation temperature Tfl~60K. This indicates that the suppression of the stripe strength by applying pressure lead to the enhancement of the superconducting fluctuation. On the other hand, upturn of Nernst signal around 150K could consider to the temperature where fluctuation of the stripe order develops.

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P1-21 Intrinsic Floquet states in High-Tc Cuprate Superconductors generate entangled electron dynamics - *W. Winkler (Laboratory for Materials, Wackenbergstr. 84-88, 13156 Berlin, Germany)*

Self-consistently generated Hilbert spaces of the electronic states within the CuO_2 planes include various symmetry breakings of quantum states in space and time [1,2]. Of particular relevance is that initially crystal symmetry adapted two dimensional quantum states are being transferred into one-dimensional quantum states with halved lattice periodicity. This leads to two topologically separated subspaces, designated by [–] and [+] that are linked in space and time. A constant dynamic exchange of these subspaces occurs determined by time with the *eigentime* $\tau_{ei_{DCBF}} = 2 \cdot \tau_{CBF}$ being a new quantized quantity and with τ_{CBF} representing an internal quantum clock. As a result, self-consistently generated time-periodic Floquet states occur corresponding to the periodic time translation $t \rightarrow t + T$ with $T = \tau_{ei_{DCBF}}$. As opposed to the common assumption of a time-independent basis state representation these Floquet states form the real basis states in high-T_c cuprate superconductors. Under hole doping, this basis representation is additionally transformed self-consistently into complementary subspaces with strong dynamic correlation. In consequence of this, two paired electrons are driven to form antisymmetrically paired quantum oscillator states in each case. The formation of such correlated states represent a particular kind of dynamic entanglement of quantum states which is causally founded on the self-consistent formation of time-periodic Floquet states.

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P1-22 Resonant x-ray scattering from YBCO family - *S. Blanco-Canosa (Max Planck Institute for Solid State Research), G. Ghiringhelli, M. Minola (CNR-SPIN, Dipartimento di Fisica, Politecnico di Milano), L. Braicovich (CNR-SPIN, Dipartimento di Fisica, Politecnico di Milano,), M. Moretti Sala (European Synchrotron Radiation Facility), M. Le Tacon, J. Chaloupka, G. Khaliullin, B. Keimer (Max Planck Institute for Solid State Research), T. Schmitt (Swiss Light Source, Paul Scherrer Institut)*

Motivated by the search for the mechanism of high-temperature superconductivity, an intense research effort has been focused on the evolution of the spin excitation spectrum upon doping from the antiferromagnetic insulating to the superconducting states of the cuprates. Here we take advantage of the recent developments of high-resolution resonant inelastic x-ray scattering [1]to show that a large family of superconductors, encompassing the model compounds YBa2Cu4O8 and YBa2Cu3O7, exhibits damped spin excitations - or paramagnons - with dispersions and spectral weights closely similar to those of magnons in undoped, antiferromagnetically ordered cuprates over much of the Brillouin zone[2]. A numerical solution of the Eliashberg equations based on the experimental spin excitation spectrum of YBa2Cu3O7 reproduces its superconducting transition temperature within a factor of two and strongly supports magnetic Cooper pairing models for the cuprates. Charge excitations are also investigated and reveal evidences for charge order in the pseudogap state of underdoped compounds [3].

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P1-23 Contrasting quantum oscillations in electron and hole doped cuprates - *S. Chakravarty (University of California Los Angeles)*

We consider quantum oscillation experiments in cuprates from both a commensurate (period-2) as well as an incommensurate (period-8) d-density wave order using an exact transfer matrix method and the Pichard-Landauer formula for the conductivity. While the electron doped materials can be understood in detail using the commensurate choice, including magnetic breakdown effects, the hole doped case is better understood using period-8 order in which the current density is unidirectionally modulated, similar to stripes. This current modulation is accompanied by a period-4 site charge modulation, as allowed by Landau theory, which is consistent with a recent high field magnetic resonance experiment, with approximately the observed magnitude of the charge modulation. Our work provides a natural explanation why in hole doped cuprates only oscillations from a single electron pocket is observed, and the hole pocket of roughly twice the frequency, as dictated by period-2 order and concomitant Luttinger sum rule, is not seen. The reason is that for period-8 order the hole pocket frequency is too small, and magnetic fields necessary to observe it are at the borderline of what is achievable. Clearly, at least a few such oscillations have to be resolved. However, the very coexistence of the hole pocket, however small, provides a simple reason for the oscillations of the Hall coefficient. The advantage of d-density wave is that it is effectively hidden, as compared to spin density wave, which is absent in the relevant range of parameters. We also find that the linear coefficient of the specific heat is within a factor of 2 of the observed value at about 45 T. I will also provide a general overview of the remaining outstanding problems.

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P1-24 Spin excitations in a single La2CuO4 layer measured with Resonant Inelastic X-ray Scattering - *M. Dean, I. Bozovic, J. Hill (Brookhaven National Laboratory), B. Dalla Piazza, H. Ronnow (Ecole Polytechnique Federale de Lausanne), J. den Brink (IDW Dresden), C. Monney, K. Zhou, A. Suter, E. Morenzoni, T. Schmitt (Paul Scherrer Institut), R. Springell (University College London)*

The dynamics of S=1/2 quantum spins on a 2D square lattice lie at the heart of the mystery of the cuprate superconductors. In bulk cuprates such as La_2CuO_4, the presence of a weak interlayer coupling stabilizes 3D Néel order up to high temperatures. In a truly 2D system however, thermal spin fluctuations melt long-range order at any finite temperature [1]. Further, quantum spin fluctuations transfer magnetic spectral weight out of a well-defined magnon excitation into a magnetic continuum, the nature of which remains controversial [2-4]. We used molecular beam epitaxy to synthesize isolated 2D La_2CuO_4 layers and employed ultra-high resolution resonant inelastic x-ray scattering to measure their spin excitation spectrum. We show that coherent magnons persist even in a single layer of La_2CuO_4 despite the loss of magnetic order, with no evidence for resonating valence bond (RVB)-like spin correlations [5]. Thus these excitations are well described by linear spin wave theory (LSWT). We also observe a high-energy magnetic continuum in the isotropic magnetic response. This high-energy continuum is not well described by 2 magnon LSWT, or indeed any existing theories.

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P1-25 Precursor superconducting phase at temperatures as high as 180 K in superconducting cuprate crystals from infrared spectroscopy. - ***A. Dubroka, M. Roessle, K. Kim, V. Malik, C. Bernhard (Fribourg university), T. Wolf (Karlsruhe institute of technology), J. Storey, J. Tallon (MacDiarmid institute), D. Munzar (Masaryk University), C. Lin, D. Haug, V. Hinkov, B. Keimer (Max-Planck institute for solid state research), D. Basov, A. Schafgans, S. Moon (University of California)***

We present results of our detailed study of the infrared c-axis response of underdoped cuprate high-temperature superconductors RBa2Cu3O7 (R=Y; Gd; Eu) [1]. In addition to competing correlations which give rise to a pseudogap that depletes the low-energy electronic states below T*>>Tc, our analysis enables us to identify the onset of another phase below Tons >Tc. In this phase in contrast to that of related with T*, the low-energy spectral weight increases with decreasing temperature. Below Tc, it transforms into the condensate and the underlying electronic states are susceptible to magnetic fields. All these characteristics are hallmarks of superconducting fluctuations and thus we conclude that the phase corresponds to a precursor superconducting state. Our conclusions are strongly supported by the data of the in-plane infrared conductivity where a gap opens below Tons which is accompanied by the shift of spectral weight towards lower frequencies [2]. We map out the doping phase diagram of Tons which reaches a maximum of 180 K at strong underdoping. A very intriguing property of the precursor superconducting phase is that it involves a very large fraction of the low-energy electronic states that increases with underdoping to that extent that for very strongly underdoped samples, the effects above Tc are much stronger than those below Tc. Our results helps to understand the mysterious phenomenology of the pseudogap showing that this phase involves two different phenomena which is likely a source of the ongoing dispute of the origin of the pseudogap.

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P1-27 Doping evolution of nodal quasiparticles in the cuprate superconductor YBCO via low-temperature thermal conductivity - ***S. René de Cotret (University of Sherbrooke), B. Ramshaw, R. Liang, D. Bonn, W. Hardy (University of British Columbia), N. Doiron-Leyraud, J. Reid, G. Grissonnanche, L. Taillefer (University of Sherbrooke)***

The thermal conductivity of the cuprate superconductor $YBa_2Cu_3O_y$ was measured at temperatures down to 50 mK in magnetic ?elds up to 15 T on high-quality single crystals with a hole concentration ranging from p = 0.08 to p = 0.18. The residual linear term at T = 0, a direct measure of the nodal quasiparticle velocities [1], is tracked as a function of doping. Comparison to corresponding data on the cuprate Tl-2201 with p > 0.20 [2] reveals a marked difference between underdoped and overdoped regimes. We discuss the possible origin of this difference and compare our data with recent high-resolution ARPES data on Bi-2212 [3], a technique which can measure directly the nodal quasiparticle dispersion.

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P1-28 Towards understanding the c-axis infrared response of underdoped cuprate superconductors - ***D. Munzar, J. Vasatko (Department of Condensed Matter Physics, Faculty of Science, and Central European Institute of Technology, Masaryk University, Brno)***

The c-axis infrared (IR) conductivity of underdoped high-Tc cuprate superconductors reveals a pronounced pseudogap (PG) and, for materials with two CuO2 planes per unit cell (the so-called bilayer compounds), signatures of coherent electronic coupling within the pair of closely spaced planes, in particular the so-called transverse plasma mode (TPM) located around 400 cm-1. The PG develops below T*>>Tc, the TPM below Tons, Tc<Tons<<T*. We report on results of our recent studies aiming at understanding these phenomena. (a) The formulas frequently used to describe the c-axis response of the coupled electron-phonon system of bilayer cuprate superconductors, that were originally obtained at the level of the phenomenological multilayer model (MLM), have been derived by using diagrammatic perturbation theory [1,2]. This provides a support for several important findings based thereon, in particular those of [3]. (b) The reported magnetic field (H perpendicular to the planes) induced changes of the TPM [4,3]have been clarified using the MLM [5]. Results of our analysis suggest that the response at H=0 and T=Tc is close to that at H = ca 25 T<Hc2 and T<<Tc, in accord with theories attributing the above Tc state to that of a superconductor lacking the long range phase coherence. (c) Manifestations of the PG in the c-axis IR data [6] are similar to those in intrinsic tunneling data and qualitatively different from those in the in-plane IR data. In the third part of our contribution, possible consequences concerning the origin of the PG will be discussed.

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P1-29 Observable NMR signal from circulating current order in YBCO – S. Lederer, S. Kivelson (Stanford University, Dept. of Physics)

Assuming, as suggested by recent neutron scattering experiments, that a broken symmetry state with orbital current order occurs in the pseudo-gap phase of the cuprate superconductors, we show that there must be associated equilibrium magnetic fields at various atomic sites in the unit cell, which should be detectable by NMR experiments.

P1-31 SUPERCONDUCTING GLUE: ARE THERE LIMITS ON Tc? - *O. Dolgov (MPI FKF Stuttgart), E. Maksimov (P.N. Lebedev Physical Institute, Moscow)*

The restrictions for possible mechanisms of high-temperature superconductivity due to requirements of stability are discussed. The condition for the static dielectric function to be positive is reexamined. In the literature up to now a number of incorrect and unfounded statements exist. One of these - that the static dielectric function cannot be negative - is discussed in detail, as well as its consequence, a strong coupling limit on the transition temperature T_c. Proofs are given that the static dielectric function is negative in many stable systems, including most of the conventional metals. Various types of electron - electron interaction in superconducting cuprates are discussed. An importance of the electron - phonon interaction in cuprates is highlighted. The role of spin-fluctuations effects in novel multiband superconductors is considered.

E.G. Maksimov passed away on April 30, 2011

P1-32 Effects of the basal-plane area on cuprate superconductivity - *J. Roehler (Universitaet zu Koeln)*

Elastic deformation has strong effects on the properties of hole doped superconducting cuprates, most significantly on T_c. While c-axis compression determines primarily the number of hole carriers n, the intrinsic trend in T_c is connected with the in-plane lattice parameter a, more precisely with the area of the basal-plane A. For optimal doping, n_opt, the charge transfer compressibility vanishes, dT_c/dn = 0. At this point all available high pressure data [1] suggest universally T_c \propto A^{-2} within the various cuprate families. Upon increasing covalency with doping this relationship requires A(n) to deviate from the Pauling-type monotonous contraction and to develop a relative extremum at n_{opt}. In fact A(n) has been universally found to bulge at n_{opt} [2]. We propose an analysis of these remarkable findings in terms of a t e n s i l e magnetoelastic strain exerted on the CuO_2 lattice by excitations in the glassy structure of preformed hole pairs at T>>T_c [3].

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P1**-33 Altering properties of Superconducting thin films for Single-Photon detector applications - *N. Masilamani (ISEM, University of Wollongong), O. Shcherbakova, A. Pan, S. Dou (Institute for Superconducting and Electronic Materials, University of Wollongong), S. Fedoseev (ISEM, University of Wollongong)***

Superconducting ultra-thin films have been emerging in Superconducting Single-Photon Detector (SSPD) research as novel replacements to semiconductor detectors [1]. In terms of exploitation, it would be practical to adjust properties of YBa2Cu3O7-x high temperature superconductor for fabrication of these detectors which would enable their operation at temperature of 77K. One of the difficulties which YBCO ultra-thin films face is degradation of superconducting properties with reduction of thin film thickness [2]. In this work, we have tried to enhance superconducting properties and morphology of ultra-thin YBCO films by introducing different buffer layers (PrBa2Cu3O7 [3] and CeO2[4]) underneath of the YBCO film. We have noticed that by increasing the thickness of buffer layer, the thickness of superconducting thin film can be effectively reduced without significant degradation of its functional properties. Comprehensive analysis of structural and electro-magnetic properties of ultrathin films will be presented and their applicability for SSPD application will be discussed.

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P1-35 The effect of Gd2Ba4CuNbOy dopants amount and its size on the levitation force of single domain GdBCO bulk superconductors - *W. Yang (Shaanxi Normal University)*

Single domain GdBCO bulk superconductors, with compositions of $GdBa_2Cu_3O_7$(Gd123):Gd_2BaCuO_5(Gd211):$Gd_2Ba_4CuNbO_y$(GdNb2411) =1:(0.4-*x*):*x*, (*x*=0, 0.02, 0.06, 0.10, 0.14), have been successfully fabricated by the Top Seeded Melt Texture Growth process (TSMTG). The effect of GdNb2411 addition and its size on the growth morphology and levitation force of single domain GdBCO bulk superconductors has been investigated. The results show that single domain GdBCO bulk samples can be fabricated with different nanometer GdNb2411 particle additions; the surface morphologies of the samples are closely related with the dopant amount *x*, the surface of the samples with *x*≤0.06 is of a smooth plane and divided into four equal regions by a cross line, but it is of a wrinkle surface for the samples with *x*≥0.10 and the single domain area is reduced with the increasing of *x*. It is also found that the levitation force of the samples increases first and then decreases with the increasing of *x*, the largest levitation force of 26 N is obtained in the samples with *x*=0.06 mol; The levitation force are closely related with the size of GdNb2411 particle in the samples, the smaller the GdNb2411 particles, the higher the levitation force,the levitation force of GdBCO bulk sample with 260nm GdNb2411 particles is about 1.53 times higher than that of sample with 660nm GdNb2411 particles. The results is helpful for us to improve the quality of GdBCO bulk samples.

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P1-36 Polarized neutron reflectometry study of proximity effects in superlattices consisting of high-Tc cuprate superconductors and ferromagnetic manganites - ***M. Uribe-Laverde (University of Fribourg, Department of Physics and Fribourg Centre for Nanomaterials, Chemin du Musée 3, CH-1700 Fribourg, Switzerland), A. Devishvili, B. Toperverg (Institute of Solid State Physics, Ruhr-Universität Bochum, D-44801 Bochum, Germany), C. Marcelot, J. Stahn (Laboratory for Neutron Scattering Paul Scherrer Institut, CH-5232 Villigen, Switzerland), J. Kim (Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, D-70569 Stuttgart, Germany), A. Rühm (Max-Planck-Institut für Intelligente Systeme, Heisenbergstrasse 3, D-70569 Stuttgart, Germany), D. Satapathy, I. Marozau, S. Das, V. Malik, C. Bernhard (University of Fribourg, Department of Physics and Fribourg Centre for Nanomaterials, Chemin du Musée 3, CH-1700 Fribourg, Switzerland)***

We have performed polarized neutron reflectometry (PNR) measurements on $YBa_2Cu_3O_7$ (YBCO) / $La_{2/3}Ca_{1/3}MnO_3$ (LCMO), YBCO/$LaMnO_{3+d}$ (LMO) and YBCO/$La_{0.7}Sr_{0.3}MnO_3$ superlattices (SL) grown with the pulsed laser deposition technique. Each SL consists of 10 repetitions of the bilayer structure with a nominal single layer thickness of 10nm. From the modeling of the PNR data we derived the depth dependence of the magnetization density in these SLs. Our studies confirmed the existence of a magnetic proximity effect (MPE) that is characterized by the occurrence of a sizeable "depleted layer" on the manganite side of the interface where the magnetic moment is drastically reduced. We found that the strength of this MPE, measured in terms of the size of the depleted layers, strongly depends on the electronic (orbital) properties of the manganite layers, i.e. it is pronounced for metallic LCMO and LSMO whereas it is almost absent for the ferromagnetic but insulating LMO. Since the structural properties of all SL do not differ considerably, we conclude that the MPE has an intrinsic and electronic, rather than structural, origin. In addition, changes in the asymmetry of the 3^{rd} SL Bragg peak below the superconducting transition for the YBCO/LCMO SL evidence superconductivity induced changes in the magnetic profile in the angstrom scale. This constitutes a remarkable evidence of the interaction between the competing superconducting and ferromagnetic orders in this system.

P1**-37 YRZ Ansatz and the Dynamical Magnetic Response of the Underdoped Cuprates -** ***A. James, R. Konik (CMPMS Dept., Brookhaven National Lab), T. Rice (Institut fur Theoretische Physik, ETH Zurich; CMPMS Dept., Brookhaven National Lab)***

We examine the dynamical magnetic response of the underdoped cuprates by employing a phenomenological theory based on the Yang-Rice-Zhang (YRZ) ansatz [1] of a doped resonant valence bond state where the Fermi surface is truncated into four pockets. In the process we connect mean field slave boson theory [2] with the YRZ ansatz. Our treatment predicts a resonant spin response which with increasing energy (0 to 100meV) appears as an hourglass. The very low energy spin response is found at (pi, pi plus/minus delta) and (pi plus/minus delta, pi) and is determined by scattering from the pockets' frontside to the tips of opposite pockets where a van Hove singularity resides. At energies beyond 100 meV, strong scattering is seen from (pi, 0) to (pi, pi). This theory thus provides a semi-quantitative description of the spin response seen in both inelastic neutron scattering [3] and resonant inelastic x-ray scattering [4] experiments at all relevant energy scales.

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P1-38 Electronic structures of superconducting ferromagnet RuSr2EuCu2O8 studied by x-ray absorption and photoemission spectroscopies* - ***D. Ling (Dept. of Physics, Tamkang University), S. Han (Basic Science Research Institute Energy Harvest-Storage Research Center University of Ulsan), J. Chiou (Department of Applied Physics, National University of Kaohsiung), W. Pong (Dept. of Physics, Tamkang University), H. Tsai, J. Lee (National Synchrotron Radiation Research Center)***

Temperature-dependent local electronic structures of ruthenocuprate $RuSr_2EuCu_2O_8$ (RuEu-1212) were investigated by using x-ray absorption near-edge structure (XANES) and valence-band photoemission (VB-PES) measurements. The XANES results reveal that electrons are transferred not only from Cu 3*d* states, but also from Ru 4*d* states, to O 2*p* orbitals in the RuO_2 layers as temperature is below magnetic ordering temperature. In addition, the partial spectral weight distributions derived from VB-PES spectra show that Ru 4 *d*states are, remarkably, much closer to the Fermi level (E_f) than Cu 3*d* and O 2*p* states. It strongly suggests that Ru 4 *d* states are more essential for determining the magnetic and electronic properties of RuEu-1212 and provides direct evidence for a weak overlapping between Ru 4 *d* states and strongly Cu 3*d*-O 2*p* hybridized states well below E_f, giving rise to a weak coupling between the CuO_2 and RuO_2 layers in RuEu-1212.[1] The analysis of extended x-ray absorption fine structure demonstrates that the appearance of weak ferromagnetism and superconductivity is accompanied by a significant decrease of dynamic local lattice distortions of high-shell Cu-Sr and Ru-Sr bonding in RuEu-1212.

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P1-39 Phase competition between superconductivity and stripe order in cuprates - ***F. Fallah Tafti (Universite de Sherbrooke), B. Ramshaw (Laboratoire National des Champs Magn´etiques Intenses), N. Doiron-Leyraud, O. Cyr-Choinière, F. Laliberté, G. Grissonnanche, S. René deCotret, E. Hassinger, L. Taillefer (Universite de Sherbrooke), R. Liang, D. Bonn, W. Hardy (University of British Colombia)***

The existence of stripe order – a unidirectional modulation of charge and spin densities – is well established in the LSCO family of cuprates, for example in Eu-LSCO and Nd-LSCO. Below its onset at a quantum critical point $p^* = 0.24$ [1], stripe order in Eu/Nd-LSCO competes with superconductivity, causing a dip in the T_c vs doping curve at $p = 1/8$, for example. Recently, strong evidence of stripe order has also been found in the archetypal cuprate superconductor YBCO [2,3]. Here we present a comparative study of phase competition in Eu/Nd-LSCO and YBCO using a variety of transport measurements in high magnetic fields.

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P1-41 Two sizes of superconducting gaps on an over-doped TlBa2Ca2Cu3O8.5+d with TC ~ 112 K by tunneling spectroscopy - ***R. Sekine (Department of Applied Physics, Tokyo Univ. of Science.), T. Watanabe (Department of Applied Electronics, Tokyo Univ. of Science), S. Kawashima, M. Minematsu (Department of Applied Physics, Tokyo Univ. of Science), A. Tsukada, N. Miyakawa (Department of Applied Physics, Tokyo Univ. of Science.), S. Mikusu, K. Tokiwa (Department of Applied Electronics, Tokyo Univ. of Science)***

We report tunneling spectroscopy on over-doped $TlBa_2Ca_2Cu_3O_{8.5+\delta}$ (Tl1223) with three CuO_2 planes in a unit cell. The tunneling conductance has been measured by point contact method using AC lock-in technique at 4.2 K. Polycrystalline Tl1223 with T_C~112 K was synthesized under ambient pressure using conventional quartz tube method. The tunneling conductances on Tl1223 exhibit two sizes of gaps that originate from two kinds of crystallographycally inequivarent CuO_2 planes, *i.e.* inner plane (IP) with four-fold oxygen coordination and outer planes (OP) with five-fold oxygen coordination. The size of larger gap Δ_L and smaller gap Δ_S are 37.9±4.8 meV and 22.2±2.0 meV, respectively. In addition, we observed a spectrum which exhibits both IP's and OP's superconducting gap together. It is one of the proof of existence of two sizes of superconducting gap on multi-layered cuprates. This two gaps story is from two experimental facts. First, hole concentration of IP is smaller than that of OP, in NMR measurements on multi-layered cuprates [1]. Second, superconducting gap Δ decreases with increasing hole concentration, in tunneling results on $Bi_2Sr_2CaCu_2O_{8+\delta}$ [2]. Combining these two results, it is naturally explained that the existence of two sizes of gaps on multi-layered cuprates and, the Δ_L and Δ_S correspond to the gap of IP and OP, respectively. Also we had observed two sizes of gaps on some multi-layered cuprates [3-6].

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P1-42 Low-Temperature Synthesis of Hole-Doped La_{2-x}Ca_{x}CuO_{4} with the Nd_{2}CuO_{4}-Type Structure - ***T. TAKAMATSU, M. KATO, T. NOJI, Y. KOIKE (Department of Applied Physics, Graduate School of Engineering, Tohoku University)***

It is well known that there are two kinds of structure in superconducting cuprates Ln_2CuO_4 (*Ln*: lanthanoid). One is the so-called T-structure of the K_2NiF_4-type and the other is the so-called T'-structure of the Nd_2CuO_4-type. Generally, it was believed that hole-doped superconducting Ln_2CuO_4 has the T-structure and electron-doped superconducting Ln_2CuO_4 has the T'-structure. However, we found a new electron-doped superconductor T-$Li_xSr_2CuO_2Br_2$ [1]. On the other hand, there has been no report on hole-doped superconducting T'-Ln_2CuO_4. Here, we report the synthesis of hole-doped T'-$La_{2-x}Ca_xCuO_4$ at low temperatures and investigate whether hole-doped T'-La_2CuO_4 shows superconductivity or not.

Polycrystalline samples of T'-$La_{2-x}Ca_xCuO_4$ ($x \le 0.1$) were prepared as follows. First, T-$La_{2-x}Ca_xCuO_4$ samples synthesized by the conventional solid-state reaction method were mixed with excess CaH_2, ground and then pressed into pellets in an Ar-filled glove box. Then, the pellets were heated at 275ºC for 24 h in an evacuated Pyrex tube and then washed with saturated NH_4Cl in anhydrous ethanol to remove the residual CaH_2 and the byproduct CaO and then dried. Next, the product was heated at 250ºC for 12 h in air. The powder X-ray diffraction pattern has shown that the product is of the single phase of T'-$La_{2-x}Ca_xCuO_4$. However, no superconductivity has been observed at temperatures above 2 K for all samples in the magnetic-susceptibility measurements. The deviation from the oxygen stoichiometry may suppress the appearance of superconductivity. [1] T. Kajita *et al*., Jpn. J. Appl. Phys. **43** (2004) L1480.

P1-43 Tunneling study on electron doped cuprates Sm1.85Ce0.15CuO4 - ***M. Minematsu, A. Tsukada, N. Miyakawa (Department of Applied Physics, Tokyo University of Science)***

We present a tunneling study on an electron-doped cuprate $Sm_{1.85}Ce_{0.15}CuO_4$ (SCCO) single crystal with T_C ~ 20 K. The SCCO single crystal was grown by travelling solvent floating zone method and T_C was determined by electrical resistivity and magnetic susceptibility measurements. The tunneling conductances have been measured by point contact method using ac lock-in technique at 4.2 K. Our data exhibit reproducible superconducting-gap peaks at 4.98 ± 0.38 mV, and the kink sturctures were observed at 30 ~ 70 mV.Furthermore we measured temperature dependence of tunneling conductances on SCCO. The tunneling conductance at 0 mV increases with increasing temperature, and the superconducting gap peaks disappeared at T_C.

In addition, a small pseudogaps has not been observed. However, the kink structure with the depletion of density of states near E_F remains above T_C and seems to disappear between 100 ~ 150 K. It suggests that the gap-like feature is not related to the superconductivity (SC). The gap-like feature is thought to be due to antiferromagnetic (AF) fluctuations or long range AF order, because in SCCO with Ce-content x = 0.15 SC coexists with AF. These results are almost consistent with other group's results [1].

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P1-44 First direct observation of the Van Hove Singularity in the tunnelling spectra of cuprates - ***A. Piriou, C. Berthod, I. Maggio-Aprile, Ø. Fischer (Départment de la Matière Condensée, University of Geneva), N. Jenkins (NYU Physics)***

In two-dimensional lattices, the electronic levels are unevenly spaced, and the density of states (DOS) displays a logarithmic divergence known as the Van Hove singularity (VHS). This is the case in particular for the layered cuprate superconductors. The scanning tunnelling microscope (STM) probes the DOS, and is therefore the ideal tool to observe the VHS. No STM study of cuprate superconductors has reported such an observation so far giving rise to a debate about the possibility of observing directly the normal state DOS in the tunnelling spectra. We will show that the VHS is unambiguously observed in our STM measurements performed on the cuprate $Bi_2Sr_2CuO_{6+delta}$ (Bi-2201) [1]. We will analyse the behavior of parameters governing the shape of tunnelling spectra and its relation with what has been observed in other cuprates. We will then especially focus on the relation between the VHS position and the superconducting gap value, opening new questions on what governs high temperature superconductivity.

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P1-45 Microscopic mechanisms for finite wave vector pairing. N. J. Robinson, F. H. L. Essler, E. Jeckelmann^2 and A.M. Tsvelik - ***A. Tsvelik (Brookhaven National Laboratory), F. Essler, N. Robinson (Department of Theoretical Physics, University of Oxford), E. Jeckelmann (Leibnitz Universitat, Hannover)***

We consider the effects of Umklapp processes in doped two-leg fermionic ladders. These may emerge either at special band fillings or as a result of the presence of external periodic potentials. We show that such Umklapp processes can lead to profound changes of physical properties and in particular stabilize pair-density wave phases. We discuss a relevance of such mechanism for the formation of two-dimensional superconductivity in x=1/8 LBCO.

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P1-46 Theory of the Time-Reversal-Symmetry Breaking and the Polar Kerr Effect in Underdoped Cuprates - ***V. Yakovenko (University of Maryland)***

Kapitulnik et al. [1] observed time-reversal-symmetry breaking (TRSB) in $YBa_2Cu_3O_{6+x}$ and Bi2201 by measuring the optical polar Kerr effect. We present the chiral *d+id* density-wave scenario [2] to explain TRSB in underdoped cuprates. In this model, staggered electron currents circulate around the plaquettes of a square lattice, whereas the symmetry between the plaquettes is broken in a checkerboard manner. The translational-symmetry breaking in this model also helps to explain the frequencies of the quantum magnetic oscillations observed in underdoped and overdoped cuprates [3].

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P1-47 Theory of the Time-Reversal-Symmetry Breaking and the Polar Kerr Effect in Sr2RuO4 - ***V. Yakovenko (University of Maryland)***

Kapitulnik et al. [1] observed time-reversal-symmetry breaking (TRSB) in Sr_2RuO_4 by measuring the optical polar Kerr effect. We present calculations [2] of the Kerr angle for Sr_2RuO_4 in the p_x+ip_y superconducting state. We find that a non-zero Kerr effect requires electron scattering on impurities. The calculated temperature dependence of $\sigma_{xy}(\omega)$ agrees with the experiment [1].

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P1-48 Distinguishing underlying mechanisms of high-temperature superconductivity in cuprates - ***X. Chen (Geophysical Laboratory, Carnegie Institution of Washington, Washington, D.C. 20015, USA), J. Wen, Z. Xu, G. Gu (Condensed Matter Physics & Materials Science Department, Brookhaven National Laboratory, Upton, NY 11973, USA), A. Goncharov, V. Struzhkin, R. Hemley, H. Mao (Geophysical Laboratory, Carnegie Institution of Washington, Washington, D.C. 20015, USA), C. Lin (Max-Planck-Institut für Festkörperforschung, D-70569 Stuttgart, Germany), J. Zhu (Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA)***

Electronic Raman scattering measurements are performed on the bilayer and trilayer Bi-based superconductors with different doping levels in order to see how electronic B_{1g} mode changes with pressure. We find that in the underdoped region the electronic B_{1g} mode is almost independent of pressure; however, the electronic B_{1g} mode increases with increasing pressure for the optimally doped and overdoped samples. These results indicate that the different mechanisms of superconductivity

compete across the optimal doping level. Below the optimal doping, spin fluctuations compete with electron-phonon interaction for the pairing of superconductivity while the electron-phonon interaction becomes the dominant mechanism responsible for superconductivity upon further doping.
This work was supported as part of the EFree, an Energy Frontier Research Center funded by the US Department of Energy, Office of Science, Office of Basic Energy Sciences (DOE-BES).

P1-49 Are preformed Cooper pairs the cause for the superconductor pseudogap? - *M. de Llano (Instituto de Investigaciones en Materiales, Universidad Nacional Autónoma de México, Apdo. Postal 70-360, 04510 México DF, MEXICO), T. Mamedov (Faculty of Engineering, Baskent University, 06530 Ankara, TURKEY and Institute of Physics, Academy of Sciences of Azerbaijan, 370143Baku, AZERBAIJAN)*

The question in our title is addressed with the recent boson-fermion (BF) binary gas mixture model (Ref. 1). This model is now *extended* to include: i) anisotropy of the BF interaction and ii) momentum-independent Coulomb repulsions. Here we test whether or not this new extended BF model accounts for the peculiarities of the pseudogap observed as function of temperature T and concentration x of holes doped onto the CuO2 planes of cuprates and whether the pseudogap evolves as T is lowered into the actual superconducting gap. Using two-time Green functions (Ref. 2) it is shown that pair breakings depend on the *separation* between the boson and fermion spectra of a BF mixture. As this separation shrinks, the pair-breaking ability of the Coulomb interaction weakens and disappears altogether at the BEC T_c, i.e., at the T below which a complete softening of bosons occurs. Simultaneous inclusion of both effects (i) and (ii) produces “islands" in momentum space of incoherent Cooper pairs above the Fermi sea as T is lowered. These islands grow upon further cooling and merge together just before T_c is reached. The new extended BF model predicts a *pseudogap phase* in 2D high-T superconductors with lines of points on the Fermi surface along which pseudogap vanishes. This describes and arguably explains the origin of T-dependent “Fermi arcs” observed (Ref. 3) in ARPES experiments in BSCCO (Bi2212).

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P1-50 Long-range incommensurate charge fluctuations in spin-gapped high-temperature superconductors - *S. Blanco-Canosa (Max-Planck-Institut für Festkörperforschung), R. Sutarto (Canadian Light Source, Univ. of Saskatchewan and Dept. of Physics & Astronomy, Univ. of British Columbia), F. He (Canadian Light Source, University of Saskatchewan), G. Ghiringhelli (CNR-SPIN, CNISM & Dipartamento di Fisica, Politecnico di Milano, Piazza), G. de Luca, M. Salluzzo (CNR-SPIN, Complesso Monte Santangelo - Via Cinthia), M. Minola, C. Mazzoli, L. Braicovich (CNR-SPIN,CNISM and Dipartamento di Fisica, Politecnico di Milano, Piazza), G. Sawatzky (Department of Physics and Astronomy, University of British Columbia), D. Hawthorn (Department of Physics and Astronomy, University of Waterloo), N. Brookes, M. Moretti Sala (European Synchrotron Radiation Facility), E. Weschke (Helmholtz-Zentrum Berlin fuer Materialien and Energie), E. Schierle (Helmholtz-Zentrum Berlin für Materialien und Energie), M. Le Tacon, A. Frano, T. Löw, D. Peets, B. Keimer (Max-Planck-Institut für Festkörperforschung)*

We have used resonant soft x-ray scattering to identify two-dimensional charge fluctuations with an incommensurate periodicity of ~3.2 lattice units, a, in the copper-oxide planes of the superconductors (Y,Nd)Ba2Cu3O6+x with hole concentrations 0.09<p<0.12 per planar Cu ion. The intensity and correlation length of the fluctuation signal increase strongly upon cooling, so that the correlation length exceeds 15 a at the superconducting transition temperature, Tc. Further cooling below Tc abruptly reverses the divergence of the charge correlations. In combination with prior observations of a large gap in the spin excitation spectrum, these data indicate an incipient charge-density-wave (CDW) instability that competes with superconductivity. Our results further imply that CDW correlations are responsible for the well-known plateau in the Tc-versus-p relation in this family of superconductors, and for the formation of the small Fermi surface pockets recently detected in quantum oscillation experiments at high magnetic fields.
This work was performed partly at the ADRESS beamline of the Swiss Ligh Source, using the SAXES instrument jointly built by Paul Scherrer Institut (Villigen, Switzerland), Politecnico di Milano (Italy) and Ecole Polytechnique Federale de Lausanne Switzerland); partly at the ID08 beam line of the ESRF (Grenoble, France); partly at the UE46-PGM1 beamline of Bessy-II (Helmholtz-Zentrum Berlin für Materialien und Energie, Germany); and partly at the REIXS beamine at the Canadian Light Source (CLS, Saskatoon, Canada). Part of this research project has been supported by the European Commission under the 7th Framework Programme: Research Infrastructures (Grant Agreement Number 226716), by the European project “SOPRANO” under Marie Curie actions (Grant No. PITNGA-2008-214040), by the German Science Foundation under SFB/TRR 80 and by the Italian Ministry of Research MIUR (GrantNo.PRIN-20094W2LAY). The research at the CLS is supported by NSERC, NRC, CIHR, and the University of Saskatchewan. We gratefully acknowledge Steve Kivelson, Tom Devereaux, and Giniyat Khaliullin for discussions; Thorsten Schmitt, Kejin Zhou and Claude Monney for support at the ADRESS beamline; and Vladimir Hinkov, Chengtian Lin, Mohamed Bakr, Markus Raichle, and Daniel Haug for preparation of some of the single-crystal samples.

P1-50 Visualizing the atomic scale electronic structure of the Ca2CuO2Cl2 Mott insulator - ***Y. Wang, C. Ye, P. Cai, X. Zhou, W. Ruan (Department of Physics, Tsinghua University), R. Yu, Q. Liu, C. Jin (Institute of Physics, Chinese Academy of Sciences)***

Although the mechanism of superconductivity in the cuprates remains elusive, it is generally agreed that at the heart of the problem is the physics of doped Mott insulators. The cuprate parent compound has one unpaired electron per Cu site, and is predicted by band theory to be a half-filled metal. The strong onsite Coulomb repulsion, however, prohibits electron hopping between neighboring sites and leads to a Mott insulator ground state with antiferromagnetic (AF) ordering. Charge carriers doped into the copper oxygen plane destroy the insulating phase and superconductivity emerges as the carrier density is sufficiently high. Therefore the natural starting point for tackling high temperature superconductivity is to elucidate the electronic structure of the parent Mott insulator and the behavior of a single doped charge. Here we use a scanning tunneling microscope (STM) to investigate the atomic scale electronic structure of the $Ca_2CuO_2Cl_2$ (CCOC) parent Mott insulator of the cuprates [1]. The full electronic spectrum across the Mott-Hubbard gap is uncovered for the first time, which reveals the particle-hole symmetric and spatially uniform Hubbard bands. A single electron donated by surface defect is found to create a broad electronic state within the Mott-Hubbard gap. The in-gap state is strongly localized in space with spatial characteristics intimately related to the AF spin background. We show that the electronic structure of the parent Mott insulator is consistent with the single band *t-J* model, but the peculiar features of the doped electronic state require further theoretical investigations.

1. "Visualizing the atomic scale electronic structure of the Ca2CuO2Cl2 Mott insulator", Cun Ye, Peng Cai, Runze Yu, Xiaodong Zhou, Wei Ruan, Qingqing Liu, Changqing Jin, and Yayu Wang, arXiv: 1201.0342 (2011).

P1-51 Intermediate Coupling (GW) model for Cuprates - ***R. Markiewicz (Northeastern University), T. Das (LANL), A. Bansil (Northeastern University)***

While cuprates were regularly assumed to be very strongly correlated, with essentially no double occupancy of the copper atoms, a number of recent calculations are based on intermediate coupling models. Here I review a particular example, the quasiparticle-GW (QP-GW) model, that we have developed in the last few years.

In this model, the bare dispersions are taken directly from local density approximation calculations, modified by the effects of d-wave superconductivity and a pseudogap taken as a [possibly short-range] antiferromagnetic order. Correlations are included via a self energy dressed by a full spectrum of spin and charge fluctuations. Good agreement is found with a number of experiments, including both high and low energy kinks in angle-resolved photoemission, optical measurements, resonant inelastic x-ray scattering, scanning tunneling microscopy, and inelastic neutron scattering studies, over a wide range of dopings and energies, including details of `two gap' physics. The model has been used in Eliashberg calculations, and leads to reasonable superconducting gap values as a function of doping.

While the pseudogap is modeled as a simple (pi, pi) antiferromagnetic order for simplicity, we have used susceptibility calculations to explore possible incommensurate ground states, and find evidence for a great variety in hole-doped cuprates, including both spin and charge-dominated stripes – the latter stabilized by electron-phonon coupling. There is evidence for competing stripe phases, and the particular stripe order found in $La_{2-x}Sr_xCuO_4$ may be distinct from that in other cuprates.

P1-52 Infinite layer cuprate superconductors: Perspectives from high quality thin films - ***Y. Krockenberger, H. Yamamoto, K. Sakuma (NTT Basic Research Laboratories)***

Infinite layer cuprates (IL) are well known associates of electron doped cuprate superconductors. The crystal structure of IL is remarkable in that it only consists of the essential building blocks required for superconductivity, i.e. the CuO_2 planes. However, single crystals or high quality thin films of IL remain elusive. IL share the same copper coordination as T'-cuprates but the superconducting transition temperature T_c is significantly higher. High T_c values of 41 K have been reported for IL grown by molecular beam epitaxy (MBE) [1] or for bulk powder samples synthesized by high pressure synthesis methods ($T_c \approx 43$ K). While T_c of infinite layered cuprates grown by PLD [2] or sputtering are low and their resistivity values are high, nearly bulk-like T_c is found for samples grown by MBE. Several competing crystal structures are impeding the synthesis of single phase samples [3]. The oxidizing conditions during the growth of infinite layer cuprates have a tremendous influence on the oxygen sub-lattice. Ideally, oxygen occupies only in-plane positions. Any deviation from such an oxygen sub-lattice, e.g., in-plane oxygen vacancies and/or occupied apical oxygen positions, results in low T_c or insulating behavior. We have prepared coherently grown thin films of IL $Sr_{1-x}La_xCuO_2$ films by MBE on (110) $DyScO_3$ substrates as confirmed by RSM as well as TEM. Moreover, distinct Laue fringes are observed for $Sr_{1-x}La_xCuO_2$ films more than 100 nm thick. A clear step-and-terrace structure for films with $T_c > 35$ K was observed by AFM by a systematic tuning of the oxidizing conditions. Our $Sr_{1-x}La_xCuO_2$ films [4] show a metallic transport behavior (RRR > 3, ρ(300 K) < 100 μΩcm, $T_c \approx 40$ K) which is not seen for films synthesized by other techniques as well as bulk samples.

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P1-54 Origin of the lattice-structure dependence of Tc in the cuprates: a two-orbital study - ***H. Sakakibara, H. Usui, K. Kuroki (The University of Electro-Communications), R. Arita, H. Aoki (The University of Tokyo)***

One of the main goals for the investigation of the high-T_c cuprates is to optimize their superconducting transition temperature, T_c. Most directly we can look at the material and/or lattice structure dependence of T_c. For this purpose we adopt a two-orbital model, which considers the d_{z2} Wannier orbital explicitly on top of the usually considered $d_{x2\text{-}y2}$ orbital[1,2]. We find that a mixture of the d_{z2} orbital component to the Fermi surface, which is strong in the materials with relatively low T_c such as La214, dramatically degrades the spin-fluctuation mediated *d*-wave pairing. This is because the d_{z2} orbital, with a dilute carrier concentration, gives ferromagnetic rather than antiferromagnetic spin fluctuations. The message, then, is the level offset, Δ*E*, between the two orbitals strongly affects T_c. Having found this, we further analyze the origin of the material/lattice structure dependence of Δ*E*[2]. We find that Δ*E* is mainly governed by two structural parameters: the apical oxygen height h_O above the CuO_2 plane, and the separation *d* between adjacent CuO_2 planes. These results enable us to capture the T_c variation among the single-layered cuprates in a simple lattice-parameter space. Specifically, the present multiorbital viewpoint for the cuprates can be applied to study the origin of the *pressure dependence* of T_c[3]. We can envisage the pressure affects Δ*E*, which in turn affects T_c. However, this alone does not give a full understanding of the T_c variation against pressure, and other important components that affect T_c will also be discussed.

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P1-55 Non-equilibrium superconductivity in light-stimulated YBa2Cu3Ox at room temperature - *C. Hunt (Department of Physics and the Frederick Seitz Material Research Laboratory, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, USA; Max Planck Department for Structural Dynamics, University of Hamburg, Center for Free-Electron La, D. Nicoletti, S. Kaiser, W. Hu, I. Gierz, H. Liu (Max Planck Department for Structural Dynamics, University of Hamburg, Center for Free-Electron Laser Science, Hamburg), A. Cavalleri (Max Planck Department for Structural Dynamics, University of Hamburg, Center for Free-Electron Laser Science, Hamburg, Germany; Department of Physics, Oxford University, Clarendon Laboratory, Oxford, United Kingdom), M. Le Tacon, T. Loew, D. Haug, B. Keimer (Max Planck Institute for Solid State Research, Stuttgart)*

Using femtosecond mid-infrared pulses, we demonstrate that a photoinduced non-equilibrium superconducting state can be generated in underdoped $YBa_2Cu_3O_x$ above T_c. Pumping nearly resonant to the Cu-O phonon mode at 15.8 micron along the *c*-axis (perpendicular to the Cu-O layers) establishes phase coherence throughout the pseudogap region of the phase diagram. The transient response at three doping levels (x = 6.5, 6.6, 7) was fully characterized using THz time-domain spectroscopy at temperatures ranging from below T_c to room temperature.

We measure the non-equilibrium superconducting state in two different ways: First, probing in-plane (along the *a*-axis) reveals a London-like inverse frequency dependence in the imaginary part of the conductivity which has a lifetime in the 20 ps range. Second, probing perpendicular to the Cu-O planes (along the *c*-axis) shows evidence of the so-called Josephson plasma resonance, which arises in the superconducting state of cuprates due to a tunnelling current of Cooper pairs between the layers.

These results offer a new perspective on condensate formation in high temperature superconductors. The photoinduced non-equilibrium state will be discussed in the context of pre-formed pairs in the pseudogap phase.

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P1-57 Muon spin rotation investigation of the pressure effect on the magnetic penetration depth in YBa$_2$Cu$_3$O$_x$ - *A. Maisuradze (Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland), A. Shengelaya (Department of Physics, Tbilisi State University, Chavchavadze av. 3, GE-0128 Tbilisi, Georgia), E. Pomjakushina (Laboratory for Developments and Methods, Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland), A. Amato (Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland), H. Keller (Physik-Institut der Universitaet Zurich, Winterthurerstrasse 190, CH-8057 Zurich, Switzerland)*

The pressure dependence of the magnetic penetration depth λ in polycrystalline samples of YBa$_{2}$Cu$_{3}$O$_x$ with different oxygen concentrations $x = 6.45$, 6.6, 6.8, and 6.98 was studied by muon spin rotation (μSR). The pressure dependence of the superfluid density $\rho_s \propto 1/\lambda^2$ as a function of the superconducting transition temperature $T_{\rm c}$ is found to deviate from the usual Uemura line. The ratio $(\partial T_{\rm c}/\partial P)/(\partial \rho_s/\partial P)$ is factor of $\simeq 2$ smaller than that of the Uemura relation. In underdoped samples, the zero temperature superconducting gap Δ_0 and the BCS ratio $\Delta_0/k_B T_{\rm c}$ both increase with increasing external hydrostatic pressure, implying an increase of the coupling strength with pressure. The relation between the pressure effect and the oxygen isotope effect on λ is also discussed. In order to analyze reliably the μSR spectra of samples with strong magnetic moments in a pressure cell, a special model was developed and applied.

P1-58 Low-temperature synthesis of La_{2-x}Sr_{x}CuO_{4} of the Nd_{2}CuO_{4}-type using reduction agent CaH_{2} - *K. Kim, T. Takamatsu, M. Kato, T. Noji, Y. Koike (Tohoku University)*

Very recently, we have succeeded in preparing bulk samples of hole-doped $La_{2-x}Ca_xCuO_4$ ($x \le 0.1$) with the Nd_2CuO_4-type structure, namely, the so-called T'-structure. They were obtained by the reduction of $La_{2-x}Ca_xCuO_4$ with the K_2NiF_4-type structure, namely, the so-called T-structure prepared by the conventional solid-state reaction method at a temperature as high as ~1000°C, using CaH_2 at a temperature as low as 300°C, and by the subsequent oxidation [1]. However, it was impossible to obtain T'-$La_{2-x}Ca_xCuO_4$ ($x > 0.1$), because the solution limit of Ca in T-$La_{2-x}Ca_xCuO_4$ is $x = 0.1$. Therefore, we have attempted to synthesize T'-$La_{2-x}Sr_xCuO_4$, for the solution limit of Sr in $La_{2-x}Sr_xCuO_4$ is much larger than that of Ca in $La_{2-x}Ca_xCuO_4$.

Pollycrystalline samples of T'-$La_{2-x}Sr_xCuO_4$ were prepared as follows. First, T-$La_{2-x}Sr_xCuO_4$ was synthesized by the conventional solid-state reaction method at high temperatures. Next, it was mixed with CaH_2 in the molar ratio of 1:2, ground finely and then pressed into pellets. Then, the pellets were heated at 275°C for 24 h in an evacuated Pyrex tube and then washed with NH_4Cl in ethanol. Finally, the products obtained thus were heated at 250°C for 12 h in air or O_2. From the powder x-ray diffraction measurements, it has been found that T'-$La_{2-x}Sr_xCuO_4$ ($x \le 0.20$) is obtained. However, T'-$La_{2-x}Sr_xCuO_4$ shows no superconductivity. Nonstoichiometry of oxygen may prevent the superconductivity from appearing.

P1-59 Explaining and Extending Homes' Law in Cuprates Using ARPES: Universal Scaling Relations of Quasiparticle Scattering Lengths, Times and Pairing Energies on the Fermi Arc - ***J. Rameau, Z. Pan, G. Gu, P. Johnson (Brookhaven National Laboratory), H. Yang (Cornell University)***

A microscopic scaling relation linking the normal and superconducting states of the cuprates in the presence of a pseudogap is presented using angle-resolved photoemission spectroscopy (ARPES). This scaling relation, complementary to the bulk universal scaling relation embodied by Homes' law, explicitly connects the momentum-dependent amplitude of the d-wave superconducting order parametera T~0 K to quasiparticle scattering mechanisms operative at T~Tc. From this result it is found that the momentum dependent superconducting coherence length along the Fermi arc, at T~0, scales with the quasiparticle mean free path at T~Tc, for the same arc momenta. The form of the scaling is proposed to be a consequence of the marginal Fermi-liquid phenomenology and the inherently strong dissipation of the normal psuedogap state of the cuprates. This scaling has so far been shown to hold for single and two layer Bismuth based cuprates with Tc's ranging between 23 K and 91 K.

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P1-60 Theory of ultrafast quasiparticle dynamics in high-temperature superconductors: Pump fluence dependence - ***J. Zhu (Theoretical Division and Center for Nonlinear Studies,Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA), R. Prasankumar, A. Taylor (Center for Integrated Nanotechnologies, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA), E. Chia (Division of Physics and Applied Physics, School ofPhysical and Mathematical Sciences, Nanyang TechnologicalUniversity, Singapore 637371, Singapore), J. Tao (Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA)***

We present a theory for the time-resolved optical spectroscopy of high-temperature superconductors at high excitation densities with strongly anisotropic electron-phonon coupling. A signature of the strong coupling between the out-of-plane, out-of-phase O buckling mode (B_{1g}) and electronic states near the antinode is observed as a higher-energy peak in the time-resolved optical conductivity and Raman spectra, while no evidence of the strong coupling between the in-plane Cu-O breathing mode and nodal electronic states is observed. More interestingly, it is observed that under appropriate conditions of pump fluence, this signature exhibits a re-entrant behavior with time delay, following the fate of the superconducting condensate.

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P1-61 Charge nematicity in the spin glass phase of lanthanum cuprates - ***G. Seibold (BTU Cottbus), C. di Castro, M. Grilli, M. Capati, S. Caprara, J. Lorenzana (University of Rome 'La Sapienza')***

A low energy incommensurate spin response has been detected in many high-temperature superconductors. In the LSCO system the associated spin modulation is rotated below the doping concentration x=0.055 and the presence of an orthorhombic lattice distortion suggests a one-dimensional magnetic scattering along the diagonal direction which is even static. Contrary to the LaBaCuO and LaNdCuO compounds where the static incommensurate spin modulation is due to the formation of charge stripes along the CuO direction, no associated charge order has been found in the spin glass phase. In order to explain this puzzling situation we propose a model where doping of holes favors the formation of stripe segments which are composed of vortex-antivortex pairs and constitute nematic seeds.The associated dipoles can be mapped to Ising variables with orientation determined by the sign of the vorticity at the extremes. Within the extended Hubbard model we find that the length and orientation of segments is governed by the ratio between next-nearest and nearest neighbor hopping and limited by the long-range Coulomb interaction. The influence of the structural distortion and the interaction between segments leads to a charge nematic with ferro orientation of the Ising variables. We show that this state implies an incommensurate response in the spin channelwhich is in agreement with elastic neutron scattering data from lanthanum cuprates in the spin-glass phase.

P1-62 Are preformed Cooper pairs the cause for the pseudogap in superconductors? - ***M. Tofik (Faculty of Engineering, Baskent University, 06530 Ankara, TURKEY and Institute of Physics, Academy of Sciences of Azerbaijan, 370143 Baku, AZERBAIJAN), D. Manuel (Instituto de Investigaciones en Materiales, Universidad Nacional Autonoma de México, Apdo. Postal 70-360, 04510 M\'{e}xico,\ DF, MEXICO)***

The question in our title is addressed with the recent boson-fermion (BF) binary gas mixture model (Ref. 1) now *extended* to include: i) anisotropy of the BF interaction and ii) momentum-independent Coulomb repulsions. It concerns whether the new extended BF model accounts for the peculiarities of the pseudogap observed as function of temperature T and concentration x of holes doped onto the CuO2 planes and whether further transformation of the pseudogap into the real superconducting gap as T is lowered occurs. Using two-time Green functions (Ref. 2) it is shown that pair breakings depend on the *separation* between the boson and fermion spectra of a BF mixture. As this separation shrinks, the pair-breaking ability of the Coulomb interaction weakens and disappears at the BEC T_c, i.e., at the T below which a complete softening of bosons occurs. Simultaneous inclusion of both effects (i) and (ii) produces "islands" in momentum space of incoherent Cooper pairs above the Fermi sea as T is lowered. These islands grow upon further cooling and merge together just before T_c is reached. The new extended BF model predicts a *pseudogap phase* in 2D high-T superconductors with lines of points on the Fermi surface along which pseudogap vanishes. This explains the origin of T-dependent "Fermi arcs" observed (Ref. 3) in ARPES experiments.

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P1-63 Deposition of YBCO films on La-based MOD and PLD buffer layers - *V. Galluzzi, A. Angrisani Armenio, F. Fabbri, A. Augieri, A. Rufoloni, A. Mancini, A. Vannozzi, G. Celentano, F. Rizzo (Enea Research Center Frascati)*

Pulsed Laser Deposition (PLD) and metal-organic decomposition (MOD) YBCO films were grown on single crystal substrates buffered with La-Based buffer layers. The $La_2Zr_2O_7$ (LZO) and $LaMnO_3$ films were deposited both by MOD and PLD method on single crystal substrates. The buffer layers, as well as the YBCO template, were studied by structural analyses with X ray diffraction (XRD) and electron backscattering diffraction (EBSD) and the morphological properties were investigated by means of scanning electron (SEM) and atomic force microscopy (AFM). The results showed that La-based films are epitaxial and with a smooth surface, suitable for the YBCO film growth. The YBCO films on La-based structures show typical critical temperatures of about of 90K and critical current density in self magnetic field higher than $1MA/cm^2$.

P1-64 Effect of Rhenium and Tellurium Doping on Critical Temperature of Tl- based Cuprate Superconductors - *P. Kalita (Sibsagar College)*

The effect of tellurium (Te) and Rhenium (Re) on the critical temperature (Tc(0)) of Thallium (Tl) based cuprate superconductors is presented.Tl1.88Re0.12 Ba2Ca2Cu3Ox and Tl1.85 Re 0.12Te0.03 Ba2Ca2Cu3Ox superconductors have been prepared with nominal starting composition by solid state reaction method. Ba-Ca-Cu-O precursors were made for this purpose by mixing and grinding stoichiometric amounts of BaCO3, CaCO3 and CuO followed by sintering at 850oC. Finally, appropriate amounts of Re2O7and (Re2O7- TeO2) with Tl2O3 were added to the precursor and the whole mixture was annealed at 950oC under oxygen flow. Doping of Re produced a chemical stabilization of the precursor against barium carbonation under ambient air. The critical temperatures Tc(o) of Re – doped compound were found 86K .Tl-1212 emerged as major phase for it. Simultaneous doping of Te and Re increased the value of Tc(o) (123K) of the superconductor. X-ray diffraction revealed the presence of some additional phases in (Te, Re)-doped compound including the high- Tc Tl-1233 and Tl-2223 phases. The grain homogeneity of the prepared specimens were excellent, as obtained through SEM analysis. Simultaneous doping of tellurium and rhenium in Tl-cuprates induced pairing mechanisms to occur outside the CuO2 layers, thus enhancing high-Tc phase formation and hence the Tc(0) value.

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P1-65 Pulsed laser deposition study and optimization of different buffer layer structures for YBCO films by using the 4th harmonic emission of a Nd:YAG solid state laser - *F. Rizzo, A. Mancini, A. Angrisani Armenio, A. Augieri, G. Celentano, F. Fabbri, V. Galluzzi, A. Rufoloni, A. Vannozzi (ENEA, Centro Ricerche Frascati, via E. Fermi 45, 00044 Frascati (Rome) - Italy)*

High quality YBCO films are nowadays grown by using many different chemical and physical techniques. In particular, pulsed laser deposition (PLD) and chemical solution deposition (CSD) methods are widely employed in the processing of YBCO based coated conductors. Since these deposition methods use quite different process parameters, optimized substrate/buffer architectures must be developed.

In this work we address our attention to different buffer layer structures grown on Ni-W cubic textured substrates and (001) MgO single crystals by means of the 4^{th} harmonic emission (266nm) of a Nd:YAG laser in the PLD process. In particular, we focus on CeO_2/YSZ/CeO_2 and MgO/CeO_2 structures studying the improvement of the epitaxial growth as a function of some relevant deposition parameters (such as the laser radiation energy, the laser pulse repetition rate, the substrate temperature and the oxygen partial pressure during the deposition process). We analyze both the morphology and the crystalline structure of the buffer layers and compare it by means of SEM microscopy analysis an X-rays diffraction technique. Finally, we have grown on the different substrate structures YBCO films deposited by both PLD and CSD, using low fluorine metallorganic precursors, having very good superconductors properties and very poor a-axis oriented grains. This allows us of evaluating the very good quality of these templates and of indicating the Nd:YAG laser based PLD process as a promising candidate for the realization of long length YBCO coated conductors.

This work is supported by the FIRB Italian national research project "SURE:ARTYST"

P1-66 Origin of the Pseudogap in High-Temperature Cuprate Superconductors - *J. Tahir-Kheli (Caltech)*

Cuprate high-temperature superconductors exhibit a pseudogap in the normal state that decreases monotonically with increasing hole doping and closes at $x \approx 0.19$ holes per planar CuO_2 while the superconducting doping range is $0.05 < x < 0.27$ with optimal T_c at $x \approx 0.16$. Using ab initio quantum calculations at the level that leads to accurate band gaps, we found that four-Cu-site plaquettes are created in the vicinity of dopants. At $x \approx 0.05$ the plaquettes percolate, so that the Cu dx2y2/O pσ orbitals inside the plaquettes now form a band of states along the percolating swath. This leads to metallic conductivity and below T_c to superconductivity. Plaquettes disconnected from the percolating swath are found to have degenerate states at the Fermi level that split and lead to the pseudogap. The pseudogap can be calculated by simply counting the spatial distribution of isolated plaquettes, leading to an excellent fit to experiment. This provides strong evidence in favor of inhomogeneous plaquettes in cuprates.

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http://pubs.acs.org/doi/abs/10.1021/jz200916t
http://arxiv.org/abs/1110.2816
J. PHYS. CHEM. LETT. vol 1, 1290-1295 (2010)
PHYS. REV. B 76, 014514 (2007)

P1-67 Spin excitations in layered antiferromagnetic metals and superconductors - ***W. Rowe, P. Hirschfeld (Department of Physics, University of Florida), I. Eremin (Institute fuer Theoretische Physik III, Ruhr-Universitaet Bochum), J. Knolle (Max-Planck-Institut fuer Physik komplexer System)***

In high-temperature superconducting materials, spin fluctuations are one of the most promising candidates for mediating superconducting pairs. We start with a one-band model in the pure spin density wave (SDW) state and in the coexistence state of SDW and superconductivity. By changing the chemical potential we study the evolution of the Fermi surfaces, SDW order parameter, and superconducting gap sizes with doping and calculate the spin excitations in the coexistence phase of AF and d-wave superconductivity, motivated by the electron-doped cuprates.

P1-68 Temperature and orientation dependent 17O NMR measurements of HgBa2CuO4+y single crystals -***A. Mounce, S. Oh, W. Halperin (Northwestern University), M. Chan, L. Ji, M. Greven (University of Minnesota), D. Xia, X. Zhao (University of Minnesota, Jilin University)***

The high superconducting transition temperature and the simple tetragonal structure of $HgBa_2CuO_{4+y}$ (Hg1201) makes this material an ideal candidate to study unconventional superconductivity in the cuprates[1]. Nuclear magnet resonance has been performed on Hg1201 single crystals which have been annealed in an ^{17}O atmosphere to various dopings. Spectra are sufficiently narrow to resolve both planar and the apical oxygen. Above T_c = 70 K for an under doped crystal, the spectral shift of the planar oxygens decreases with temperature, characteristic of the pseudogap while the apical oxygen has no shift above T_c, to an accuracy of a few Gauss, contrary to the behavior of other off-planar nuclei in different cuprates. Below Tc both oxygen sites exhibit a decrease of the spin shift consistent with singlet pairing. The orientation dependent shifts are examined in the context of circulating orbital currents[2] in the pseudogap state, observed by neutron scattering[3], which have been predicted to exhibit an additional ~200 Gauss local field[4].

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P1-69 Charge Stripe Correlations in Cuprate Superconductors - ***S. Wilkins, M. Dean, M. Hucker, G. Gu, J. Tranquada, J. Hill (Brookhaven National Laboratory), V. Soltwisch, E. Weschke, E. Schierle (Helmholtz-Zentrum Berlin für Materialien und Energie), N. Ichikawa (Kyoto University), J. Fink, J. Geck (Leibniz-Institute for Solid State and Materials Research Dresden), S. Uchida (University of Tokyo)***

One-dimensional modulations of charge and spin, so-called stripes are ubiquitous in the cuprates. These modulations are closely tied to the physics of these materials: they have been linked to the broken symmetry present in the pseudogap phase of the high Tc cuprates, and even the pairing mechanism of superconductivity itself. Resonant soft x-ray scattering is an excellent tool for the study of electronic ordering in these materials, as it directly measures the hole distribution. We will present soft x-ray scattering results comparing the prototypical stripe ordered cuprates LBCO and LNSCO.We find, surprisingly that the amplitude of both the electronic modulation of the hole density and the strain modulation of the lattice is significantly larger in LBCO than in LNSCO and is also better correlated. We find that the modulations are temperature independent in LBCO in the low temperature tetragonal phase while in contrast, in LNSCO, the amplitude grows smoothly from zero, beginning 13 K below the LTT phase transition. We speculate that it is the reduced average tilt angle in LBCO which results in reduced charge localization and incoherent pinning, leading to the longer correlation length and enhanced periodic modulation amplitude. Finally, we will present further experiments on charge correlations other cuprate systems such as LSCO and YBCO.

Wilkins et al., Phys. Rev. B 84, 195101 (2011)

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P1-70 Anisotropic Fermi surface reconstruction in the underdoped cuprate YBCO - ***G. Grissonnanche, N. Doiron-Leyraud, F. Fallah Tafti, O. Cyr-Choinière, F. Laliberté, S. René de Cotret, E. Hassinger, L. Taillefer (Université de Sherbrooke), B. Ramshaw, R. Liang, D. Bonn, W. Hardy (University of British Columbia)***

The in-plane anisotropy of the Seebeck effect was measured in the orthorhombic cuprate superconductor $YBa_2Cu_3O_y$ in the underdoped regime. We find a strong anisotropy in the way the Seebeck coefficient drops from positive at high temperature to negative at low temperature. This sign change is a result of a Fermi-surface reconstruction attributed to the onset of stripe order at low temperature [1]. The in-plane anisotropy reveals the unidirectional character of the Fermi surface reconstruction, and hence of its underlying cause. We discuss the possible connection between this in-plane anisotropy of the Seebeck response at low temperature and the strong in-plane anisotropy of the Nernst response reported to onset at the pseudogap temperature T^* in underdoped $YBa_2Cu_3O_y$ [2].

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P1-71 Fermi surface reconstruction by stripe order in cuprate superconductors - ***F. Laliberté (Université de Sherbrooke), K. Behnia (École supérieure de physique et de chimie industrielles), I. Sheikin (Laboratoire National des Champs Magnétiques Intenses, Grenoble), D. LeBoeuf, L. Malone, C. Proust (Laboratoire National des Champs Magnétiques Intenses, Toulouse), R. Daou (Max Planck Institute for Chemical Physics of Solids), J. Chang (Paul Scherrer Institut), N. Doiron-Leyraud, E. Hassinger, M. Rondeau, L. Taillefer (Université de Sherbrooke), B. Ramshaw, R. Liang, D. Bonn, W. Hardy (University of British Columbia), S. Pyon, T. Takayama, H. Takagi (University of Tokyo)***

In the cuprate high-temperature superconductor YBCO, application of a magnetic field to suppress superconductivity reveals a ground state that appears to break the translational symmetry of the lattice, pointing to some density-wave order [1, 2, 3]. In another cuprate, Eu-LSCO, the onset of stripe order – a modulation of spin and charge densities – at low temperature is well established [4]. By a comparative study of thermoelectric transport in the cuprates YBCO and Eu-LSCO, we show that the two materials exhibit a very similar process of Fermi-surface reconstruction as a function of temperature and doping [5, 6]. This strongly suggests that Fermi-surface reconstruction is caused by stripe order in both cases, compelling evidence that stripe order is a generic tendency of hole-doped cuprates.

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P1-73 Magnetic field, frequency and temperature dependence of complex conductance of ultrathin La1.65Sr0.45CuO4/La2CuO4 films - ***I. Bozovic (Brookhaven National Laboratory), V. Gasparov (Institute of Solid State Physics RAS, 142432, Chernogolovka, Moscow district)***

We used atomic-layer molecular beam epitaxy to synthesize multilayer films using as blocks the layers of a cuprate metal ($La_{1.65}Sr_{0.45}CuO_4$) and a cuprate insulator (La_2CuO_4). In these heterostructures, HTS is confined to a single CuO_2 layer [1]. We have studied the magnetic field, temperature and frequency dependencies of the complex sheet conductance, s(w,T), of these films. Experiments have been carried out at frequencies between 2 MHz - 20 MHz, using a single-spiral coil technique. We found that: (i) the inductive response, L_k^{-1}(T) starts at 2K lower temperature than Res(T), characterized by a peak close to transition, and that this shift is almost constant with the magnetic field up to 8T; (ii) the vortex diffusion constant D(T) is not linear with T at low temperature range as in the case for free vortices, but is rather exponential due to pinning of vortex cores; (iii) the BKT transition temperature is the peak position of Res(T), which almost coincides with the point where $Y = (lw/x_+)^2=1$. We have compared our experimental results with the extended dynamic theory for the BKT transition, and found resemblance to the dynamics expected from bound vortex-antivortex pairs with short separation lengths.

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P1-74 ARPES-parameterized Hubbard model approach to d-wave cuprate superconductors - ***C. Galvan (Instituto de Investigaciones en Materiales, Universidad Nacional Autonoma de Mexico), L. Perez (Instituto de Fisica, Universidad Nacional Autonoma de Mexico), C. Wang (Instituto de Investigaciones en Materiales, Universidad Nacional Autonoma de Mexico)***

In the last decade, the Angle Resolved Photoemission Spectroscopy (ARPES) has achieved important advances in both energy and angular resolutions, which provide a direct measurement of the single-particle dispersion relation and superconducting gap. These dispersion relation data permit a full determination of the self-energy, first and second neighbor parameters in the Hubbard model. This model and its generalizations offer a simple and general way to describe the electronic correlation in solids. In particular, the parameters of correlated hopping interactions, responsible of the d-wave superconductivity in the generalized Hubbard model, are determined from ARPES data within the mean-field approximation. In this work, we study the doping effects on the critical temperature (Tc), d-wave superconducting gap, and electronic specific heat of cuprate superconductors, such as La_{2-x}Sr_{x}CuO_{4} [1] and Bi_{2}Sr_{2-x}La_{x}CuO_{6+\delta} [2], by solving numerically two coupled integral equations for determining the chemical potential and superconducting gap or Tc [3]. Finally, the calculated electronic specific heat without adjustable parameters is compared with experimental results.

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P1-75 Landau Levels and Quantum Oscillations in the Presence of a Modulated Pairing Gap - ***J. Berlinsky (Perimeter Institute and McMaster University), M. Zelli, C. Kallin (McMaster University)***

We consider a model of a two-dimensional metal with a superconducting order parameter that is modulated on a microscopic scale, having zero average value at some small, commensurate wave vector. Such a system will have a non-zero density of states at zero energy and a Fermi surface. In the presence of a magnetic field it exhibits Landau levels and quantum oscillations in its physical properties. An example of such a model would be a Pi-striped phase of a d-wave superconductor which has been conjectured to occur near 1/8 doping in $La_{2-x}Ba_xCuO_4$. It can also be viewed as a kind of microscopic FFLO state.
We show how the electronic states evolve as a function of the amplitude of the modulated gap and of the applied magnetic field, based on the results of Bogoliubov-deGennes calculations. We also describe a semi-classical picture of the motion of quasiparticles around closed orbits. The Fermi surface itself evolves from the underlying band structure through Andreev-Bragg scattering by the modulated pairing gap. Quantum oscillations arise from orbits around closed sections of the reconstructed Fermi surface as well as from orbits involving magnetic breakdown tunneling between different sections of Fermi surface. For a wide range of parameters, this model displays both the Fermi arcs in zero field and the small area associated with quantum oscillations at large fields that are observed in the cuprates. A comparison is made of this theory to data for quantum oscillations in the specific heat of YBCO measured by Riggs et al.

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P1-76 Quantum Oscillations in Vortex-liquids - ***S. Banerjee, S. Zhang, M. Randeria (Department of Physics, The Ohio State University, 191 W. Woodruff Avenue, Columbus, OH 43210***

Motivated by observations of quantum oscillations in underdoped cuprates [1], we examine the electronic density of states (DOS) in a vortex-liquid state, where long-range phase coherence is destroyed by an external magnetic ?eld H but the local pairing amplitude survives. We note that this regime is distinct from that studied in most of the recent theories, which have focused on either a Fermi liquid with a competing order parameter or on a d-wave vortex lattice. The cuprate experiments are very likely in a resistive vortex-liquid state. We generalize the s-wave analysis of Maki and Stephen [2] to d-wave pairing and examine various regimes of the chemical potential, gap and ?eld. We ?nd that the (1/H) oscillations of the DOS at the chemical potential in a d-wave vortex-liquid are much more robust, i.e., have a reduced damping, compared to the s-wave case. We critically investigate the conventional wisdom relating the observed frequency to the area of an underlying Fermi surface. We also show that the oscillations in the DOS cross over to a √H behavior in the low ?eld limit, in agreement with the recent specific heat measurements [3].

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P1-77 Signatures of incipient order in the pseudogap phase of underdoped cuprates - ***E. da Silva Neto (Princeton University), J. Wen, Z. Xu, G. Gu (Brookhaven National Laboratory), S. Ono (Central Research Institute of Electric Power Industry), P. Aynajian, A. Gyenis, C. Parker, A. Yazdani (Princeton University)***

We investigate the spatial and momentum structure of electronic excitations in underdoped samples of the high-temperature superconductor $Bi_2Sr_2CaCu_2O_{8+x}$ using spectroscopic mapping with the scanning tunneling microscope. A defining feature of the electronic states in these samples is a strong Cu-O bond oriented modulation of the local density of states (Q*). Characterizing Q* as a function of energy, we have established that it has phase coherence consistent with incipient electronic order.[1] Temperature dependent studies show Q* to appear at the onset of the pseudogap phase at T*, above the regime attributed to fluctuating superconductivity. The doping dependence also reveals that the modulations are strongest in intensity around 1/8 doping, suggesting its relation to incipient stripe order. These measurements can be contrasted with model calculations that include both the effects of impurity-induced quasiparticle scattering and incipient order.[2] Remarkably, the model calculations reproduce the energy-dispersion of the measured Q* below and above T_c near optimal doping — where incipient order effects are weak. To extend our understanding to the deeply underdoped samples, where incipient order appears to be stronger, we have carried out a new high-resolution experiment, which reveals a strong electron-hole asymmetry in these samples. The connection between this newly discovered feature of electronic modulations in underdoped samples and the incipient order will be discussed.[3]

This work is support by Office of Basic Energy Science of the DOE.
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P1-78 Thermal Hall effect in the underdoped cuprate YBCO - ***O. Cyr-Choinière (Université de Sherbrooke), C. Proust (LNCMI-Toulouse), F. Laliberté, S. Dufour-Beauséjour, G. Grissonnanche, R. Gordon, N. Doiron-Leyraud, L. Taillefer (Université de Sherbrooke), B. Ramshaw, R. Liang, D. Bonn, W. Hardy (University of British Columbia)***

The thermal Hall (Righi-Leduc) effect was measured in the cuprate superconductor $YBa_2Cu_3O_y$ at a doping p = 0.11, as a function of magnetic field H up to 29 T. At temperatures well below the zero-field superconducting T_c, the thermal Hall conductivity k_{xy} is positive at low field and then turns over to become negative at fields above 15 T. The negative k_{xy} is consistent with the negative Hall and Seebeck coefficients observed in the normal state above 25 T [1, 2]. This further supports our interpretation: the Fermi surface of $YBa_2Cu_3O_y$ contains a small electron-like pocket [3] in that region of the phase diagram, the result of a Fermi-surface reconstruction attributed to stripe order [2, 4]. The fact that k_{xy} changes sign at $H \approx 15$ T is consistent with a scenario of phase competition whereby stripe order emerges only at finite field, in agreement with recent NMR studies that detect the onset of charge-stripe order above 15 T [5].

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P1-79 THz Spectroscopy of overdoped Y(1-x)Ca(x)Ba(2)Cu(3)O(7-y) thin films - ***E. Farber, N. Bachar (Ariel University Center of Samaria, Ariel)***

Complex conductivity of Ca doped YBCO thin films was measured in the *THz* frequency range using time domain and frequency domain spectroscopy methods. An opening of a sub-gap was observed for overdoped samples of 5% and 10% Ca doping. The sub-gap appears as a sharp decrease in the real part of conductivity at frequencies equivalent to gap energy of 1 meV and is more prominent with increased doping. We suggest that this decrease in conductivity is related to a ***d(x^2-Y^2)-wave*** pairing symmetry with an imaginary component of ***is*** or ***idxy***. The imaginary part of the conductivity shows the well known ***1/f*** behavior, but its product ***f*sigma(2)*** shows a dip in the spectrum at about 1meV.

P1-80 Coupling of Smectic Modulations to Intra–Unit-Cell Nematicity in Cuprates - ***M. Lawler (Binghamton University, Cornell University), E. Kim (Cornell University), J. Davis (Cornell University, Brookhaven National Lab, University of St. Andrews), K. Fujita (Cornell University, Brookhaven National Lab, University of Tokyo), S. Sachdev (Harvard University), H. Eisaki (Institute of Advanced Industrial Science and Technology, Tsukuba), J. Zaanen (Universiteit Leiden), A. Mesaros (Universiteit Leiden, Cornell University), S. Uchida (University of Tokyo)***

There is accumulating evidence that the pseudo gap phase is spatially anisotropic, a symmetry breaking known as nematic order[1-3]. However, it is not known if this symmetry breaking is formed by stripes or arises from another mechanism. I will present our investigations into the coexistence of nematic order and "smectic modulations" in STM data on under-doped BSCCO. I will show that nematic order exists over at least 40 nm[3], that the degree of this anisotropy is impacted by local variations in the smectic modulations[4] and that the two forms of spatial organization peacefully coexist. We proposed a Landau functional that explains these observations. By testing it with a simulation of smectic topological defects, surprisingly the data is best fit with a strong coupling between the phase of the smectic waves and the nematic order parameter. These results strongly support a strongly coupled view of nematic order; that it arises in the pseudo gap phase from the melting of stripes.

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P1-81 Signatures of orbital loop currents in the spatially resolved local density of states - ***B. Andersen (University of Copenhagen), W. Atkinson (Trent University), W. Nielsen (University of Copenhagen)***

The understanding of the pseudogap phase in cuprate materials constitutes an outstanding challenge in condensed matter physics. At present, it remains unsolved whether the phase is caused by singlet formation naturally exhibited in strong-coupling models, or rather by an elusive long-range ordered phase. Polarized neutron scattering measurements have suggested that intra-unit cell antiferromagnetism is associated with the pseudogap phase. Assuming that loop current order is responsible for the observed magnetism, we calculate some signatures of such circulating currents in the local density of states around a single non-magnetic impurity in a coexistence phase with superconductivity. We find a distinct 90 degree rotational symmetry breaking near the disorder which is also evident in the quasi-particle interference patterns. The origin of this signature of loop order in the local density of states comes from a momentum-selective shift of the Dirac cones in the presence of both d-wave superconductivity and circulating currents.

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P1-82 PRODUCTION AND CHARACTERIZATION OF THE TYPE SUPERCONDUCTING PEROVSKITES Tr3Ba5Cu8O18 (Tr= Yb, Sm, Dy, Ho, Gd) - ***C. Parra Vargas (Universidad Pedagógica y Tecnológica de Colombia, Tunja- Colombia), A. Rosales Rivera, N. Salazar H. (Universidad Nacional de Colombia- Sede Manizales), O. Ortiz Diaz, J. Otalora Acevedo, D. Marinez Buitrago (Universidad Pedagógica y Tecnológica de Colombia, Tunja-Colombia), D. Marques, J. Aguiar (Universidade Federal de Pernambuco)***

In this work we report the synthesis and characterization of the system $RE_3Ba_5Cu_8O_{18}$ (RE= Yb, Sm, Dy, Ho, Gd), in order to reproduce the results reported by A. Aliabadi et. al. about the Tc ≅ 100K for the superconducting system $Y_3Ba_5Cu_8O_{18}$ and

[1,2], to evaluate the superconductor behavior of $RE_3Ba_5Cu_8O_{18}$ samples (RE= Yb, Sm, Dy, Ho, Gd). The system $RE_3Ba_5Cu_8O_{18}$ (RE= Yb, Sm, Dy, Ho, Gd), was produced by the method of solid state reaction following a thermal process similar to that used for the superconductor RE:123 and different to that used by Aliabadi. The experimental results obtained by the technique of X-Ray Diffraction and Rietveld analysis show that these samples have the expected crystal structure (Pmm2). On the other hand, the magnetization measurements of samples produced ensure the superconductor transition in the system $RE_3Ba_5Cu_8O_{18}$ (RE= Yb, Sm, Dy, Ho, Gd), with critical temperatures near Tc = 92K. This work opens a new avenue of research in the area of superconductivity for systems RE:358.

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P1-83 High Field SANS measurements of the structure and melting of the Vortex Lattice in YBa2Cu3O7 - ***T. Forgan (School of Physics and Astronomy, University of Birmingham, Birmingham), C. Dewhurst (Institut Laue-Langevin, 6 rue Jules Horowitz, 38042 Grenoble), T. Loew (Max Planck Institut fuer Festkoerperforschung, D-70569 Stuttgart), J. White, J. Gavilano (Paul Scherrer Institut, Villigen PSI, CH-5232), A. Cameron, A. Holmes, E. Blackburn (School of Physics and Astronomy, University of Birmingham), A. Erb (Walther Meissner Institut, BAdW, D-85748 Garching)***

Using a recently-commissioned beamline cryomagnet[1] capable of small-angle measurements at fields up to 17 T, we report on small angle neutron scattering (SANS) measurements of the vortex lattice (VL) in de-twinned highly-oxygenated $YBa_2Cu_3O_7$ between 8 and 16.7 T with the field applied parallel to the ***c*** axis. In this field range, the vortices form a rhombic lattice with a field-dependent structure. On increasing the field, the angle between the vortex lattice vectors *passes through* 90 degrees, corresponding to a square structure, with no sign of a lock in transition. We also report on measurements approaching the VL melting transition, which appears to be first order (with a small amount of smearing due to slight sample inhomogeneity) at all measured fields. The irreversibility line (at which the motion of the vortex lattice is pinned) lies well *below* the melting line in this material. Interestingly, the vortex lattice *improves* in perfection as the sample is heated above the irreversibility line towards the melting line, although the intensity of the signal due to the VL falls rapidly on approaching the melting line. No sign of a signal from a vortex liquid is seen above the melting temperature.

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P1-84 Growth of Heteroepitaxial La2-xSrxCuO4/La0.67(Ca,Sr)0.33MnO3 Superlattices using Pulsed Laser Deposition - ***S. Das (University of Fribourg, Department of Physics and Fribourg Centre for Nanomaterials, Chemin du Musee, CH-1700 Fribourg.), C. Schneider (Materials Group, Paul Scherrer Institut, CH-5232 Villigen), I. Marozau, M. Uribe Laverde, C. Bernhard (University of Fribourg, Department of Physics and Fribourg Centre for Nanomaterials, Chemin du Musee 3, CH-1700 Fribourg)***

The complex interplay between the competing SC and FM order parameter across the interface of high T_c superconductor and ferromagnetic manganite layers in $YBa_2Cu_3O_7/La_{0.67}Ca_{0.33}MnO_3$ superlattices has lead to the observation of a number of intriguing phenomena e.g. a giant magnetoresistance[1] and a magnetic proximity effect[2-4]. Here we present the growth of superlattices which contain instead of $YBa_2Cu_3O_7$ the cuprate high T_c superconductor $La_{2-x}Sr_xCuO_4$(LSCO). The latter has a simpler crystallographic structure and offers access to a wide doping range by controlling the Sr doping concentration. In our poster we shall present the Pulsed Laser Deposition growth of $La_{2-x}Sr_xCuO_4$(x=0.15,0.2) thin films on $SrLaAlO_4$ (001) substrates.We have applied a new approach of using pure N_2O as the background gas to obtain stoichiometric samples. The film growth has been monitored and characterized by *in-situ* RHEED as to ensure a layer-by-layer growth. The samples exhibit excellent metallic properties with a superconducting transition temperature of T_c(R=0ohm)=36K for the optimally doped sample. Moreover we have managed to grow ultrathin (~10nm) samples without reducing the superconducting transition temperature. X-ray diffraction analysis reveals that the samples are highly c-axis oriented and have excellent crystallinity. Subsequently, we developed heteroepitaxial $La_{2-x}Sr_xCuO_4/La_{0.67}(Ca,Sr)_{0.33}MnO_3$superlattices. A brief overview of their transport, magnetic as well as structural properties will also be presented in this poster.

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P1-85 Search for spontaneous magnetism near the surface of (110)-oriented YBCO films using LE-μSR - ***H. Saadaoui (Laboratory for Muon-Spin Spectroscopy, Paul Scherrer Institute, CH-5232 Villigen PSI), H. Huhtinen (Department of Physics, University of Turku, FIN-20014 Turku), E. Morenzoni, Z. Salman, T. Prokscha, A. Suter (Laboratory for Muon-Spin Spectroscopy, Paul Scherrer Institute, CH-5232 Villigen PSI)***

We report the results of an experiment to search for spontaneous magnetization due to a time reversal symmetry breaking phase in the superconducting state of (110)-oriented YBa$_{2}$Cu$_{3}$O$_{7-\delta}$ (YBCO) films, expected to develop near the [110] surface. Zero and weak transverse field measurements are performed using Low-Energy muon spin rotation (\lem) technique few nm to 120 nm inside the optimally-doped films. These results showed no appearance of spontaneous magnetization below the superconducting temperature up to 2.9 K. Our results give an upper limit of 0.01 mT for spontaneous internal fields in these films.

P1-86 Magnetoresistance of Y-Ba-Cu-O nano wires - ***D. Levi, A. Shaulov, Y. Yeshurun (Department of Physics, Institute of Superconductivity and Institute of Nanotechnology and Advanced Materials, Bar-Ilan University)***

We patterned wires of width 50 – 500 nm on laser ablated 20 nm thick $YBa_2Cu_2O_{7-\delta}$ films. Measurements of the resistance versus temperature revealed broadening of the transition as the wire width decreases. For wire widths below 80 nm no transition to a superconducting state was observed. The observed behavior is reminiscent of thermal and quantum phase slips. Moreover, analysis of the data is consistent with the phase slips scenario. However, the granular nature of the film questions this interpretation. An alternative explanation will be discussed.

P1-87 Many-body effects in high Tc materials: the anomalous magnetic susceptibility and the jump of specific heat in the pseudogap region - ***A. Troper (Centro Brasileiro de Pesquisas Fisicas), S. Magalhães (Federal Fluminense University), C. Lobo, E. Calegari (University of Santa Maria)***

Anomalous properties of the normal state of a strongly correlated electron system described by an attractive extended Hubbard model are investigated. We use two-pole approximation [1] which leads to a set of correlation functions. In particular, the antiferromagnetic correlation function $<S_i.S_j>$ plays an important role as a source of anomalies in the normal state of the model. The uniform static magnetic susceptibility as a function of occupation n_T and temperature is calculated. At low temperatures, the susceptibility presents a peak for n_T~ 0.80 in the region where a van Hofe singularity appears in the density of states.. Our results suggest the onset of short range antiferromagnetic correlations as a mechanism for the pseudogap [2,3]. The Fermi surface is presented for different dopings. Above n_T~ 0.80 the ordinary Fermi surface evolves to a hole-pocket with pseudogaps near the antinodal points (0,π) and (π,0).

We have also calculated the specific heat as a function of temperature T and occupation n_T . Our results show the appearance of a pronounced peak for T/|t|~[0,1.], t being the next neighbor hopping. This peak appears also in the region where the van Hove singularity of the density of state occurs. Another smaller peak appears at different temperature, which we attribute to charge fluctuations [4]. The presence of such peak can be enhanced when pressure is applied (compressibility effect). In fact using $t_2/|t| \neq 0$, t_2 being next-nearest neighbor, one gets this effect.

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P1-88 Kinetics-Driven Superconducting Gap in Underdoped Cuprate Superconductors Within the Strong-Coupling Limit - ***W. Ku, Y. Yildirim (Brookhaven National Laboratory)***

A generic theory [1] of the quasiparticle superconducting gap in underdoped cuprates is derived in the strong-coupling limit, and found to describe the experimental ``second gap'' in absolute scale. In drastic contrast to the standard pairing gap associated with Bogoliubov quasiparticle excitations, the quasiparticle gap is shown to originate from anomalous kinetic (scattering) processes, with a size unrelated to the pairing strength. Consequently, the k dependence of the gap deviates significantly from the pure $d_{x^2-y^2}$ wave of the order parameter. Our study reveals a new paradigm for the nature of the superconducting gap, and is expected to reconcile numerous apparent contradictions among existing experiments and point toward a more coherent understanding of high-temperature superconductivity.

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P1-89 Evolution of a bosonic mode across the superconducting dome in the high-Tc cuprate Pr2-xCexCuO4-delta - ***I. Diamant (Raymond and Beverly Sackler school of Physics and Astronomy, Tel Aviv University), S. Hacohen-Gourgy, Y. Dagan (Raymond and Beverly Sackler school of Physics and Astronomy, Tel-Aviv University)***

Despite intense scientific effort, high Tc superconductivity in the cuprates is still a puzzle. Several theoretical possibilities were suggested as the mechanism responsible for the pairing in these compounds, including: paring by lattice vibrations and by magnetic excitations. However, no conclusive evidence was found to resolve the longstanding problem.

The properties of the high T_c cuprates strongly depend on doping (holes or electrons). While most of the scientific effort has been focused on the hole-doped side of the phase diagram, electron-doped cuprates seem easier to understand. These cuprates exhibit an accessible critical magnetic field and a relatively low T_c. This makes it possible to probe both the superconducting and the normal state.

We study the electron doped cuprate superconductor $Pr_{2-x}Ce_xCuO_{4-delta}$ by point contact spectroscopy. We measure three different doping levels: under doped x=0.125, optimally doped x=0.15 and over doped x=0.17. In the conductance spectra we are able to identify bosonic excitations above the superconducting energy gap. These excitations disappear above the critical magnetic field.

We analyze the energy at which these features appear in terms of a strong electron-boson coupling theory. We find that the energy of the excitations decreases with doping. This suggests that spin excitations are more likely to be the bosonic mediator for electron pairing in these cuprates.

I. Diamant *et al.* PRB **84**, 104511 (2011)

P1-91 Persistence of the pseudogap below Tc and disappearance of the kinetic energy change in YBa2(Cu,Zn)3Oy - ***S. Tajima, E. Uykur, T. Masui, K. Tanaka, S. Miyasaka (Dept. of Physics, Osaka University)***

The c-axis polarized optical spectra provide useful information about the electronic state near the anti-nodal region of the Fermi surface which characterizes the unusual electronic properties of high Tc superconductors (HTSC). Among all the HTSC, YBa2Cu3Oy (YBCO) is the most appropriate system to study the c-axis optical spectra because of its large c-axis conductivity.

However, a huge structure of the transverse Josephson plasma (TJP) mode appearing at low T introduces complication in analyzing the spectra.

In this work, using lightly Zn-doped YBCO where the TJP is well suppressed[1], we precisely investigated the T-dependence of c-axis optical spectra over a wide energy range. We got two interesting results. One is the clear evidence for continuous development of the pseudogap with decreasing T even below Tc, which strongly suggests the origin of the pseudogap is different from the superconducting gap. The other is that the change of kinetic energy at Tc completely disappears with Zn-doping. The latter observation is similar to the recent report of the magnetic field effect on the interlayer phase coherence[2].

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P1-92 Magneto-optical signatures of a cascade of transitions in La_{1.875}Ba_{0.125}CuO_4 - ***H. Karapetyan (Stanford University), M. Hucker, G. Gu, J. Tranquada (Brookhaven National Laboratory), M. Fejer, A. Kapitulnik (Stanford University), J. Xia (University of California, Irvine)***

Recent experiments in the original cuprate high temperature superconductor, La$_{2-x}$Ba$_x$CuO$_4$, have revealed a remarkable sequence of transitions [1]. Here we investigate such crystals with polar Kerr effect using a Sagnac interferometer [2], which is sensitive to time-reversal-symmetry breaking (TRSB). Concurrent birefringence measurements accurately locate the structural phase transitions from high-temperature tetragonal to low temperature orthorhombic, and then to lower temperature tetragonal, at which temperature a strong Kerr signal onsets. Hysteretic behavior of the Kerr signal suggests that TRSB occurs well above room temperature, an effect that was previously observed in high quality YBCO crystals [3]. Our observations clearly highlight the connection between magnetic and TRSB effects and charge and spin-ordering in La$_{2-x}$Ba$_x$CuO$_4$ and possibly in all HTSC, in particular single-layer BSCO [4]. We see that charge order appears to be the leading order that both competes and coexists with the bulk superconductivity.

This work was supported by the U.S. DOE, Office of Basic Energy Sciences, under contract DEAC02-76SF00515.

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P1-93 Superconducting coherence along c-axis in the stripe phase of high-Tc cuprates - ***K. Tanaka, Y. Sakai, T. Miyake, S. Miyazaki, S. Miyasaka, S. Tajima, M. Tonouchi (Osaka university), T. Sasagawa (Tokyo Institute of Technology)***

Recently, a two-dimensional superconducting state has been reported from transport studies in the stripe-ordered $La_{2-x}Ba_xCuO_4$ with x = 1/8 [1]. This is consistent with the results of *c*-axis (E//*c*) infrared optical studies for $La_{2-x}Ba_xCuO_4$ and $La_{2-x-y}Nd_ySr_xCuO_4$, that the Josephson plasma edge originating from the Josephson coupling of the CuO_2 planes disappears in the stripe phase [2]. These results indicate the disappearance of the superconducting coherence along *c*-axis and the decoupling of the CuO_2 planes. To clarify the universality of this phenomena, we performed terahertz time-domain spectroscopy (THz-TDS) measurement, in which one can obtain lower frequency information than the conventional Fourier transform type spectrometer, on static stripe-ordered $La_{1.84-y}Eu_ySr_{0.16}CuO_4$ (y = 0, 0.1, 0.2) and $La_{2-x-y}Nd_ySr_xCuO_4$ (x=0.125, 0.16, y=0.1~0.5), where the stability of the stripe phase can be controlled by y. We found that the Josephson plasma edge shows systematic shift to the lower frequency with increasing y and survives in the extremely low frequency region in the stripe-ordered phase. By comparing the superfluid density along c-axis and in-plane, we conclude that the system is not going toward two-dimensional superconducting state with stabilizing the stripe order.

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P1-94 Carrier doping into bulk polycrystalline oxides by using a field effect transistor structure - ***A. Tsukada, K. Saiki, N. Miyakawa (Department of Applied Physics, Tokyo University of Science)***

Electronic double layer field-effect transistors (EDLFETs) were fabricated on bulk ZnO, SnO_2, and In_2O_3. Pellet-shape samples were prepared from commercially available ZnO SnO_2, and In_2O_3 powders. Mixtures of potassium perchlorate and polyethylene oxide (PEO+$KClO_4$), or ionic liquid (DEME-TFSI) were used as a gate insulating material.

Four order of magnitude of resistance at room temperature for SnO_2 decreased with increasing the gate voltage. Temperature dependence of resistance changes from semiconducting to metallic. Similar results were observed for ZnO and In_2O_3. However, some EDLFETs were not worked. Comparison of SEM images between the not worked and worked samples revealed that surface of not worked samples were porous and size of grains was small. The porous or small grain samples absorb the gate insulating material and it might degrade the property of EDLFETs. Our result indicates that requirement of flatness of sample, which is one of a restriction to fabricate FETs, is not so severe for EDLFETs, but dense material is required to prevent penetration of the gate insulating material. Hence, single crystal is better for EDLFETs. With respect to gate insulator, PEO+$KClO_4$ give a better result for porous samples. Efficiency of EDLFETs with PEO+$KClO_4$ is worse than that of DEME-TFSI, but PEO+$KClO_4$ stays at surface of porous samples due to viscosity.

EDLFETs were also fabricated on undoped cuprates T'-$La_{2-x}Eu_xCuO_4$. Presence of impurity oxygen in the T'-cuprates makes difficult to clarify the origin of carriers in undoped cuprates because reduction process of impurity oxygen also removes regular oxygen. Conductivity of T'-$La_{2-x}Eu_xCuO_4$ increases with increasing doping by EDLFETs but the system was not superconducting.

P1-95 Pseudogap and electron-boson coupling in single layer HgBa2CuO4 - *S. Mirzaei, D. Stricker, D. vander Marel (Universite de Geneve), S. Dordevic (University of Akron), M. Chan, X. Zhao, M. Greven, N. Barisic (University of Minnesota)*

The single layer compound HgBa2CuO4 is one of the cleanest and simplest representatives of the cuprate high Tc superconductors. Studies in recent years using inelastic neutron scattering and optical spectroscopy have revealed the presence of a conspicuous sharp magnetic collective mode in the 60-meV range. Optical studies of optimally doped samples have indicated strong coupling of modes of the same energy to the free charge carriers.

We measured the optical conductivity of strongly underdoped single crystals HgBa2CuO4. The frequency dependent scattering rate and effective mass show distinct changes at the pseudogap temperature. Analysis of the electron-boson coupling function reveals the presence of a low energy component peaked at approximately 60 meV, and a second high energy component peaked at 0.25 eV. Electronic collective modes are the only plausible candidates for the latter, in view of their high energy. The former component exhibits conspicuous temperature dependence with distinct changes associated at the pseudogap temperature, indicating that also this part of the electron-boson coupling function has a strong electronic component. It thus appears that electron-phonon coupling, while present in the cuprates as revealed by isotope substitution, constitute an interaction of minor importance for the optical properties of the cuprates.

P1-96 Broken-symmetry nature of the pseudogap in Bi2212 studied by angle-resolved photoemission spectroscopy - *M. Hashimoto (SSRL, SLAC National Accelerator Lab.), R. He, Z. Hussain (ALS, LBNL), Y. Yoshida, H. Eisaki (Nanoelectronics Research Institute, AIST), M. Ishikado (Quantum Beam Science Directorate, Japan Atomic Energy Agency), R. Moore (SIMES, SLAC), D. Lu (SSRL, SLAC), T. Devereaux, Z. Shen (Stanford University)*

The nature of the pseudogap, which persists above Tc in cuprate high-Tc superconductors, is one of the most important subject in the field of condensed matter physics. Our recent studies [1,2] have suggested that the pseudogap is a new distinct phase with symmetry breakings by applying three experimental techniques, angle-resolved photemission spectroscopy (ARPES), Kerr effect measurement, and time-resolved reflectivity (TRR) to a single-layer cuprate Bi2201. In this study, we have measured a double-layer cuprate Bi2212 for several doping levels using ARPES to confirm that the observed symmetry breakings in the ARPES spectra (misalignment of the dispersion back-bending in the pseudogap state and the Fermi momentum kF in the true normal state above the pseudogap temperature T*). The results of detailed temperature dpendence study suggest that a similar misalignment of the back-bending and kF exist in the ARPES spectra of the antinodal region of Bi2212 for different dopoing levels.Our results suggest that the broken symmetry nature is not only in Bi2201, but a more generic feature in cuprate superconductors.

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P1-97 Low-field current-voltage characteristics YBCO near Tc - *M. Vasyutin, N. Kuzmichev (Machine-Construction institute, Mordovian University)*

The current-voltage characteristics (CVC's) of a high-temperature superconductor (HTSC) $YBa_2Cu_3O_{7-x}$ (YBCO) near to temperature of transition in a superconducting state in a low magnetic field (? < 150 Oe) are investigated. Characteristic sharp change of kind CVC's is revealed at the certain current depending on temperature and a magnetic field. Two alternative models are proposed.

P1-98 Superconducting properties of ternary (Nd,Sm,Gd)-Ba-Cu-O filaments with different Nd/Sm/Gd ratio in magnetic fields - *Y. Ikebe, E. Ban (Department of Materials Science and Engineering, Meijo University), H. Oguro, S. Awaji (Institute for Materials Research, Tohoku University)*

The effect of initial composition on superconducting properties and microstructure for ternary (Nd,Sm,Gd)-Ba-Cu-O filaments was investigated. Precursor filaments with $(Nd_{0.33}Sm_{0.33}Gd_{0.33})_{1.18}Ba_{2.12}Cu_{3.09}O_y$, $(Nd_{0.50}Sm_{0.25}Gd_{0.25})_{1.18}Ba_{2.12}Cu_{3.09}O_y$, $(Nd_{0.25}Sm_{0.50}Gd_{0.25})_{1.18}Ba_{2.12}Cu_{3.09}O_y$ and $(Nd_{0.25}Sm_{0.25}Gd_{0.50})_{1.18}Ba_{2.12}Cu_{3.09}O_y$ prepared by a solution spinning method were partially melted at temperature range of 1020-1090 °C in flowing 0.1%O_2+Ar atmosphere gas. All samples after heat treatment showed dense microstructure with well aligned texture along the filament diameter as well as the direction of filament length. The J_c value higher than 10^4 A/cm^2 at 77 K and 0 T were exhibited for all samples partially melted at over a wide temperature range of 1030-1080 °C. Especially, Nd-rich sample treated at 1050 °C obtained extremely high J_c value of 7.2×10^4 A/cm^2, although normal composition, Sm-rich and Gd-rich samples treated at 1050 °C showed the J_c value around 2.5×10^4 A/cm^2. Furthermore, we investigated the field dependence of J_c at ranging from 77 to 90 K for filamentary samples. The superconductivity of normal composition, Nd-rich and Gd-rich composition samples disappeared in applied magnetic field from 10 to 15 T at 77 K. In contrast, the Sm-rich sample maintained high $J_c$value of 0.7×10^4 A/cm^2 in applied magnetic field up to 17 T. From these results, it was found that the Nd-rich and Sm-rich composition were effective in enhancement of J_c at self-field and high magnetic field, respectively.

P1-99 Fluctuating Stripes in Strongly Correlated Electron Systems and the Nematic-Smectic Quantum Phase Transition - *B. M. Fregoso (University of Maryland), M. Lawler (Cornell University), E. Fradkin (University of Illinois at Urbana Champaign), K. Sun (University of Maryland)*

We discuss the quantum phase transition between a quantum nematic metallic state to an electron metallic smectic state in terms of an order-parameter theory coupled to fermionic quasiparticles. Both commensurate and incommensurate smectic (or

stripe) cases are studied. Close to the quantum critical point (QCP), the spectrum of fluctuations of the nematic phase has low-energy ``fluctuating stripes''. We study the quantum critical behavior and find evidence that, contrary to the classical case, the gauge-type of coupling between the nematic and smectic is irrelevant at this QCP. The collective modes of the electron smectic (or stripe) phase are also investigated. The effects of the low-energy bosonic modes on the fermionic quasiparticles are studied perturbatively, for both a model with full rotational symmetry and for a system with an underlying lattice, which has a discrete point group symmetry. We find that at the nematic-smectic critical point, due to the critical smectic fluctuations, the dynamics of the fermionic quasiparticles near several points on the Fermi surface, around which it is reconstructed, are not governed by a Landau Fermi liquid theory. On the other hand, the quasiparticles in the smectic phase exhibit Fermi liquid behavior. We also present a detailed analysis of the dynamical susceptibilities in the electron nematic phase close to this QCP (the fluctuating stripe regime) and in the electronic smectic phase.
National Science Foundation Grant No. DMR 0442537 and No. DMR 0758462 at the University of Illinois EF, Department of Energy, Division of Basic Energy Sciences under Award DE-FG02-07ER46453, the Stanford Institute of Theoretical Physics EF, and by NSERC, CIFAR, and CRC MJL.

P1-100 Phase competition in trisected superconducting dome: An ARPES study - ***I. Vishik (Stanford University), R. He (Advanced Light Source, Lawrence Berkeley National Lab), Z. Hussain (Advanced Light Source, Lawrence Berkeley National Lab, Berkeley,), K. Fujita (Cornell University), M. Ishikado (Japan Atomic Energy Agency, Tokai, Ibaraki), T. Sasagawa (Materials and Structures Laboratory,Tokyo Institute of Technology), R. Moore, T. Devereaux (Stanford Institute for Materials and Energy Science), M. Hashimoto, D. Lu (Stanford Synchrotron Radiation Lightsource), W. Lee, F. Schmitt, Z. Shen (Stanford University), C. Zhang (State Key Laboratory of Crystal MaterialsUniversity), H. Eisaki, Y. Yoshida (Superconducting Electronics Group,Electronics and Photonics Research Institute,National Institute of Advanced Industrial Scienceand Technology), W. Meevasana (Suranaree University of Technology), S. Uchida, S. Ishida (University of Tokyo)***

The momentum-resolved nature of angle-resolved photoemission spectroscopy (ARPES) has made it a key probe of emergent phases in the cuprates, such as superconductivity and the pseudogap, which have anisotropic momentum-space structure. ARPES can be used to infer the origin of spectral gaps based on their distinct phenomenology, and this principle has helped build the argument that the pseudogap is a distinct phase from superconductivity, rather than a precursor. We have studied much of the superconducting phase diagram of $Bi_2Sr_2CaCu_2O_{8+□}$ (Bi-2212) using laser-ARPES, and our data give spectroscopic evidence for three distinct quantum phases comprising the superconducting ground state in Bi-2212, accompanied by abrupt changes at p~0.076 and p~0.19 in the doping-and-temperature dependence of the gaps near the bond-diagonal (nodal) direction. The latter doping likely marks the endpoint of the pseudogap phase inside the superconducting dome, while the former represents the emergence of a distinct phase at the underdoped edge of the superconducting dome. Additionally, we find that the pseudogap advances closer towards the node when superconductivity is weak, just below T_c or at low doping, and retreats towards the antinode well below T_c and at higher doping. This momentum-space phase competition picture together with the three phase regions established at low temperature are synthesized into a revised phase diagram, which also reconciles conflicting phase diagrams commonly used in the field.
This work is supported by the Department of Energy, Office of Basic Energy Science under Contract No. DEAC02-76SF00515.

P1-101 (Sm,Gd,Dy)-Ba-Cu-O filaments fabricated by a solution spinning method - ***E. Ban, M. Sugiura, Y. Ikebe (Meijo University), H. Oguro, S. Awaji (Tohoku University)***

Investigations have been carried out on the (Sm,Gd,Dy)-Ba-Cu-O filaments fabricated by a solution spinning method via chemical route. The effects of starting composition and heat treatment conditions on superconducting properties of (Sm,Gd,Dy)-Ba-Cu-O filaments were examined. It was found that the superconducting properties of (Sm,Gd,Dy)-Ba-Cu-O filaments were strongly dependent on the starting composition, and the sample with composition of $(Sm_{1/3}Gd_{1/3}Dy_{1/3})$:Ba:Cu=1.18:2.12:3.09 melt-processed in 1%O_2+Ar showed a high J_c value of 3.6×10^4 A/m^2 at 77K, 0T. These samples thus prepared exhibited a high J_c value higher than 10^4 A/m^2 with good reproducibility, and had a dense microstructure in which fine SGD211 particles homogeneously distributed in SGD123 matrix. From the experiments on the J_c measurement in magnetic fields, J_c value in high magnetic fields and 77K was extremely enhanced for the $(Sm_{1/4}Gd_{1/2}Dy_{1/4})_{1.18}Ba_{2.12}Cu_{3.09}O_y$ samples melt-processed in 3%O_2+Ar.

P1-102 Anisotropic Photoresponse of Cuprate Superconductors - ***S. Anlage (CNAM, Physics Department, University of Maryland and CFN, Karlsruhe Institute of Technology), A. Zhuravel (B. I. Verkin Institute of Low Temperature Physics, Ukraine Academy of Sciences, Kharkov), P. Jung, O. Lukashenko, A. Ustinov (CFN, Karlsruhe Institute of Technology), J. Abrahams (CNAM, Physics Department, University of Maryland), B. Ghamsari (CNAM, Physics Department, University of Maryland), S. Remillard (Physics Department, Hope College), C. Kurter (Physics Department, University of Illinois)***

Epitaxial cuprate superconducting films have been patterned into self-resonant RF structures for use as meta-atoms in superconducting metamaterials [1]. The resonant modes of the spiral involve currents that flow uniformly around the Fermi surface [2]. We have discovered that these structures show anisotropic photoresponse at low temperatures when excited on resonance and locally heated in a laser scanning microscope. The anisotropy is consistent with that expected from the anisotropic nonlinear Meissner effect in a d-wave superconductor. We will present results on the angular and temperature dependence of the photoresponse and compare to the predictions of Dahm and Scalapino for the anisotropic nonlinear Meissner effect.

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P1-103 The effect of Y2Ba4CuBiOy addition on the properties of single domain YBCO superconductors by TSMTG technique - *X. Chao, W. Yang, P. Gao (Department of Physics, Shaanxi Normal University, Xi'an, China, 710062)*

Single domain YBCO bulk superconductors, with different $Y_2Ba_4CuBiO_y$ (YBi2411) additions, have been fabricated by top seeded melt texture growth technique (**TSMTG**). The solid phase pellet is made of a mixture of Y_2BaCuO_5(Y211) + xwt% YBi2411 powders, x=0,4,6,8,12,15,20. The growth morphology, microstructure and levitation force of the YBCO bulks have been investigated. It is found that the single domain YBCO bulks can be fabricated when YBi2411 addition x≤8wt%, When x≥8wt%, the single domain area is reduced and random nucleations are difficult to be depressed. The largest levitation force of the sample can be obtained with x=8wt%. This is closely related with the microstructure of the samples with different $Y_2Ba_4CuBiO_y$ (YBi2411) additions, which is very helpful for us to fabricate high quality YBCO bulk superconductors.

Single domain YBCO bulk Top seeded melt texture growth technique $Y_2Ba_4CuBiO_y$ addition Levitation force

P1-104 The Effect of Barium Doping on the Selective Structure of Bi-2223Phase - *H. Salamati, I. Abdolhosseini Sarsari, P. Kameli (Physics Dept. Isfahan University of Technology)*

Partial substitution of Sr by Ba in the two nominal compositions of Bi1.8Pb0.4Sr2 −*x*Ba*x*Ca2.2Cu3O*y*[*x* = 0.0, 0.1, 0.2, and 0.3 (A group)] and Bi1.66Pb0.34Sr2−*x* Ba*x*Ca2Cu3O*y* [*x* = 0.0, 0.1, 0.2, 0.3, 0.4, and 0.5 (B group)]have been investigated by resistivity, ac susceptibility measurements and by XRD and SEM analysis. In general, thenature of the temperature dependence of resistivity and susceptibility measurements indicate the presence of a superconducting transition between grains coupled by weak links.However, the XRD and SEM analyses show that the relative composition of initial elements used in Bi-(2223) is essential to the site that is selected by the Ba ions. In A group, Ba doping up to *x* = 0.1 will improve the phase formationof Bi-2223, and improve the superconductivity properties of the samples. In B group, although Ba doping up to*x* = 0.1 will enhance the phase formation of Bi-2223, it will decrease the coupling between the grain and the superconductivity properties of these systems. The presence of lowerTc phases will begin to appear for *x* >0.1, in both of these systems. The superconductivity properties and the phase formation of Bi-(2223) will decrease as the Ba concentration increases.
Isfahan University of Technology is acknowledged.

P1-105 Infrared optical properties of the cuprate superconductors: a Yang-Rice-Zhang ansatz study. - *N. Singh (Physical research Laboratory, Ahmedabad)*

In the overdoped region, optical properties of the cuprate superconductors agree, qualitatively, with BCS form for d-wave pairing. But in the pseudogap regime a number of anomalous features appear not explainable by BCS form. We analyze this using YRZ ansatz. The optical self energy is computed and compared with the experiment. We qualitatively explain the anomalous aborption band in the planar conductivity in the pseudogap state.
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P1-106 Grand-canonical Variational Studies in the Extended t-J Model - *C. Chou (Institute of Physics, Academia Sinica), F. Yang (Department of Physics, Beijing Institute of Technology), T. Lee (Institute of Physics, Academia Sinica)*

Gutzwiller-projected BCS (p-BCS) wave function in a 2D extended t-J model is investigated by using the variational Monte Carlo approach [1]. We show that the ground-state energy and excitation spectra calculated in the grand-canonical scheme allowing particle number to fluctuate are essentially the same as previous results obtained by fixing the number of particle in the canonical scheme if the grand thermodynamic potential is used for minimization. Thus, to account for the effect of Gutzwiller projection, a fugacity factor proposed by Laughlin and Anderson has to be inserted into the p-BCS state. We find that except for La-214 materials, the doping dependence of chemical potential is consistent with experimental observations on several cuprates. Similar to what has been reported by scanning tunneling spectroscopy experiments, the tunneling asymmetry becomes much stronger as doping decreases, well consistent with the results in the canonical ensemble. We also found a very large enhancement of phase fluctuation in the underdoped regime.
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This work supported by the National Science Council in Taiwan with Grant NO.98-2112-M-001-017-MY3 and NSCF under grant NO.10704008.

P1-107 Superconductor to Insulator Transition of Electrostatically Doped La2CuO4+d - *J. Garcia-Barriocanal (University Complutense of Madrid / University of Minnesota), J. Kinney, A. Kobrinskii, B. Yang, S. Snyder, A. Goldman (University of Minnesota), X. Leng (University of Minnesota / Brookhaven National Laboratory)*

The application of Field Effect Transistor (FET) concepts to electrostatically doped strongly correlated electron systems has been the focus of intense research during the last years [1] due to its potential impact on applied and basic science. From the technological point of view, the control of the charge carrier density by means of an applied electric field may provide a tool to modify the electronic and magnetic properties of novel materials in a reversible way. From a fundamental point of view, electrostatic doping would allow the systematic study of electronic correlations as a function of essential quantities such as

electrostatic repulsion, hopping amplitude, etc., without altering the level of disorder associated with conventional chemical substitution.
In this contribution I will show our recent results on Electronic Double Layer Transistor (EDLT) techniques applied to high T_C cuprates. The EDLT configuration, which employs ionic liquids as gate dielectrics, has succeeded in achieving unprecedented charge transfers, of the order of 10^{15} carriers/cm^2. This large accumulation and depletion of carriers have allowed us to explore the phase diagram of $La_2CuO_{4+\delta}$ I will focus on the physics of the superconductor to insulator transition of high quality ultrathin epitaxial films fabricated by ozone assisted Molecular Beam Epitaxy.
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P1-108 HIGH Tc IN THE ELECTRON-PHONON SYSTEM OF CUPRATES - *E. Mazur (National Research Nuclear University "MEPHI"), Y. Kagan (NRC Kurchatov Institute)*

Eliashberg theory generalized forthe account of the peculiar properties of the finite zone width electron-phonon(EP) system, the electron-hole nonequivalence, chemical potential variationwith doping, and electron correlations in the vertex function is used for thestudy of T_c in cuprates.The pairing in the full zone width, not just at the Fermisurface has been taken into account. The frequency, temperature and doping dependent complex mass renormalization ReZ, ImZ , complex chemical potential renormalization Re chi (omega), Im chi (omega), density of electron states N (epsilon) obtained using the theorydeveloped in [1], have been used tocalculate anelectron nodal anomalous Green function. High $T_c$value in the optimally hole-doped cuprates is reproduced with the moderatestrength of the electron-phonon coupling. It is shown that with the electron-hole nonequivalence degree increase the chemical potential shift and its renormalization *chi (omega)* with hole - dopinglead to the T_c increase. In the cuprates' EP system highT_c» 120K at lambda ³ 1 at the optimal level p=0.16 of hole doping and customary T_c » 0.15omega$_D$ for the same level of electrondoping has been obtained. The result obtained for the case of hole -doping may not be reproduced in a standard version of the Eliashberg theory, in which the high T_c values were obtained only for unrealistic large EP interaction constant lambda ³10. Increase in ReDelta(omega) at 0<omega<omega$_D$ due to a sharp weakening ofthe negative ReDelta (omega > omega$_D$) contribution is the crucial factor in increasing T_c in cuprates. The contribution Im *Z(z')* in T_c equations, which reflects the degree of electron-hole non-equivalence in the EP system, leads to the T_c decrease with the Im *Z(z)* increase. The competition between two above mentioned factors leads to the dome shaped T_c dependence behavior on the hole-dopingdegree in cuprates.
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P1-109 Two-dimensional Fluctuations in the Magnetization of La1.9Ca1.1Cu2O6 - *X. Shi, I. Dimitrov, G. Gu, Q. Li (Condensed Matter Physics and Materials Science Dept., Brookhaven National Laboratory)*

We report the results and analysis of a magnetization measurement with the magnetic field applied along the *c* crystallographic axis on a superconducting $La_{1.9}Ca_{1.1}Cu_2O_6$ single crystal annealed under a high oxygen pressure. Both the high-field (H = 1 – 5 T) scaling of the magnetization data based on a Ginzburg-Landau Lowest Landau Level fluctuation theory, as well as a fit of the low-field (H < 1000 Oe) magnetic susceptibility with the Lawrence-Doniach model, suggest very consistently that $La_{1.9}Ca_{1.1}Cu_2O_6$ is a *quasi*-2D superconductor. By comparing the experimental results with the 2D $Bi_2Sr_2Ca_2Cu_3O_{10}$ and 3D $YBa_2Cu_3O_{7-\delta}$systems, we suggest that the relatively high anisotropy and interspacing distance between the superconducting layers of $La_{1.9}Ca_{1.1}Cu_2O_6$ may be behind the 2D fluctuation superconductivity suggested by the analysis of the magnetization data.

P1-110 Antinodal quasi-particle scattering in Bi-2201 - *Y. He, Y. Yin, A. Soumyanarayanan, T. William, M. Zech, J. Hoffman (Harvard University), T. Kondo (Nagoya University), E. Hudson (Penn State University)*

The relationship between superconductivity and the mysterious `pseudogap' phase in the cuprate superconductors is a source of much controversy. To address this, we perform a systematic spectroscopic imaging study on the cuprate Bi2-xPbxSr2CuO6+δ using scanning tunnelling microscopy. Our studies support a competing interaction between the pseudogap phase and superconductivity in this material. Furthermore, we find an antinodal in-gap state with d-wave coherence, and attempt to understand its origin.
NSF DMR-0508812; NSF DMR-1106023

P1-111 Scanning Tunneling Spectroscopy and Vortex Imaging on Transition Metal Dichalcogenides - *P. Samuely, P. Szabo (Institute of Experimental Physics Slovak Academy of Sciences, Kosice), T. Samuely (Safarik University, Faculty of Science, Kosice), J. Rodrigo (Universidad Autonoma de Madrid)*

Many correlated electron systems, including cuprates, transition metal dichalcogenides, and iron pnictides/selenides reveal a complex phase diagram Temperature vs. doping that reflects the delicate balance of competing ground states. In the case of transition metal dichalcogenides a suppression of charge density waves order by doping or pressure may be accompanied by the emergence of a superconducting phase [1]. Anisotropic and multiband superconducting pairing including various scenarios of multigap superconductivity are at play in some of these systems as well [2]. Scanning Tunneling Microscopy and Spectroscopy - STM/S at various temperatures incl. subkelvin range as well as the superconducting Vortex Imaging has been a powerful tool of exploration of the electronic structure with extreme spatial and energy resolution in these systems. Our recent STM/S and Vortex Imaging studies on several transition metal dichalcogenides will be presented. We will compare results on $NbSe_2$, NbS_2, $(LaSe)_{1.14}NbSe_2$ and Cu_xTiSe_2.

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P1-112 Emergence of superconductivity at the structural phase boundary in platinum doped IrTe2 - *S. Pyon, K. Kudo, M. Nohara (Okayama University)*

We will report that enigmatic superconductivity emerges in transition metal dichalcogenide $IrTe_2$ when structural phase transition is suppressed by a partial chemical substitution. $IrTe_2$ is a paramagnetic metal and crystallizes in a trigonal structure ($P3$-$m1$), in which Ir ions form an equilateral triangular lattice so that three Ir-Ir bonds are equivalent. Below 250 K, an Ir-Ir bond along the *b* axis shrink, and the trigonal structure transforms to a monoclinic structure ($C2/m$) with an isosceles triangular lattice of Ir Ions [1]. Paramagnetic susceptibility and electric resistivity exhibit anomalies at the transition with a hysteresis, indicative of the first-order transition [1]. We found that the trigonal-monoclinic structural phase transition, which is accompanied by the distortion of Ir triangular lattice, is suppressed by substituting Pt for Ir. The monoclinic phase disappears for $x > 0.035$ in $Ir_{1-x}Pt_xTe_2$. At the structural critical point of $x_c = 0.035$, Debye temperature is reduced, which indicates the phonon softening at the structural phase boundary between monoclinic and trigonal phase. Furthermore, superconducting phase emerges in the narrow range of $x > x_c$. Bulk superconductivity appears for $x > 0.03$, starting from its maximum, $T_c = 3.1$ K, at $x = 0.03$, followed by a decrease in T_c. Superconductivity disappears for $x > 0.10$. These results suggest that structural fluctuations in the vicinity of the structural phase boundary can be involved in the emergence of superconductivity.

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P1-113 Pressure Dependent Anomalous Phase Transition in Ternary Superconductor Bi2Rh3Se2 - *C. Chen, H. Yang (Department of Physics, National Sun Yat-Sen University, Kaohsiung, 804 Taiwan), C. Chen, M. Chu (Center for Condensed Matter Sciences, National Taiwan University, Taipei 10617, Taiwan), C. Chan, Y. Chin, C. Huang (Department of Physics, National Sun Yat-Sen University, Kaohsiung, 804 Taiwan)*

We report temperature (2-350 K) dependent resistivity measurements under pressure (up to 22.23 kbar) and low temperature (0.4-2 K) specific-heat study on the ternary superconductor $Bi_2Rh_3Se_2$ to observe the possible coexistence of charge-density-wave (CDW) and superconductivity. Interestingly, resistive anomaly (at T_s~250 K) is shifted to high temperature with increasing pressure. This experimental finding is not consistent with the traditional CDW transition as reported previously by Sakamoto *et al*. [1]. Moreover, the temperature dependent electron diffraction measurements imply that there is a structural phase transition from space group "*C*1 2/m 1" ($T_s > 250$ K) to "*P*1 2/m 1" ($T_s < 250$ K).

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P1-114 Systematic study of Cu_{x}TiSe_{2} by ac-calorimetry - *Z. Pribulová (Institute of Experimental Physics, Slovak Academy of Sciences), G. Karapetrov (Department of Physics, Drexel University, 3141 Chestnut St., Philadelphia, PA 19104, USA), P. Baranceková Husaníková, V. Cambel (Institute of Electrical Engineering, Slovak Academy of Sciences, Dúbravská cesta 9, 841 04 Bratislava, Slovakia), J. Kacmarcík, P. Samuely (Institute of Experimental Physics, Slovak Academy of Sciences, Watsonova 47, 040 01 Košice, Slovakia)*

Phase transitions between different ground states of the material can by induced by altering the balance of competing interactions through changes in composition, pressure, or external applied magnetic field. Interplay between competing orders can lead to new materials with unexpected properties. One such class of materials where two orders compete is dichalcogenides. Namely, in $TiSe_2$ the charge density wave is suppressed when intercalated by copper and for certain concentration of Cu superconductivity emerges. We performed ac-calorimetry measurements in order to study the evolution of the specific heat C_p in the series of Cu_xTiSe_2 samples with different Cu content for two perpendicular orientations of the magnetic field with respect to crystallographic orientation of the sample. We also realized the transport measurements in both directions of the field. We will show the temperature dependences of $C_p(T)$ down to very low temperatures and analyze the data in order to determine the coupling in this material. We will also address the possibility to detect signatures of multiple gaps in the $C_p(T)$ for an optimally doped sample. The upper critical field H_{c2} has been derived from both specific heat and resistivity measurements in different magnetic fields. The temperature dependence of H_{c2} and its anisotropy will be presented.

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P1-115 Spin Orbit Coupling in Sr2RuO4 as measured by high resolution and spin resolved ARPES - *C. Veenstra, Z. Zhu, B. Ludbrook, A. Nicolaou, G. Levy, I. Elfimov, A. Damascelli (Department of Physics & Astronomy, University of British Columbia), Y. Maeno (Department of Physics, Kyoto University), H. Dil (Paul Scherrer Institute)*

Spin-triplet superconductor Sr2RuO4 has been well studied by a wide variety of techniques, yet the details of it's underlying pairing mechanism remain a mystery. The recent discovery of new features by angle resolved photoemission spectroscopy (ARPES) [1] as well as work suggesting that spin-orbit coupling (SOC) facilitates mixed parity pairing [2,3] has prompted us to investigate this material with both high resolution and spin resolved ARPES (SARPES).

As SOC may cause interesting effects on the surface, we revisit this electronic structure by ARPES with improved angular resolution. We find an apparent splitting of all features, contradictory to the accepted model of a single surface layer structural reconstruction. By measuring the evolution of these features throughout the aging process we are able to exclude ferromagnetism, bilayer splitting and the Rashba effect. Instead we propose that the sub-surface layer undergoes a structural reconstruction which is qualitatively similar, but smaller in magnitude.
Following this we search the bulk electronic structure for direct evidence of SOC effects near the Fermi level with SARPES. Using circularly polarized light we transform the j=1/2 and j=3/2 states into spin-polarized photoemission signals which we can directly observe - a first for the technique, and find agreement with LDA+SOC predictions [4]. These observations validate further SOC predictions for the normal state including mixed orbital character and k-dependant spin quantization, which has implications for the superconducting state which arises from it.
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P1-116 THz time-domain spectroscopy for superconducting RE_2Pt_3Ge_5 (RE = La and Pr) single crystals. - ***T. Hong, K. Choi, J. Kim (Institute of Physics and Applied Physics, Yonsei University), N. Sung, B. Cho (School of Material Science and Engineering, Gwangju Institute of Science and Technology (GIST))***
We present our THz time-domain spectroscopy data of rare-earth ternary germanide intermetallic compounds, RE_2Pt_3Ge_5 (RE = La and Pr). La_2Pt_2Ge_5 and Pr_2Pt_3Ge_5 single crystals were synthesized by a high temperature metal flux method using Ge self flux. The frequency dependent complex conductivity was taken as a function of temperature across the superconducting transition temperature Tc=8.1 K of La_2Pt_3Ge_5 and Tc=7.9 K of Pr_2Pt_3Ge_5. We perform an extended Drude model analysis and analyzed the frequency and temperature dependence of the scattering rate and mass renormalization.

P1-117 Investigation of the phase diagram for a pnictide oxide compound with hole doped titanium-oxygen layers: normal and superconducting states. - ***M. Gooch (TCSUH and Dept. of Physics, University of Houston, Houston, TX 77204, USA), P. Doan, Z. Tang, A. Guloy (TCSUH and Dept. of Chemistry, University of Houston, Houston, TX 77204, USA), B. Lorenz (TCSUH and Dept. of Physics, University of Houston, Houston, TX 77204, USA), C. Chu (TCSUH and Dept. of Physics, University of Houston, Houston, TX 77204, USA and Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA)***
The discovery of the iron pnictides has fueled a renewed interest into previously discovered compounds with layered structures and inspired many to search for new layered compounds. Two such examples are $Na_2Ti_2Pn_2O$[1] and $BaTi_2As_2O$[2]. $Na_2Ti_2Pn_2O$[1] had been previous investigated and $BaTi_2As_2O$[2] was recently discovered, both compounds are comprised of a layered structure and exhibit a SDW/CDW. The iron pnictide parent compounds exhibit both of these characteristics and it is well established that by suppressing the SDW, superconductivity emerges. Then is it possible then to suppress the SDW in these titanium based pnictide oxides and have superconductivity emerge? To date, the lowering of the critical temperature for the SDW/CDW has been reported, but no superconductivity was seen.
We report the effects of hole doping on the normal and subsequently discovered superconducting state for a similar titanium based pnictide oxide system. Our parent compound, which is similar to the $BaTi_2As_2O$ in structure, shows a SDW/CDW at 57 K. With increased doping, there is a systematic lowering of the critical temperature for the SDW/CDW. In addition, the superconducting temperature increases up to 6 K. The phase diagram as a function of doping is derived from the normal and superconducting states of the system. The lowering of the critical temperature of the SDW/CDW seems to be the key for the emergence of superconductivity in this system.
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P1-118 Superconductivity induced by hole doping into the titanium-oxygen layer of a pnictide oxide compound - ***B. Lorenz (TCSUH and Department of Physics, University of Houston, Houston, TX 77204), P. Doan, Z. Tang, A. Guloy (TCSUH and Department of Chemistry, University of Houston, Houston, TX 77204), M. Gooch, C. Chu (TCSUH and Department of Physics, University of Houston, Houston, TX 77204)***
Titanium based pnictide oxide compounds, like $Na_2Ti_2Pn_2O$ [1] and $BaTi_2As_2O$ [2], have attracted attention recently because of their interesting structural features, particularly the layer of Ti_2Pn_2O which has some resemblance to the high-T_c copper oxide superconductors (Ti_2O forms a plane which can be considered as "inverted" CuO_2 plane of the cuprates) as well as the iron pnictide superconductors (the Ti_2O plane is accompanied by two layers of pnictide ions above and below). The physical properties are similar to those of iron pnictides with a charge/spin density wave forming at temperatures between 100 and 320 K. The materials have been considered as potential parent compounds for a new class of superconductors, however, attempts to introduce carrier through doping and the search for superconductivity have been unsuccessful so far [2].
We report the successful doping of holes into a titanium based pnictide oxide system and, consequently, the discovery of superconductivity. Bulk superconductivity is observed up to 6 K through dc magnetization, resistivity, and heat capacity measurements. The emergence of a superconducting state in the Ti_2Pn_2O layer may set a new paradigm in the search for novel superconducting materials.
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P1-120 Intrinsic mechanism of dichroism in chiral multiband superconductors -

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A superconducting state of Sr_2RuO_4 [1] is believed to be the solid state analogue of the superfluid A phase of ^{3}He. The evidence for spin triplet, chiral p-wave symmetry of the superconducting state in Sr_2RuO_4 [1] are experiments which show that the superconducting state breaks time reversal invariance. Recently, the dichroism was observed in polar Kerr effect measurements of the 1.5K superconductor Sr_2RuO_4 by Xia et al. [2], which showed a small Kerr rotation of light of wavelength λ =1550 nm, corresponding to a rotation of the plane of polarization by an amount approaching 100 nrad at T=0 and going to zero at T_c approximately linearly in (T_c-T).

We have performed [3] an analysis of the Hall conductivity $\sigma_{xy}(\omega,T)$ in time reversal symmetry breaking states of exotic superconductors and found that the dichroic signal is non-zero in systems with inter-band order parameters. This is new and intrinsic mechanism which may explain the Kerr effect observed in strontium ruthenate and possibly other superconductors. The proposed mechanism does not rely on impurity scattering or a finite width of the incident photon beam. With our standard model parameters for strontium ruthenate and the experimental value of plasma frequency ω_{ab}=4.5 eV we obtained the rotation of 200 nrad, which is reasonably close to the experimental value. These calculations suggest that a non-zero Hall conductivity may arise in other materials having intra-orbital order parameters. Additionally we also predict coherence factor effects in the temperature dependence of the imaginary part of the ac Hall conductivity $\mathrm{Im}\sigma_{xy}(\omega,T)$, which can be tested experimentally.

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P1-121 Superconductivity and upper critical field beyond Pauli limit in Ta2PdxS5 -

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For applications of superconductors, not only high T_c, but also high H_{c2} are strongly demanded. There are two pair breaking effects which limit H_{c2}, orbital limit and Pauli limit. The former depends on coherence length of a superconductor, and thus can be enhanced by adding impurities. Meanwhile, Pauli limit, which is determined by the competition between condensation energy and paramagnetic magnetization energy, is intrinsic and hard to be controlled [1]. In order to realize high H_{c2} superconductors, we focused on the effect of spin-orbit coupling which may suppress the paramagnetic pair breaking. We have explored materials including heavy elements like 5*d* transition metals, and found the new superconductor, $Ta_2Pd_xS_5$.

$Ta_2Pd_xS_5$ crystallizes in a monoclinic structure containing quasi-one-dimensional chains formed by TaS_6 prisms, and has non-stoichiometry in Pd [2]. We discovered this exhibits superconductivity below 6.2 K, and the T_c slightly depends on the Pd contents. The electron heat capacity decays exponentially below T_c, and the estimated magnitude of the superconducting gap suggests BCS weak coupling superconductivity.

Surprisingly, $Ta_2Pd_xS_5$ displays quite large H_{c2} (up to 31 T at 0 K), which exceeds the Pauli limiting field, $H_p = 1.84\ T_c$ (T). We argue that strong spin-orbit coupling of Ta plays the key role to achieve the apparent absence of Pauli limiting in this superconductor.

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P1-122 K2NiF4-type iridates: unconventional magnetic behabior just like a high-Tc cuprate's -

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The discovery of the novel Mott insulating state in Sr_2IrO_4 has developed a new research field on solid-state physics [1]. The strong spin-orbit coupling with the moderate on-site Coulomb interaction in the 5*d* electron system yields the unconventional J_{eff} = 1/2 Mott ground state. The “spin-orbit Mott state” is similar to conventional Mott states in 3*d* or 4*d* electron systems. However, the J_{eff} = 1/2 state is a considerably complex state hybridizing spin and orbital degrees of freedom. Therefore, investigation of this state may give a new insight into *d*-electron physics, and it may lead to possible unusual cooperative phenomena such as anisotropic superconductivity.

In this presentation, we review electronic and magnetic states in the novel K_2NiF_4-type iridate Ba_2IrO_4 [2]. We found that Ba_2IrO_4 is a quasi-2-D (square lattice) Heisenberg antiferromagnet (T_N ~ 240 K) in which the magnetic moment (~0.34 $\square_B$/Ir-atom) is significantly reduced by the low-dimensional quantum spin fluctuation with a large magnetic correlation |*J*|. Its electronic state undergoes an M-I transition from the Mott insulating state to a non-Fermi-liquid state under high pressure (P_C ~ 13.8 GPa) [3]. For the moment, superconductivity has not been observed at least down to 4 K. However, these behaviors in the quasi-2-D iridate are very similar to those in high-T_C cuprates.

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P1-123 High Pressure Synthesis and Superconductivity in LaTMBN (TM: Transition Metal) and RFeC2 (R: Rare Earth) Containing Dimeric Unit - ***N. Imamura (Frontier Research Center, Tokyo Institute of Technology), H. Hosono (Materials and Structures Laboratory, Tokyo Institute of Technology)***

Since the discovery of superconductivity in Fe-based pnictides, layered compounds containing tetrahedrally-coordinated square nets of Fe^{2+} has attracted considerable attention as a new platform for high T_c superconductivity. Among the various transition metal (T_M)-based compounds, which are isostructural to the Fe-based superconductors, boron or carbon ligand is atypical from structural point of view because the linear (BC), (BN), or (C_2) structural unit is often present perpendicular to the T_M sheet in borocarbides, -nitrides, and carbides. In other words such rigid structural unit can be considered as diatomic ligand and its electronic state depends on the distance between the two constituents.

Here we report the successful synthesis (under 2-5 GPa) of several new layered T_M-based compounds containing (BN) or (C_2) dimer, *i.e.* LaT_MBN and RFeC_2 (R: rare earth), through high pressure synthesis route. Bulk superconductivity was found in LaNiBN and LaPtBN, whereas Pauli paramagnetic behavior was observed for other T_M-based LaT_MBN. In the RFeC_2 system it was found that crystal structure changed with decreasing the size of R from the $CeNiC_2$-type structure to the $UCoC_2$-type structure containing Fe square net. The electronic states of distinguishing (BN) or (C_2) unit are discussed on the basis of density functional theory calculation.

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P1-124 Gate-Induced Superconductivity in a Transition Metal Dichalcogenide - ***J. Ye, Y. Zhang (Quantum-Phase Electronics Center,Department of Applied Physics,School of Engineering,The University of Tokyo,Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan), Y. Iwasa (Quantum-Phase Electronics Center,Department of Applied Physics,School of Engineering,The University of Tokyo,Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, JapanTEL +81-3-5841-6822)***

Ion-gated devices using the electrochemical concept of electric double layer are attracting increasing interests due to its high gate efficiency and broad applicability to a wide range of materials. The stronger field effect using ion gating provides unique abilities to reach the high carrier densities required for inducing superconductivity. The introduction of new gate dielectrics: ionic liquid further improves the ability of ion gating by promoting the surface charge density to the order of ~10^{14} cm^{-2}.

Combining ionic liquid gate dielectrics with novel materials provide new opportunities in manipulate their electronic properties. Atomically flat surface can be fabricated from the layered material easily with the graphene techniques. Using EDLT and a layered semiconducting chalcogenide, we started the search for gate-induced superconductivity and found at a very different carrier density from the previously reported intercalated samples. The newly developed double gating technique allows us to study the electronic properties of materials at well-controlled carrier densities to resolve a detailed phase diagram, where the T_c followed a dome like curve with the maximum transition temperature over 10 K, which could be highest value in this class of materials.

P1-125 Transport property of Cu-intercalated Bi2Se3 - ***Y. Imai, T. Yoshinka, K. Miyatani, F. Nabeshima, A. Maeda (Department of Basic Sciences, the University of Tokyo), R. Kondo (Department of Physics, Okayama University)***

Cu-intercalated Bi_2Se_3 ($Cu_xBi_2Se_3$) shows superconductivity with T_c ~ 3.8 K[1]. The parent material, Bi_2Se_3, is the topological insulator with a relatively large (~ 0.3 eV) band gap. In a subsequent study on this superconductor, the existence of the topological surface states was also confirmed [2]. Thus, $Cu_xBi_2Se_3$ is the promising candidate material to be a topological superconductor, and it is very important to clarify the origin of its superconductivity. However, $Cu_xBi_2Se_3$ synthesized by Hor *et al*. does not show zero resistivity belowT_c[1, 2], and some concerns still remain in the quality of samples. Very recently, several groups reported the successful preparation of Cu-intercalated Bi_2Se_3 with zero resistivity by an electrochemical method[3] and the Bridgman method[4, 5]. Here, we report the transport properties of the single crystals of $Cu_xBi_2Se_3$ with zero resistivity prepared by the Bridgman method. We stress that the process of the quenching from a temperature of about 1000 K into cold water is of crucial importance in the crystal growth. The grown crystal with x=0.10 shows zero resistivity at about 3.2 K. We also report the results of the intercalations of different metal elements.

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P1-126 Superconducting and anti-localization properties of BaPbO3/BaBiO3 bi-layers - ***G. Hassink, K. Munakata, R. Hammond, M. Beasley (Geballe Laboratory for Advanced Materials, Stanford University)***

Doped $BaBiO_3$ is a 3D oxide superconductor with a maximum T_c of 30 K for $Ba_{0.6}K_{0.4}BiO_3$. There has been a lot of discussion on whether this high T_c can be explained purely by BCS-like electron-phonon coupling with a high coupling constant λ[1]. Similarly, the behavior of H_{c2} as a function of temperature has been a subject of interest as depending on the method of experimental determination it is either claimed to be BCS-like[2] or non-BCS[3]. In addition, the real-space paired $6s^2$ electrons in the $BaBiO_3$ parent compound raise intriguing questions about whether there is an attractive electron-electron interaction, so-called negative-U pairing, as well.

This possible negative-U interaction might be used to implement the suggestion by Berg, Orgad and Kivelson[4] that for a two-layer system where one layer ($BaBiO_3$) provides electron pairing interaction and the other layer ($BaPbO_3$) is conducting, the whole can be superconducting with a high T_c. We are studying such bi-layers and see preliminary evidence for superconductivity in the case of the thinner $BaPbO_3$ layers. In any event, the bi-layers show anti-localization behavior for thin

$BaPbO_3$ layers, both in monolayers and bi-layers, indicating that disorder is present. Optical reflectivity shows spectra similar to that of bulk $Ba(Pb,Bi)O_3$[5]. The plasma frequency shifts with film thickness, seemingly tracking the electron density. The mobility is much lower, indicating a higher scattering rate, probably due to grain boundaries.

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P1-127 Coexistence of ferromagnetism and superconductivity in single-phase Bi3Ni nanostructures - *T. Herrmannsdoerfer (Dresden High Magnetic Field Laboratory, Helmholtz-Zentrum Dresden-Rossendorf), D. Koehler, M. Ruck (Department of Chemistry, TU Dresden), R. Skrotzki, R. Schoenemann, I. Scurschii, J. Wosnitza (Dresden High Magnetic Field Laboratory, Helmholtz-Zentrum Dresden-Rossendorf), R. Boldt (Leibniz Institut fuer Polymerforschung Dresden)*

We have demonstrated the coexistence of superconductivity and ferromagnetism in Bi3Ni nanostructures which have been prepared by making use of novel chemical-reaction paths [1]. We have characterized their magnetic and superconducting properties by means of SQUID magnetometry, ac susceptometry, thermodynamic and electrical-transport measurements in a wide field and temperature range. Here, we also present recent experiments on novel nanostructures, such as monodisperse spherical clusters with a diameter of 8 nm as well as nanofibers. Pulsed-field susceptibility data up to 60 T allow for a determination of the saturation magnetization of Bi3Ni nanostructures. Resistivity measurements performed on moderately compacted Bi3Ni nano fibers down to 40 mK have shown clear evidence for the existence of an isosbestic point. Superconductivity in confined Bi3Ni emerges in the ferromagnetically ordered phase and is stable up to remarkably high magnetic fields. The onset of superconductivity is even shifted to higher temperatures compared to bulk Bi3Ni which is simply Pauli paramagnetic. This coexistence of superconductivity and ferromagnetism in confined Bi3Ni would most likely be possible in the case of triplet pairing. The absence of an inversion center of the lattice of Bi3Ni nanostructures would allow for the formation of an antisymmetric spatial component of the electron-wave function and could lead to a significant admixture of a spin-triplet component of the order parameter.

Part of this work was supported by EuroMagNET, EU-contract No. 228043.

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P1-128 Magnetic response and superconductivity in electron-doped cobaltates - *Y. Liang (Department of Physics, Beijing Normal University), B. Liu (Department of Physics, Beijing Jiaotong University)*

Based on the charge-spin separation fermion-spin theory, the mechanism of superconductivity in NaxCoO2 •yH2O is studied. It is shown that dressed fermions interact occurring directly through the kinetic energy by exchanging magnetic excitations. This interaction leads to a net attractive force between dressed fermions (then the electron Cooper pairs), and their condensation reveals the superconducting ground state. Within this framework, we study the doping and energy evolution of the magnetic excitations in the superconducting state by calculating the dynamical spin structure factor. It is shown that there is a broad commensurate scattering peak at low energy, then the resonance energy is located among this low energy commensurate scattering range. This low energy commensurate scattering disperses outward into a continuous ring-like incommensurate scattering at high energy, which is similar to the case in electron-doped cuprates, and could be measured by the inelastic neutron scattering experiment.

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P1-129 Strong coupling superconductivity in new antiperovskite phosphide SrPt3P - *T. Takayama (Dept. of Advanced Materials, University of Tokyo), K. Kuwano (Department of Advanced Materials, University of Tokyo), D. Hirai (Department of Advanced Materials, Unviersity of Tokyo), H. Takagi (Department of Physics, University of Tokyo), Y. Katsura, A. Yamamoto (RIKEN)*

The discovery of iron pnictide superconductors[1] has triggered tremendous activity in search for new high-T_c superconductors. One of the features of iron pnictides is disconnected Fermi surfaces which, together with magnetic fluctuation, are considered to be key ingredients for high-T_c superconductivity. We have explored new superconductors with multipocket Fermi surfaces in transition-metal pnictides, and discovered new platinum-based superconductors APt_3P (A = Ca, Sr, La).

APt_3P crystallize in an anti-perovskite structure containing distorted PPt_6 octahedra. Since the direction of the distortion alternates within the *ab*-planes, the structure includes inversion symmetry and can be regarded as a non-polar analogue of the polar superconductor $CePt_3Si$[2].

All of the new platinum phosphides displayed clear Meissner signals and zero resitivities below 6.6 K, 8.4 K and 1.5 K for $CaPt_3P$, $SrPt_3P$ and $LaPt_3P$, respectively. The analysis of heat capacity showed that the highest T_c compound $SrPt_3P$ exhibits strong coupling superconductivity with $2D/k_B T_c$ of ~ 5 (D: superconducting gap), and evidenced the presence of low energy phonons. The presence of multiple Fermi surface pockets was inferred from the magnetotransport properties, which we argue might enhance the coupling with low-energy phonons.

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P1-130 Irreversibility and carriers control in two-dimensional electron gas at LaTiO3/SrTiO3 interface - ***J. Biscaras (LPEM UPMC-CNRS-ESPCI, Paris), A. Rastogi, R. Budhani (Dpt of Physics, Indian Institut of Technology, Kanpur), D. Leboeuf, C. Proust (Laboratoire National des Champs Magnétiques Intenses, Toulouse), S. Hurand, N. Bergeal, C. Feuillet - Palma, J. Lesueur (LPEM UPMC-CNRS-ESPCI, Paris)***

Transition metal oxides display a great variety of quantum electronic behaviors where correlations often play an important role. The achievement of high quality epitaxial interfaces involving such materials gives a unique opportunity to engineer artificial materials where new electronic orders take place. It has been shown recently that a two-dimensional electron gas 2DEG could form at the interface of two insulators such as LaAlO3 and SrTiO3 [1], or LaTiO3 (a Mott insulator) and SrTiO3 [2][3].

We present low temperature transport measurements on LaTiO3/SrTiO3 hetero-structures, whose properties can be modulated by field effect using a metallic gate on the back of the substrate [4]. We report for the first time that the irreversible behavior that has been observed by many authors working on these interfaces is related to carriers spilling over the potential maximum formed by SrTiO3 conduction band bending for positive gate voltage. Based on a complete self-consistent description of the biased potential well, a thermal model for the carriers escape has been developed, which quantitatively accounts for the data. On this basis, we built a strategy such as a fully reversible behavior can be obtained by suitable electrostatic polarization of the system. This study opens onto a more accurate control of the 2DEG at oxides interfaces.

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P1-131 Rashba coupling and anisotropic magnetoresistance in two-dimensional electron gas at LaTiO3/SrTiO3 interface. - ***J. Biscaras (LPEM UPMC-CNRS-ESPCI, Paris), A. Rastogi, R. Budhani (Dpt of Physics, Indian Institut of Technology, Kanpur), S. Hurand, C. Grossetete, N. Bergeal, C. Feuillet - Palma, J. Lesueur (LPEM UPMC-CNRS-ESPCI, Paris)***

Transition metal oxides display a great variety of quantum electronic behaviors where correlations often play an important role. The achievement of high quality epitaxial interfaces involving such materials gives a unique opportunity to engineer artificial materials where new electronic orders take place. It has been shown recently that a two-dimensional electron gas 2DEG could form at the interface of two insulators such as LaAlO3 and SrTiO3 [1], or LaTiO3 (a Mott insulator) and SrTiO3 [2][3].

We present low temperature transport and magneto-transport measurements on LaTiO3/SrTiO3 hetero-structures, whose properties can be modulated by field effect using a metallic gate on the back of the substrate [4]. Quantum correction to transport are observed, and analyzed in the framework of weak localization theory. Sign change of the magnetoresistance upon varying the gate voltage clearly evidences a tunable Rashba-type spin orbit coupling in these systems. When the magnetic field is applied parallel to the 2DEG, anisotropic magnetoresistance with respect to the current direction is observed. This effect and its possible relationship to magnetism will be discussed.

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P1-132 superconducting propertiy of β-Na$_{0.33}$V$_{2}$O$_{5}$ under magnetic field. - ***T. Yamauchi, Y. Ueda (Materials Design and Characterization Laboratory, Institute for Solid State Physics, University of Tokyo), H. Ueda (Solid State Physics and Chemistry Lab., Division of Chemistry, Graduate School of Science, Kyoto University)***

The pressure induced superconducting phase (PISP) in β-Na$_{0.33}$V$_{2}$O$_{5}$ is hard to probe due to its relatively high critical pressure. The some experimental trails (ex. NMR etc..) have been done attemting to observe its superconducting properties, these however are still unscucessful. This experimantal difficulty probably arides from the very high hydrostaticity required for emerging the PISP from the charge orderd insulating ground state in low-pressure region.

There are two-type of presssure cells; the one is a clamp-type and the another is a continuous-press-type pressure cell. The PISP of β-Na$_{0.33}$V$_{2}$O$_{5}$ has been observed only in later one. The former one has a big advantage that this type of pressure cell can be enough small to be mounted in superconducting magnet and has a serious disadvantage that inevitable non-hydrostatic compressing occurs in temperature lowering process below the freezing temperature of the liquid pressure medium around the sample crystal.

Therefore, we have evolved a small cubic-avil-type pressure cell and have built continous pressing system that can be equipped in the superconducting magnet. This system can generate quite high hydrostatic pressure up to 9 GPa with applying magnetic field of 7T. In this presentation, we will show the resistivity-temperature curves observed in several magnetic fields applied along the several directions to the sample crystal and discuss the superconducting properties of this PISP.

P1-133 Superconducting characteristics in Rh17S15-xSex single crystals - ***Z. Wang (Nanjing University), Z. H. Wang, H. Yang, L. Qiu, H. H. Wen Center for Superconducting Physics and Materials, National Lab for Solid State Microstructures,Department of Physics, Nanjing University, Nanjing 210093, China***

The $Rh_{17}S_{15-x}Se_x$ (x=0, 0.25, 0.5, and 0.75) single crystals were grown in sealed tube with a temperature gradient, respectively. We have measured the temperature dependences of resistivity, magnetization and hall coefficient. The critical temperature decreases with the increasing of Se-doping. The phase diagram of superconducting charactertics was presented.

P1-134 Magnetocaloric effect of Sr2RuO4 near the upper critical field - *T. Kajikawa, S. Yonezawa, Y. Maeno (Kyoto University)*

Sr_2RuO_4 is widely known as a leading candidate for a spin triplet superconductor. Interestingly, the specific heat and magnetization studies [1,2] have revealed rapid recoveries of these quantities to the normal state values just below the upper critical field H_{c2} when the field is parallel to the *ab* plane. In order to investigate the origin of such unusual superconduting transition, we study the magnetocaloric effect (MCE). The MCE is a phenomenon in which the temperature of a material changes in response to a change in the applied magnetic field. MCE is suitable to observe in-field phase transitions, because we can obtain the magnetic-field derivative of the entropy by measuring MCE.

We developed a sensitive calorimeter for MCE measurements of Sr_2RuO_4. We revealed that the superconducting phase transition is accompanied by supercooling below 600 mK for *H* // *a* axis. This result provides evidence that the superconducting transition of this oxide is of 1st order at low temperatures and for *H* // *a* axis. It has been known that the Pauli effect for spin-singlet superconductors can be an origin of a first order superconducting transition. However, in the case of Sr_2RuO_4, the Pauli effect should not be relevant, because the Knight shift[3] and the polarized neutron scattering[4] studies of Sr_2RuO_4 have revealed that the spin susceptibility in the superconducting state is equal to the spin susceptibility in the normal state. Therefore we must consider unknown pair-breaking effects in a spin triplet superconductor.

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P1-135 Interplay of superconductivity and charge density wave ordering in pseudoternary alloy system: Lu2Ir3(Si1-xGex)5 - *S. N.S, S. Basu, D. Pal (IIT Guwahati), T. A, R. S (TIFR, Mumbai)*

With the discovery of pnictide superconductors, the study of interplay between superconductivity (SC) and electron spectrum instabilities, namely charge density wave (CDW) and spin density wave (SDW), have gained considerable attention [1]. SC and CDW are two very different cooperative phenomena both of which occur due to Fermi surface (FS) instabilities and results an opening up of a gap at the FS which leads to a reduction in the DOS at the FS. CDW effects have been known to happen only in quasi-low dimensional structures. However, recently CDW phenomena have been established in the series of polycrystalline compounds $R_2Ir_3Si_5$ which essentially have a 3-dimensional structure. Among these compounds, $Lu_2Ir_3Si_5$ shows superconducting below 3K [2-3]. Also, it shows CDW like transition at high temperature accompanied by a huge thermal hysteresis. Another case of $Er_2Ir_3Si_5$ also exhibits a weak anomaly at 150K but could be only seen in the electrical resistivity data. Thus, it would be interesting to study the interplay between the superconductivity and the CDW transition in $Lu_2Ir_3Si_5$. In this paper, we use pseudoternary system $Lu_2Ir_3(Si_{1-x}Ge_x)_5$ to study the effect of lattice volume on both CDW and superconductivity via dc magnetic susceptibility, electrical resistivity and heat capacity . The Polycrystalline samples of $Lu_2Ir_3(Si_{1-x}Ge_x)_5$ x=0 - 0.2 were prepared by arc melting method. Our results reveal that CDW transition temperature shows non monotonic behaviour along with SC transition temperature upon doping. The maximum value of SC transition temperature and the minimum value of CDW transition temperature are seen in the sample $Lu_2Ir_3Si_{4.9}Ge_{0.1}$. We shall present the transition temperature -concentration phase diagram in this paper.

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P1-136 A penetration depth study on the filled skutteride superconductor PrPt4Ge12 - *H. Yuan (Department of Physics, Zhejiang University), J. Zhang (Department of Physics, Zhejiang Univeristy), L. Jiao, Y. Chen, B. Fu (Department of Physics, Zhejiang University), M. Nicklas, R. Gumeniuk, W. Schnelle, H. Rosner, A. Leithe-Jasper, Y. Grin, F. Steglich (Max Planck Institute for Chemical Physics of Solids)*

The order parameter of the newly discovered skutterudite superconductor PrPt4Ge12 (Tc=7.9K) is currently under debate. The mSR experiments showed evidence of time reversal symmetry breaking and of point nodes in the superconducting energy gap [1]. On the other hand, the NMR results display a pronounced coherence peak just below T_c in $1/T_1$ [2], giving evidence for S-wave-type superconductivity. Here we present the first measurement of magnetic penetration depth $\Delta\lambda(T)$ down to 0.4K (0.05Tc) for single crystalline $PrPt_4Ge_{12}$ by using a tunnel-diode oscillation (TDO) based technique which is powerful for studying the gap symmetry of a superconductor. It is found that $\Delta\lambda(T)$ follows a power law behavior of $\Delta\lambda \sim T^n$ （n~3） at temperature below 0.3Tc, indicating non-BCS superconductivity. The corresponding superfluid density $\rho_s(T)$ can also be fitted by a two-gap model with two gaps of Δ_L=1.8±0.1 K_BT_c and Δ_S= 0.7±0.1 K_BT_c. Further measurements and analyses are under way in order to elucidate the unconventional behavior of superconductivity in $PrPt_4Ge_{12}$.

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P1-137 STUDY OF STRUCTURAL, TRANSPORT AND MAGNETIC PROPERTIES OF Re- DOPED RUTHENOCUPRATE Ru1-xRexSr2GdCu2Oy - *L. Corredor (Universidad Nacional de Colombia), D. Landínez Téllez, J. Roa-Rojas (Grupo de Física de Nuevos Materiales, Departamento de Física, Universidad Nacional de Colombia, Bogotá DC,Colombia), P. Pureur, F. Mesquita (Instituto de Física, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brasil), J. Aguiar (Laboratório de Supercondutividade e Materiais Avançados, Departamento de FísicaUniversidade Federal de Pernambuco, 50670-901, Recife, PE, Brasil)*

We have performed a study of the structural, transport, and magnetic properties of polycrystalline samples of the rhenium-doped ruthenocuprate Ru1-xRexSr2GdCu2Oy (x=0.00, 0.03, 0.06, 009, 0.12). The samples were prepared by a two-step solid-state reaction procedure, including the synthesis of the double perovskite Sr2GdRu1-xRexOy. The thermal treatment was performed at temperatures up to 1050oC for 45 hours, with a subsequent annealing under 1 atm oxygen pressure. Structural analysis was carried out by X-ray diffraction, showing a nearly single phase with tetragonal structure belonging to P4mmm space group (#123), with variations in original lattice parameters up to 5%. Magnetic characterization revealed the ferromagnetic character of the samples, with transition temperatures between 135-155K, and absence of Meissner state. The first three samples (x=0.00-0.06) show a non-zero transition in resistivity, with transition temperatures between 21-41K, while the x=0.09-0.12 samples show a semiconductor type behavior. This transition is shifted to lower temperatures by applied magnetic field, keeping its behavior under fields up to 10000 Oe. It is evidenced a granularity effect in the broadening of rho(T) curves in applied field. Magnetoresistivity measurements show positive values for temperatures above the magnetic transition, and slightly negative values below, without appreciable variation even for high applied magnetic fields. The Re doping effect on the Ru-1212 superconducting and magnetic properties are widely discussed.
This work was partially supported by the Colombian agencies Colciencias, the Division of Investigations, Universidad Nacional de Colombia (DIB - Bogotá); and Brazilian CNPq, CAPES and FACEPE (APQ-0589-1.05/08).
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P1-138 TiNx thin films superconducting properties by UHV reactive sputtering - *I. Lorite, M. Parra, E. Alvarez, J. Bueno (Centro de Astrobiologia), J. Costa Krämer (Instituto de Microelectronica)*

TiNx thin films present interesting properties which make them outstanding materials for a large number of applications: corrosion resistant coatings because of its exceptional hardness, high wear resistance, high melting point, good chemical inertness, thermodynamic stability, and for surface decorationi-ii. In addition TiNx also exhibits a large electrical conductivity and is used in microelectronics as a diffusion barrier, Schottky contacts, and contact layers in solar cellsiii. TiNx also behaves as a superconductor at low temperatures, with a critical temperature between 0 and 5K. This critical temperature depends on growth conditions and the resulting stoichiometry. Recently, TiN flms have been considerediv for superconducting Lumped Element Kinetic Inductance Detectors (LEKIDs)v for astrophysical sensing devices. A thorough study on TiNxf films, grown by UHV reactive dc magnetron sputtering at room temperature is presented. The N2 and Ar gas partial pressures, and plasma power conditions, affect the composition and deposited structures (from amorphous to crystalline) which are characterized by Rutherford Back Scattering, Raman spectroscopy, X-Ray Diffraction. These are also correlated with the superconducting properties
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P1-139 New Data on Modified Compositions of Strontium Ruthenates - *A. Gulian (Chapman University), V. Nikoghosyan (Chapman University & Institute for Physics Research, National Academy of Sciences, Ashtarak, 0203, Armenia)*

In 2004-2007 we discovered unusual properties (including resistive and magnetic transitions) in laser-processed crystals of strontium ruthenates [1]. The samples were irreversibly damaged during these measurements. However, being interested in understanding and reproducing their properties we explored their composition further.
In addition to previously reported unexpected finding of ferromagnetic components (Fe, Ni, Cr) in the composition [2], we obtained, via Auger-analysis, the presence of Sulfur in the most remarkable sample.
The appearance of iron-based superconductors further enhanced our interest, which initially was discouraged by the revealed nichrome content. Indeed, compositionally our materials turned out to be close to some of iron-based superconductors. If the observed transitions [1] have been caused by superconductivity, doesn't that mean that one can get T_c as high as 200-250K or even higher with these materials at proper processing?
We undertook systematic research of ceramic materials Sr_2RuO_4 with added Sulfur, Silver, and nichrome. Detailed data on resistive, magnetic and other physical properties will be reported.
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P1-140 Inter-band scattering effects in the Chevrel phase superconductors - ***A. Cheung (University of Cambridge)***

Recent scanning tunneling spectroscopy on the Chevrel phases SnMo_6 S_8 and PbMo_6 S_8 by Petrovic et al. demonstrates clear signatures of multi-band superconductivity. In contrast with MgB_2, where there is extremely weak scattering between the sigma and pi bands, the inter-band scattering rate is relatively high compared to the intra-band scattering rate in the Chevrel phases. We calculate the quasi-classical Green's function in the presence of strong inter-band scattering and derive comparable results to the measured density of states. We make predictions for proposed measurements on the vortex cores.

P1-141 Transport Properties of Doped Triangular-Lattice Organics Under Hydrostatic and Uniaxial Pressure - ***H. Oike (University of Tokyo, Department of Applied Physics), H. Okamoto (Kanazawa University, Department of Quantum Medical Technology), H. Taniguchi (Saitama University, Department of Physics), K. Miyagawa, K. Kanoda (University of Tokyo, Department of Applied Physics)***

Up to now, the highest-T_c superconductivity occurs in doped Mott insulator. In order to clarify the origin of high-T_c superconductivity, experiments under control of correlation strength and spin frustration in doped Mott insulators are informative because strong electronic correlation characterizes the properties of doped Mott insulators. The quasi-two-dimensional organic conductor, k-$(ET)_4Hg_{2.89}Br_8$, is considered to be a good stage to control these parameters in doped Mott insulator. In conducting layers, ET dimers form an isosceles triangular lattice. Owing to the large compressibility of organic materials, pressure is a good way to control transfer integrals. It is expected that hydrostatic pressure varies on-site Coulomb repulsion relative to transfer integrals while uniaxial pressure varies the anisotropy of triangular lattice, which relates to spin frustration.

We investigated the transport properties of k-$(ET)_4Hg_{2.89}Br_8$ under hydrostatic and uniaxial pressures. Superconducting transition temperature varies differently under hydrostatic pressure and uniaxial pressure depending on the pressurizing direction. We discuss theses pressure dependences in terms of correlation strength-spin frustration phase diagram of doped Mott insulator.

P1-142 Equal Spin Pairing in the Heavy Fermion Superconductor UPt3 - ***W. Gannon (Northwestern University), A. Stunault (Institut Laue Langevin), W. Halperin (Northwestern University), C. Rastovski, M. Eskildsen (University of Notre Dame), P. Dai (University of Tennessee)***

Long considered a candidate for triplet superconductivity, the heavy-fermion superconductor UPt_3 has been at the center of experimental and theoretical efforts for more than two decades [1]. However, evidence for equal spin pairing of the cooper pairs rests on NMR measurements that probe only a London penetration depth into the crystal. We report bulk measurements of the susceptibility of UPt_3 using polarized neutron scattering. These measurements show that the in-plane susceptibility is temperature independent from the low temperature normal state into all three superconducting phases. Further, measurements up to 200 K show known features of the in-plane susceptibility [2] associated with the formation of the heavy fermion state. The absence of a decrease in susceptibility for temperatures below the superconducting transition is strong evidence that the in-plane cooper pairs are indeed in an equally spin paired state. These measurements confirm earlier Knight shift results [3-6] by measuring the bulk susceptibility independent of any possible effects from the sample surfaces.

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P1-143 NMR Study of Field Induced Magnetic Order in the FFLO phase of CeCoIn_5 - ***K. Kumagai (Department of Physics, Faculty of Science, Hokkaido University, Sapporo 060-0810), H. Shishido, T. Shibauchi, Y. Matsuda (Department of Physics, Kyoto University, Kyoto 606-8502)***

A strongly-correlated superconductor, CeCoIn$_{_5}$ is believed to host a Fulde-Ferrell-Larkin-Ovchinnkov (FFLO) state in a restricted region of high field and very low temperature. We have confirmed the coexistence of the field induced magnetic order and the FFLO state from the field evolution of In-NMR spectra for *H//a*-axis. [1] The Knight shift of CeCoIn$_{_5}$ provides a direct evidence for the emergence of the spatially-distributed normal quasiparticle region. The quantitative analysis for the field evolution of the paramagnetic magnetization and low-lying energy quasiparticle density of state is consistent with the nodal plane formation, which is characterized by an order parameter in the FFLO state. Here, we will also report our recent results of the angle,θ, dependence of NMR for external field with respect to the *ab* planes down to ~50mK. Detail phase diagram for θ-, *B*-, and *T*-parameters is obtained. The NMR spectra change dramatically upon entering the novel SC phase. A characteristic structure of the In(2)-NMR spectra suggests that the magnetic order, which is emerging in the newly-discovered SC state, occurs forθ< ~20°. The structure of the spin density wave (SDW) seems to be modified with angle of external field. We will discuss implication of the coexistence of the magnetism and the spatially-modulated SC order parameter in the Pauli limited superconductor of CeCoIn.

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P1-144 Hybridization gap versus hidden order gap in URu_2Si_2 as revealed by optical spectroscopy -
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We present the in-plane optical reflectance measurement on single crystals of URu_2Si_2. The study revealed a strong temperature-dependent spectral evolution. Above 50 K, the low frequency optical conductivity is rather flat without showing a clear Drude-like response, indicating very short transport life time of the free carriers. Well below the coherent temperature, there appears an abrupt spectral weight suppression below 400 cm^{-1}, yielding evidence for the formation of a hybridization energy gap arising from the mixing of the conduction electron and narrow f-electron bands. A small part of the suppressed spectral weight was transferred to the low frequency side, leading to a narrow Drude component, while the majority of the suppressed spectral weight was transferred to the high frequency side centered near 4000 cm^{-1}. Below the hidden order temperature, another very prominent energy gap structure was observed, which leads to the removal of a large part of the Drude component and a sharp reduction of the carrier scattering rate. The study revealed that the hybridization gap and the hidden orger gap are distinctly different: they occur at different energy scales and exhibit completely different spectral characteristics.

P1-145 Twofold symmetry breaking in the gap function of UPt3 probed by the angle-resolved thermal conductivity -
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A number of intensive studies have been made on heavy-fermion superconductor UPt3 because it unambiguously shows nontrivial behaviors having multiple superconducting phases: A, B and C phases in the field-temperature plane [1]. On the basis of comprehensive studies on the gap symmetry, it has been widely believed that the two-component order parameter belonging to the E2u representation is most promising candidates to explain the superconductivity in UPt3. However, the superconducting gap structure, especially the direction of the nodes, is still under debate because of the lack of compelling experimental evidence. In this study, we measured the c-axis thermal conductivity κ_{zz} as a function of the field orientation in order to clarify the gap structure of UPt3. Striking twofold oscillations in the angular dependence of κ_{zz} was observed only in the C phase, indicating spontaneous twofold symmetry breaking in the gap function. The twofold symmetry breaking in the C phase is not expected from the E2u scenario. Moreover, we found an abrupt vanishing of the oscillation across a transition to the B phase, as a clear indication of a change of gap symmetries. On the basis of the present results combined with the symmetry consideration, we demonstrate that the symmetry of UPt3 most likely belongs to a E1u representation in the f-wave category [2]. We also show that the proposed gap symmetry is compatible with most of the experimental results reported until now.

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P1-146 Momentum dependent f-hybridzation in CeCoIn5 from angle-resolved photoemission spectroscopy -
A. Koitzsch, U. Treske, M. Khoshkhoo, D. Evtushinsky, S. Borisenko, M. Knupfer, B. Büchner (IFW Dresden), E. Bauer (Los Alamos National Lab)

The heavy fermion compounds CeTIn5 (T = Co, Ir, Rh) continue to attract considerable research interest due to the appearance of superconductivity at relatively high temperatures (Tc =2.3 K for CeCoIn5) in close vicinity to magnetic phases. Of particular importance is the role of the f-electrons for the low energy electronic structure, which has to be clarified in detail to obtain a full understanding of the materials properties.

We have measured the electronic structure of CeCoIn5 by angle resolved photoemission spectroscopy. Special emphasis is laid on the temperature evolution of the f-derived electronic states near the Fermi energy. To this end the Ce4d – 4f resonance is exploited and measurements down to T = 1 K, well below the coherence temperature T* ~ 40 K, have been performed.

Furthermore we elaborate on the surface structure of CeTIn5 (T = Co, Ir, Rh). By angle dependent x-ray photoemission two sharply distinct phases are observed, the relative intensity of which depends sensitively on temperature history of the sample.

P1-147 Berezinskii-Kosterlitz-Thouless Transition in Heavy Fermion Superlattices -
J. She, A. Balatsky (Los Alamos National Lab)

Recently unconventional superconductivity has been observed in epitaxially grown heavy fermion superlattices, where Cooper pairs are confined within two-dimensional Kondo lattices (Nature Physics 7,849(2011)). Motivated by these experiments we investigate the mechanism for the onset of superconductivity in such systems. We focus on the interplay of Kondo lattice physics and Berezinskii-Kosterlitz-Thouless (BKT) mechanism of superconducting transitions. We point that the observed behaviors of the gap and superconducting transition temperature can be understood in terms of phase fluctuations controlled by vortex-antivortex (un)binding. Coupling the vortices to spins via an exchange coupling, we find that spin fluctuations renormalize the vortex core size and vortex core energy, giving rise to a large dielectric constant. We consider also the possibility of emergence of a new hexatic phase in such a dense vortex matter.

P1-148 Superconducting gap symmetry of heavy-Fermion compound URu$_2$Si$_2$ - *H. Won (Dept. of Physics, Hallym University)*

To identify the superconducting gap symmetry of heavy-Fermion compound URu$_2$Si$_2$, we present the quasiparticle density of state in the vortex state where both the Doppler shift and Pauli term are incorporated consistently. We show that the field-angle-dependent magnetospecific heat data by Yano et al.[1], indicates the superconducting order-parameter $\Delta(\vec{k}) \sim e^{\pm i \phi} \sin(\chi)$, the chiral d-wave symmetry.

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P1-150 Direct observation of a Quantum Critical Point in CeRhSi3 – *Jorge L. Gavilano, Laboratory for Neutron Scattering, PSI, Switzerland; Nikola Egetenmeyer, Laboratory for Neutron Scattering, PSI, Switzerland; Alexander Maisuradze, Laboratory for Muon Spin Spectroscopy, PSI and Physics Dept. of the University of Zurich, Switzerland; Simon Gerber, Laboratory for Neutron Scattering, PSI, Switzerland; Michel Kenzelmann, Laboratory for Developments and Methods, PSI, Switzerland; Gabriel Seyfarth, DPMC, University of Geneva, Switzerland; Daniel Andreica, Faculty of Physics, Babes-Bolyai University, Romania; Alexandre Desilets-Benoit, Departement de Physique, University of Montreal, Canada; Andrea Bianchi, Departement of Physique, University of Montreal, Canada; Christopher Baines, Laboratory for Muon Spin Spectroscopy, PSI, Switzerland; Rustem Khasanov, Laboratory for Muon Spin Spectroscopy, PSI, Switzerland; Douglas MacLaughlin, Department of Physics and Astronomy, University of California, Riverside, California, United States of America*

The noncentrosymmetric heavy-fermion CeRhSi3 displays an interesting temperature-pressure phase diagram [1]. It orders antiferromagnetically below TN = 1.6 K at ambient pressure, involving the order of tiny magnetic moments. The material turns superconducting SC below 1.2 K for pressures p above 12 kbar. We have studied the pressure-evolution of the antiferromagnetic AF state using MuSR techniques. Our results show that the ordered moments are gradually quenched with increasing pressure, but we find no evidence for a pressure-induced change of the magnetic structure. At a critical pressure of p* = 23.6 kbar the ordered magnetic moments are completely suppressed and TN is zero, revealing the presence of a quantum critical point QCP at p*. Between 12 and 23.6 Kbar the AF and SC phases coexist. We have directly observed a QCP hidden deep inside the superconducting phase [2]. The QCP is triggered by the fluctuations of the magnetic order parameter leaving the Kondo screening unaffected.

This work was performed at the Swiss Muon Source, PSI, Switzerland. We acknowledge partial financial support from the SNF Switzerland, NSF US, UEFISCDI Romania and NSERC, Canada.

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P1-151 Single crystal growth of a new heavy fermion compound CePt2In7 - *H. Shishido (Department of Physics and Electronics, Graduate School of Engineering, Osaka Prefecture University), H. Fujiwara (Department of Chemistry, Graduate School of Science, Osaka Prefecture University), T. Yoshihara, S. Noguchi, T. Ishida (Department of Physics and Electronics, Graduate School of Engineering, Osaka Prefecture University)*

$CeTIn_5$(T: Co, Rh and Ir) and Ce_2Tin_8(T: Co, Rh, Ir and Pd) family have been attracted much attentions for their quantum critical behavior and anisotropic superconductivity. These compounds have unique tetragonal crystal structures with stacking layers of $CeIn_3$ (1 and 2, respectively) and TIn_2 alternatively along the [001] direction. According to the unique crystal structures, these compounds have quasi-two dimensional properties and quasi-cylindrical Fermi surfaces. $CePt_2In_7$ is a new member of quasi-two dimensional heavy fermion family $Ce_mT_nIn_{3m+2n}$ [1, 2]. An pressure induced superconductor $CePt_2In_7$ orders antiferromagnetically below the Néel temperature T_N = 5.2 K at ambient pressure [2]. The crystal structure of $CePt_2In_7$ consists of $CeIn_3$ layers separated by two layers of $PtIn_2$, stacked along the [001] axis. The rise of two-dimensionality is expected in $CePt_2In_7$, because of the increment of the distance between $CeIn_3$ layers.

We grow high quality single crystals of $CePt_2In_7$ by the In-self-flux method. Single crystal X-Ray diffraction measurements reveals the body-centered tetragonal crystal structure (I4/mmm) with lattice parameters *a* = 4.620 ? and *c* = 21.675 ?, which are well reproduce previous reports [1, 2]. Temperature dependence of the electrical resistivity shows shoulder like anomaly 60 K due to the Kondo effect. The resistivity shows a kink like anomaly at T_N, consistent with the previous report [2]. Relatively high resistance ratio of *R*(300K)/*R*(4.2K) = 23 indicate high quality of our single crystals.

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P1-152 Valence Fluctuations in heavy fermion superconductor Ce1-xYbxCoIn5 from bulk properties - *L. Shu (Department of Physics, University of California, San Diego, La Jolla, Ca 92093), J. Paglione (Center for Nanophysics and Advanced Materials, Department of Physics, University of Maryland, College Park, Maryland 20742), P. Ho (Department of Physics, California State University, Fresno, Ca 93740), T. Sayles (Department of Physics, University of California, La Jolla, Ca 92093), J. Hamlin, D. Zocco, C. McElroy, M. Maple (Department of Physics, University of California, San Diego, Ca 92093), R. Baumbach, M. Janoschek, E. Gonzaes, K. Huang (Department of Physics, University of California, San Diego, La Jolla, Ca 92093), J. Brien (Quantum Design, San Diego, Ca 92121)*

Heavy fermion superconductivity has continuously attracted broad scientific attention. One of the important issues in this study is the relationship between quantum criticality, non-Fermi-liquid behavior (NFL), and unconventional superconductivity. It is generally thought that critical fluctuations associated with a magnetic quantum critical point (QCP) can provide a mechanism for NFL behavior and unconventional superconductivity in a narrow “dome” around the QCP . However, the precise nature of

the relationship between these phenomena remains to be understood, particularly since many compounds have been reported where the NFL behavior persists over an extended region of the phase diagram in the absence of any identifiable QCP . Recently, intermediate valence phenomena has been found in the heavy fermion superconductor system $Ce_{1-x}Yb_xCoIn_5$ [5]. The stability of the correlated electron state is apparently due to cooperative behavior of the Ce and Yb ions, involving their unstable valences. Low temperature NFL behavior is observed which varies with x, even though there is no readily identifiable quantum critical point. The NFL state is tuned by valence fluctuations. The strongly intermediate-valence state of Yb in $Ce_{1-x}Yb_xCoIn_5$ has been inferred by a simple model under the assumptions that Kondo effects can be ignored and the Ce valence is essentially 3+. The results are in very good agreement with the values found from x-ray photoemission spectroscopy. The x-dependence of the valences can also be combined with atomic radii information to predict x-dependent unit cell volumes that are in fair agreement with the measured values.
This research was sponsored by the U.S. DOE under Research Grant No. DE-FG02-04ER46105 (crystal growth) and the NSF under Grant No. 0802478 (low temperature measurements).

P1-154 Model construction and pairing symmetry analysis of ß-(BDA-TTP)2MF6 (M=P, As, Sb, Ta) based on first principles band calculation - ***H. Aizawa (Institute of Physics, Kanagawa University), K. Kuroki (Department of Engineering Science, The University of Electro-Communications), J. Yamada (Department of Material Science, University of Hyogo)***

We focus on a group of organic conductors β-$(BDA\text{-}TTP)_2MF_6$ (*M*=P, As, Sb, Ta), which exhibit superconductivity with T_c=7.5, 5.8, 5.9 K for *M*=Sb, As, P, respectively [1], except for *M*=Ta [2]. Extended Huckel calculation has shown a two-dimensional Fermi surface, which has been consistent with an AMRO measurement [3]. As for the superconducting state, H_{c2} and specific heat measurements have exhibited a spin-singlet pairing with nodal gap [4]. STM measurement has shown a d-wave gap symmetry with nodes along a*±c* direction [5]. On the other hand, a recent AMRO measurement shows a different anisotropy of the Fermi surface compared to Ref. [3], and an anisotropy of H_{c2} in the conducting plane suggests that the nodal direction of the SC gap may differ from the previous STM result [6].

Here, we perform first principles band calculation based on DFT exploiting the WIEN2K package, and construct a tight-binding model Hamiltonian which nicely reproduces the *ab-initio* band structure. Comparing the *ab-initio* calculation result with the extended Huckel band structure shows that the width of the *ab-initio* band is larger, and the direction of the Fermi surface anisotropy is different. As for the superconducting state, we assume spin-fluctuation-mediated pairing, and apply the random phase approximation (RPA) method to the two-band Hubbard model obtained by adding the on-site (intra-molecule) repulsion to the tight-binding model derived from the first principles band structure. The obtained superconducting gap shows that the sign of the gap changes four times along the Fermi surface like in a d-wave gap. We compare the superconducting gap structure with the one obtained with the extended Huckel model.

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P1-155 NMR study of the superconducting state in the organic system, k-(BEDT-TTF)2Cu(NCS)2 - ***K. Miyagawa, K. Kanoda (University of Tokyo)***

A quasi-two-dimensional conducting system, k-(BEDT-TTF)2Cu(NCS)2, which is situated near Mott transition [1], is the first-10K-class superconductor among organic conductors [2]. We already reported that in the superconducting state the nuclear spin-lattice relaxation rate, 1/T1, has no coherence peak just below Tc and a T3 temperature dependence well below Tc, which points to a nodal superconductor [1].

We have performed 13C and 1H NMR measurements with changing the external field from the in-plane to out-of-plane configuration. The 1/T1 at 1H sites shows a sharp drop in a narrow angle region around the parallel field direction. This indicates the onset of vortex lock'in state without pancake vortices. The anglular range where the lock'in state appears increases with decreasing temperature. This behavior is qualitatively consistent with temperature dependence of Hc1.

The Knight shift at 13C sites in the in-plane configuration suddenly decreases below Tc, indicating the formation of singlet paring. When the filed deviates from the in-plane configuration, the motion of vortices can be observed in 1/T1. Above Tc, there is no sign of pseudo-gap.

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[2] H. Urayama et al, Chem. Lett.**1988**, 55 (1988)

P1-156 Superconductivity vs charge order in quarter-filled quasi-two-dimensional organic conductors - ***N. Drichko (Department of Physics and Astronomy, Johns Hopkins University), S. Kaiser (1 .Physikalisches Institut, 1. Physikalisches Institut, Universität Stuttgart), C. Clauss, M. Dressel (1. Physikalisches Institut, Universität Stuttgart), A. Girlando, M. Masino (Dip. Chimica and INSTM-UdR Parma, Parma University), A. Greco (UNR-CONICET, Rosario)***

By now there exist both theoretical proposals that superconductivity in quarter-filled quasi-two-dimensional (2D) organic conductors is mediated by fluctuations of charge order, and experimental evidence of interplay of charge order and superconductivity in a quarter-filled 2D organic conductor [1].

Here we summarize the optical data for BEDT-TTF-based quarter-filled 2D organic conductors of alpha and beta" phases, ranging from charge order insulators to superconductors and metals. We use a possibility to detect charge value per lattice site

and estimate charge order fluctuations rate by use of vibrational spectroscopy, the latter method is uniquely and successfully applied to organic conductors. We show that independent of details of conducting layer structure, the main parameter defining the ground state is the size of effective electronic correlations. The insulating ground state is characterized by a charge separation nearly 1:0, while homogeneously charged lattice is observed for metals. Superconductivity occurs in the compounds where the small charge separation of 0.2 exists with a fluctuation rate of about 10-20 cm^{-1}. In the in-plane optical conductivity we identify electronic features due to optical transitions between Hubbard-like bands, as well as the low-frequency features related to charge order fluctuations, in agreement with calculations on the extended Hubbard model.
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Acknowledgement**s:** H. Blewett Fellowship of American Physical Society; Margerete-von-Wrangell Fellowship

P1-157 Resonance in-plane magnetic field effect in FFLO state in layered superconductors - *M. Croitoru, A. Buzdin (Université Bordeaux I, LOMA)*

Almost 50 years ago, Fulde and Ferrell, at the same time as Larkin and Ovchinnikov, suggested that in clean superconductors at $T <0.56 T_c$ a paired state described by the spatially modulated order parameter becomes favourable when the spin effect of the magnetic field dominates over the orbital effect of the magnetic field. There have been observed several hints indicating the experimental realization of the FFLO state in organic superconductors when external magnetic field is aligned along the conducting planes and in heavy fermion superconductors. In particular, the anomaly in the thermal conductivity for the clean organic sample λ-$(BETS)_2GaCl_4$,[1] the calorimetric and magnetic torque evidence for the appearance of an additional first-order phase transition line within the superconducting phase in the in-plane high field regime for organic sample κ-$(BEDT\text{-}TTF)_2Cu(NCS)_2$,[2,3] as well as an anomalous in-plane anisotropy of the onset of superconductivity in $(TMTSF)_2ClO_4$[4] conductor have been interpreted as related to a stabilization of the superconducting phase with the modulated order parameter in real space. Although searches for the FFLO state have been carried out exhaustively, unambiguous experimental evidence has remained elusive.

In Ref. 5 we have demonstrated that the character of the in-plane critical field anisotropy can give important information on the orientation of the FFLO modulation vector. Our subsequent analysis of the properties of the organic superconductors, which are the candidates to the FFLO phase realisation, revealed that in some of them the resonance between the period of the FFLO modulation and the period of the interlayer coupling modulation induced by the external field is possible. To deal with this situation we developed the special theoretical approach. The obtained results predict the anomalous cusps in the temperature and angular dependencies of the in-plane critical field. Their experimental observation may serve as an unambiguous evidence for the appearance of the FFLO phase in layered superconductors. Furthermore, we give the criteria for layered compounds which can exhibit this effect. The proposed tool for exhibiting the FFLO phase is directly based on its main feature, the spatial modulations of the order parameter and directly measure the wavelength of the FFLO modulation.

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Invited Sessions

I1 - Superconducting Fluctuations in Cuprates
Regency, 3:30 PM to 6:00 PM
Session Chair: Louis Taillefer

I1-01 Superconducting Correlations in the Normal State of the Cuprate Superconductors - *N. Armitage (The Johns Hopkins University)*

In the underdoped pseudogap regime of the high-temperature superconductors, one expects that due to low superfluid densities and short correlation lengths, superconducting correlations will be significant for transport and thermodynamic properties. However, there has been disagreement about how high in temperature they may persist, their role in the phenomenology of the pseudogap regime, and their significance for understanding high-temperature superconductivity. We use THz time-domain spectroscopy (TTDS) to probe the temporal fluctuations of superconductivity above the critical temperature (T_c) in $La_{2-x}Sr_xCuO_4$ (LSCO) thin films over a doping range that spans almost the entire superconducting dome. Signatures of the fluctuations persist in the conductivity in a narrow temperature range above T_c. Our measurements show that superconducting correlations do not make an appreciable contribution to the charge transport anomalies of the pseudogap in LSCO at temperatures well above T_c. I will compare our results for an underdoped (x=0.095) sample with measurements of diamagnetism in a similarly doped crystal of $La_{1.905}Sr_{0.095}CuO_4$ and show through a vortex-plasma model, that if the fluctuation diamagnetism originates solely in vortices, then they must exhibit an anomalously large vortex diffusion constant, that is more than two orders of magnitude larger than the Bardeen-Stephen estimate. This points to either the unusual properties of vortices in the underdoped d-wave cuprates or a contribution to the diamagnetic response that is not superconducting in origin. Finally, I will introduce preliminary results of THz conductivity measurements of critically underdoped LSCO films, where superconductivity is fully suppressed.

Support for the measurements at JHU was provided by 10DOE DE-FG02-08ER46544 and the Gordon and Betty Moore Foundation. High quality thin films were provided by Ivan Bozovic of Brookhaven National Laboratory. The work at BNL was supported by U.S. DOE under Project No. MA-509-MACA.

I1-02 Nernst Effect and diamagnetism in cuprate superconductors - *N. Ong (Princeton University)*

Two diametrically opposed scenarios for hole-doped cuprates in the underdoped (UD) regime have emerged. In the strong-pairing, vortex-fluctuation scenario, derived from Nernst and torque experiments, the pairing energy and superconducting gap are extremely large across the UD regime. However, the low hole density leads to a soft phase-stiffness modulus that is highly susceptible to spontaneous vortex creation. In zero magnetic field, the Meissner transition at T_c is caused by the loss of phase stiffness, but the pair condensate, absent rigidity, survives up to temperatures as high as ~130 K. Below T_c, the soft modulus leads to vortex-solid melting at moderate magnetic fields B (<< the upper critical field H_{c2}). Hence, at very low temperatures, a field B of ~20 T is sufficient to induce vortex solid melting (and loss of phase coherence), but the pair condensate survives to H_{c2} of 100-200 Tesla. The opposite scenario (weak-pairing with Gaussian fluctuation) based on quantum oscillations posits that pairing in UD YBCO is in the weak limit, and readily destroyed by B~20 T. I will review the issues. Recent heat capacity, STM, IR plasmon and ARPES experiments favoring the strong-pairing, vortex-fluctuation scenario will be discussed.
Collaborators: Lu Li, and Yayu Wang.
Supported by NSF MRSEC grants Grants No. DMR-0213706 and No.
DMR-0819860.

I1-03 Disentangling Cooper-pair formation above the transition temperature from the pseudogap state in the cuprates. - *A. Kaminski (Ames Laboratory and Department of Physics and Astronomy, Iowa State University)*

Pseudogap state in cuprates is one of most interesting topics in modern condensed matter physics. The idea of arcs, segments of Fermi surface that are not closed contours in the momentum states challenges our understanding of most basic concepts in solid state physics. By studying the spectral weights associated with pseudogap and superconductivity using Angle Resolved Photoemission Spectroscopy (ARPES) we found that there is a direct correlation between the loss of the low energy spectral weight due to the opening of the pseudogap and a decrease of the spectral weight associated with superconductivity as a function of momentum and doping. High accuracy data lead us to conclude that the pseudogap competes with the superconductivity by depleting the spectral weight available for pairing in the region of momentum space, where the superconducting gap is largest. We also found evidence for a spectroscopic signature of pair formation and demonstrated that in a region of the phase diagram commonly referred to as the ``pseudogap", two distinct states coexist: one that persists to an intermediate temperature Tpair and a second that extends up to T*. The first state is characterized by a doping independent scaling behavior and is due to pairing above Tc, but significantly below T*. The second state is the "proper" pseudogap – characterized by linear dependence of the spectral weight at Ef, absence of pair formation and is likely linked to Mott physics of pristine CuO_2 planes. This new quantitative approach to analyzing ARPES data also revealed new, very unexpected property of Fermi arcs.

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I1-04 Decrease of upper critical field with underdoping in cuprate superconductors - *J. Chang (Université de Sherbrooke)*

It is still unclear why the transition temperature T_c of cuprate superconductors falls with underdoping. The doping dependence of the critical magnetic field H_{c2} is directly relevant to this question, but different estimates of H_{c2} are in sharp contradiction. We resolve this contradiction by tracking the characteristic field scale of superconducting fluctuations as a function of doping, via measurements of the Nernst effect in Eu-LSCO. H_{c2} is found to fall with underdoping, with a minimum where stripe order is strong. The same non-monotonic behavior is observed in the archetypal cuprate superconductor YBCO. We conclude that competing states such as stripe order weaken superconductivity and this, rather than phase fluctuations, causes T_c to fall as cuprates become underdoped.
Work done in collaboration with: N. Doiron-Leyraud, O. Cyr-Choinière, F. Laliberté, E. Hassinger, J.-Ph. Reid, R. Daou, S. Pyon, T. Takayama, H. Takagi and L. Taillefer.

I1-05 Infrared study of pseudogap and precursor superconductivity in YBa2Cu3O7-d - *C. Bernhard (Department of Physics and Fribourg Center for Nanomaterials, University of Fribourg)*

Measurements of the far-infrared response of the cuprate high T_c superconductor $ReBa_2Cu_3O_{7-d}$ are presented. In particular, it is shown that a multilayer analysis of the *c*-axis response provides important new information about the anomalous normal state properties in the underdoped state [1]. Besides competing correlations which give rise to a pseudogap that depletes the low-energy electronic states below $T^{*}>>T_c$, it enables one to identify the onset of a more coherent response below T^{ons} (with $T^{*}>T^{ons}>T_c$) that can be associated with a precursor superconducting state. The doping phase diagram of T^{ons} is presented and it is shown that the in-plane response exhibits corresponding changes below T^{ons}.

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I1-06 High field determination of superconducting fluctuations in high-Tc cuprates - ***F. Rullier-Albenque (Service de Physique de l'Etat Condensé, CEA Saclay), H. Alloul (Laboratoire de Physique des Solides, Université d'Orsay), D. Colson (SPEC - CEA Saclay)***

The origin of the pseudogap phenomenon remains a very controversial issue in the physics of the cuprates. It has been assigned either to a precursor pairing state or to a variety of distinct orders independent or competing with superconductivity. We address this question in this talk by studying the superconducting fluctuation (SCF) contributions to the ab plane conductivity.

The SCF paraconductivity has been determined accurately in a series of $YBa_2Cu_3O_{6+x}$ single crystals using high magnetic fields to restore the normal state behavior [1]. This allows us to determine within the same set of transport measurements both the field $H'_c(T)$ and the temperature T'_c above which the SCFs are fully suppressed, and the pseudogap temperature T^*. A careful investigation near optimal doping shows that T^* becomes smaller than T'_c, which unambiguously evidences that the pseudogap cannot be assigned to preformed pairs [2].

In the nearly optimally doped samples, the SCF contribution to conductivity can be accounted for by Gaussian Aslamazov-Larkin fluctuations in the Ginzburg-Landau approach [3]. A phase fluctuation contribution might be invoked in the most underdoped sample in a *T* range which increases when controlled disorder is introduced by electron irradiation.

Finally, the analysis of the fluctuation magnetoconductance allows us to determine the critical fields $H_{c2}(0)$ which are found to be very similar to $H'_c(0)$ and to increase with hole doping. These two depairing fields which are directly connected to the magnitude of the superconducting gap therefore follow the evolution of T_c, which is at odds with the sharp decrease of the pseudogap with increasing hole doping.

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I2 - Spin Dynamics of Pnictides
Palladian, 3:30 PM – 6:00 PM
Session Chair: John Tranquada

I2-01 Incommensurate SDW order in 122 iron pnictides - ***A. Goldman (Department of Physics and Astronomy, Iowa State University and Ames Laboratory, USDOE), S. Khan (4Department of Physics, University of Illinois and Ames Laboratory, USDOE), D. Johnson (Department of Materials Science and Engineering, Iowa State University and Ames Laboratory, USDOE), D. Pratt, M. Kim, A. Kreyssig, J. Lamsal, G. Tucker, J. Zarestky, A. Thaler, N. Ni, Y. Lee, S. Bud'ko, B. Harmon, P. Canfield, R. McQueeney (Department of Physics and Astronomy, Iowa State University and Ames Laboratory, USDOE), M. Lumsden, K. Marty (Neutron Scattering Science Division, Oak Ridge National Laboratory), W. Tian (Neutron Science Division, Oak Ridge National Laboratory), T. Heitmann (The Missouri Research Reactor, University of Missouri)***

The systematics of transition metal substitution in BaFe_2As_2 provides an opportunity to study the relationship between magnetism and the emergence of unconventional superconductivity. Here we describe recent neutron scattering measurements of Ba(Fe_{1-x}M_x)_2As_2 (M = Co, Ni, Cu) which reveal that commensurate antiferromagnetic order gives way to incommensurate magnetic order for Co compositions between 0.056 < x < 0.06 and Ni compositions between 0.031 < x < 0.035. The incommensurability has the form of a small transverse splitting from the commensurate antiferromagnetic propagation vector **Q**_AFM =(1 0 1). For Co and Ni substitutions, the results are consistent with the formation of a spin-density wave driven by Fermi surface nesting of electron and hole pockets and confirm the itinerant nature of magnetism in the iron arsenide superconductors. Our results indicate that Co and Ni substitutions act as effective electron donors, where the appearance of incommensurate spin-density wave order and the suppression of ordered magnetism mimic a simple rigid-band picture. For Cu, the magnetic phase diagram does not display incommensurate order demonstrating that the rigid-band approach breaks down. We will discuss these results in light of recent models that consider the importance of impurity scattering for both incommensurability and superconductivity in the iron pnictides.

This work was supported by the Division of Materials Sciences and Engineering, Office of Basic Energy Sciences, U.S. Department of Energy. The work at the High Flux Isotope Reactor,Oak Ridge National Laboratory (ORNL), was sponsored by the Scientific User Facilities Division, Office of Basic Energy Sciences, U.S. DOE.

I2-02 Unconventional superconductivity in hole-doped BaFe2As2 from inelastic neutron scattering - ***R. Osborn, S. Rosenkranz, J. Castellan (Argonne National Laboratory), I. Eremin (Ruhr-Universität Bochum), A. Chubukov (University of Wisconsin-Madison)***

Resonant spin excitations have proved to be a valuable signature of unconventional superconductivity, sensitive to both the symmetry of the superconducting order parameter, the Fermi surface geometry, and the strength of electron-electron interactions. In an itinerant model, this resonance occurs when the superconducting energy gap changes sign on different parts of the electron Fermi surface, producing an excitonic mode within the superconducting gap. Its observation by inelastic neutron scattering in Ba0.6K0.4Fe2As2 represented the first phase-sensitive evidence of s±-symmetry [1]. It has been proposed that unconventional superconductors exhibit a universal scaling of the energy of the resonance to Tc. However, measurements of magnetic excitations in Ba1–xKxFe2As2 from x = 0.3 to 1.0 show that the scaling is strongly dependent on the degree of Fermi surface nesting. The wavevector of the magnetic scattering splits into two with hole-doping because of the growing mismatch

in the hole and electron Fermi surface volumes, accompanied by a decrease in the resonant spectral weight. We propose that the postulated scaling represents the maximum binding energy of the spin exciton before superconductivity is suppressed by spin density wave order, a conclusion backed by a more detailed study of the phase diagram [3].
Supported by U.S. DOE, Office of Science, under contract No. DE-AC02-06CH11357.
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I2-03 Friedel-like Oscillations from Interstitial Iron in Superconducting Fe1+yTe0.62Se0.38 - *V. Thampy, J. Kang, Z. Tesanovic (Institute for Quantum Matter and Department of Physics and Astronomy, Johns Hopkins University)*

Using polarized and unpolarized neutron scattering we show[1] that interstitial Fe in superconducting $Fe_{1+y}Te_{1-x}Se_x$ induces a magnetic Friedel-like oscillation that diffracts at **Q** = (10) and involve > 50 neighboring Fe sites. The interstitial > 2 μ_B moment is surrounded by compensating ferromagnetic four spin clusters that may seed double stripe ordering in $Fe_{1+y}Te$. A semi-metallic 5-band model with Fermi surface nesting and four-fold symmetric super-exchange between interstitial Fe and two in-plane nearest neighbors largely accounts for the observed diffraction.
Work at IQM was supported by DoE, Office of BES, Division of Materials Sciences & Engineering under DE-FG02-08ER46544.
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I2-04 Superconductivity, magnetic interactions and electron correlations in iron pnictides and selenides - *Q. Si (Rice University)*

I will summarize the approach to the iron pnictides as correlated metals near a Mott transition [1], basing on the fact that they are bad metals. Within this approach, increasing the kinetic energy will suppress antiferromagnetic order; this provided the basis for the early theoretical proposal of using an isoelectronic P for As substitution as a means to reach a quantum critical point [2]. Reducing the kinetic energy, on the other hand, pushes the system to the Mott insulating side, as when the Fe-square lattice is expanded in La2O3Fe2Se2 [3] or when there is a vacancy order in the alkaline iron selenides [4]. Magnetic order and dynamics in this approach are described in terms of J1-J2 and related exchange interactions [1,5]. Such short-range exchange interactions drive superconducting pairing; importantly, in this approach, the resulting pairing for the alkaline iron selenides is as strong as that for their pnictides counterparts in spite of the missing hole Fermi pocket [6]. The competing J1-J2 interactions lead to A1g s(x2y2) and B1g d(x2-y2) pairings as the two dominant channels that are quasi-degenerate; for the pnictides case, the A1g s(x2+y2) component is also competitive.
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I2-05 Selection of magnetic order and spin response of underdoped Fe-pnictides - *I. Eremin (Ruhr-University Bochum)*

A comprehensive understanding of the relationship between magnetism and superconductivity in the Fe-based superconductors, discovered in 2008 by Hideo Hosono and collaborators ultimately requires an analysis of the magnetic ground states in these compounds and their evolution with doping. In this talk I will analyze the itinerant description of antiferromagnetism in parent materials of the iron-based superconductors. In contrast to a purely localized scenario this theory allows for a coherent understanding of the full phase diagram of these materials as a function of doping, disorder and pressure. In particular, I will start by analyzing the selection of the stripe magnetic order in the unfolded BZ and the resulting spin excitations within itinerant description. Selecting one hole and two electron pockets we find that SDW order is highly degenerate if electron pockets are circular and interactions involved are between holes and electrons only. Repulsive charge interactions between two electrons as well as ellipticity of the electron pockets break the degeneracy and select metallic (0, p) [(p,0)] SDW state in the unfolded BZ -- the same order as seen in the experiments. Next we analyze the evolution of the spin excitations from the parent antiferromagnetic phase to the superconducting phase and address in particular the coexistence phase of antiferromagnetism and superconductivity. Finally, we address the salient experimental features of the magnetic excitations in the spin-density-wave phase of iron-based superconductors. We show that ellipticity of the electron bands accounts for the anisotropy of the spin waves along different crystallographic directions and the spectral gap at the momentum conjugated to the ordering one.
The work is done in collaboration with A.V. Chubukov, J. Knolle, R. Moessner, J. Schmalian

I2-06 Biquadratic magnetic interaction in parent ferropnictides - *K. Belashchenko (University of Nebraska-Lincoln), V. Antropov (Ames Laboratory), A. Wysocki (University of Nebraska-Lincoln)*

The discovery of superconductivity in LaFeAsO introduced ferropnictides as a new class of superconducting compounds with critical temperatures second only to those of the cuprates. Although the presence of iron makes the ferropnictides radically different from the cuprates, antiferromagnetism in the parent compounds suggests that superconductivity and magnetism are interrelated in both of them. However, the character of magnetic interactions and spin fluctuations in ferropnictides is not reasonably described by conventional models of magnetism. We show that the most puzzling features can

be naturally reconciled within a rather simple effective spin model with biquadratic interaction, which preserves the symmetry of the lattice and is consistent with electronic structure calculations. By going beyond the Heisenberg model, our description explains numerous experimental observations, including the peculiarities of the spin-wave spectrum, thin domain walls and crossover from a first- to second-order phase transition under doping. The model also offers insight into the occurrence of the nematic phase above the antiferromagnetic phase transition.
Work at UNL supported by NSF (DMR-1005642 and EPS-1010674) and by Research Corportation. Work at Ames Laboratory supported by U.S. Department of Energy (BES-DMSE) under Contract No. DE-AC02-07CH11358.
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I3 - Material Trends in Pnictides
Diplomat, 3:30 PM – 6:00 PM
Session Chair: Robert Cava

I3-01 Properties of new iron-based and related superconductors - *H. Hosono (Tokyo Institute of Technology)*

Iron-based superconductors have several features among superconducting families. One of them is a vast variety of parent compounds such as 1111, 122, 11, and compounds with thick blocking layers. Robust nature of superconductivity to impurity is a unique property as exemplified by emergence of superconductivity by substitution of Fe sites with Co or Ni>

In this talk, we report several new iron-based superconductors and related superconductors with similar crystal structures; $REFeAsO_{1-x}H_x$ (Rerate earth), $Ba_{1-x}RE_xFe_2As_2$:Co, $RECo_2B_2$, $LaNi_{0.8}Bi_2$ with 1111 structure, LaTMBN and $La_3TM_2B_2N_3$ (TM = Transition Metal). In addition, recent advance in epitaxial thin film growth of Ba-122:Co is presented with emphasis on advantageous grain boundary nature for high Jc over high Tc-cuprates and application to flexible tapes.

I3-02 CaFe2As2: Model system for Fe-based superconductivity - *P. Canfield (Ames Laboratory / Iowa State University)*

The discovery of $CaFe_2As_2$ as a third member of the $BaFe_2As_2$ and $SrFe_2As_2$ family [1] revealed the extreme importance of the coupling between structural, magnetic and electronic degrees of freedom in these materials. [1,2] $CaFe_2As_2$ is the most pressure and strain sensitive of these parent materials,[3-6] manifesting a sudden and clear transition into a non-magnetic, collapsed tetragonal phase with very modest pressure or strain. This phase can be induced by hydrostatic pressures as small as 5 kbar, or at ambient pressure by controllable strain fields associated with nanoscopic inclusions of Fe-As based percipitates.[7]

In addition $CaFe_2As_2$ can support Co substitution for Fe and be brought into a superconducting state. In this talk I will review the interplay between superconductivity, long-range magnetic order and the collapsed tetragonal phase in this rich and highly responsive material.

Work at the Ames Laboratory was supported by the Department of Energy, Basic Energy Sciences under Contract No. DE-AC02-07CH11358.

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[2] PRB **78**, 100506 (2008).
[3] PRL **101**, 057006 (2008).
[4] PRB **79**, 020511 (2009).
[5] PRB **78**, 184517 (2008).
[6] PRB **78**, 100506 (2008).
[7] PRB **83**, 144517 (2011).

I3-03 Enhancement of the superconducting transition temperature of FeSe by intercalation of a molecular spacer layer - *S. Blundell, S. Clarke (University of Oxford)*

The recent discovery of high temperature superconductivity in a layered iron arsenide has led to an intensive search to optimize the superconducting properties of iron-based superconductors by changing the chemical composition of the spacer layer that is inserted between adjacent anionic iron arsenide layers. Until now, superconductivity has only been found in compounds with a cationic spacer layer consisting of metal ions: Li+, Na+, K+, Ba2+ or a PbO-type or perovskite-type oxide layer. Electronic doping is usually necessary to control the fine balance between antiferromagnetism and superconductivity. Superconductivity has also been reported in FeSe, which contains neutral layers similar in structure to those found in the iron arsenides but without the spacer layer. We have demonstrated the synthesis [1] of Lix(NH2)y(NH3)1-yFe2Se2 (x ~0.6 ; y ~ 0.2), with lithium ions, lithium amide and ammonia acting as the spacer layer, which exhibits superconductivity at 43(1) K, higher than in any FeSe-derived compound reported so far and four times higher at ambient pressure than the transition temperature, Tc, of the parent Fe1.01Se. We have determined the crystal structure using neutron powder diffraction and used magnetometry and muon-spin rotation data to determine the superconducting properties. This new synthetic route opens up the possibility of further exploitation of related molecular intercalations in this and other systems in order to greatly optimize the superconducting properties in this family.

1] Matthew Burrard-Lucas, David G. Free, Stefan J. Sedlmaier, Jack D. Wright, Simon J. Cassidy, Yoshiaki Hara, Alex J Corkett, Tom Lancaster, Peter.

I3-04 Materials Perspective on the Iron-based Superconductors: Insights into the Superconductivity Mechanism and Applications - ***A. Safa-Sefat (Oak Ridge National Laboratory)***

High-temperature superconductors were discovered in materials synthesis laboratories, serendipitously. Although there are many findings on the physics of Cu- and Fe-based superconductors, we are still puzzled by their mechanism and yearn for better properties. Because the phenomenon of high-Tc is not well-understood, it is impossible to predict superconducting materials, theoretically. As a result, large synthesis efforts focus on the use chemical intuition to create variants of known superconductors (by doping and chemical substitutions), and on the creation of new materials. In this talk, we will review some of my ongoing materials efforts aligned with basic energy sciences mission, with aim on potential applications.

This work was supported by the Department of Energy, Basic Energy Sciences, Materials Sciences and Engineering Division.

I3-05 The role of different negatively charged layers in Ca10(Fe1-xPtxAs)10(Pt3+yAs8) and superconductivity at 30 K in electron-doped (Ca0.8La0.2)10(FeAs)10(Pt3As8) - ***D. Johrendt (Department Chemie, Ludwig-Maximilians-Universtät München), T. Stürzer, G. Derondeau (Department Chemie, Ludwig-Maximilians-Universität München)***

The recently discovered compounds Ca10(Fe1-xPtxAs)10(Pt3+yAs8) exhibit superconductivity up to 38 K, and contain iron arsenide (FeAs) and platinum arsenide (Pt3+yAs8) layers, separated by layers of Ca atoms [1-3]. We have identified four crystal structures by single crystal X-ray diffraction, one referred to as the 1038 phase, and three polymorphs (alpha, beta, gamma) of the 1048 phase. In contrast other reports [2,4], our results show that superconductivity is not only controlled by platinum-doping of the FeAs-layers [5]. Moreover, the latter is rather unfavorable for higher Tc above 15 K, which we show to occur in the phase diagram of Ca10(Fe1-xPtxAs)10(Pt4As8) near x = 0, which means in compounds without Pt-substitution in the FeAs layers. Band structure calculations and the analysis of the charge distribution by QTAIM indicates, that the iron arsenide layers of the 1048-phases become electron doped by excess electrons, provided by a small charge imbalance between the FeAs and Pt3+xAs8 layers. This is supported experimentally by the fact that we were able to increase Tc also of the 1038-phase (Tc < 15 K so far) to 30 K by La- doping in (Ca0.8La0.2)10(FeAs)10(Pt3As8) [5]. This emphasizes the important fact, that these compounds iron-based superconductors contain two chemically different negatively charged layers, which opens new perspectives to tune the electronic state of FeAs materials.

[1] C. Löhnert et al., Angew. Chem. Int. Ed. 50, 9195 (2011).
[2] N. Ni et al., Proc. Natl. Acad. Sci. U. S. A. 108, E1019 (2011).
[3] S. Kakiya et al., J. Phys. Soc. Jpn. 80, 093704 (2011).
[4] M. Nohara et al., Solid State Commun. 152, 635 (2012).
[5] T. Stürzer et al., arXiv:1203.6767

I3-06 Superconductivity and magnetism in (Tl,K,Rb)xFe2-ySe2 - ***M. Fang (Department of Physics, Zhejiang University), H. Wang (Department of Physics, Hangzhou Normal University), C. Dong (Department of Physics, Zhejiang University)***

Cuprates and Fe-based compounds are two families with highest superconducting (SC) transition temperatures. A common feature in both families is that the superconductivity emerges as antiferromagnetic (AFM) long range order is suppressed. While the parent compound of cuprates is a Mott insulator where the electron repulsion is strong, the parent compound of Fe-based materials is metallic implying weak or moderate electron correlation. A key strategy to develop a unified picture for the Fe- and Cu-based high temperature superconductivity (HTSC) is to explore the possibility to tune the Fe-based compound into an insulator. Here, I shall report our discovery of superconductivity above 30K in $(Tl,K,Rb)_xFe_{2-y}Se_2$ system[1,2], in which the onset SC transition temperature is as high as 40K. While the compound with more Fe vacancies shows an AFM insulator behavior, which has been confirmed to be associated with the Fe-vacancy ordering in the crystals[3]. Our discovery represents the first Fe-based HTSC at the verge of an AFM insulator. A review on the recent results of Fe-vacancy super-lattice, block AFM ordering, electronic structure, superconductivity and phase separation in $(Tl,K,Rb)_xFe_{2-y}Se_2$ system will be presented in this talk.

This work is supported by the NSFC (No. 10974175) and NBRPC(2011CBA00103) and we discussed with Qimiao Si, Fuchun Zhang.

Minghu Fang, Hangdong Wang et al. ***EPL***, 94 (2011) 27009, arXiv. 1012.5036
Hangdong Wang, ***Minghu Fang*** et al., ***EPL***, 93 (2011) 47004, arXiv. 1101.0462
F. Ye, Wei Bao, X. H. Chen, and ***Minghu Fang*** et al. ***PRL***,107, (2011)137003, arXiv. 1102.2882

I4 - Topological Superconductors
Empire, 3:30 PM – 6:00 PM
Session Chair: Yoichi Ando

I4-01 Seeking Majorana Fermions in SC-TI devices - *J. Williams, A. Bestwick (Stanford), D. Goldhaber-Gordon (Stanford Univeristy), P. Gallagher, J. Analytis, S. Hong, Y. Cui, I. Fisher (Stanford University)*

The ability to measure and manipulate complex particles in the solid state is a cornerstone of modern condensed-matter physics. Typically, excitations of a sea of electrons, called quasiparticles, have properties very similar to those of free electrons. However, excitations with properties very different from electrons have been created in designer quantum materials: for example, Dirac quasiparticles in graphene and fractionally-charged quasiparticles in fractional quantum Hall systems. I will report on our experiments designed to measure a new quasiparticle -- a Majorana fermion -- in devices in which a 3D topological insulator couples to conventional superconducting materials.

I4-02 Two dimensional Josephson supercurrent through a topological insulator - *M. Veldhorst (University of Twente)*

The long-sought yet elusive Majorana fermion is predicted to arise from a combination of a superconductor and a topological insulator. An essential step in the hunt for this emergent particle is the unequivocal observation of supercurrent in a topological phase. Here, direct evidence for Josephson supercurrents in superconductor (Nb)–topological insulator (Bi2Te3)–superconductor electron-beam fabricated junctions is provided by the observation of clear Shapiro steps under microwave irradiation, and a Fraunhofer-type dependence ofthe critical current on magnetic field. Shubnikov–de Haas oscillations in magnetic fields up to 30 T reveal a topologically non-trivial two-dimensional surface state. This surface state is attributed to mediate the ballistic Josephson current despite the fact that the normal state transport is dominated by diffusive bulk conductivity. The lateral Nb–Bi2Te3–Nb junctions hence provide prospects for the realization of devices supporting Majorana fermions.

I4-03 Observation of topological order in a superconducting doped topological insulator - *L. Wray (Lawrence Berkeley National Laboratory), D. Qian (Jiaotong University), A. Fedorov (Lawrence Berkeley National Laboratory), Y. Hor (Missouri University of Science and Technology), H. Lin, A. Bansil (Northeastern University), S. Xu, Y. Xia, R. Cava, M. Hasan (Princeton University)*

The Bi2Se3 class of topological insulators has recently been shown to undergo a superconducting transition upon hole or electron doping (Cux-Bi2Se3 with Tc=3.8K and Pdx-Bi2Te3 with Tc=5.5K), raising the possibility that they realize a superconducting state that can be used as a non-Abelian Majorana platform. I will present measurements in which angle resolved photoemission spectroscopy is used to examine elements of bulk and surface band structure that determine the spin-orbital ground states of superconducting Cux-Bi2Se3 and Bi2Te3. In optimally doped Cux-Bi2Se3, we find that the spin-momentum locked topological surface states remain well defined and non-degenerate with respect to bulk electronic states at the Fermi level, providing a non-trivial surface band topology expected to give rise to a Majorana fermion mode at each superconducting vortex on the crystal surface. Analysis of the three dimensional bulk band structure suggests the additional likelihood that Cux-Bi2Se3 may be the first known realization of a state of matter termed the "topological superconductor", associated with a novel microscopic structure of Cooper pairs.

I4-04 From odd-parity pairing to topological superconductivity - *L. Fu (Massachusetss Institute of Technology)*

Topological superconductors are unconventional superconductors which possess massless itinerant Majorana fermions on the surface. There is currently intensive search for topological superconductors. In this talk, I will first demonstrate that odd-parity pairing symmetry is a key ingredient for topological superconductivity. Next I will describe our theoretical proposal that such an odd-parity topological phase may be realized in a recently discovered superconductor Cu-doped Bi2Se3. Properties of this unusual superconducting state will be discussed in connection with recent experiments.

I4-05 Physical properties of superconductors and topological insulators at high pressure - *C. JIN (Institute of Physics, Chinese Academy of Sciences)*

We report experimental updates about effects of pressure on superconductivity of iron based compounds or the related systems & pressure induced superconductivity in three dimensional topological compounds. Pressure tuned superconductivity will be discussed in conjunction with on site high pressure structure investigations. Phase diagrams of superconductivity as function of pressure for the studied systems will be presented.

The works are supported by NSF & MOST of China through research projects.

I4-06 Surface Majorana Fermions in Topological Superconductors - *M. Sato (The Institute for Solid State Physics, The University of Tokyo)*

Recently, there is much interest in Majorana fermions (MFs) in topological superconductors (TSCs). MFs were originally introduced as elementary particles such neutrinos, but no elementary particles have been identified as MFs yet. Now it has been known that MFs can be realized as topologically protected surface states of TSCs. In this talk, I will report on our recent works of MFs in TSCs.

Although spin-triplet superconductors had been known to host MFs, recently it was found that even s-wave superconducting states may support MFs [1] if the spin-orbit interaction is taken into account [2]. By combing with Zeeman magnetic fields, one finds that the system hosts chiral MFs on its surface and Majorana zero modes in a vortex, which implies the non Abelian topological order. This scheme was first established in Ref [1], and later applied to various systems. Very recently, an experimental realization of MFs based on this scheme was reported in a nanowire system[3].

I also discuss MFs of the recent discovered superconducting topological insulator (STI), $Cu_xBi_2Se_3$, which is expected to be an odd-parity superconductor. From the Fermi surface criterion [4], surface helical MFs have been predicted. Here we develop a theory of the tunneling spectroscopy for STIs [5]. Based on the symmetry and topological nature of parent topological insulators, we find that the MFs in the STIs have a profound structural transition in the energy dispersions .We clarify that MFs in the vicinity of the transitions give rise to robust zero bias peaks that is consistent with the recent experimental result [6] of the tunneling conductance.

[1] M. Sato et al, Phys. Rev. Lett. 103, 020401 (2009); Phys. Rev. B 82, 134521 (2010).
[2] M. Sato, S. Fujimoto, Phys. Rev. B 79, 094504 (2009).
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[5] A. Yamakage, K. Yada, M.Sato, Y. Tanaka, arXiv:1112.5036.
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I5 - Organic Superconductors
Congressional, 3:30 PM – 6:00 PM
Session Chair: Kosmas Prassides

I5-01 Zeeman interaction and high-field superconductivity in molecular superconductors - *S. Brown, UCLA*

Molecular conductors are commonly known for the influence of correlations and for large anisotropies in electronic structure. Examples include the quasi-two dimensional (q2d) family of compounds κ-$(BEDT\text{-}TTF)_2X$, and the q1d Bechgaard salts $(TMTSF)_2X$. A consequence is the stabilization of a sequence of ground states for a given compound or family when the relative importance of band-widths to Coulomb interactions is tuned with either chemical or mechanical pressure, including superconductivity.

The physical properties are consistent with magnetically-mediated pairing. Also, the superconductivity is generally stable against in-plane magnetic fields, because of interlayer coherence lengths less than, or of order of, the interlayer spacing. A consequence of particularly weak interlayer coupling for the κ-phase materials is the dominant influence of the Zeeman interaction for in-plane fields. For weak fields, the spin lattice relaxation rate $[T_1T]^{-1}$~B^2, as expected for the nodal superconductivity associated with magnetic mediation. In the limit of low temperatures, there is evidence from NMR, and from magnetic torque measurements, for a line of phase transitions to a distinct, high-field superconducting state. As the critical field H_s for the transition is consistent with estimates for the paramagnetic limiting field H_P, the high-field phase is discussed in the context of inhomogeneous (FFLO-type) superconductivity.

I5-02 Linear-T scattering and pairing from spin fluctuations in organic, cuprate, and iron-pnictide superconductors - *N. Doiron-Leyraud (Université de Sherbrooke)*

The $(TMTSF)_2X$ series of organic superconductors, with X=PF_6 or ClO_4, are clean single-band metals that exhibit unconventional superconductivity in the vicinity of a pressure-induced spin-density wave (SDW) quantum critical point (QCP). As such, they epitomize the interplay between magnetism and superconductivity observed in heavy fermion, cuprate, and iron-pnictide superconductors. At the SDW QCP in $(TMTSF)_2PF_6$, we observed a strictly linear temperature dependence of the resistivity [1,2] which, with increasing pressure, decreases in parallel with the weakening superconductivity. The amplitude of the linear-*T* resistivity was found to correlate with the superconducting T_c [1,2], showing that both phenomena share a common origin. A similar correlation was also found with the spin fluctuations seen by NMR experiments, revealed as a deviation from the Korringa law [3]. To be explained, this connection between spin fluctuations, scattering, and superconductivity requires the hitherto overlooked mutual reinforcement of SDW and pairing correlations [3]. The same empirical correlation between linear-*T* resistivity and T_c is observed in the hole-doped [2,4] and electron-doped [5] cuprates, iron-pnictides [1,2,4], and heavy fermion [6] superconductors, showing that the same mechanism is at play in these materials. This points to a common, magnetic origin to the superconducting pairing. Work done in collaboration with S. René de Cotret, P. Auban-Senzier, D. Jérôme, C. Bourbonnais, K. Bechgaard, and L. Taillefer.

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[2] N. Doiron-Leyraud *et al.*, arXiv:0905.0964.
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[4] L. Taillefer, Annu. Rev. Condens. Matter Phys. 1, 51 (2010)
[5] K. Jin *et al.*, Nature 476, 73 (2011)
[6] N. Tateiwa *et al.*, PRB 85, 054516 (2012)

I5-03 The Bechgaard salts: the archetype of magnetic-mediated superconductivity - ***C. Bourbonnais (Regroupement Quebecois des Materiaux de Pointe, RQMP, Département de physique, Université de Sherbrooke (QC), Canada and Canadian Institute for Advanced Research, Toronto, Canada)***

The (TMTSF)2X known as the Bechgaard salts series of low dimensional organic conductors stand out as prototypical compounds where unconventional superconductivity interacts with antiferromagnetism. This interaction demarcates from the usual competition of order parameters and results from the quantum interference between the nesting and Cooper pairing scattering channels that characterize the weakly interacting anisotropic electron gas. Weak coupling renormalization group analysis shows that interference not only reproduces the observed characteristic sequence of instabilities in which spin-density-wave and superconducting orders succeed one another under pressure, but it also describes how the interfering channels lead to various nonFermi liquid anomalies in the normal state [1-2]. Among these, the linear temperature resistivity [3], and Curie-Weiss nuclear spin relaxation rate [4] are found to correlate in strength with both the amplitude of spin correlations and Cooper pairing or Tc under pressure. On experimental grounds, this correlation is now pretty well documented for the Bechgaard salts showing besides an amazing similarity with what is found in other unconventional superconductors like pnictides and cuprates. The scaling of nonFermi liquid properties with Tc leads to an anomalous range of quantum criticality extending over the broad range of pressure where superconductivity is present [1-2], a feature at odds with the more conventional scheme of a quantum critical point as induced by a single channel of order parameter fluctuations.

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[4] W. Wu *et al.,* Phys. Rev. Lett. **94**, 97004 (2005); **98,**147002 (2007); F. Creuzet *et al.,* Synth. Metals **19**, 277 (1987).

I5-05 The Fulde-Ferrell-Larkin-Ovchinnikov state in organic superconductors - ***J. Wosnitza (Dresden High Magnetic Field Laboratory, Helmholtz-Zentrum Dresden-Rossendorf)***

In the so-called FFLO state, named after Fulde, Ferrell, Larkin, and Ovchinnikov, the superconducting state can survive even at high magnetic fields above the Pauli paramagnetic limit. The quasi-two-dimensional (2D) organic superconductors have been suggested as good candidates for exhibiting the FFLO state. When applying the magnetic field exactly parallel to the conducting layers the orbital pair breaking is greatly suppressed and the Pauli limit is reached. We performed high-resolution specific-heat and torque-magnetization experiments in magnetic fields up to 32 T for such 2D organic superconductors. Besides an upturn of the upper critical field towards lowest temperatures, we observe a second thermodynamic transition within the superconducting phase signaling the existence of an additional superconducting phase. These features appear only in a very narrow angular region close to parallel-field orientation as evidenced by comprehensive angular- and field-dependent specific-heat measurements for one organic superconductor. Our results give strong evidence for the realization of the FFLO state in rganic superconductors.

This work was done in cooperation with R. Beyer, B. Bergk, A. Demuer, I. Sheikin, Y. Wang, Y. Nakazawa, R. Lortz, and G. Zwicknagl. Part of this work was supported by EuroMagNET II (EU contract No. 228043).

I5-06 FFLO phase in magnetic-field-induced superconductivity of lambda-(BETS)2FeCl4 - ***B. Zhou, H. Kobayashi, A. Kobayashi (Department of Humanities and Sciences, Nihon University), K. Kodama, k. Sugii, T. Terashima, T. Yamaguchi, S. Tsuchiya, N. Kurita (National Institute for Materials Science)***

A two dimensional organic conductor lambda-$(BETS)_2FeCl_4$ shows both a metal-insulator and antiferromagnetic transitions at 8 K. The antiferromagnetic insulating (AFI) phase is broken by a field of about 10 T, after which a paramagnetic metallic (PM) phase is recovered. When a magnetic field is applied parallel to the conducting ac planes, superconductivity (SC) is induced in the field range 17 T to 42 T.[1] The Fe^{+3} ions in the $FeCl_4$ layers have large spins (S=5/2) and the exchange interaction (pi-d interaction) J between the conducting pi spins in the BETS layers and the localized 3d spins in the $FeCl_4$ layers play a crucial role in the field-induced SC. In the SC phase, the presence of the inhomogeneous SC phase, Fulde and Ferrell, and Larkin and Ovchinnikov (FFLO) phase has been discussed.[1,2] The interlayer resistance shows characteristic dips in the SC phase below 24 T, which are interpreted as the magnetic field-dependent commensurability effect between the spatially varying wavelength of the order parameter and the JV lattice constant. The dips disappear when the field is tilted from the layers only by 1 degree, showing the FFLO phase is easily broken by the orbital effect. The in-plane upper critical field of the field-induced SC phase determined by the magnetic torque measurements steeply decreases with decreasing temperature below 2.2 K. The in-plane field dependence of the diamagnetic susceptibility shows a significant decrease below 25 T at low temperatures, showing that magnetic fluxes are less excluded from the sample. These results gives the FFLO phase diagram with the triple point between the FFLO, homogeneous SC, and PM phases at 2.2 K and 23 T.[3]

[1] S. Uji *et al.*, Nature (London) 410 (2001) 908, Phys. Rev. Lett. **97** (2006) 157001
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ICAM / I2CAM Sponsored Session: The Foundations of High-Temperature Superconductivity: Twenty-five Years Young

Regency, 7:00 PM to 8:45 PM
Session Chair: Laura Greene

S1-01 Some unique superconductive Properties of Cuprates -*K. A. Müller, Physics Institute, University of Zurich, CH 8057, Switzerland.*

Copper oxides are the only materials that show transition temperatures, T_c, *above* the boiling point of liquid nitrogen, with a maximum T_c^m of 162 K under pressure. Their structure is layered, with one to several CuO_2 planes, and upon hole doping, their transition temperature follows a dome-shaped curve with a maximum at T_c^m. In the underdoped regime, i.e., below T_c^m, a pseudogap T* is found, with T* always being larger than T_c, a property unique to the copper oxides [1)]. In the superconducting state, Cooper pairs (two holes with antiparallel spins) are formed that exhibit coherence lengths on the order of a lattice distance *in the* CuO_2 plane and one order of magnitude less perpendicular to it. Their macroscopic wave function is parallel to the CuO_2 plane near 100% *d* at their surface, but only 75% *d* and 25 % *s* in the bulk, and near 100% s perpendicular to the plane in YBCO. There are two gaps with the same T_c [2)]. As function of doping, the oxygen isotope effect is novel and can be quantitatively accounted for by a two-band vibronic theory [3)] near T_c^m, and underdoped below it till $T_c = 0$ with by a formula valid for (bi)polarons [4)] . These cuprates are intrinsically heterogeneous in a dynamic way. In terms of quasiparticles, Jahn Teller bipolarons are present at low doping, and aggregate upon cooling [1)], so that probably ramified clusters and/or stripes are formed, leading over to a more Fermi-liquid-type behavior at large carrier concentrations above T_c^m.

1) For an overview see: K.A. Müller, J. Phys: Condens. Matter 19, 251002 (2007).
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S1-02 High Temperature Superconductivity: Past, Present, and a Promising Future with Evidence" – Paul C. W. Chu, Texas Center for Superconductivity and Lawrence Berkeley National Laboratory

Last year the world celebrated the 100th anniversary of the discovery of superconductivity. This year we commemorate the 25th anniversary of the discovery of YBCO ($YBa_2Cu_3O_7$), first superconductor with a high transition temperature (T_c) of 93 K, above the liquid nitrogen boiling point of 77 K. In the ensuing years after the discovery, great progress has been made: many other high temperature superconductors (HTSs) have been discovered, various theoretical models proposed, and numerous devices constructed and tested with performance superior to their non-superconducting counterparts. However, a commonly accepted theory is yet to be found, the full prowess of high temperature superconductivity is yet to be realized, a T_c above the current record of 134 K at ambient and 164 K under pressure is yet to be broken. In this talk, a review of the HTS history, a summary of its current status, the prospect of higher T_c, and evidence of possible interface-induced T_c-enhancement will be briefly presented and discussed.

S1-03 25 YEARS WITH CUPRATES - *P. Anderson (Princeton)*

I will talk about the tortuous history of my engagement with high Tc cuprate superconductivity—from starting with the right model in the first place, via many red herrings, to almost complete understanding. The essential physics of the very complex phase diagram of these wonderful substances is now available.

Panel: 8:30 – 8:45PM

Tuesday, July 31, 2012

Plenary 4 - An Overview on the Experimental Progress in the Iron Pnictide/Chalcogenide Superconductors

H. Wen (Center for Superconducting Physics and Materials, National Lab of Solid State Microstructures and Dept. of Physics, Nanjing University)

Regency, 8:30 AM to 9:15 AM

Session Chair: Shin-ichi Uchida

First of all I will give a brief survey of the material and structural categories and research status in the new iron based superconductors[1-3]. Then I will review the experimental progress in understanding the underlying pairing mechanism. Many transport, thermodynamics, penetration depth and tunneling experiments have revealed clearly the existence of multiband superconductivity. The NMR, inelastic neutron scattering, etc., have uncovered the intimate relationship between the superconductivity and the fluctuating antiferromagnetism. In many measurements a full-gap feature is favored, while in others, anisotropic gaps, even with nodes are observed. The unconventional superconductivity is evidenced by many experiment results, which will be illustrated by a close relationship between superconductivity and a bosonic mode, or a neutron resonance mode. It seems that the ingredients for supporting the well documented S□ pairing manner are enormous.[4-7] However, I will also raise some concerns to this model based on the recent progress, mainly on the unexpected weak (nonmagnetic) impurity scattering, the unavoidable orbital physics, and the possible absence of the hole pockets in some systems, like the recently discovered KxFe2Se2. All these suggest that a final recognition on the superconducting pairing mechanism in the iron-based superconductors is not yet reached.

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[6] P. J. Hirschfeld, et al., Rep. Prog. Phys. 74, 124508 (2011).
[7] I. I. Mazin, Physics 4, 26 (2011).

Plenary 5 - A Material Physics View on New Superconductors

H. TAKAGI (Department of Physics, University of Tokyo & RIKEN Advanced Science Institute)

Regency, 9:15 AM to 10:00 AM

Session Chair: Shin-ichi Uchida

Although superconductivity is a strange phenomenon, it is not a rare one - many elemental metals exhibit conventional BCS superconductivity at sufficiently low temperatures. There exists reasonable chance to find superconductivity once a new paramagnetic metal is discovered. The big challenge in materials physics and chemistry is to discover new superconductors with a high transition temperature Tc (for example >20 K) and/or with a nontrivial paring state and/or in unexpected places. I will discuss strategies to explore new high-Tc superconductors, such as close proximity to electronically ordered state, doping a system with strongly covalent bands and, most perhaps most importantly, serendipity, which emerged from a variety of superconductors discovered in the last 25 years including cuprates, Fe pnictides, organics, heavy fermions, and borides. Development of superconductors with a novel pairing state, such as topological superconductors and non-centrosymmetric superconductors, will also be addressed.

Keynote Sessions

K1 - Experimental trends in Cuprates, Pnictides, Intermetallic
Regency, 10:30 AM to 12:00 PM
Session Chair: Peter Johnson

K1-01 Infrared electrodynamics of iron-based high-Tc superconductors - *D. Basov (Department of Physics, UCSD)*

Infrared (IR) methods enable experimental access to energy gaps in a superconductor, strong coupling effects responsible for pairing, the collective response of the superfluid and allow one to quantify the strength of electronic correlations [Basov et al. Reviews of Modern Physics 83, 471 (2011)]. In this talk, I will overview recent IR experiments unraveling rather exotic electrodynamics of iron-based superconductors. In Ba122 series of materials electronic correlations appear to be moderately strong and do not appreciably change across the spin-density wave transition or with doping [Schafgans et al. PRL 2012 (in press)]. The low-frequency response of superconducting Ba122 phases is dominated by coupling to a bosonic mode at 20 meV and is significantly impacted by a pseudogap. IR data for both$BaFe_2(As_{1-x}P_x)_2$ and $Ba(Fe_{1-x}Co_x)As_2$ indicate that the pseudogap is not a precursor of superconductivity but may be related to the spin-density state of the parent compound. The pseudogap is also prominent in the interlayer response of both Ba122 and FeSeTe superconductors [Moon et al. PRL 106, 217001 (2011)]. Common patterns as well as contrasting trends between the iron-based and copper-based high-T_c materials unveiled by these and other experiments are instrumental to identify factors favoring higher T_c in exotic superconductors [Basov and Chubukov Nature-Physics 7, 271 (2011)].
Support: NSF and AFOSR.

K1-02 Phase Competition in Trisected Superconducting Dome - *Z. Shen (Stanford University and SLAC National Accelerator Laboratory)*

Angle resolved photoemission spectroscopy (ARPES) has been used to distinguish between different" phases" in cuprates based on their distinct spectroscopic phenomenology—temperature, doping, and momentum dependence, as well as location in momentum space. We found evidence for three distinct quantum phases comprising the superconducting ground state in $Bi_2Sr_2CaCu_2O_{8+\delta}$(Bi-2212), accompanied by abrupt changes at p~0.076 and p~0.19 in the phenomenology of the superconducting gap near the bond-diagonal (nodal) direction. Temperature dependence studies of the energy gap provides further supports for the microscopic distinction of these three phase regions, and additionally present hitherto unseen evidence that the pseudogap is not static below T_c. Together, these results indicate interweaving multiple quantum phases as natural ingredients of cuprate superconductivity, provide a microscopic picture of phase competition in momentum space, and predict the existence of phase boundaries inside the superconducting dome which are different from simple extrapolations from outside the dome.

K1-03 experimental trends in cuprates and pnictides: STM - *T. Hanaguri (RIKEN)*

Recent progress in STM/STS technology has enabled us to examine details of the electronic states in unconventional superconductors. In particular, spectroscopic-imaging STM (SI-STM), which measures the tunneling spectrum at every pixel of the atomic-resolution STM topography, has provided many insights into the superconducting gap. Each tunneling spectrum of SI-STM reflects quasi-particle density of states from which one can identify the superconducting gap. By examining the effect of local defects (e.g. impurities and vortices) on superconductivity, we can infer the superconducting gap structure. Even more important aspect of SI-STM is that we can determine the energy-momentum dispersion relation of anisotropic superconducting gap by taking Fourier transformations of quasi-particle interference patterns observed in the energy-dependent tunneling-conductance maps. Furthermore, by applying magnetic field to break time-reversal symmetry, not only amplitude but also phase of the superconducting gap can be inferred. We will review the results of SI-STM experiments and current understanding of the superconducting gap in cuprates and iron-based superconductors. We also discuss the future direction.

K2 - Nonequilibrium Probes of Superconductivity
Palladian, 10:30 AM to 12:00 PM
Session Chair: Dirk Van der Marel

K2-01 Looking for the pairing glue in cuprates by non-equilibrium optical spectroscopy - *C. Giannetti (I-LAMP (Interdisciplinary Laboratories for Advanced Materials Physics) & Department of Mathematics and Physics, Università Cattolica del Sacro Cuore), D. van der Marel (Départment de Physique de la Matière Condensée, Université de Genève, Genève CH1211), A. Damascelli (Department of Physics and Astronomy & Quantum Matter Institute, University of British Columbia, Vancouver), F. Parmigiani (Department of Physics, Università degli Studi di Trieste & Sincrotrone Trieste S.C.p.A., Basovizza I-34012), F. Banfi, G. Ferrini (I-LAMP (Interdisciplinary Laboratories for Advanced Materials Physics) & Department of Mathematics and Physics,*

Università Cattolica del Sacro Cuore), G. Coslovich (Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720), S. Dal Conte (Physics Department, Eindhoven University of Technology, 5600 MB Eindhoven), M. Greven (School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455), F. Cilento (Sincrotrone Trieste S.C.p.A., Basovizza I-34012)

In strongly-correlated systems the electronic and optical properties are strongly affected by different degrees of freedom, such as lattice vibration, bosonic excitations of electronic origin, quasi-particle excitations. Broadband ultrafast spectroscopy [1] is emerging as the premier technique to clarify the subtle interplay of fermionic quasiparticles and bosonic excitations of electronic and phononic origin, by their different characteristic timescales and spectral responses. The basic idea of these experiments is to use ultrashort light pulses to prepare the system in a non-equilibrium state, e.g., with the electronic distribution decoupled from the phononic one, and probe the recovery of the equilibrium dielectric function over a wide frequency range.

By investigating the dynamics of the optical conductivity of $Bi_2Sr_2Ca_{0.92}Y_{0.08}Cu_2O_{8+\delta}$ crystals at room temperature, we disentangle the electronic and phononic contributions to the generalized electron-boson Eliashberg function [2], showing that the spectral distribution of the electronic excitations, such as spin fluctuations and current loops, and the strength of their interaction with fermionic quasiparticles fully account for the high critical temperature of the superconducting phase transition [3]. Finally, we discuss how this technique can be extended to investigate the opening of a pseudogap and the apperance of new modes interacting with fermionic quasiparticles, as the temperature of the system is decreased.

The microscopic modeling of the non-equilibrium dynamics of correlated superconductors, unveiled by the time-resolved spectroscopy, will be one of the key challenges of the next-years materials science.

[1] F. Cilento et al. *Appl. Phys. Lett.* **96**, 021102 (2010).

[2] E. van Heumen et al. *Phys. Rev. B* **79**, 184512 (2009).

[3] S. Dal Conte et al. Disentangling the electronic and phononic glue in a high-Tc superconductor. *Science* **335**, 1600 (2012).

K2-02 Controlling superconductivity with light - ***A. Cavalleri (Max Planck Department for Structural Dynamics)***

In this talk I will discuss some of our recent work aimed at controlling the properties of cuprate superconductors with light. The focus is on the use of high-field THz radiation and on the nonlinear excitation of low-energy degrees of freedom. This stands in contrast to the widespread application of near-visible pulses used routinely to analyze the dynamics of hot quasi-particles. For example, we have used mid-infrared pulses to drive lattice vibrations directly, to quench competing stripe order in 1/8 doped compounds, or excite apical oxygen distortions in bi-layer YBCO. By these means, we have induced non-equilibrium superconducting states at higher temperatures than at equilibrium. By using the X-ray Free Electron Lasers at the SLAC laboratory, we have probed the underlying dynamics of lattice and charges, which was used to identify some of the underlying physical processes and timescales. Finally, by using nonlinear THz excitations at very low frequencies, i.e. below all vibrational resonances, we have manipulated the phase of layered cuprate superconductors, leading to ultrafast dimensionality oscillations in single layer cuprates.

Different aspects of this work have been performed in collaboration with D. Fausti, A. Dienst, S. Kaiser, D. Nicoletti, C. Hunt, I. Gierz, W. Hu, B. Keimer, H. Takagi

K2-03 Light induced meltdown of quasiparticles in high temperature superconductors probed by pump and probe photoemission spectroscopy - ***A. Lanzara (Physics Department, University California, Berkeley)***

Understanding how superconductivity emerges from other competing phases and how this balance evolves through the phase diagram is one of the biggest challenges in the field of high Tc superconductors.

By using high resolution *time*- and angle- resolved photoemission spectroscopy (tr-ARPES) we are able to directly probe collective dynamics after optical excitation and study their influence on quasiparticles dynamics, Cooper pair formation, superconducting gap and other competing orders. In particular, through systematic pump fluence dependence we were first able to induce a meltdown of quasiparticles and measure their recovery dynamics. Interestingly we observed that only quasiparticles beyond a particular boson mode respond to the pump laser excitations, while the others remain untouched and that the entire decay is governed by two different time scale. We observe that quasiparticles recombination is also a fluence and momentum dependent process with enhanced recombination at the antinode. As we move away from the nodal direction and along the Fermi arc, we observe a closing of the superconducting gap, a crossover from a weakly perturbed to a strongly perturbed regime. These results point to a new dichotomy between the ultrafast gap and quasiparticles response within and beyond the Fermi arc and reveal a new window into the nature of the pairing interaction in high Tc superconductors.

K3 - Interface and E-field Induced Superconductivity
Diplomat, 10:30 AM – 12:00 PM
Session Chair: Jochen Mannhart

K3-01 Superconductivity, magneto-transport and electronic structure of the interfacial LaAlO3/SrTiO3 system - ***J. Triscone, A. Fête, S. Gariglio, A. Caviglia, D. Li, D. Stornaiuolo, B. Sacépé, A. Morpurgo (Département de Physique de la Matière Condensée, University of Geneva, 24 Quai Ernest-Ansermet, 1211 Genève 4), M. Gabay (Laboratoire de Physique des Solides, Bat. 510, Université Paris-Sud 11, Centre d'Orsay, 91405 Orsay Cedex), M. Reinle-Schmitt, C. Cancellieri, P. Willmott (Paul Scherrer Institut, CH-5232 Villigen)***

Oxide materials are often characterized by strong electronic correlations, complex phase diagrams and competing ground states. This competition makes these materials very sensitive to external parameters. An interface, which naturally breaks inversion symmetry, is a major perturbation and one may thus expect that electronic systems with unusual properties can be generated at oxide interfaces [for a recent review, see 1]. A striking example is the interface between $LaAlO_3$and $SrTiO_3$, two good band *insulators*, which was found in 2004 to be conducting [2], and, in some doping range, superconducting with a maximum critical temperature of about 200 mK [3]. The thickness of the electron gas is found to be a few nanometers at low temperatures. This electron gas with low electronic density, typically 5 10^{13} electrons/cm^2, and naturally sandwiched between two insulators is ideal for performing electric field effect experiments allowing the carrier density to be tuned. Such an approach revealed the sensitivity of the normal and superconducting states to the carrier density. In particular, the electric field allows the tuning of the critical temperature between 200 mK and 0 K and thus the on-off switching of superconductivity. A large, interfacially generated, tunable spin-orbit coupling and a remarkable correlation between the spin-orbit coupling strength and the system phase diagram are other hallmarks of this fascinating system [4].
I will describe recent experiments aiming at determining the origin of the electron gas. I will then discuss superconductivity and the phase diagram of the system, magnetotransport in "standard" and in recently obtained high mobility samples that display Shubnikov de Haas (SdH) oscillations [5].

[1] P. Zubko et al., Annual Review : Condensed Matter Physics **2**, 141 (2011).
[2] A. Ohtomo, H. Y. Hwang, Nature 427, 423 (2004).
[3] A. Caviglia et al., Nature **456**, 624 (2008).
[4] A.D. Caviglia et al., Physical Review Letters **104**, 126803 (2010).
[5] A.D. Caviglia et al., Physical Review Letters **105**, 236802 (2010).

K3-02 Electrostatic Tuning of the Superconductor to Insulator Transition of YBCO Using Ionic Liquids - ***A. Goldman (University of Minnesota), J. Garcia-Barriocanal (Complutense University), X. Leng, J. Kinney, B. Yang (University of Minnesota)***

Ultrathin YBa2Cu3O7-x (YBCO) films were grown on SrTiO3 (STO) substrates using a high-pressure oxygen sputtering system. The films were placed in a field effect transistor configuration to study the control of superconductivity by electrostatic charging. While devices using $SrTiO_3$ as the gate dielectric induced relatively modest Tc shifts, a clear transition between superconducting and insulating behavior was realized using the ionic liquid DEME-TFSI. The required large charge transfers are achievable using ionic liquids because an electronic double layer forms at the interface between the liquid and the film. Employing a finite size scaling analysis, curves of resistance versus temperature, R(T), over the temperature range from 6K to 22K were found to collapse onto a single scaling function, which suggests the presence of a quantum critical point. However the scaling failed at the lowest temperatures indicating the possible presence of an additional phase between the superconducting and insulating regimes. When carriers were added, an unexpected two-step mechanism for electrostatic doping was revealed. It was possible to dope YBCO over the top of the dome in the curve of transition temperature vs. carrier concentration. Also Hall effect measurements exhibited anomalous features which suggest that there is an electronic phase transition at a charge concentration near that corresponding to optimal doping.
This work was supported in part by the National Science Foundation under grants NSF/DMR-0709584 and 0854752.

K3-03 Electro-static tuning of superconductivity through electric double layers - ***M. Kawasaki (Quantum Phase Electronics Center (QPEC) and Department of Applied Physics, University of Tokyo, Tokyo 113-8656, Japan and Correlated Electron Research Group (CERG) and Cross-Correlated Materials Research Group (CMRG), RIKEN Advanced Science Institute, Japan***

Oxide interface has attracted increasing interest from the viewpoints of basic physics as well as possible application [1]. Inducing superconductivity through a charge accumulation by electric-field had been a challenge and has been recently accomplished by using electric double layer transistor geometry for such compounds as $SrTiO_3$ [2], ZrClN [3], and $KTaO_3$ [4]. Self-organized formation of two-dimensional (2D) ions at the crystal surface induces high density ($10^{15}cm^{-2}$) image-charge accumulation. The depth of charge distribution depends on materials (dielectric constant) [5]. This is a sort of metal-insulator-semiconductor gating. Another way of charge accumulation is to use rectifying hetero-junction with a notch and a spike in its band profile and to apply a reverse bias. Sm_2CuO_4 / Nb doped $SrTiO_3$ junction is one of them that shows clear indication of insulator-metal transition by modulation spectroscopy [6]. However, superconductivity was not induced. With showing recent data on the field effect charge accumulation for other compounds such as Co doped TiO_2 [6] and Sr_2MnO_4 [7], the limitation and prospect of electric field gating will be discussed.

[1] H. Y. Hwang et. al., Nature Materials, **11**, 103 (2012)
[2] K. Ueno et. al., Nature Materials, **7**, 855 (2008)
[3] J. T. Ye et. al., Nature Materials, **9**, 125 (2009)
[4] K. Ueno et. al., Nature Nanotechnology, **6**, 408 (2011)
[5] Supplementary information of Ref. 1 and 3.
[6] Y. Yamada et. al., Science, **322**, 1065 (2011)
[7] M. Nakamura et. al., submitted

Poster Session - Hotel Exhibit Hall, 1:30 PM to 3:30 PM

P2 - Iron-based Superconductors

P2-01 Angular dependence of pinning potential, upper critical field, and irreversibility field in underdoped BaFe1.9Co0.1As2 single crystal - *M. Shahbazi (1Institute for Superconducting and Electronic Materials, Faculty of Engineering), K. Choi (Frontier Physics Research Division and Department of Physics and Astronomy, Seoul National University,), X. Wang, S. Ghorbani, S. Dou (Institute for Superconducting and Electronic Materials, Faculty of Engineering)*

Under-doped $BaFe_{1.9}Co_{0.1}As_2$ single crystal was characterized bymagneto-transport and magnetic measurement up to 13 T over a wide range oftemperature with rotating sample along c-axis. The angle dependence ofresistivity under different magnetic field shows a dip-like structure with themaximum resistivity at 0^o and 180^o and minimum at 90^o, below thesuperconducting transition temperature, T_c. According toanisotropic Ginzburg-Landau theory, the anisotropy was determined by scalingthe resistivity under different magnetic fields below T_c. Anisotropy, Γ, in theunder-doped crystal is found to be temperature dependent and decreases from 2.1to 1.8, as T is reduced from 17 to 12.5 K. The magneto- resistivity below T_c shows Arrhenius thermally activatedbehaviour: Ln $\rho(T,H)$=Ln ρ_0-U_0/T, where U_o is the thermally activated energy.Our results show that pinning potential, U_o, decreases slightly for $\vartheta \leq 45°$ and remains constant for $\vartheta \geq 45°$, while the upper critical field, H_{c2}, and the irreversibility field, H_{irr}, increase with ϑ.

This work is supported by the Australian Research Council (ARC) through Discovery projects DP 1094073 and DP0558753.

P2-02 Interplay between spin density wave and superconducting orders in Co-BaFe2As2 - *Y. Gallais (Université Paris Diderot), D. Colson (SPEC CEA Saclay), L. Chauvière, A. Sacuto (Université Paris Diderot)*

We report electronic Raman scattering results on electron doped $Ba(FeAs)_2$ iron pnictide superconductor. In the spin density wave (SDW) phase, the low energy Raman spectrum shows clear signatures of the reconstructed electronic structure. At least 2 SDW induced gaps are observed. Selection rule analysis indicates they do not originate from Fe related bands with well-defined orbital content. The reconstruction weakens considerably with doping before the system reaches the coexistence regime between SDW and superconducting (SC) orders. Our data in the superconducting state show a two-component Raman response consistent with an anisotropic s-wave gap around the electron pocket. In the SDW-SC coexistence region. the superconducting response is suppressed in selected parts of the electron pocket where the gap amplitude is maximum. This suppression is interpreted in terms of competition between SDW and SC orders for electronic states near the Fermi level. Our results shed light on how SDW and SC orders coexist microscopically in these systems.

Funding: Agence National de la Recherche, project ANR PNICTIDES

L. Chauvière et al. Phys. Rev. B 82, 180521(R) (2010)
L. Chauvière et al. Phys. Rev. B 84, 104508 (2011)

P2-03 Evolution of the magnetic order parameter in ?uorine-doped CeFeAsO: from long- to short-range order - *G. Lamura (CNR-SPIN & Università di Genova, Genova, Italy), R. Cimberle (CNR-IMEM, Genova,Italy), M. Tropeano, A. Martinelli, A. Palenzona, C. Ferdeghini, M. Putti (CNR-SPIN & Università di Genova, Genova, Italy), R. Fittipaldi, A. Vecchione (CNR-SPIN & Università di Salerno, Salerno,Italy), T. Shiroka (Laboratorium für Festkörperphysik, ETH, Zürich, Switzerlan), R. De Renzi (Università di Parma & CNISM, Parma, Italy), S. Sanna, P. Carretta (Università di Pavia & CNISM, Pavia, Italy), G. Prando (Università di Pavia & CNISM, Pavia, Italy; Università Roma3 & CNISM, Roma, Italy)*

Most of the parent compounds of iron pnictides present a long-range antiferromagnetic order (LRO) which is suppressed upon electron/hole doping to give rise to superconductivity. The extent and the nature of the crossover region between this magnetically ordered phase and superconductivity (SC) remains unclear. In La1111 a first-order transition separates LRO from the superconducting (SC) phase [1] and neither a short-range antiferromagnetic order (SRO) region [2], nor SRO-SC nanoscopic coexistance [2] have been detected up to date. This is not the case for RE1111 compounds with a magnetic rare earth (RE). Thanks to its high sensitivity, zero-?eld muon-spin spectroscopy (ZF-μSR) can distinguish between LRO and SRO, as evidenced by the existence of a point-like sized region in$SmFeAsO_{1-x}F_x$ where SRO and SC coexist nanoscopically [3]. Even more interesting is the case of Ce1111: in this work we present the evolution of the AFM order parameter as a function of the ?uorine content x investigated by ZF-μSR. The LRO observed in the undoped compound gradually turns into SRO at x = 0.04, with a drastic reduction of the magnetic moment of the iron ions. Well inside SRO phase, SC appears upon further doping (x >

0.04) and both orders parameters coexist on a nanoscopic range scale [4]. These results are complementary with former powder neutron diffraction data [7], where LRO and SC are fully separated as well.

[1] H. Luetkens et al., Nat. Mater. 8, 305 (2009).
[2] R. Kahsanov et al., PRB 84, 100501 (2011).
[3] S. Sanna et al., PRB 80, 052503 (2009).
[4] S. Sanna et al., PRB 82, 060508(R) (2010); T. Shiroka et al., ibid, 84, 195123 (2011).
[5] J. Zhao et al., Nat. Mater. 7, 953 (2008).

P2-04 Microscopic Coexistence of Superconductivity and Commensurate Antiferromagnetism in the Underdoped Superconductor Ba(Fe1-xRux)2As2 - ***W. Yu (Department of Physics, Renmin University of China, Beijing 100872, China), M. Eom, J. Kim (Department of Physics, Pohang University of Science and Technology, Pohang 790-784, Korea), L. Ma, G. Ji, J. Dai, X. Lu, B. Normand (Department of Physics, Renmin University of China, Beijing 100872, China)***

Whether or not superconductivity can coexist microscopically with strong antiferromagnetic order has recently become a very hotly debated topic in Fe-based superconductors such as the intercalated iron selenides. Evidence for the coexistence of superconductivity and antiferromagnetism has been found in iron pnictides, but usually only in a narrow doping regime where the ordered moment is small. Because carrier inhomogeneity strongly affects the properties of these phases, it is difficult to determine whether such coexistence is microscopic, or of a more macroscopic nature, and whether the magnetic structure is commensurate. Materials showing superconductivity induced by isovalent doping, as in $Ba(Fe_{1-x}Ru_x)_2As_2$, may be ideal systems to search for microscopic coexistence, because bulk coexistence extends across a large doping range and therefore carrier inhomogeneity is less effective.

Here we report NMR studies on high-quality single crystals of the underdoped superconductor $Ba(Fe_{1-x}Ru_x)_2As_2$. For a doping of x = 0.23 with Tc=15K, our ^{75}As NMR spectra show the sample to be completely magnetically ordered below T_N = 70 K, with no evidence for paramagnetism. The magnetic structure is commensurate as in $BaFe_2As_2$. The ordered moment is about $0.4\mu_B$/Fe, but is reduced on the Ru sites. Below Tc, a prominent drop in the relaxation rate $1/^{75}T_1$ is observed on the magnetic spectrum, demonstrating the opening of a homogeneous superconducting gap on all magnetic sites. Signatures of competition between two orders are also seen. Our data are consistent with a magnetic dilution effect upon Ru doping and are unambiguous evidence for the microscopic coexistence of superconductivity and commensurate antiferromagnetism with a large moment.

This work is supported by NSFC and the National Basic Research Program of China.

P2-05 Effects of disorder in iron-based superconductors - ***E. de Mello (Instituto de Física-Universidade Federal Fluminense), S. Magalhaes (Instituto de Fisica-Universidade Federal Fluminense)***

The presence of microscopic inhomogeneous states in high-Tc superconductors can be important to explain many of properties found in these physical systems. The phase diagram of cuprates, particularly in the underdoped region, is one example in which the inhomogeneities can play an important role. More recently, there are evidences that inhomogeneities are also present in the new iron-based superconductors [1]. To address the effect of such inhomogeneities in this kind of superconductors, we study the d-wave and extended s-wave superconductive state within the framework of Bogoliubov-deGennes mean field theory. The model used in the present work is a Hubbard model with an on-site repulsive interaction U and non-local attractive interaction V. Moreover, we considered a hopping in a square lattice with -t for nearest neighbors, t2 for next-nearest-neighbors. For V=0 and in the case of half-filled band and strong repulsive interaction, this model gives as effective Hamiltonian, the J1-J2 Heisenberg model which, recently, has been used to describe spin properties of the iron-based superconductors [2].

The inhomogeneities are introduced by local chemical potentials whose distribution is determined by using the Cahn-Hilliard equation for phase separation. Then, a mean field decomposition of the model gives an effective Hamiltonian which can be written in terms of local gaps. An expression for the local staggered magnetization is derived and studied for different doping levels and the temperatures. Particularly, the local gap is affected and the by the inhomogeneities present in the model. Finally, the problem can be exactly diagonalized and phase diagrams can be obtained.

[1]-G. R. Boyd, P. J. Hirschfeld, T. P. Devereaux, Phys. Rev. B 82, 134506 (2010).
[2]-E. Abrahams, Q. Si, J. Phys.: Condens. Matter 23, 223201 (2011).

P2-06 Superconducting and normal state thermal properties of the electron-correlated superconductor SrNi2Ge2* - ***H. Ku (Department of Physics, National Tsing Hua University), Y. Hsu (Department of Physics, National Taiwan Normal University), C. Hung, C. Lin, Y. You (Department of Physics, National Tsing Hua University), I. Chen (Department of Physics, National Tsing Hua University), T. Hung, Y. Chen (Institute of Physics, Academic Sinica)***

The $SrNi_2Ge_2$ compound is isostructural to the high temperature superconducting AFe_2As_2 (122) (A = Ca, Sr, or Ba) layer system with the $ThCr_2Si_2$-type body-centered-tetragonal (bct) structure and space group *I4/mmm*. Low temperature heat capacity C(T) of the $SrNi_2Ge_2$ superconductor shows a heat capacity jump at T_c = 0.72 - 0.78 K with heat capacity jump ΔC = 12.0 mJ/mol K. The heat capacity T_c is slightly lower than T_c(zero) = 0.87 K determined by electrical resistivity measurements. The C/T vs. T^2 plot shows that normal state heat capacity above 1.4 K (heat capacity superconducting upturn) can be fitted with the formula $C_N = \gamma T + AT^3$ with an electronic coefficient γ = 1.53 mJ/mol-K^2 and a phonon coefficient A = 0.413 mJ/mol-K^4 (with Debye temperature ϑ_D = 168 K). The superconducting electronic heat capacity C_{es} can be fitted with $C_{es}/\gamma T_c = 10.1\exp(-1.30T_c/T)$ with an average superconductive energy gap E_g = 0.162 meV. The E_g/kT_c ratio of 2.6 is close to the BCS ratio of 3.5, which suggests a fully opened s-wave multi-band superconducting gap for this low T_c superconductor in the weakly electron-correlated Fermi liquid region.

This work was supported by Grant No. NSC98-2112-M-007-013-MY3 of National Science Council of Republic of China.

P2-07 Doping and substitutions in LnFeAsO single crystals grown at high pressure: influence on superconducting properties and structure - *J. Karpinski (Laboratory for Solid State Physics ETHZ 8093 Zurich), F. Balakirev (High Magnet. Field Lab. Los Alamos), S. Katrych, P. Moll, B. Batlogg (Laboratory for Solid State Physics ETHZ 8093 Zurich), N. Zhigadlo (Laboratory for Solid State Physics ETHZ 8093 Zurich), S. Weyeneth, H. Keller (Physik-Institut der Universität Zürich 8057 Zurich), M. Tortello, R. Gonnelli (Politecnico di Torino, 10129 Torino)*

Investigations of intrinsic properties of LnFeAsO (Ln=La, Pr, Nd, Sm, Gd) oxide high T_c superconductors require single crystal studies. LnFeAsO single crystals were grown from flux at high-pressure of 30 kbar. An overview of the basic superconducting properties measured on single crystals of LnFeAsO will be presented. LnFeAsO compounds show the highest T_c and the highest upper critical fields. Superconductivity in LnFeAsO has been induced by partial substitution of O by F, Sm by Th, Fe by Co, As by P or by oxygen deficiency. Single crystal structure investigations show structure modification due to substitutions, which is linked to superconducting properties. By comparing our experimental data for $Sm_{1-x}Th_xFeAsO$, $SmFeAsO_{1-x}F_y$ and $SmFeAs_{1-x}P_xO$ compounds with other Fe-based pnictides it was found that the pnictogene height is a key factor that determines critical temperature. In SmFe(As,P)O samples superconductivity appears only after high pressure treatment which generates oxygen deficiency and induces electron doping. P substituted SmFeAsO samples without O deficiencies are non-superconducting however spin density wave is suppressed. Our detailed study of the transport properties of SmFeAs(O,F) single crystals reveals a promising combination of high (> 2 10^6 A/cm^2) and nearly isotropic critical current densities up to 30 T at low temperatures. Point-Contact Andreev-Reflection spectroscopy studies show the existence of two gaps in the $SmFeAsO_{1-x}F_x$ and $SmFeAs_{1-x}P_xO$ crystals, which energy varies with doping level.

P2-08 Study of the Superconducting Order Parameter of LiFeAs via Point Contact Spectroscopy - *X. Zhang (Department of Physics and CNAM, University of Maryland, College Park), I. Takeuchi (Department of Materials Science and Engineering, University of Maryland, College Park), S. Khim, B. Lee, K. Kim (Department of Physics and Astronomy, Seoul National University), R. Greene (Department of Physics and CNAM, University of Maryland, College Park)*

As one of the few stoichiometric iron-based superconductors, LiFeAs provides a unique system for the study of the pairing mechanism and the intrinsic electronic properties of iron pnictide superconductors. In this work, we fabricated *c*-axis point contact junctions between high-quality LiFeAs single crystals and Pb or Au tips in order to study the nature of the superconducting order parameter of LiFeAs.[1] In our *c*-axis Pb/LiFeAs junctions, a weak-link type Josephson effect was consistently observed where the Josephson currents were completely suppressible under microwave irradiation. The observation of the Josephson current in *c*-axis junctions between a conventional *s*-wave superconductor and a LiFeAs single crystal rules out pure *d*-wave or pure *p*-wave symmetries for the pnictide superconductor. The weak-link type *I-V* characteristics and the Fraunhofer-like diffraction pattern confirmed the contacts between Pb and LiFeAs were in the highly-transparent ballistic regime. Further investigation of the conductance spectra obtained in Pb/LiFeAs and Au/LiFeAs junctions revealed a superconducting gap with a gap value of≈ 1.7 meV ($2\Delta/ k_B T_C \approx 2.3$), determined by model fits to the Blonder-Tinkham-Klapwijk theory with a lifetime broadening term. Our analysis indicates that the observed gap corresponds to the electron pockets while the possible formation of a van Hove singularity in the hole band[2] may cause the suppression of the gap feature in point contact Andreev reflection measurements.

The work at UMD was supported by the NSF under Grant No. DMR-1104256 and DMR-0520471, and by the AFOSR-MURI under Grant No. FA9550-09-1-0603.

1. X. H. Zhang *et al*., arXiv 1109.1537.
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P2-09 Nodeless d-wave in superconductivity in layered iron-selenide superconductors and magnetic resonance - *T. Das, A. Balatsky (Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM)*

Iron-selenide based layered compounds have been realized to be high-transition temperature superconductor in December, 2010. The superconductivity is tuned by varying number of iron vacancies in the crystal. This unique tunability of the high-temperature superconducting properties has reinforces the debate of universal properties in Fe based superconductors. Experiments and band structure calculations have shown that the electronic and magnetic structures of these compounds are significantly different from other iron-based superconductors. This fact leads us to propose that the superconducting state is nodeless d-wave pairing which is still driven by magnetic interactions. Nodeless gap leads to the fully gapped quasiparticle spectrum. Sign-changing gap lends itself naturally to the sharp feature in neutron scattering spectrum, the so called spin resonance. We predict the upward horseshoe dispersion of the spin resonance, in a sharp contrast with the hourglass dispersion in highT c oxides where similar spin resonance is ubiquitously seen. In conclusion, despite–selenide systems exhibit very different observables, we show that the underlying pairing mechanism is driven by similar spin–fluctuation instabilities as in other high–temperature superconductors.

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P2-10 Superconducting gap anisotropy in iron-pnictide LiFeAs: laser-ARPES - ***H. Yamamoto (Institute for Solid State Physics (ISSP), University of Tokyo, Kashiwa, Chiba 277-8581, Japan), C. Chen (Beijing Center for Crystal R&D, Chinese Academy of Science (CAS), Zhongguancun, Beijing 100190, China), T. Shimojima (Department of Applied Physics, University of Tokyo, Tokyo 113-8656, Japan), T. Kiss (Graduate School of Engineering Science, Osaka University, Osaka 560-8531, Japan), K. Okazaki, Y. Kotani (Institute for Solid State Physics (ISSP), University of Tokyo, Kashiwa, Chiba 277-8581, Japan), K. Kitagawa (Institute for Solid State Physics (ISSP), University of Tokyo, Kashiwa, Chiba 277-8581, Japan TRIP, JST, Chiyoda-ku, Tokyo 102-0075, Japan), S. Shin (Institute for Solid State Physics (ISSP), University of Tokyo, Kashiwa, Chiba 277-8581, Japan CREST, JST, Chiyoda-ku, Tokyo 102-0075, Japan TRIP, JST, Chiyoda-ku, Tokyo 102-0075, Japan RIKEN SPring-8 Center, Sayo-gun, Hyogo 679-5148, Japan), K. Matsubayashi, Y. Uwatoko, M. Takigawa (Institute for Solid State Physics (ISSP), University of Tokyo, Kashiwa, Chiba 277-8581, Japan TRIP, JST, Chiyoda-ku, Tokyo 102-0075, Japan), Y. Ota (Institute for Solid State Physics (ISSP), University of Tokyo, Kashiwa, Chiba 277-8581, Japanj), S. Watanabe (Research Institute for Science and Technology, Tokyo University of Science, Chiba 278-8510, Japan)***

LiFeAs and LiFeP do not show any magnetic orders but exhibit superconductivities without additional doping charge carriers. These behaviors are quite different from *R*FeAsO1-xFx(1111-system) or Ba1-xKxFe2As2(122-system). In addition, it has been suggested that LiFeP has a nodal superconducting (SC) gap structure in contrast to the full SC gap in LiFeAs. It can be a key to figure out the mechanism of this intriguing superconductivity understanding the origin for this difference between nodal and nodeless superconducting (SC) gap structures.

Recently, we have developed a new apparatus of laser-excited angle-resolved photoemission spectroscopy (laser ARPES) achieving the ultrahigh energy resolution ~ 70 μeV and the sample temperature ~ 1.5 K. Owing to this high energy resolution, SC gaps of LiFeAs (*T*c = 18 K) can be observed very clearly. Three hole-like bands have been observed around the Brillouin-zone (BZ) center as predicted by band-structure calculations. Furtheremore, an unusual dispersion has been observed for one of these three bands. SC-gap anisotropies are also clearly observed and we identify the FS-sheet dependence in the SC-gap anisotropies. We will discuss the origin of these SC-gap anisotropies.

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P2-11 Detection of Orbital Fluctuations Above the Structural Transition Temperature in the Iron Pnictides and Chalcogenides - ***H. Arham (University of Illinois at Urbana), A. Thaler, S. Ran, S. Bud'ko, P. Canfield (Ames Laboratory & Iowa State University), D. Chung, M. Kanatzidis (Argonne National Laboratory), Z. Xu, J. Wen, Z. Lin, Q. Li, G. Gu (Brookhaven National Laboratory), J. Gillett, S. Das, S. Sebastian (University of Cambridge), C. Hunt, W. Park, L. Greene (University of Illinois at Urbana)***

We use point contact spectroscopy (PCS) to probe the differential conductance (dI/dV) of the following compounds at both superconducting and non-superconducting dopings and temperatures: $AEFe_2As_2$ (AE=Ca, Sr, Ba), $Ba(Fe_{1-x}Co_x)_2As_2$, $Ba_{0.8}K_{0.2}Fe_2As_2$ and $Fe_{1+y}Te$ (arXiv:1201.2479v2). For $Fe_{1+y}Te$, $SrFe_2As_2$ and underdoped $Ba(Fe_{1-x}Co_x)_2As_2$ we detect a conductance enhancement well above the magnetic (T_N) and structural (T_S) transition temperatures; for $CaFe_2As_2$ this enhancement is only observed below T_N and T_S while it is not observed at all for $Ba_{0.8}K_{0.2}Fe_2As_2$ and overdoped $Ba(Fe_{1-x}Co_x)_2As_2$. Our data are examined in light of the recent work by W.-C. Lee and P. Phillips (arXiv:1110.5917v2). They calculate that orbital ordering fluctuations above T_S give rise to additional single particle density of states at the Fermi level and are therefore responsible for the enhancement in the dI/dV we detect by PCS. In addition, they predict that these orbital fluctuations above T_S would only be observed in those materials that exhibit an in-plane resistance anisotropy in detwinned crystals above T_S. Our data agree with this prediction and the presence or absence of the in-plane resistive anisotropy matches with whether a conductance enhancement is detected or not. Due to inherent difficulties in detwinning $Fe_{1+y}Te$, it has not been tested for resistive anisotropy, but since we observe conductance enhancement above T_S, we predict an in-plane resistive anisotropy of $Fe_{1+y}Te$ above T_S.

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P2-12 Phase separation and element substitution effect in KxFe2-ySe2-zPnz (Pn=As and P) (0 - ***Y. Liu, Q. Xing, K. Dennis, R. McCallum, T. Lograsso (Division of Materials Science and Engineering, Ames Laboratory, US-DOE, Ames, Iowa 50011, USA)***

Among iron-based superconductors $K_xFe_{2-y}Se_2$ is a unique system characteristic of phase separation phenomenon. It is generally accepted that the coexistence of two phases, i.e., insulating iron-vacancy-ordering phase and superconducting phase with less density of iron vacancy defects or relative complete FeSe layers, lead to the abnormal superconducting sate accompanied by large Fe moment. This feature can be explained by a simple picture, where charge balance is realized in an ideal iron-vacancy-ordering phase in a formula of $K_{0.8}Fe_{1.6}Se_2$, whereas charge imbalance is compensated through phase separation in superconducting $K_xFe_{2-y}Se_2$ (1.6<2-*y*<2). In this study, we report that the crystal growth of superconducting $K_xFe_{2-y}Se_2$ in a controllable way by varying Fe content in the starting materials $K_xFe_{2+\delta}Se_2$. The role of excess Fe (δ) is discussed how to suppress Fe precipitate in high-temperature liquid melt. Single crystals of $K_xFe_{2-y}Se_{2-z}Pn_z$ (Pn=As and P) (0<*z*<1) were grown by Bridgman technique. The growth mechanism is further studied by thermal analysis by DSC (Differential Scanning Calorimeter) instruments. Crystal structure and microstructure were characterized by x-ray diffraction measurements and high resolution transmission electron microscopy (HRTEM), respectively. Transport and magnetization properties of $K_xFe_{2-y}Se_{2-z}Pn_z$ system are also reported.

P2-14 Te-doped K0.80Fe1.81Se2-xTex single crystals - *C. Lin, W. Liu, M. Li, R. Dinnebier, F. Peng (Max Planck Institute für Festköperforschung, Heisenbergstraße 1, D-70569 Stuttgart, Germany)*

We report the growth of a series of Te-substituted $K_{0.80}Fe_{1.81}Se_{2-x}Te_x$ (x~0, 0.09, 0.16, 0.34, 0.42 and 0.51) single crystals using the optical floating-zone technique under application of 8 bars of argon pressure. XRD studies indicate that the undoped single crystals contain a significant intergrowth of two sets of *c*-axes characterized by slightly different lattice constants, i.e., the phase separation phenomenon. We demonstrate that the partial substitution of Se by Te atoms can lead to the expansion of the *c*-lattice constant, whereas the phase separation phenomenon is increasingly suppressed with the increase of substitution level. The magnetization data show that the superconducting transition temperature is gradually depressed to T_c ~32, 27, 25, 15, 8 and 0 K with increasing substitution level x~0, 0.09, 0.16, 0.34, 0.42 and 0.51, respectively. Our results indicate that superconductivity in $K_{0.80}Fe_{1.81}Se_{2-x}Te_x$ is related to the substitution level of Te, which induces a lattice distortion in the crystal and is unable to achieve the optimal superconducting transition temperature, although the secondary phase is remarkably minimized.

P2-15 Optical properties of the Fe-pnictide analog BaMn2As2 - *D. Wu, M. Dressel (1. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany), Y. Singh, P. Gegenwart (I . Physikalisches Institut, Georg-August-Universität Göttingen, 37077 Göttingen, Germany), A. Antal (Institute of Physics, Budapest University of Technology and Economics and Condensed Matter Research Group, Hungarian Academy of Sciences, 1521 Budapest, Hungary)*

We have investigated the temperature dependence of the optical properties of $BaMn_2As_2$ in the *ab*-plane and along the *c*-axis. Compared to the iron-pnictide analog AFe_2As_2, this compound is much more two-dimensional in its electronic properties. For the polarization $E||c$-axis, the overall reflectivity is low with basically no electronic excitations within the infrared range of frequency. Within the *ab*-plane the material exhibits a semiconducting behavior indicating a two-dimensional electron system. Two energy gaps can be clearly identified: below room temperature a large gap is found at $2\Delta_1$ = 48 meV while a smaller gap of $2\Delta_2$ = 12 meV opens only below T = 75 K. The most prominent features in the spectra are the E_u and A_{2u} phonon modes that are assigned to the Mn-As displacement. They exhibit a “blue shift” with decreasing temperature. The Ba mode, on the other hand, remains almost unchanged for all temperatures and does not influence the charge distribution of Mn and As. Thus we suggest that the “blue shift” of Mn-As mode is mainly due to the lattice distortion.

P2-16 Modified phase diagram of EuFe2(As1-xPx)2 - *D. Wu, S. Zapf, F. Klingert, L. Bogani, M. Dressel (1. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, D-70550 Stuttgart, Germany), H. Jeevan, P. Gegenwart (I. Physikalisches Institut, Universität Göttingen, Friedrich-Hund-Platz 1, D-37077 Göttingen, Germany)*

Based on low-field magnetization measurements on a series of single crystals, we propose a modified phase diagram for $EuFe(As_{1-x}P_x)_2$ taking in particular into account the moments of the Eu^{2+} ions. We suggest the Eu^{2+} spin to be canted with a ferromagnetic contribution along the *c*-direction that becomes stronger with pressure, until superconductivity sets in.The spin-density wave and superconducting phase coexist with an antiferromagnetic interlayer coupling of the canted spins. Reducing the interlayer distance finally leads to a ferromagnetic coupling of the Eu^{2+} ions between the layers and to a suppression of superconductivity. We have furthermore concentrated on samples close to the superconducting dome (x = 0.165, 0.26, 0.35) and present a systematic study over a broad magnetic field range (2-70000 Oe), including in-situ sample rotation measurements. We suggest a broader superconducting dome and describe the complex interplay between Eu magnetism and superconductivity.

P2-17 The effect of three dimensional gap anisotropy in BaFe2(As,P)2 - *K. Suzuki (Department of Applied Physics and Chemistry), H. Usui, K. Kuroki (University of Electro-Communications)*

It is now widely accepted that the superconducting gap of the iron based superconductors is non-universal, and some of them have nodes, while others do not. A way to understand this gap variation was proposed in ref [1], where the presence/absence of gap nodes on the electron Fermi surface is controlled by the pnictogen height. Although this theory explains the nodes in the gap in low T_c materials such as LaFePO, another candidate for nodal superconductor, $BaFe_2(As,P)_2$, has a relatively high T_c of 30K. Although various experiments suggest presence of nodes in the gap [2,3], a specific heat experiment shows results against the presence of nodes [4].

In the present study, we address these puzzling issues based on a model calculation. We first obtain a three-dimensional ten orbital model of $BaFe_2(As,P)_2$ from the first principle calculation. We apply the random phase approximation to this model and solve the Eliashberg equation assuming spin fluctuation mediated pairing. We find that the gap symmetry is basically $s_\pm$-wave, but three-dimensional nodal structure appear in the strongly warped hole Fermi surface having a strong $Z^2/XZ/YZ$ orbital character [5]. We analyze the effect of such gap structure, and in particular discuss how the effect should appear in experimental observations.

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P2-18 Interplay between magnetism and superconductivity in electron doped oxypnictides - ***P. Carretta (University of Pavia), G. Lamura, A. Martinelli (CNR-SPIN), T. Shiroka (ETH-Zurich), M. Tropeano, A. Palenzona, M. Putti (University of Genova), P. Bonfà, G. Allodi, R. De Renzi (University of Parma), S. Sanna, G. Prando (University of Pavia)***

The appearance of superconductivity (SC) close to the disruption of static magnetic (M) order is a general feature of the Fe-based superconductors either as a function of doping or external pressure. In the REFeAsO family (RE1111) it is found that SC and M strongly compete and hardly coexist simultaneously [1,2], apart for RE = Sm and Ce [3] where within a small doping range both order parameters are depressed. The competition between superconducting and magnetic ground states must be reconciled with the prevailing models of pairing mediated by spin fluctuations.

Here we show, by means of muSR and ^{75}As NQR, that magnetism is surprisingly still at play in optimally F-doped $SmFe_{1-x}Ru_xAsO_{0.85}F_{0.15}$ [4]. The isoelectronic Fe:Ru substitution is found to deteriorate the superconducting state in optimally-doped $SmFeAsO_{0.85}F_{0.15}$ samples and simultaneously to recover static magnetism within the FeAs layers, for 0.1< x < 0.5. The two reduced order parameters coexist within nanometer-size domains in the FeAs layers and eventually disappear around a common critical threshold x_c around 0.6. It is shown that x_c corresponds to percolation of a magnetic square lattice with nearest neighbor and next-nearest neighbor hopping for $LaFe_{1-x}Ru_xAsO$ [5].

Superconductivity and magnetism in RE1111 are shown to be closely related to two distinct well-defined local electronic environments of the FeAs layers [4,6]. The two transition temperatures, controlled by the isoelectronic and diamagnetic Ru substitution, scale with the volume fraction of the corresponding environments. The results suggest that superconductivity cannot exist if magnetism is definitely suppressed by magnetic dilution, supporting a magnetic coupling mechanism for superconductivity.

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P2-19 NMR investigation of vortex dynamics in Ba(Fe0.93Rh0.07)2As2 superconductor - ***P. Carretta (University of Pavia), A. Thaler, P. Canfield (Ames Lab.), L. Bossoni (CNISM)***

One of the most interesting aspects of the novel Fe-based superconductors is the extremely high upper critical field, exceeding 100 Tesla even in materials with releatively low critical temperatures. Accordingly, for the future applicability of these materials it is of utmost importance to investigate the magnetic field (H)-temperature phase diagram of the flux lines lattice (FLL). One useful tool to study the FLL at the microscopic level, providing information complementary to that obtained from resistivity and susceptibility measurements, is represented by nuclear magnetic resonance (NMR). Thanks to the works performed on the cuprates, and looking at the structural similarities between cuprates and pnictides, some obvious questions arise: is it still possible to detect the vortices thermal dynamics in iron-pnictides with NMR? What are the vortices structure and dimensionality in the new iron based compounds? In order to answer at least part of these open questions we performed a ^{75}As NMR study of the superconducting state of $Ba(Fe_{0.93}Rh_{0.07})_2As_2$ compound. The NMR relaxation rates and linewidth evidenced the presence of motions, which showed a remarkable anisotropic behavior. Below the superconducting transition temperature T_c, when **H** is applied along the c axes, a peak in 1/T1 and 1/T2 is observed. Remarkably those peaks are suppressed for **H** **p**erpendicular to c, leading us to a description in terms of FLL motions. From an heuristic model we estimated the hopping correlation times and pinning energy barriers. Further information was derived from the narrowing of the linewidth below T_c and found to be consistent with that obtained from $1/T2$ measurements.

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P2-20 Universal pair-breaking in transition metal-substituted iron-pnictide superconductors - ***K. Kirshenbaum, S. Saha, S. Ziemak, T. Drye, J. Paglione (University of Maryland at College Park)***

The substitution of transition metal elements into the iron site in iron-pnictide superconductors yields a phase diagram similar to that seen in pressure and other forms of doping, such as hole-doping on the alkaline earth site in 122 systems. In all of these cases the antiferromagnetic ordering temperature is suppressed and as some doping superconductivity appears. It has been shown that despite very similar phase diagrams, substituting different transition metals yields differing transition temperatures [1-3]. In this study we have determined the experimental transport scattering rate for a wide range of optimally doped transition metal-substituted FeAs-based compounds with the ThCr2Si2 (122) crystal structure. We find that the maximum transition temperature, Tc, for several Ba-, Sr-, and Ca-based 122 systems follows a universal suppression with increasing scattering rate indicative of a common pair-breaking mechanism. A fit to the Abrikosov-Gor'kov pair-breaking formalism puts a limit of approx. 25 K on the maximum Tc for all transition metal-substituted 122 systems, in agreement with experimental observations, and sets a maximum scattering rate of 2x10^14 s^-1 for the superconducting phase to exist. The rate of suppression of Tc with scattering rate is shown to be much slower than expected for a d-wave order parameter or an s with pure interband scattering, providing important constraints on the nature of the order parameter in these systems.

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P2-21 Structural and physical properties of the iron chalcogenide thin films - *L. Cao, B. Xu, B. Zhu, W. Huang, G. Chen, Z. Zhao, Y. Wang (Institute of Physics, Chinese Academy of Sciences)*

The arsenic-free iron chalcogenide possesses the simplest structure in the families of iron-based superconductors though its transition temperature is relatively not too high under the ambient pressure, while the very recently discovered K/Tl intercalating iron chalcogenide possesses the ordered Fe-vacancies and relatively high transition temperature.

We deposited single-phased, epitaxial, superconducting FeSe, Fe(Se,Te), and FeTe thin films, studied their structural and physical properties, found that the non-superconducting parent compound FeTe goes to superconduct in the form of thin films, and further found that the superconducting FeTe films possesses the so-called second long-range order of several hundreds nanometers long.

We also deposited successfully the single-phased, epitaxial KFe_xSe_2 thin films. Structural and physical properties of such newly obtained KFe_xSe_2 thin films are under investigation and will also be reported.

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P2-22 Origin of the lattice structure dependence of Tc in iron-based superconductors - *H. Usui, K. Suzuki, K. Kuroki (The University of Electro-Communications)*

The discovery of superconductivity in the iron-based superconductors[1] and its T_c up to 55K[2] has given great impact to the field of condensed matter physics. From the early stage, the correlation between T_c and the lattice structure has been an issue of great interest[3]. In the present study, we focus on the condition for optimizing superconductivity in the iron pnictides, varying hypothetically the Fe-As-Fe bond angle and the Fe-As bond length of LaFeAsO[4]. Studying the band structure of the hypothetical lattice structure of LaFeAsO, the hole Fermi surface multiplicity is found to be maximized around the bond angle regime where the arsenic atoms form a regular tetrahedron. Superconductivity is optimized within this three hole Fermi surface regime, thereby providing a natural explanation as to why T_c is optimized around the regular tetrahedron angle. Interestingly, the tendency toward magnetism (the strength of the spin fluctuation at zero energy) is not necessarily correlated with the hole Fermi-surface multiplicity, and therefore the correlation between superconductivity and the strength of the spin fluctuations is complicated. Superconductivity and the bond length are positively correlated mainly due to the increase of the density of states without affecting the Fermi surface. Similar analysis on the model obtained from hypothetical lattice structures of $Ca_4Al_2O_6Fe_2As_2$ is also performed, and combining these results, we provide a guiding principle for obtaining high T_c.

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P2-23 Tuning the phase transitions in Fe1+yTe - *S. Rößler (Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Straße 40, D-01187 Dresden), D. Cherian, S. Elizabeth (Department of Physics, C.V. Raman Avenue, Indian Institute of Science, Bangalore 560012), U. Rößler (IFW Dresden, Postfach 270016, D-01171 Dresden), P. Materne, M. Doerr, H. Klauß (Institut für Festkörperphysik, Technische Universität Dresden, D-01062 Dresden), C. Koz, U. Schwarz, S. Wirth (Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Straße 40, D-01187 Dresden)*

The compound $Fe_{1+y}Te$ with simple PbO-type crystal structure displays a very rich phase diagram. It exhibits an antiferromagnetic order that is not driven by Fermi surface nesting and a relatively large ordered moment on the Fe sublattices [1, 2]. These properties are different than those found in the pnictide counterparts. Here we present the influence of external pressure and Fe-excess on the magneto-structural phase transition in $Fe_{1+y}Te$ and show that both, pressure and Fe-excess have similar influence on the phase transitions. Further, for y ³ 0.12, upon cooling, a continuous magnetic transition takes place at temperatures above the structural transition [3]. For these compositions, we identify a magnetically inhomogeneous precursor state above the Néel temperature by using Mössbauer spectroscopy. The existence of quasi-static moments with short-range correlations can be understood based on a phenomenological Landau theory as a soliton-liquid state that precedes the low-temperature incommensurate helimagnetic phase. This helimagnetic phase undergoes a further magneto-elastic transition at lower temperatures which can be interpreted as a lock-in transition, where the magnetic transformation from the helical into a collinear structure drives a structural first-order transition. The succession of the different structural and magnetic phases suggests a strong spin-lattice coupling in $Fe_{1+y}Te$.

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P2-24 Pressure impact on intrinsic and extrinsic superconducting parameters of single-crystalline FeTe0.5Se0.5 - *A. Wisniewski, J. Pietosa, D. Gawryluk, R. Puzniak, J. Fink-Finowicki, M. Berkowski (Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, PL-02-668 Warsaw, Poland)*

The pressure impact, up to 11.3 kbar, on basic intrinsic parameters of the superconducting state, such as the critical temperature (Tc), the lower and the upper critical field (Hc2), the coherence length, the penetration depth, as well as on critical current density (jc) was determined from magnetic measurements performed for two $FeTe_{0.5}Se_{0.5}$ single crystals of significantly different crystallographic quality. Pressure-induced enhancement of all of the superconducting state properties was found, what indicates a growth of the density of superconducting carriers. Comparison of pressure impact on superconducting properties of two samples with different amount of defects leads to the following conclusion: significant suppression of strong curvature of Hc2(T) in the vicinity of Tc for the sample with extended amount of defects indicates the increasing interband scattering as a result of increasing structural inhomogeneity. Since the suppression of the curvature of Hc2(T) in the vicinity of Tc is correlated with observed improvement of superconducting state properties one may suppose that an increase of interband scattering is directly responsible for the improvement of superconducting properties in the studied multiband superconductor. It may explain the origin of relatively poor superconducting state properties of the single crystals of better crystallographic quality. The jc increases under pressure by at least one order of magnitude.

P2-25 Spectroscopy and Anisotropies in the magnetic state of iron pnictides - ***E. Bascones, B. Valenzuela, G. León, M. Calderón (Instituto de Ciencia de Materiales de Madrid)***

Parent iron pnictides are metallic antiferromagnets with columnar order. Simple folding seems not to be sufficient to describe the electronic reconstruction induced by the magnetic transition what could be associated to the multiorbital character of these materials. The role played by the orbital degree of freedom on magnetism and that of orbital ordering are under debate. Interest on orbital ordering proposals has been boosted by the observation of in-plane anisotropic properties such as dc resistivity and optical conductivity. Whether an intrinsic instability or not, to find orbital ordering in the magnetic state is not surprising. Both orbital ordering and the columnar magnetic state break the tetragonal symmetry and to unveil the origin of the anisotropic properties is difficult.

In order to address these issues we analyze the Drude weight, the optical conductivity and the Raman spectrum of iron pnictides in the magnetic state [1]. To this end we consider an interacting five-orbital model treated at the Hartree-Fock level [2,3]. By comparing band structure, Raman and optical spectra we identify the regions in k-space from which the different features in the spectra originate. To disentangle the effect of magnetism and of orbital ordering on the anisotropic properties we compare the dependence of the orbital ordering with that of the Drude anisotropy on the interaction parameters and the optical conductivity anisotropy with the frequency dependent orbital reorganization. We discuss these results in connection with available experiments.

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P2-26 Relationships between the Iron-Based Superconductors and Sr2RuO4 - ***D. Singh (Oak Ridge National Laboratory)***

Common features of Sr_2RuO_4 and iron-based superconductors are discussed based on comparison of first principles results with experimental data, within the framework of spin fluctuation mediated pairing. We emphasize competition between different magnetic states, the interplay between magnetism and the Fermi surface and renormalizations due to quantum fluctuations.

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P2-27 Nucleation-mediated flux creep in pristine and artificially disordered iron-pnictide superconductors - ***M. Konczykowski (Laboratoire des Solides Irradiés, CNRS UMR 7642 & CEA - DSM - IRAMIS,Ecole Polytechnique, F 91128 PALAISEAU cedex), T. Shibauchi, Y. Matsuda (Department of Physics, Kyoto University, Sakyo-ku, Kyoto 606-8501, Japan), C. van der Beek (Laboratoire des Solides Irradiés, CNRS UMR 7642 & CEA - DSM - IRAMIS,Ecole Polytechnique, F 91128 PALAISEAU cedex), S. Kasahara, T. Terashima (Research Center for Low Temperature and Materials Sciences, KyotoUniversity,Sakyo-ku, Kyoto 606-8501, Japan), P. Canfield, R. Prozorov (The Ames Laboratory, Ames, Iowa 50011, USA Department of Physics &Astronomy, Iowa State University, Ames, Iowa 50011, USA)***

Magnetic relaxation is a common feature of iron-based pnictide superconductors (IBS). The amount of decay of the persistent current (a few percent per time decade) does not allow for the reliable determination of the dependence of the flux creep energy barrier, U, on the current density J, or the identification of the underlying flux creep process. The irreversible magnetization of most IBS exhibit a central peak arising from strong pinning by nanoscale defects, followed by a plateau or a second magnetization peak related to weak collective pinning by atomic scale point defects. The flux creep process and the U(J) variation should reveal the differences between these flux pinning regimes. Using a Hall probe array-based method, we have measured the magnetic relaxation as a function of temperature and the magnetic field in pristine as well as electron- and heavy ion-irradiated $BaFe_2(As_{1-x}P_x)_2$and $Ba(Fe_{1-x}Ru_x)_2As_2$ crystals. An extension of the explored current range was obtained by the annealing of the critical state and the use of an improved Maley-type analysis [1]. The divergence of the flux creep barrier at low currents, following a $U \propto (J_c/J)^{\mu}$, compatible with a half-loop nucleation process of flux creep [2] was observed, with μ varying from 0.2 in the strong pining regime, to 0.5–1 in the high-field weak collective pinning region.

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Work supported by the French Nat. Res. Agency, ANR-07-Blan-0368, and by US DOE/BES, Contract DE-AC02-07CH11358 .

P2-28 Effect of artificial disorder on superconducting properties of isovalently substituted iron-pnictide superconductors - *M. Konczykowski (Laboratoire des Solides Irradiés, CNRS UMR 7642 & CEA - DSM - IRAMIS,Ecole Polytechnique, F 91128 PALAISEAU cedex), T. Shibauchi, Y. Matsuda (Department of Physics, Kyoto University, Sakyo-ku, Kyoto 606-8501, Japan), C. van der Beek (Laboratoire des Solides Irradiés, Centre National de la Recherche Scientifique UMR7642 & CEA - DSM - IRAMIS, Ecole Polytechnique, F 91128 PALAISEAU cedex), S. Kasahara, T. Terashima (Research Center for Low Temperature and Materials Sciences, KyotoUniversity,Sakyo-ku, Kyoto 606-8501, Japan), P. Canfield, R. Prozorov (The Ames Laboratory, Ames, Iowa 50011, USA Department of Physics &Astronomy, Iowa State University, Ames, Iowa 50011, USA)*

We have investigated the effects of two different types of irradiation-induced disorder on the superconducting transition temperature and vortex pinning in the isovalently substituted 122 iron pnictide superconductors $BaFe_2(As_{1-x}P_x)_2$ and $Ba(Fe_{1-x}Ru_x)_2As_2$). Irradiation with 1 GeV Pb ions produces correlated disorder in form of amorphous tracks. This type of disorder yields a strong enhancement of vortex pinning (and the critical current) without any measurable change of the critical temperature. The exposure of the samples, cooled down to 20 K, to a beam of 2.5 MeV electrons produces elementary defects in form of Frenkel pairs and point-like disorder. Such disorder results in a strong depression of critical temperature T_c as function of the electron fluence Φt . The rate of decrease $\partial T_c/\partial \Phi t$ remains constant within the explored range of doses (ΔT_c = 5K for $BaFe_2(As_{1-x}P_x)_2$ and ΔT_c=3K for for $Ba(Fe_{1-x}Ru_x)_2As_2$) without sign of saturation for the highest doses. The emergence of a second peak in the irreversible magnetization, associated with weak collective pinning, was observed in electron-irradiated in electron-irradiated $BaFe_2(As_{1-x}P_x)_2$. The observed difference of the effect of point-like and correlated disorder is compatible with s+/- coupling of Cooper pairs. Low angle scattering by point like disorder is destructive for s+/- coupling, while scattering by large defects may not have any pair-breaking effect [1].

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Work supported by the French Nat. Res. Agency, ANR-07-Blan-0368, and by US DOE/BES, Contract DE-AC02-07CH11358.

P2-29 Multiband Model for the Dynamical Conductivity of Superconducting Pnictides Manifestation of the impurity induced S+--> S++ transition. - *O. Dolgov (MPI FKF Stuttgart), D. Efremov (MPI FKF Stuttgart, Germany), A. Golubov (University of Twente, Enschede)*

The multiband (4x4 bands) model and its reduction to the effective two-band model taking into account the strong interaction with intermediate spin-fluctuations have been successively applied to the description of the properties of $Ba_{1-x}K_xFeAs_2$. On the base of this approach and using the extension of the formalism developed for the multiband system MgB_2 we have calculated free energy and frequency dependent optical complex conductivity \sigma(\omega,T) in the superconducting as well as the normal states of pnictides. An application of the presented approach to the ellipsometry data for single crystals of $Ba_{1-x}K_xFeAs_2$ allows to describe some experimental features connected to multigap nature and strong coupling effects.

Effects of rather strong nonmagnetic impurities beyond the Born approximation which can lead to the transitions in the superconducting order parameter S_{+-}□□□S_{++} were investigated.

P2-31 Doping dependence of the superconducting-gap anisotropy in Ba1-xKxFe2As2 - *Y. Ota (Institute for Solid State Physics (ISSP), University of Tokyo), C. Chen (Beijing Center for Crystal R&D, Chinese Academy of Science (CAS)), T. Shimojima (Department of Applied Physics, University of Tokyo), T. Saito (Department of Physics, Chiba University), T. Kiss (Graduate School of Engineering Science, Osaka University), K. Okazaki (Institute for Solid State Physics (ISSP), University of Tokyo), S. Shin (Institute for Solid State Physics (ISSP), University of Tokyo, CREST, JST, TRIP, JST, RIKEN), Y. Kotani (Institute for Solid State Physics (ISSP), University of Tokyo,CREST, JST), S. Watanabe (Research Institute for Science and Technology, Tokyo University of Science), H. Fukazawa, Y. Kohori (TRIP, JST, Department of Physics, Chiba University), K. Kihou, A. Iyo, H. Eisaki (TRIP, JST, National Institute of Advanced Industrial Science and Technology (AIST)), C. Lee (TRIP, JST,National Institute of Advanced Industrial Science and Technology (AIST)*

Among the iron-pnictides, $(Ba,K)Fe_2As_2$ (BaK122) system is the most interesting: while the optimally-doped BaK122 has a full gap (no node in the superconducting(SC) gap), the extremely hole-doped KFe_2As_2 (K122), which has no electron pocket, has been suggested to have SC-gap nodes from several experiments. From the previous studies of laser-excited angle-resolved photoemission spectroscopy (laser ARPES), the optimally doped BaK122 has no anisotropy and Fermi surface (FS) sheet dependence in SC-gap sizes on the three hole FS around the Brillouin zone center. On the other hand, we found that K122 has clear anisotropies and sheet dependence. In addition, we found that the middle hole FS has eight nodes and identified their Fermi momenta. To clarify the paring mechanism at each doping level, it should be important to investigate doping dependence of the anisotropies and FS-sheet dependence of SC-gap sizes, and node existence. In this study, using a laser ARPES apparatus (the highest energy resolution 70 meV and the cooling temperature of 1.5 K), we have investigated doping dependence of the anisotropies and FS-sheet dependence of SC-gap sizes in the overdoped BaK122. In the heavily overdoped BaK122, we found that the anisotropies and the FS-sheet dependence of BaK122 change dramatically. We will discuss these results and contrast them with other experimental and theoretical results available in literature.

Effects of rather strong nonmagnetic impurities beyond the Born approximation which can lead to the transitions in the superconducting order parameter S_{+-}-> S_{++} were investigated.

P2-32 Strong Pinning, vortex energy distributions and nanoscale disorder in iron-based superconductors. - ***S. Demirdis (LABORATOIRES DES SOLIDES IRRADIES, ECOLE POLYTECHNIQUE), T. Shibauchi, Y. Matsuda (Department of Physics, Kyoto University), C. van der Beek, M. Konczykowski (LABORATOIRE DES SOLIDES IRRADIES, ECOLE POLYTECHNIQUE), Y. Fasano (Laboratorio de Bajas Temperaturas, Instituto Balseiro, Centro Atomico Bariloche), T. Terashima (Research Center for Low Temperature and Materials Sciences, Kyoto University), S. Kasahara (Research Center for Low Temperature and Materials Sciences, Kyoto University)***

Strong pinning of vortices in iron-based superconductors determines the behavior of the critical current density at low field, including the sharp peak around B=0 and the subsequent power-law $B^{-1/2}$ decrease [1]. Simultaneously, vortex imaging experiments performed on iron-based superconductors of different compositions at widely different fields have revealed highly disordered vortex ensembles [2,4,5]. Recent Bitter decoration experiments carried out by us on Co-doped $BaFe_2As_2$ reconcile the disordered vortex ensembles with the measured critical current densities by invoking nanoscale disorder of the superconducting parameters (T_c, superfluid density, inhomogeneity of the gap). This is done using the local variations of the pinning energies and pinning forces extracted from the vortex ensemble configuration [2].

In this contribution we present a vortex decoration study of the isovalently doped iron-based superconductor $BaFe_2(As_{1-x}P_x)_2$. Notably, we present spatially resolved maps and distributions of the pinning forces and energies of vortices in $BaFe_2(As_{1-x}P_x)_2$ single crystals of different compositions x. Pinning energies in this compound depend on the doping x, and are generally lower than in the Co-doped 122 material. We also discuss the large Meissner effect observed in single crystalline $BaFe_2(As_{1-x}P_x)_2$.

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P2-34 Pinning energy of vortices and glassy exponent in particle-irradiated Ba(Fe1-xCox)2As2 - ***T. Taen, Y. Nakajima, T. Tamegai (Department of Applied Physics, The University of Tokyo), H. Kitamura (Radiation Measurement Research Section, National Institute of Radiological Sciences), T. Murakami (Research Center of Charged Particle Therapy, National Institute of Radiological Sciences)***

In high temperature cuprate superconductors, many curious phenomena in vortex dynamics have been discovered such as giant-flux creep. In parallel with these findings, theories have been developed to describe these phenomena [1]. In particular, the collective pinning theory dealing with a system with weak quenched disorder and collective creep of vortex bundles has been very successful. One example is the explanation of a plateau-like behavior of the normalized relaxation rate (S) as a function of temperature [2]. Recently discovered iron-based superconductors have relatively high critical temperature (T_c) and critical current density (J_c). Magnetization hysteresis loops in iron-based superconductors are found to be quite similar to those in cuprate superconductors. Furthermore, magnetic relaxation measurements have shown that even vortex dynamics is similar in these two high temperature superconductor systems. In $YBa_2Cu_3O_{7-y}$, proton (H^+) irradiation enhances J_c, while glassy behavior is almost unchanged. With these in mind, how the introduction of pinning center into iron-based superconductors affects J_c and glassy behavior is also interesting.

In this presentation, we report the effect of H^+ irradiation on vortex states in $Ba(Fe_{0.93}Co_{0.07})_2As_2$ single crystals. We analyze the obtained results in the framework of vortex glass theory with temperature dependent J and temperature dependent S. Glassy exponent and barrier height for vortex creep are extracted.

This work is partly supported by a Grant-in-Aid for Scientific Research from the MEXT Japan and the Research Project with Heavy Ions at NIRS-HIMAC.

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P2-35 Point-Contact Andreev Reflection Spectroscopy in Pt-Substituted BaFe2As2 - ***S. Ziemak (University of Maryland, College Park), X. Zhang (National Institute of Standards and Technology), S. Saha, T. Drye, R. Greene, J. Paglione (University of Maryland, College Park)***

We have investigated the superconducting order parameter of BaFe2-xPtxAs2 using point-contact Andreev reflection spectroscopy (PCAR). The samples used were large single crystals with measured Pt concentrations consistent with optimal doping (x = 0.15). Junctions were made between gold or lead tips and the c-axis of the superconducting samples. Conductivity spectra were measured over a range of temperatures and fit to curves generated using the Blonder-Tinkham-Klapwijk (BTK) model for two gaps, one isotropic and one angle-dependent gap with nodes. These preliminary results contrast with other published PCAR studies on BaFe2-xCoxAs2 and Ba1-xKxFe2As2, which suggest a nodeless order parameter with one or two gaps.

P2-36 Experimental determination of band structure, supeconducting gap, and electronic correlations on LiFeAs. - ***G. Levy, G. Hodgson, S. Chi, R. Liang, D. Bonn, I. Elfimov, G. Sawatzky, A. Damascelli (Department of Physics and Astronomy, University of British Columbia), R. Szedlak (University of Konstanz)***

We perfomed angle-resolved photoemission spectroscopy experiments (ARPES) on LiFeAs single crystals. The absence of a polar surface or surface reconstruction, as evidenced experimentally by low energy electron diffraction (LEED), makes LiFeAs an ideal system to compare the experimentally determined band structure with ab-initio density functional calculations. We will discuss the pitfalls encountered on such a comparison and the different approaches to address them. From this comparison, we determine a band renormalization which we relate to the strength of the electronic correlations obtained from Auger electron spectroscopy using Cini-Sawatzky theory. Once the electronic correlations are determined, we focus on their coupling with bosonic excitations as evidenced by kinks in the band dispersion. Lastly, we discuss our recent observation of the superconducting gap and its evolution along the Fermi surface.

P2-37 Magnetic eld dependence of spin-lattice relaxation in the s state of Ba0.67K0.33Fe2As2 - *S. Oh (Northwestern University), A. Reyes, P. Kuhns (National High Magnetic Field Laboratory), A. Mounce, W. Halperin (Northwestern University), C. Zhang, P. Dai (The University of Tennessee)*

The magnetic field dependence of the spatially averaged density of states, <N(0)>, of an unconventional *d*-wave superconductor shows $H^{1/2}$ due to the Doppler shift of quasiparticle excitations by vortex supercurrents[1,2]. Volovik was the first one who predicted this effect in an unconventional superconductor. This effect, the Volovik effect, has been predicted to exist for a sign changing *s*±state [3], although there is no Doppler shift of quasiparticle excitations by vortex supercurrents in a single band *s*-wave superconductor. Since the NMR spin-lattice relaxation rate, $1/T_1 \propto \langle N(0)^2 \rangle$, can probe the contribution to the density of states by the Doppler shift, the rate should have magnetic field dependence for the *s*± state. We have measured ^{75}As $1/T_1$ in a high-quality, single crystal of $Ba_{0.67}K_{0.33}Fe_2As_2$ over a wide range of field up to 28 T. Our spatially resolved measurements show that indeed there are Doppler contributions to $1/T_1$ which increase closer to the vortex core, with a spatial average proportional to H^2, inconsistent with recent theory [4].

This work is supported by DE-FG02-05ER46248, DE-FG02-05ER46202 and the NHMFL by NSF and the State of Florida.

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P2-38 Non Fermi Liquid Behavior due to Orbital Fluctuations in Iron Pnictide Superconductors - *W. Lee, P. Phillips (University of Illinois at Urbana-Champaign)*

The discovery of new classes of high-temperature superconductors, iron pnictides in 2008, launched an international wave of research in the past few years. Whether or not these materials are strongly correlated is one of the central issues under hot debate. In this talk, we will present a theoretical study [1] pointing out that a non-Fermi liquid behavior could be present in various iron based superconductors, and several new experiments supporting this proposal will be discussed [2][3].

Using a five orbital tight binding model with generalized Hubbard on-site interactions, we find that within a one-loop treatment, a branch of overdamped collective modes develops at low frequency in scattering channels associated with quasi-1D d_{xz} and d_{yz} bands. When the critical point for the C_4 symmetry broken phase (structural phase transition) is approached, these overdamped collective modes soften, and acquire increased spectral weight, leading to a non-Fermi liquid behavior at the Fermi surface. We argue that this non-Fermi liquid behavior is responsible for the recently observed zero-bias enhancement in the tunneling signal in point contact spectroscopy [2][3]. Our result suggests that quantum criticality plays an important role in understanding the normal state properties of iron-pnictide superconductors.

This work is supported by the Center for Emergent Superconductivity, Grant No. DE-AC0298CH1088.

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P2-39 Doping effect on superconducting gap in Na1-d FeAs and NaFe1-xCoxAs - *K. Cho, M. Tanatar, N. Spyrison, H. Kim, R. Prozorov (The Ames Laboratory), G. Tan, J. Yan, P. Dai, C. Zhang (The University of Tennessee)*

The gap structures on single crystals of self electron-doped $Na_{1-\delta}FeAs$ and chemically electron-doped $NaFe_{1-x}Co_xAs$ superconductors were studied by measuring London penetration depth, l(T). Doping level δ in self-doped $Na_{1-\delta}FeAs$ was controlled by the deintercalation of Na^+ ions, stimulated by ultrasonic treatment. Use of the two doping techniques allowed us to cover the whole doping phase diagram from underdoped parent NaFeAs to heavily Co-overdoped compositions, with the optimal doping, T_c ~ 25 K, achieved for x = 0.025. Use of two protocols also allowed us to monitor the effect of disorder, introduced by chemical substitution in Fe sublattice. The low-temperature variation of l(T), measured as a function of doping, was analyzed using a power-law fit, $\Delta l = A T^n$. The exponent, n, changes from n~1.9 at the optimal doping to much lower values in the underdoped, n~1.1 , and heavily overdoped, n~1.3, samples. On the other hand, a dome-like variation of the exponent n (and of the prefactor A) with x is universal in iron-pnictides regardless of the compounds and the type of doping, - electrons or holes. This suggests that the development of a significant gap anisotropy at the dome edges is intrinsic and universal trend in Fe-based superconductors, while the behavior at the optimal doping depends on a particular system. Recently, the superconducting gap structure evolution with doping was described theoretically considering a competition of the inter-band attraction and intra-band Coulomb repulsion [1, 2]. This theory predicts a universal tendency towards nodal gap in highly overdoped regimes within extended $s_\pm$ pairing symmetry. The universal trend found in the present work is consistent with this model.

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P2-40 SUPERCONDUCTING PROPERTIES OF FeSe WIRE AND TAPE FABRICATED BY CHEMICAL-TRANSFORMATION PIT PROCESS - ***H. Izawa, Y. Mizuguchi, O. Miura (Department of Electrical and Electronic Engineering, Tokyo Metropolitan University), T. Ozaki, Y. Takano (National Institute for Materials Science)***

Fe-based superconductor is one of the candidate materials for superconducting applications, owing to the high transition temperature (T_c) and high upper critical field (H_{c2}). Furthermore, the toxicity of Fe chalcogenides is relatively low compared to the FeAs-based compounds, and the anisotropy is low. Recently, T_c = 53 K was observed in the single-layer FeSe thin film, suggesting a possibility of further enhancement of Tc in Fe-chalcogenide superconductors. [1] In these points, we fabricated FeSe superconducting wires by the chemical-transformation PIT process [2, 3]. An obvious correlation between annealing temperature and evolution of the phase transformation was observed. By annealing above 500 ℃, wire-core transformation from hexagonal to tetragonal phase was gradually produced. And then, the hexagonal phase completely transformed into the tetragonal phase by annealing at 1000 ℃. With increasing annealing temperature (T_a), the superconducting properties were dramatically improved, associated with the evolution of the tetragonal phase. A dramatic enhancement of T_c^{onset} was observed in between T_a = 400 and 500 ℃. For T_a = 1000 ℃, the highest T_c^{onset} and T_c^{offset} were observed, and the critical current density (J_c) were estimated to be 218 A/cm^2 (T = 4.2 K, H = 0 T) by transport measurements for the single-core wire. Furthermore, a higher J_c of 588 A/cm^2 (T = 4.2 K, H = 0 T) was obtained for the 3-core wire.

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P2-41 Vortex Pinning Mechanism in Iron Based Superconductors FeSe1-xTex and SrFe1.7Co0.3As2 - ***A. Thakur (Indian Institute of Technology, Patna), M. Lees, G. Balakrishnan (Department of Physics, University of Warwick), A. Yadav, C. Tomy (Indian Institute of Technology, Bombay), P. Das (Institute of Materials Science, The University of Tsukuba), A. Thamizhavel, A. Grover (Tata Institute of Fundamental Research, Mumbai), S. Ramakrishnan (Tata Institute of Fundamnetal Research, Mumbai)***

We address the issue of vortex pinning in Fe based superconductors. As key examples, we consider the cases of iron chalcogenide superconductor FeSe_(1-x)Te_x and the iron arsenide superconductor SrFe1.7Co0.3As2. The current density (Jc) is obtained experimentally for the single crystals of FeSe_(1-x)Te_x and SrFe1.7Co0.3As2 and is analyzed within several theoretical frameworks. Using scaling relationships obeyed by Jc, we present evidence in favor of pinning related to spatial variations of the charge carrier mean free path in the case of FeSe_(1-x)Te_x. We compare and contrast the observations in case of FeSe_(1-x)Te_x with those for SrFe1.7Co0.3As2.

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P2-42 Physical properties of FeTe-based bulk and thin crystals - ***Y. Mizuguchi, K. Hamada, H. Izawa, O. Miura (Tokyo Metropolitan Universty)***

FeTe-based superconductor is one of the candidates for application of Fe-based superconductivity, because of the simple composition and structure, less toxicity, and low anisotropy [1]. Further advantage of this system is that we can obtain large single crystals easily. We recently reported on successful fabrication of $FeTe_{1-x}S_x$ thin crystals by cleaving the crystal using the Scotch-tape method which has been used in studies of grapheme [2]. In this presentation, we will show systematic crystal growth of $Fe_{1+d}Te$ and FeTe-based superconductors, and physical properties of the obtained bulk crystals and that of thin crystals fabricated by cleaving. Latest advances in superconducting devices of FeTe-based thin crystals will also be presented.

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P2-43 Thin film fabrication of BaFe2(As,P)2 superconductor by Nd:YAG-PLD method - ***S. Adachi, T. Shimode, Y. Murai, N. Chikumoto, K. Nakao, K. Tanabe (SRL-ISTEC), M. Miura (SRL-ISTEC, Seikei Univ.)***

After the discovery of a LaFeAs(O,F) superconductor, the existence of a variety of iron pnictide superconductors was found. Huge efforts have been made with the aim of basic research and application using various forms of samples such as single crystals and thin films. We have tried fabricating thin films of BaFe2(As,P)2 superconductor by using Nd:YAG-PLD. Anisotropy of the so-called 122-type superconductor is rather small among the iron pnictide superconductors, and the BaFe2(As,P)2 superconductor exhibits a relatively high Tc of 31 K among the 122-type ones. We chose a PLD method for the film fabrication, since non-equilibrium process of the method has an advantage for the introduction of effective pinning centers in future research. We prepared ceramic targets with a nominal composition of BaFe2(As2/3P1/3)2. Processing of the raw and precursory materials was carried out in a glove box. The pellet was sealed in a quartz tube and then heat-treated at 1000ºC. The 2nd harmonic laser of Nd:YAG (532 nm) was used for ablation of the target. The energy density at the target surface was 2-10 J/cm2 and the pulse repetition was 5-30 Hz. LSAT was used for substrate. Substrate was heated at 500-800ºC. Distance between substrate and target was 7 cm. Deposition was carried out in vacuum. We succeeded in fabricating superconducting thin films with c-axis orientation. Presently obtained highest Tc's are 30 and 27 K for the onset and zero-resistivity temperatures, respectively. The attainment of in-plane alignment was confirmed by X-ray diffraction.

This work was supported by the Japan Society for the Promotion of Science (JSPS), through the Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program).

P2-44 Muon-spin-relaxation study of the magnetic penetration depth in single crystals of the iron-chalcogenide superconductor FeSe1-xTex (x = 0.6 – 0.8) - *T. Adachi (Department of Applied Physics, Graduate School of Engineering, Tohoku University), K. Ohishi, I. Watanabe (Advanced Meson Science Laboratory, Nishina Center for Accelerator-Based Science, RIKEN), M. Imaizumi, K. Suzuki, T. Noji, Y. Koike (Department of Applied Physics, Graduate School of Engineering, Tohoku University)*

We have performed transverse-field (TF) muon-spin-relaxation measurements of the iron-chalcogenide superconductor $FeSe_{1-x}Te_x$, in order to investigate superconducting (SC) properties of our high-quality single-crystals obtained through the annealing in vacuum [1-3]. In the annealed single-crystals of x = 0.6 and 0.7, exhibiting bulk superconductivity without magnetism, it has been found that the ab-plane magnetic penetration depth, lambda_ab, proportional to the SC carrier density divided by the effective mass in the ground state decreases with increasing x. Combined with our former specific-heat results [2,3], these results suggest the enhancement of the effective mass with increasing x toward the magnetic phase of x ~ 1.0 in the phase diagram, which is consistent with the change of the band dispersion observed by the photoemission spectroscopy using our single-crystals [4]. On the other hand, it has been found that the temperature dependence of the inverse square of lambda_ab continues to increase down to 2 K for x = 0.6, while it tends to be saturated at ~ 2 K for x = 0.7, although both samples have similar T_c of ~ 14 K. These might imply the change of the paring symmetry of superconductivity with x in $FeSe_{1-x}Te_x$.

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P2-45 Features of angular dependent critical current density in U irradiated Ba(Fe0.93Co0.07)2As2 - *T. Tamegai (Department of Applied Physics, The University of Tokyo), T. Kambara (Atomic Physics Laboratory, RIKEN), H. Yagyuda, T. Taen, Y. Nakajima (Department of Applied Physics, The University of Tokyo)*

Heavy-ion irradiations into cuprate superconductors have been successful to enhance the critical current density, J_c [1]. This is due to the fact that introduced columnar defects match geometrically with the shape of vortices. Several features accompanying the introduction of columnar defects have been clarified. Heavy-ion irradiation has turned out to be effective also in iron-based superconductors [2].

In this work, effects of 2.6 GeV Uranium (U) irradiations are studied for $Ba(Fe_{0.93}Co_{0.07})_2As_2$ (T_c~24.5 K) with different angles of injected ions as a function of the direction of external magnetic field. In the case of U irradiation, though the enhancement of J_c at zero field is modest, J_c keeps large values even at high fields. In addition, magnetic field dependence of J_c shows a peculiar suppression at low fields. We interpret this low-field suppression of J_c as a result of curvature of vortices below the self-field in thin superconductors when the field is applied perpendicular to the plate. Actually, when the magnetic field is tilted at a large angle from the ion tracks, the low-field anomaly is wiped away and J_c enhancement is strongly suppressed. However, when the field is tilted by 10-20 degrees from the ion tracks, peculiar asymmetry in the magnetic hysteresis loop is found.

Namely, in the field-decreasing branch, J_c is higher in positive field than that in the negative field with the same magnitude. Possible origins for this asymmetry will be discussed.

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P2-46 Abrupt change in the superconducting gap size with hole doping in Ba1-xKxFe2As2 - *W. Malaeb (University of Tokyo), T. Saito, H. Fukazawa, Y. Kohori (Chiba University), C. Chen (Chinese Academy of Science), H. Ikeda (Kyoto University), K. Kihou, C. Lee, A. Iyo, H. Eisaki (National Institute of Advanced Industrial Science and Technology (AIST)), Y. Ishida, S. Shin (University of Tokyo), T. Shimojima, K. Okazaki, Y. Ota, K. Ohgushi, S. Ishida, M. Nakajima, S. Uchida, S. Watanabe (University of Tokyo)*

The superconducting (SC) gaps in $Ba_{1-x}K_xFe_2As_2$ (BaK) compound are expected to change from fully opened at optimal doping [1] to nodal gaps at the end member KFe_2As_2 [2]. Here we have studied the doping dependence of these gaps using Laser ARPES with high energy resolution and bulk sensitivity. First we have assigned the orbital character of each of the hole bands around the Brillioun zone (BZ) center, and then precisely determined the doping evolution of the SC gaps on each band. While the gap size of the inner and middle Fermi surface (FS) sheets roughly scales with T_c, the outer hole FS gap shows an abrupt drop with overdoping (at x≈ 0.6). This is accompanied by the simultaneous disappearance of the electron FS sheet with simila r orbital character at the BZ corner. This behavior browses the different contributions of X^2-Y^2 and XZ/YZ orbitals to superconductivity in BaK. We will discuss these results and contrast them with the available experimental and theoretical studies on iron-based superconductors [3].

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P2-47 Antiferromagnetism and superconductivity in BaFe2(As1-xPx)2 studied by 31P-NMR -

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Iron pnictide $BaFe_2As_2$, one of the parent compounds of iron-based superconductors, shows an antiferromagnetic (AFM) transition at T_N accompanied simultaneously with a tetragonal-to-orthorhombic structural transition. Both transitions occuring at ~ 135 K are gradually suppressed by substituting isovalent P for As in $BaFe_2(As_{1-x}P_x)_2$ [1]. Superconductivity appears at x ~ 0.20 and shows a maximum T_c of 31 K at x ~ 0.3. Based on various experimental results, unconventional superconductivity with nodes in the superconducting (SC) gap was suggested in $BaFe_2(As_{1-x}P_x)_2$ [2-5]. The phase diagram of $BaFe_2(As_{1-x}P_x)_2$ is similar to that of the other unconventional superconductors such as organic, heavy-fermion and cuprate superconductors.

Intriguing issues in $BaFe_2(As_{1-x}P_x)_2$ are that whether an AFM quantum critical point (QCP) exists or not, and how AFM and SC phases interrelates with each other. To clarify these, we have investigated $BaFe_2(As_{1-x}P_x)_2$ with site-selective P-NMR measurements. P-NMR spectrum becomes broadened below T_N due to the appearance of internal fields at the P site originating from magnetically ordered moments at the Fe site. We tracked x dependence of the ordered moments at 1.5 K and found that the moments are successively suppressed with x and disappear at around x ~ 0.35. These results indicate the presence of an AFM QCP, consistent with the behavior of resistivity and nuclear spin-lattice relaxation rate $1/T_1$ in the normal state [1,6]. In addition, we report experimental evidences of the direct coupling between AFM and SC order parameters in the samples locating at the boundary of the two phases. The observed interrelation between two phases in $BaFe_2(As_{1-x}P_x)_2$ is compared with the other unconventional superconductors.

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P2-48 Local effect of the excess Fe atom in Fe1+deltaTe probed by scanning tunneling microscopy and spectroscopy -

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In the iron-chalcogenide superconductors, the excess Fe atoms which inevitably exist in the crystal cause the several macroscopic effects on the physical properties including (i) the reduction of the superconducting transition temperature [1][2], (ii) the change from the commensurate antiferromagnetic (AFM) order to the incommensurate one in their parent materials [3][4], and so on. Even though the excess Fe atom plays an important role on the bulk properties, the microscopic effect remains unknown.

To elucidate the microscopic effect of the excess Fe atoms, we have performed scanning tunneling spectroscopy experiments on $Fe_{1+\delta}Te$ single crystals which are the parent compound of the iron-chalcogenide superconductors. We found that (i) the particle-hole asymmetry in the tunneling spectra becomes pronounced and (ii) the conductance near 0 mV is enhanced around excess Fe atoms. The spatial distribution of this conductance near 0 mV was found to reflect the spatial symmetry of the spin configuration of the underlying AFM order or of the crystal monoclinicity. We will discuss how the observed microscopic effect of the excess Fe links to the macroscopic effect reported previously.

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[3]W. Bao, *et al*., Phys. Rev. Lett. 102, 247001 (2009)
[4] E. E. Rodriguez, *et al*., Phys. Rev. B 84, 064403 (2011)

P2-49 Evidence of coexisting magnetic and superconducting order in underdoped CaFe1.94Co0.06As2 -

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In recent times understanding the nature of the superconducting state in the Iron Arsenide class of superconductor shows that doping leads to the suppression of antiferromagnetic order in the parent compound and the emergence of superconductivity. Magnetic order and superconductivity are usually considered as mutually antagonistic phenomena[1]. However recent theories[2] suggest that magnetic fluctuations may be important to mediate superconductivity in pnictides. Using a novel variation of the high sensitivity Magneto-Optical Imaging (MOI) technique we image the local magnetic field distribution in high quality single crystal of 122 iron-pnictide $CaFe_{1.94}Co_{0.06}As_2$ (underdoped) superconductor. Local measurement of the field distribution reveals that the shielded Meissner like regions of these samples is anomalous and exhibits significant remnant magnetization response even when the field is reduced to zero from a field value below the lower critical field. In isofield MOI measurements, we observe locally a gradual transformation from a strongly diamagnetic to a positive magnetization response. While globally the magnetization hysteresis loop computed from the MOI measurements shows a predominant superconducting fraction, local magnetization loops reveal the presence of a magnetic fraction coexisting along with superconductivity. From our measurements we see that two order parameters coexist below the superconducting transition. Interestingly we observe that the area of the magnetic phase shrinks at the expense of a growing superconducting phase as the temperature is lowered[3].

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P2-50 Disorder and chemical substitutions in superconducting FeTe1-xSex single crystals: influence on superconducting properties - *R. Puzniak, D. Gawryluk, M. Berkowski, J. Pietosa, P. Dluzewski, A. Wittlin, A. Wisniewski (Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, PL-02-668 Warsaw, Poland)*

It was found that chemical and structural disorder in Fe(Te,Se), originating from kinetics of crystal growth process, influences superconducting properties of the single crystals of $FeTe_{1-x}Se_x$. Sharpness of transition to the superconducting state is evidently inversely correlated with crystallographic quality of the studied crystals. The evidence that faster grown crystals of inferior crystallographic properties are a better superconductor is presented. Ions inhomogeneous spatial distribution seems to enhance the superconductivity and might be an intrinsic feature of superconducting Fe(Te,Se) chalcogenides. On the other hand, studies of $FeTe_{0.65}Se_{0.35}$ doped with Co, Ni, and Cu into Fe ions site indicate that small disorder introduced into magnetic sublattice, by partial replacement of Fe ions by slight amount of nonmagnetic ions of Cu or magnetic ions of Ni and Co, completely suppresses superconductivity. Even if superconductivity is observed in the system containing magnetic ions, it can not survive when the disorder in magnetic ions sublattice is introduced. For superconducting single crystals of $Fe_{1-x}Ni_xTe_{0.65}Se_{0.35}$ substituted with very small amount of Ni, significant decline of the lower and the upper critical fields was found. The change in the superconducting carrier density as a result of Ni substitution is presented and discussed in terms of mechanism controlling the changes in T_c as a result of magnetic ion substitution in iron based chalcogenides.

P2-51 Universal heat conduction in the iron-based superconductor KFe2As2: Evidence of a d-wave state - *A. Juneau-Fecteau (Université de Sherbrooke), K. Kihou, C. Lee, A. Iyo, H. Eisaki (AIST & JST-TRIP), M. Tanatar (Ames Laboratory), R. Prozorov (Ames Laboratory & Iowa State University), T. Saito, H. Fukazawa, Y. Kohori (Chiba University & JST-TRIP), J. Reid, R. Gordon, S. Rene de Cotret, N. Doiron-Leyraud, L. Taillefer (Université de Sherbrooke)*

The thermal conductivity of the iron-arsenide superconductor KFe_2As_2 was measured down to 50 mK for a heat current parallel and perpendicular to the tetragonal axis [1]. A residual linear term (RLT) at $T = 0$ is observed for both current directions, confirming the presence of nodes in the superconducting gap. Our value of the RLT in the plane is equal to that reported by Dong *et al*. [Phys. Rev. Lett. **104**, 087005 (2010)] for a sample whose residual resistivity was ten times larger. This independence of the RLT on impurity scattering is the signature of universal heat transport, a property of superconducting states with symmetry-imposed line nodes. This argues against an *s*-wave state with accidental nodes. It favours instead a *d*-wave state, an assignment consistent with four additional properties: the magnitude of the RLT, its dependence on current direction and on magnetic field, and the temperature dependence of the thermal conductivity.

[1] A. Juneau-Fecteau *et al.*

P2-52 Ordering modulation of superconductivity in alkaline iron selenides - *X. Chen (Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015, USA), W. Bao (Department of Physics, Renmin University of China, Beijing 100872, China), J. Zhang, L. Tang (Department of Physics, South China University of Technology, Guangzhou 510641, China), M. Fang (Department of Physics, Zhejiang University, Hangzhou 310027, China), V. Struzhkin, R. Hemley, H. Mao (Geophysical Laboratory, Carnegie Institution of Washington, Washington, D.C. 20015, USA), J. Liu (Institute of High Energy Physics, Chinese Academy of Science, Beijing 100190, China), Q. Huang (NIST Center for Neutron Research, National Institute of Standards and Technology Gaithersburg, MD 20899, USA), J. Zhu (Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA)*

High-pressure measurements of transport and structural properties are performed on $Rb_{0.374}Tl_{0.374}Fe_{1.752}Se_2$ with mixed structures of space groups of *I*4/*m* and *I*4/*mmm* at ambient conditions. An extended phase diagram is obtained for the superconducting transition and structural transformation in the temperature range of 4-600 K and at pressures up to 40 GPa. Applying pressure leads to the charge diffusion from the fully occupied Fe site to the almost empty Fe site. The degree of iron vacancy ordering in the*I*4/*m* structure is found to scale well with the superconducting transition temperature of the material in the low-pressure cycle below 4 GPa. Upon further compression above 10 GPa, iron vacancy becomes fully disordered in a single *I*4/*mmm* phase having superconductivity at a constant value of 11 K. In the intermediate region between 4 and 10 GPa the iron vacancy is poorly ordered and superconductivity is undetectable. These results show that the *I*4/*m* and *I*4/*mmm* phases are the superconducting phases in the low-pressure and high-pressure cycles, respectively.

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P2-53 Suppression of superconductivity and spin-glass behavior in Cu-doped K0.8Fe2Se2 - *R. Hu, J. Palione, S. Saha, R. Greene (Center for Nanophysics & Advanced Materials and Department of Physics, University of Maryland)*

Single crystals with nominal compositions of K0.8Fe2-xCuxSe2 were grown and studied with low temperature electrical transport and magnetic susceptibility measurements. We show that the superconductivity present in undoped K0.8Fe2Se2 crystals with transition temperature of 31 K is very quickly suppressed with Cu doping into the Fe site, and the system very quickly becomes insulating. We discuss anomalous behavior at higher doping, including spin-glass like behavior with further Cu doping.

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P2-54 Effect of rare-earth substitutions in (Sr,Ca)Fe2As2 - ***T. Drye, S. Saha, J. Paglione (Center for Nanophysics and Advanced Materials, Department of Physics, University of Maryland), P. Zavalij (Department of Chemistry and Biochemistry, University of Maryland)***

Recently, aliovalent rare earth substitution into the iron-based superconducting compound $CaFe_2As_2$ has induced 47 K superconductivity, which is the highest in the intermetalic 122 family [1]. The $(Sr,Ca)Fe_2As_2$ system shows an unusual persistence of the Neel ordering temperature of ~200 K, up to a concentration of 70% calcium, despite a continuous monotonic decrease of both the *a*- and *c*-axis lattice parameters, the *c/a* tetragonal ratio, and the unit cell volume with decreasing atomic radius of the alkaline earth, as expected by Vegard's law [2]. The ionic radii of lighter rare earths (R^{3+}) are comparable to the ionic radius of Ca^{2+}, thus substitutions of R^{3+} into the Sr/Ca site can simultaneously create chemical pressure and dope electrons, giving an opportunity to study the combined role of lattice density and charge doping. We will present electrical transport, magnetic susceptibility and structural characterization data as a function of rare earth substitution into $Sr_{0.3}Ca_{0.7}Fe_2As_2$ single crystals, focusing on the resultant phase diagram and the comparisons of solubility limit of rare earth substitution as compared to end members $SrFe_2As_2$ and $CaFe_2As_2$.

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P2-55 Phase soliton and pairing symmetry of a two-band superconductor: Role of the proximity effect - ***V. Vakaryuk, V. Stanev (Argonne National Lab), A. Levchenko (Michigan State University), W. Lee (University of Illinois at Urbana Champaign)***

We suggest a mechanism which allows one to tune the energy of a topological defect -- phase soliton -- formed in the relative phase between the superconducting gaps in a two-band superconductor. The mechanism exploits the proximity effect between a two-band and a conventional s-wave superconductor which favors, in the area of contact, the alignment of the phases of the two gaps in the two-band superconductor. This effect leads to the reduction of the energy of the phase soliton for the s^{+-} pairing and to the increase in the energy when the pairing is of s^{++} type for which the equilibrium phases on the bands are the same. Although even for the s^{+-} case the energy of the soliton cannot be reduced below the energy of a soliton-free state, we argue that the soliton state can still be accessed as a metastable configuration. We consider an experimental setup which would allow one to distinguish between s^{+-} and s^{++} types of symmetry through the observation of such configurations. We also discuss applicability of our results to several families of multiband superconductors including pnictides and magnesium diboride.

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P2-56 Specific-heat study of the strong-coupling multi-band superconductivity in FeSe1-xTex (0.6?x?0.9) single crystals of good quality - ***Y. Koike, M. Imaizumi, T. Adachi, T. Noji, T. Kawamata (Department of Applied Physics, Tohoku University)***

We have investigated the superconductivity in $FeSe_{1-x}Te_x$ (0.6?x?0.9) from the specific heat measurements, using annealed single-crystals of good quality exhibiting bulk superconductivity [1,2]. The thermodynamic critical field, H_c, estimated from the superconducting condensation energy has been 0.406 T and 0.486 T at 0 K for x = 0.6 and 0.7, respectively. The temperature dependence of $H_c(T)$ markedly deviates from the simple parabolic law, $H_c(T) = H_c(0)\{1-(T/T_c)^2\}$, suggesting low-dimensional, strong-coupling and/or multi-band superconductivity. It has been found that both the electronic specific-heat divided by temperature, C_{el}/T, and the gradient of the C_{el}/T vs T^2 plot increase with increasing applied magnetic field for x = 0.6 and 0.7. These results suggest that the superconductivity is of multiple bands and that the relatively small superconducting gap is closed with increasing temperature and applied magnetic field.

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P2-57 Andreev reflection spectroscopy in nano-scale normal metal/superconductor devices featuring Fe1+yTe1-xSex - ***H. Peng, D. De, Z. Wu, C. Diaz-Pinto (University of Houston)***

Point-contact Andreev reflection (AR) spectroscopy has been an important tool for the study of superconductors. However, there remain significant challenges to overcome poor thermal and mechanical stability and the lack of diagnostic information on normal metal/superconductor (N-S) point contacts. In particular, for recently discovered Fe-based superconductors, diagnostic information is indispensable due to a degraded surface layer at the N-S point contact. Here we describe a distinct experimental method for AR spectroscopy with diagnostic capability via a design of nano-scale N-S devices with excellent thermal and mechanical stability, and have employed it to unveil the existence of two energy gaps in Fe1+yTe1-xSex which is crucial for understanding its pairing mechanism. Our approach can be widely applied for the study of various types of superconductors, and provide fundamental information inaccessible via traditional methods.

P2-58 Orbital Resolved Electronic States and Magnetism in Iron Pnictides in Correlated Electron Scenario - ***L. Zou (Key Laboratory of Materials Physics, Institute of Solid State Physics, Chinese Academy of Sciences), H. Lin (Department of Physics, Chinese University of Hong Kong, Shatin, New Territory, Hong Kong, China), Y. Quan, D. Liu (Key Laboratory of Materials Physics, Institute of Solid State Physics, Chinese Academy of Sciences)***

The electron correlation plays an important role in understanding the properties of iron pnictides. In this work, we investigate the electron correlation on the microscopic origin of magnetic moments and the orbital resolved properties of striped antiferromagnetic (AFM) iron pnictides based on an effective three-orbital model in the Kotliar-Ruckenstein slave-boson approach with the spin degree of freedom. We show that correlation leads to different renormalizations and relative shift of spin-up and spin-down bands, contributes to magnetic moments in Fe sites. The contribution of narrow d_{xz} orbital to magnetic moment is larger than that of d_{yz} and d_{xy} ones. Accompanying the appearance of striped AFM order, the orbital polarization emerges due to the splitting of d_{xz} and d_{yz} orbitals and becomes large with increasing Coulomb correlation U and Hund's coupling J_H, in sharp contrast with the two-orbital situation. The Fermi surface topology is strongly affected by electron correlation. Analysis to the symmetric character of orbitals involved in the formation of Fermi surfaces in LaFeAsO, the d_{xz}- or $d_{yz/xy}$-component mainly dominates the Fermi surface around M point or around Γ point, respectively, and no orbital selective Mott phase is found in these orbitals in realistic intermediate correlation regime. Only in the strongly correlated region all of the small pockets disappear eventually in the SAFM phase with large magnetic moment.

Sen Zhou and Ziqiang Wang, *Phys. Rev. Lett.*, **105** (2010) 096401.

P2-59 Electron-lattice coupling stabilizing ferro-orbital order in orthorhombic iron-based compounds - ***L. Zou (Key Laboratory of Materials Physics, Institute of Solid State Physics, Chinese Academy of Sciences), H. Lin (Department of Physics and Institute of Theoretical Physics, Chinese University of Hong Kong), D. Liu, Y. Quan (Key Laboratory of Materials Physics, Institute of Solid State Physics, Chinese Academy of Sciences)***

Magnetic and orbital properties of iron-based compounds, which are closely related to a tetragonal-orthorhombic structural phase transition, are explored within the multi-orbital Hubbard models. The electron-lattice coupling associated with the orthorhombic distortion, interplaying with electron-electron interaction, is self-consistently treated on the same foot. Our results reveal that in LaFeAsO the orbital polarization favors striped antiferromagntism (SAFM) in the orthorhombic phase. The ferro-orbital order (FO) with density wave character only occurs in the orthorhombic phase, rather than in the tetragonal one. The magnetic moments of Fe are small and compared with the experimental data in the SAFM phase. The anisotropic Fermi surface obtained in the SAFM/FO orthorhombic phase is good agreement with the ARPES experiments [1]. These results support a scenario that the FO is driven by the electron-lattice coupling and the orthorhombic lattice distortion. On the contrary, for pure KFe_2Se_2 compound, due to the absence of the orthorhombic lattice distortion, there is no evidence for the existence of the orbital order and magnetic order in our calculations based on an effective three-orbital model. It further demonstrates that the orthorhombic lattice distortion is crucial for understanding the orbital ordering and magnetic ordering in the iron-based materials.

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P2-60 Evidence for filamentary superconductivity nucleated at antiphase domain walls in antiferromagnetic CaFe$_2$As$_2$ - ***H. Xiao (University of Crete and FORTH), N. apRoberts-Warren, A. Shockley (Department of Physics, University of California, Davis, CA), Z. Viskadourakis (Department of Physics, University of Crete and FORTH), C. Almasan (Kent State University), T. Hu (Kent State University, KSU), X. Tee (Nanyang TechnologicalUniversity), A. Dioguardi, J. Crocker, D. Nisson, N. Curro (University of California, Davis, CA), I. Radulov (University of Crete and FORTH), C. Panagopoulos (University of Crete and FORTH and Nanyang TechnologicalUniversity)***

Resistivity, magnetization and microscopic ^{75}As nuclear magnetic resonance (NMR) measurements in the antiferromagnetically ordered state of the iron-based superconductor parent material CaFe$_2$As$_2$ exhibit anomalous features that are consistent with the collective freezing of domain walls. Below $T^*\approx 10$ K, the resistivity exhibits a peak and downturn, the bulk magnetization exhibits a sharp increase, and ^{75}As NMR measurements reveal the presence of slow fluctuations of the hyperfine field. These features in both the charge and spin response are strongly field dependent, are fully suppressed by $H^*\approx 15$ T, and suggest the presence of filamentary superconductivity nucleated at the antiphase domain walls in this material.

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P2-61 Flux flow and novel quasiparticle dissipation in LiFeAs investigated by microwave surface impedance measurements - ***A. MAEDA, T. OKADA, Y. IMAI, H. TAKAHASHI (Department of Pure and Applied Sciences, University of Tokyo), K. KITAGAWA, K. MATSUBAYASHI, Y. UWATOKO, M. TAKIGAWA (ISSP, University of Tokyo)***

In order to investigate the quasiparticle dynamics in the vortex core of iron-based superconductors, which are thought to be possibly novel s+- superconductor, we measured the in plane surface impedance at 19 GHz of LiFeAs single crystals under finite magnetic fields up to 8 T [1]. The flux flow resistivity, ρ_f, increased linearly with magnetic fields except for near B_{c2}, as $\rho_f/\rho_n \propto B/B_{c2}$, representing the complete gap opening. However, the gradient is larger than that theoretically predicted value for conventional s-wave superconductors [2, 3], suggesting that the multiply gapped feature shows up. This also means that the flux-flow is insensitive to the sign-reversal of the order parameters.

More significant findings are that the estimated mean free path of quasiparticles inside the vortex core was found to be much shorter than that outside, and rather comparable to that in the normal state. Similar tendencies have been observed in many cuprate superconductors [4], and in Y_2C_3 [5]. Therefore, we believe that this must be a generic nature in all superconductors; representing that there must be a common dissipation mechanism, which had not been considered in any existing theories.

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[5] S. Akutagawa *et al*., JPSJ **77** (2008) 1064701.

P2-62 Infrared signature of the superconducting gap symmetry in iron-arsenidesuperconductors - ***B. Xu, Y. Dai, B. Shen, X. Qiu (Beijing National Laboratory for Condensed Matter Physics,National Laboratory for Superconductivity, Institute of Physics,Chinese Academy of Sciences, Beijing 100190, China), R. Lobo (LPEM, ESPCI-ParisTech, CNRS, UPMC, 10 rue Vauquelin, F-75231 Paris Cedex 5, France), H. Wen (National Laboratory of Solid State Microstructures and Department of Physics, Nanjing University, Nanjing 210093, China)***

A crucial issue in the superconducting mechanism of iron-arsenide superconductors is understanding the properties of the superconducting gaps. Band structure calculations suggest that the pairing symmetry in the iron-arsenide superconductors is $s_\pm$ characterized by a sign reversal between s gaps in different Fermi surface sheets. We measured the in-plane optical conductivity of a nearly optimally doped $Ba_{0.6}K_{0.4}Fe_2As_2$ single crystal with Tc = 39.1 K. Upon entering the superconducting state the optical conductivity below about 20 meV vanishes, strongly suggesting a fully gapped system. A BCS-like fit requires two different isotropic gaps to describe the optical response of this material. The temperature dependence of the gaps and the penetration depth suggest a strong interband coupling, but no impurity scattering induced pair breaking is present. This contrasts to the large residual conductivity observed in optimally doped $Ba(Fe_{1-x}Co_x)_2As_2$ and strongly supports an $s_\pm$ gap symmetry for these compounds.

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P2-63 Pseudogap and its origin in underdoped Ba$_{1-x}$K$_{x}$Fe$_{2}$As$_{2}$ as revealed by optical spectroscopy - ***Y. Dai (LPEM, ESPCI-ParisTech, CNRS, UPMC, 10 rue Vauquelin, F-75231 Paris Cedex 5, France and Beijing National Laboratory for Condensed Matter Physics, National Laboratory for Superconductivity, Institute of Physics, Chinese Academy of Sciences, P.O. Box, B. Xu, B. Shen, X. Qiu (Beijing National Laboratory for Condensed Matter Physics, National Laboratory for Superconductivity, Institute of Physics, Chinese Academy of Sciences, P.O. Box 603, Beijing 100190, China), J. Hu (Department of Physics, Purdue University, West Lafayette, Indiana 47907, USA), R. Lobo (LPEM, ESPCI-ParisTech, CNRS, UPMC, 10 rue Vauquelin, F-75231 Paris Cedex 5, France), H. Wen (National Laboratory of Solid State Microstructures and Department of Physics, Nanjing University, Nanjing 210093, China)***

We report the observation of a pseudogap in the \emph{ab}-plane optical conductivity of underdoped \BKFAx\ ($x = 0.2$ and 0.12) single crystals. Both samples show prominent gaps opened by a spin density wave (SDW) order and superconductivity at the transition temperatures $T_{\it SDW}$ and T_c, respectively. In addition, we observe an evident pseudogap below $T^{\ast} \sim$ 75 K, a temperature much lower than $T_{\it SDW}$ but much higher than T_{c}. A spectral weight analysis shows that the pseudogap is closely connected to the superconducting gap, indicating the possibility of its being a precursor of superconductivity. The doping dependence of the gaps is also supportive of such a scenario.

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P2-64 RAMAN SPECTROSCOPY OF IRON BASED SUPERCONDUCTORS - ***G. Blumberg (Rutgers University)***

The discovery of new families of layered quasi-2D iron-based multi-band high-T superconductors has revealed a complicated and often contradictory picture of the structural, magnetic and superconducting properties of these materials and has generated considerable excitement as well as confusion regarding the delicate interplay between magnetism and superconductivity. For example, recently discovered alkali-doped iron selenide superconductors with 2D ordered iron vacancies reach a superconducting transition temperature as high as 32K while exhibiting co-existing antiferromagnetism with extremely high Néel transition temperature of roughly 500K.

Electronic and magnetic Raman scattering has become an indispensable tool in the study of magnetism and superconductivity in strongly correlated materials. I will review recent results of Raman spectroscopic studies from several families of superconductors, including iron selenides and related compounds: (1) from systematic phononic, magnetic and electronic polarized Raman scattering data as a function of temperature we evaluate an interplay between structural, magnetic, and superconducting transitions; (2) using polarized ultra-low-frequency electronic Raman scattering data we examine the symmetry of the superconducting order parameter, the magnitude of the superconducting gaps and their evolution; (3) by analyzing two-magnon Raman scattering for parent and lightly doped superconducting compounds we establish the evolution of magnetically ordered state; from the interpretation of two-magnon scattering bands we make a quantitative estimate of the exchange interaction strength.

The work is done in continuing collaboration with A. Ignatov and P. Lubik (Rutgers), N.-L. Wang (IOP, Beijing), J. Karpinski (ETH), J. Paglione (U Mariland), E. Giannini (U Geneva). Research at Rutgers is supported by the U.S. Department of Energy under Award DE-SC0005463 and by the National Science Foundation under Award DMR-1104884.

P2-65 57Fe AND 151Eu MöSSBAUER SPECTROSCOPY AND MAGNETIZATION STUDIES OF DOPED AFe2As2 AND BFe2Se2 SYSTEMS - ***I. Felner, I. Nowik (Racah Institute of Physics, The Hebrew University, Jerusalem 91904, Israel)***

In AFe_2As_2 (A=Ba, Eu) and $B_xFe_2Se_2$ (B=K, Rb and Tl) single crystals ^{57}Fe Mössbauer spectroscopy (MS) may contribute much, since the Fe ions are part of the layers to which SC is confined. MS and Magnetization studies of a large variety of these systems including substitutions (i) of Fe by Co or Ni or (ii) As by P in the AFe_2As_2 system have been performed. In some materials, the paramagnetic Meissner effect is observed. In $B_xFe_2Se_2$, the AFM state (T_N> 500 K) coexists with SC (below 30 K) within the **same** Fe layers. Of particular interest is the $EuFe_2(As_{1-x}P_x)_2$ system, for which two Mössbauer isotopes, ^{57}Fe and ^{151}Eu, enable to investigate simultaneously the mutual interactions between the magnetic Eu and the Fe layers. $EuFe_2(As_{1-x}P_x)_2$ is SC for 0.2<x<0.5. For $x \leq 0.2$ the Eu^{2+} ions are AFM ordered with the moments in the *ab* planes. Whereas for $x \geq 0.2$ the Eu is FM ordered along the *c*-axis. In the FM region, the magnetic transition and the magnetic hyperfine fields (H_{eff}) of the Eu nuclei are higher than those in the AFM region. The ^{57}Fe Mössbauer studies show no magnetism in the iron site for x >0.2, yet exhibit at 5 K transferred magnetic hyperfine fields (~1 T) from the FM ordered Eu sub lattice, even in the SC region. *The observation of superconductivity in the presence of ferromagnetism is rarely observed, transferred magnetic hyperfine fields in the superconducting state are observed here for the first time*.

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P2-66 NMR Study on high temperature Fe-pnictide Ln-Fe-As-O superconductor with Tc=50 K - ***H. Mukuda (Osaka university), P. Shirage, A. Iyo (AIST), S. Furukawa, M. Yashima, Y. Kitaoka (Osaka university)***

Superconducting transition temperature (Tc) of Ln-FeAsO (1111)-based compounds (Ln: Rare earth) rises to 55 K when the Ln=Sm. In NMR investigation, however, Ln-1111 compounds are affected by the magnetism of rare earth ions, which prevents us from probing the intrinsic nuclear relaxation rate 1/T1 of the quasi-particles in the superconducting (SC) state. In order to reveal the mechanism of high Tc more than 50 K in Ln-1111 system, we have investigated the normal-state and SC characteristics of (La0.05Y0.95)FeAsOy (La0.05Y0.951111) with Tc=50 K by means of 57Fe/75As-NMR measurements. In the SC state, the measurements of 1/T1 have revealed in terms of a multiple fully-gapped s(+-)-wave model that the SC gap becomes larger than that in optimally-doped LaFeAsOy (La111(OPT)) with Tc=28 K. In the normal state, the increase of 1/T1T upon cooling indicates that the antiferromagnetic(AFM) spin fluctuations develop toward Tc, which is more significant than in La1111(OPT) and (La0.8Y0.21111) (Tc=34K). However, these antiferromagnetic spin fluctuations were weaker than in Ba0.6K0.4Fe2As2 (Tc=38K) and (Ca4Al2O6)(Fe2As2) (Tc=27K), which have lower Tcs than in La0.05Y0.951111, suggesting that the AFM spin fluctuations are not an unique factor to increase the Tc in Fe-pnictide superconductors.

P2-67 Contrasting Superconducting Property in Fe-based superconductors (Ca_4Al_2O_{6-y})(Fe_2Pn_2)[Pn=As and P] - ***H. Kinouchi, H. Mukuda, M. Yashima, Y. Kitaoka (Graduate School of Engineering Science, Osaka University), P. Shirage, H. Eisaki, A. Iyo (National Institute of Advanced Industrial Science and Technology (AIST))***

We report As-nuclear quadrupole resonance (NQR) study on (Ca_4Al_2O_{6-y})(Fe_2As_2) with Tc=27K, and P-nuclear magnetic resonance (NMR) study on (Ca_4Al_2O_{6-y})(Fe_2P_2) with Tc=17K. (Ca_4Al_2O_{6-y})(Fe_2As_2) possesses the characteristic structural parameters such as short a-axis length, high pnictgen height, narrow As-Fe-As angle, and thick perovskite-type blocking layer. A measurement of the nuclear spin relaxation rate 1/T1 revealed a significant evolution of antiferromagnetic (AFM) spin fluctuations in normal state, which originates from the possible well nested hole and electron Fermi surfaces. Below Tc, the 1/T1 decreases steeply upon cooling without any trace of Hebel-Slichter peak, which is consistently accounted for within the framework of nodeless s(+-)-wave multiple gap model[1]. On the other hands, (Ca_4Al_2O_{6-y})(Fe_2P_2) is characterized by lower pnictgen height and wider As-Fe-As angle than that of (Ca_4Al_2O_{6-y})(Fe_2As_2), where FeP_4 forms nearly regular tetrahedron. The P-NMR-1/T1 measurement revealed the presence of AFM spin fluctuations in normal state and gapless SC state. These facts indicate the close relationship between the local structural characters of FePn_4 and the SC properties.

[1]H. Kinouchi *et al.,*PRL 107, 047002 (2011)

P2-68 Interplay between superconductivity and antiferromagnetism in some iron-pnictides single crystals studied by 57Fe Mössbauer spectroscopy - ***E. Baggio-Saitovitch (Brazilian Center for Research in Physics), H. Luo (Beijing National Laboratory for Condensed Matter Physics), J. Munevar, H. Micklitz, J. Agüero (Brazilian Center for Research in Physics), P. Dai (Department of Physics and Astonomy, University of Tennessee), C. Zhang (Department of Physics and Astronomy, University of Tennessee), C. Argüello, Y. Uemura (Department of Physics, University of Columbia)***

We have performed detailed 57Fe Mössbauer spectroscopy measurements on Ba0.78K0.22Fe2As2 and BaFe2-xNixAs2 single crystal mosaics showing antiferromagnetic ordering below TN with superconductivity below TC. Analysis of the Mössbauer spectra shows a decrease in the magnetic hyperfine (hf) field but no change in the magnetic volume fraction below TC. This is an indication for the coexistence of magnetism and superconductivity in these compounds. The decrease in the magnetic hf field below TC depends on the difference between TN and TC, being the largest for TN close to TC. Two different explanations for this observation are given. We also find that the non-magnetic volume fraction below TN correlates with the Ni doping x, being large for high TC and small for high TN.

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P2-69 Magnetism in superconducting EuFe2As1.4P0.6 single crystals studied by local probes - ***J. Munevar, H. Micklitz, M. Alzamora, E. Baggio-Saitovitch (Brazilian Center for Research in Physics), A. Aczel, T. Munsie, T. Williams, G. Luke (Department of Physics and Astronomy, McMaster University), C. Argüello, T. Goko, F. Ning, Y. Uemura (Department of Physics, Columbia University), G. Chen (Renmin University of China)***

We have studied the magnetism in superconducting single crystals of EuFe2As1.4P0.6 by using the local probe techniques of zero-field muon spin rotation/relaxation and 151Eu/57Fe Mössbauer spectroscopy. All of these measurements reveal magnetic hyperfine fields below the magnetic ordering temperature Tm= 18 Kof the Eu2+ moments. The analysis of the data shows that there is a coexistence of ferromagnetism, resulting from Eu2+ moments ordered along the crystallographic c-axis, and superconductivity below Tsc = 15 K. We find indications for a change in the dynamics of the small Fe magnetic momets (~ 0.07 mB) at the onset of superconductivity: below Tsc the Fe magnetic moments seem to be "frozen" within the ab-plane.

Support by US NSF under the Materials World Network (MWN: DMR-0502706 and 0806846) and Partnership for International Research and education (PIRE: OISE-0968226) programs at Columbia, by Canadian NSERC and CIFAR at McMaster, and by CIAM (CNPq-NSF), CNPq and Faperj at CBPF in Rio, Brazil and NSFC and MOST of China: 973 project 2011CB605900 at IOP Beijing.

P2-70 Magnetotransport in La(Fe,Ru)AsO as a probe of band structure and mobility Magnetotransport in La(Fe,Ru)AsO as a probe of band structure and mobility - ***M. Putti (Università di Genova), I. Pallecchi, A. Palenzona, A. Martinelli (CNR-SPIN), F. Bernardini, S. Massidda (Università di Cagliari)***

In this work we investigate the Ru substituted LaFeAsO compound, by studying the magnetotransport behaviour and its relationship with the band structure, in different regimes of temperature, magnetic field and Ru content. In particular we analyse the magnetoresistance of $LaFe_{1-x}Ru_xAsO$ ($0 \le x \le 0.6$) samples with the support of *ab initio* calculations and we find out that in the whole series: (i) the transport is dominated by electron bands only; (ii) the magnetoresistance exhibits distinctive features related to the presence of Dirac cones; indeed,*ab initio* calculations confirm the presence of anisotropic Dirac cones in the band structure; (iii) the low temperature mobility is exceptionally high and reaches 18.6 $m^2/(Vs)$ in the Ru-free sample at T=2K, in the extreme limit of a single Landau level occupied in the Dirac cones; (iv) the mobility drops abruptly above 10K-15K; (v) the disorder has a very weak effect on the band mobilities and on the transport properties; (vi) there exists a correlation between the temperature ranges of Dirac cones and SDW carrier condensation. These findings may be of crucial importance in the investigation of superconductivity in the F-doped La(Fe,Ru)As(O,F) compounds related to this series of parent compounds.

P2-71 Crystal growth and superconductivity of Fe-base materials - ***g. gu, J. Schneeloch, Z. Xu, J. wen, g. xu, J. Tranquada, q. li, h. yang, C. Homes, P. Johnson (BNL)***

A number of Fe-base superconducting materials have been discovered recently. The Fe-11 phase $FeTe_{1-x}Se_x$ and Fe-112 phase KFe_2Se_2 superconducting materials are very interesting new materials. We have grown a number of the $FeTe_{1-x}Se_x$ and KFe_2Se_2 single crystals by using a Bridgman growth technique and zone method. The effects of the growth condition and the compositions of a raw materials on the single crystal growth of $FeTe_{1-x}Se_x$ and KFe_2Se_2 has been studied by using a Bridgman growth technique. Various physical properties of these single crystals will be presented.

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P2-72 Temperature-dependent transformation of the magnetic excitation spectrum on approaching superconductivity in Fe1-x(Ni/Cu)xTe0.5Se0.5 - ***z. xu, j. wen, W. Ku, X. Liu, g. gu, j. tranquada, g. xu (Brookhaven national lab), Y. Zhao (NIST), M. Matsuda (Oak ridge national lab), D. Lee, R. Birgeneau (UC Berkeley)***

Spin excitations are one of the top candidates for mediating electron pairing in unconventional superconductors. Their coupling to superconductivity is evident in a large number of systems, by the observation of an abrupt redistribution of magnetic spectral weight at the superconducting transition temperature, Tc, for energies comparable to the superconducting gap. Here we report inelastic neutron scattering measurements on Fe-based superconductors Fe1-x(Ni/Cu)xTe0.5Se0.5, that emphasize an additional signature. The overall shape of the low energy magnetic dispersion changes from two incommensurate vertical columns at T>>Tc to a distinctly different U-shaped dispersion at low temperature. Importantly, this spectral reconstruction is apparent for temperature up to 3Tc. If the magnetic excitations are involved in the pairing mechanism, their surprising modification on the approach to Tc demonstrates that strong interactions are involved.

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P2-73 Multiband nature of electronic transport in FeSe_1-x observed by magnetoresistance and Hall coefficient - ***T. Urata, K. Huynh, S. Heguri, G. Mu (Department of physics, Graduate school of science, Tohoku University), K. Tanigaki (Department of physics, Graduate school of science, Tohoku University. WPI-Advanced Institute for Materials Research (WPI-AIMR), Tohoku University.), Y. Tanabe, J. Xu (WPI-Advanced Institute for Materials Research (WPI-AIMR), Tohoku University)***

$FeSe_{1-x}$ is one of iron based superconductors [1], which has the simplest structure without block layers. It is essential to investigate the Fermi surfaces to understand the electronic states of $FeSe_{1-x}$. Due to the difficulties in single crystal growth, the real electronic states of $FeSe_{1-x}$ are still controversial. From band calculations, the electronic structure in $FeSe_{1-x}$ is close to that of other families of iron based superconductors and the SDW transition has been proposed due to the nesting between electron and hole pockets [2]. On the other hand, NMR measurements have revealed that there are no magnetically ordered states [3].

In order to clarify the electronic states of $FeSe_{1-x}$, we have performed transverse magnetoresistance (MR) and Hall coefficient measurements under magnetic field (-9 T ≤ B ≤ 9 T) for $FeSe_{0.94}$. As temperature decreases, the sign of Hall coefficient gradually changed below the structural transition temperature (T_s) [4] and a markedly nonlinear Hall resistivity against B was observed. Present results indicate that the electronic structure of $FeSe_{1-x}$ is characterized as a multiband system and an enhancement of carrier mobilities takes place below Ts, being similar to what has been observed for other families of iron based superconductors.

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P2-74 Transition metal substitution effect on Dirac cone states in Ba(Fe1-xTMxAs)2 (TM = Co, Ru, Mn) studied by magnetoresistance - ***Y. Tanabe (Tohoku University), J. Xu (Tohoku Iniversity), K. Huynh, T. Urata, S. Heguri, G. Mu, R. Nouchi, K. Tanigaki (Tohoku University)***

Impurity effects on an ideally massless fermion are an intriguing research subject in physics of Dirac cone. Two Dirac cones are created in pairs as a node of spin density wave (SDW) in a parent compound of iron pnictide superconductors due to multi-orbital nature of the system [1]. In this case, the two Dirac cones have the same chirality due to the compensation of the chirality between the two Dirac cones and the parabolic hole pocket [2]. As a consequence, the Dirac cones are robust against both nonmagnetic and magnetic impurities. Because a variety of transition metals (TMs) can be substituted to the Fe site, the iron pnictide compounds are suitable for studying the impurity effects on the Dirac cones.

We report the Co, Ru, Mn substitution effects on the Dirac cones in $Ba(Fe_{1-x}TM_xAs)_2$ from magnetoresistance (MR). Theoretically, a linear MR against the magnetic field (B) has been predicted in the quantum limit of Dirac cones [3] and is experimentally confirmed in $Ba(FeAs)_2$ [4]. For Ru and Co substitution, it has been found that the behaviors of MR have changed from quadratic to linear against B in -9 T < B < 9 T below x = 0.15 for Ru [5] and below x = 0.03 for Co. Moreover, the temperature dependence of onset (B^*) of linear MR can be explained in terms of the quantum limit of Dirac cones [3]. Therefore, the Dirac cones are robust for both Ru and Co substitutions in $Ba(FeAs)_2$, being consistent with the theoretical prediction [2]. For the Mn substitution, although the linear MR against B tends to develop below x = 0.025, the temperature dependence of B^* has deviated from that given by theoretical models at low temperatures, being in contrast with what is observed in the case of Co and Ru substitution.

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P2-75 Electronic phase diagram of the iron-platinum-based superconductors Ca10(Pt4As8)(Fe2-xPtxAs2)5 and Ca10(Pt3As8)(Fe2-xPtxAs2)5 - ***K. Kudo, S. Kakiya, M. Nohara (Okayama University)***

$Ca_{10}(Pt_4As_8)(Fe_{2-x}Pt_xAs_2)_5$ (alpha phase) and $Ca_{10}(Pt_3As_8)(Fe_{2-x}Pt_xAs_2)_5$ (beta phase) are novel iron-platinum-based superconductors which possess the covalent spacer layers Pt_nAs_8 (n = 3, 4) [1,2,3]. These spacer layers are in sharp contrast to the ionic spacer layers in the previous iron-based superconductors. The reported T_c is high: T_c = 38 K at x = 0.36 in the alpha phase [1] and T_c = 13 K at x = 0.16 in the beta phase [1]. Thus, the detailed study in these compounds will provide a renewed key-ingredient to realize a higher T_c in pnictides.

In this paper, we report the electronic phase diagram for alpha and beta phases. We observed the bell-shaped x dependence of T_c in both systems and the antiferromagnetic ordered phase in the low x range of beta-phase. These results follow generic features of the iron-based superconductors. On the other hand, it is unusual that the superconductivity is extremely robust against the Pt doping. The maximum T_c of 38 K for the alpha phase and 17 K for the beta phase are located at high x values of 0.36 (Pt 18 %) and 0.29 (14.5%), respectively. Moreover, the superconductivity in both phases survives even at x = 0.50 (25 %). These results are quite different from the 1111-type and the 122-type superconductors, in which the superconductivity disappears upon 8 – 15 % doping of transition metals [4,5]. Our results suggest that Pt in the present compounds hardly induces randomness and/or provides a small number of carriers compared to other dopant.

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P2-76 Superconductivity in the platinum-based arsenide SrPt2As2 with a CaBe2Ge2-type structure - *K. Kudo, Y. Nishikubo, M. Nohara (Okayama University)*

$SrPt_2As_2$ crystallizes in a tetragonal $CaBe_2Ge_2$-type structure with the space group P4/nmm [1]. The structure consists of the alternate stacking of two kinds of Pt_2As_2 layers: one made by normal $PtAs_4$ tetrahedra (Pt_2As_2 layer) and the other made by inverse $AsPt_4$tetrahedra (As_2Pt_2 layer). The structure contrasts sharply with that of $BaFe_2As_2$, which consists of one specific Fe_2As_2 layer, made by normal $FeAs_4$ tetrahedra.
In this paper, we report that $SrPt_2As_2$ exhibits superconductivity at T_c = 5.2 K [2], together with a charge-density wave (CDW) ordering at approximately 470 K [1]. T_c of $SrPt_2As_2$ is markedly higher than those reported in $ThCr_2Si_2$-type 122 pnictides without iron. This result provides two suggestions to realize a higher T_c in pnictides. One is the importance of Peierls instabilities. The coexistence of superconductivity and CDW indicates that $SrPt_2As_2$ can be viewed as a nonmagnetic analogue of iron-based superconductors, in which superconductivity emerges in close proximity to spin-density-wave (SDW) ordering. The other is the advantage of the $CaBe_2Ge_2$-type structure. The LDA band calculations predicted the charge disproportionation between Pt_2As_2 and As_2Pt_2 layers, which is originated from the asymmetric stacking sequence in the structure [3,4]. The prediction promises the self-doped carriers and the enhanced two-dimensionality in $SrPt_2As_2$. The discovery of superconductivity in $SrPt_2As_2$ shows a novel route to develop pnictide superconductors with higher T_c.

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P2-77 Superconductivity influenced by Eu2+-magnetism in Eu(Fe1-xMx)2As2 (M=Co, Ru and Ir) - *G. Cao, W. Jiao (Department of Physics, Zhejiang University.), J. Bao (Department of Physics, Zhejiang University), H. Zhai, Z. Xu (Department of Physics, Zhejiang University.)*

Among 122-type ferroarsenides, $EuFe_2As_2$ is the unique member due to a large local moment of S=7/2 for the Eu^{2+} ions which orders antiferromagnetically at 20 K. By the Fe-site doping with Co, Ru and Ir in $EuFe_2As_2$, the spin-density wave at the Fe sublattice is suppressed, and superconductivity emerges. Simultaneously the magnetic ordering of the Eu^{2+} sublattice changes to render ferromagnetic components both along and perpendicular to *c*-axis. Consequently the superconductivity is influenced by the ferromagnetic internal fields. Depending on the dopants and doping levels, interesting phenomena such as absence of Meissner effect, reentrant superconductivity, and anisotropic superconductivity were observed.

P2-78 High-resolution ARPES study of electronic structure on LaCo2B2 superconductor - *E. Ieki (Department of Physics, Tohoku University), T. Kuroda, H. Mizoguchi, S. Kim, H. Hosono (Department of Materials Science and Engineering, Tokyo Institute of Technology), T. Takahashi (Department of Physics, and WPI-AIMR, Tohoku University), K. Nakayama, K. Umezawa (Department of Physics, Tohoku University), T. Sato (Department of Physics, Tohoku University and TRiP-JST), S. Souma (WPI-AIMR, Tohoku University)*

Since the discovery of iron-based superconductors, great efforts have been devoted to search for new types of superconductors. The recent discovery of superconductivity below 4 K in doped $LaCo_2B_2$ [1], which is isostructural to so-called 122 system, has attracted much attention because this compound is the first Co-based superconductor among the 122 compounds. To clarify the superconducting mechanism of this novel superconductor, an experimental investigation of the electronic structure responsible for superconductivity is of particular importance. Here we report the first angle-resolved photoemission results on $LaCo_2B_2$ superconductor. We clearly observed several dispersive bands crossing the Fermi level, which are mostly derived from hybridized states of Co *3d* and B *2p* orbitals. We revealed that the Fermi surface topology is distinctly different from that in iron-based superconductors. In the presentation, we also demonstrate three dimensionality of the electronic states, and discuss the mechanism of superconductivity.

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P2-79 Fermi surface and superconducting gap of iron pnictides and chalcogenides studied by angle-resolved photoemission spectroscopy - *T. Sato (Tohoku University), P. Richard, H. Ding (Beijing National Laboratory for Condensed Matter Physics, and Institute of Physics, Chinese Academy of Sciences), T. Takahashi (Department of Physics and WPI-AIMR, Tohoku University), S. Wang (Department of Physics, Renmin University of China), K. Nakayama, Y. Tanaka, K. Umezawa (Department of Physics, Tohoku University)*

We report our recent high-resolution angle-resolved photoemission spectroscopy (ARPES) results on various iron-based superconductors, by particularly focusing on 111 and 11 systems which show relatively low superconducting transition temperatures. We determined precise temperature, Fermi-surface, and momentum dependence of the superconducting gap, and found possible universality on the superconducting-gap function suggestive of the common superconducting mechanism. We also revealed a difference in the nesting condition of Fermi surfaces, which would naturally lead to the difference in the appearance/absence of the magnetic order in the parent compounds. We discuss observed superconducting-gap behavior in relation to spin/orbital fluctuations and to the previous ARPES results of cuprates.

P2-80 Anisotropic diamagnetism of superconducting BaFe2-xNixAs2 single crystals - ***X. Dong, Y. Wu, Z. Li, F. Zhou, Z. Zhao (National Laboratory for Superconductivity, Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Science, Beijing 100190, China)***

We investigated the anisotropic magnetic properties of the $BaFe_{2-x}Ni_xAs_2$ single crystals in the vicinity of optimally doping level. We found that the diamagnetic signal with field along ab plane is larger than that along c-axis. This phenomenon indicated a remarkable difference of the superconducting diamagnetism anisotropy between iron pnictide and cuprate despite similar layered structure. Possible reason was discussed in terms of dopant and pairing mechanism.

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P2-81 High pressure flux growth, structural and superconducting properties of LnFePnO (Ln: lanthanide, Pn: pnictogen) single crystals - ***N. Zhigadlo (Laboratory for Solid State Physics, ETH Zurich, 8093 Zurich, Switzerland), M. Tortello, R. Gonnelli (Dipartimento di Scienza Applicata e Tecnologia, Politecnico di Torino, 10129 Torino, Italy), K. Rogacki (Institute of Low Temperature and Structure Research, 50-950 Wroclaw, Poland), R. Puzniak (Institute of Physics, Polish Academy of Sciences, PL-02-668 Warsaw, Poland), M. Bendele, R. Khasanov (Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institute, 5232 Villigen, Switzerland), S. Katrych, P. Moll, J. Karpinski, B. Batlogg (Laboratory for Solid State Physics, ETH Zurich, 8093 Zurich, Switzerland), S. Weyeneth, H. Keller (Physik-Institut der Universität Zürich, 8057 Zürich, Switzerland)***

Over the past three years exhaustive experimental effort evidenced that the crystal growth of *Ln*Fe*Pn*O (*Ln*1111, *Ln*: lanthanide, *Pn*: pnictogen) oxypnictides is a difficult task. The *Ln*1111 crystals grown by various methods are still limited in size, their superconducting critical temperature (T_c) is often not reduced, and some crystals contain inclusions of secondary phases or impurities, both affecting physical properties seriously. We adopted the high pressure crystal growth method and carried out a systematic investigation of the parameters controlling the growth of single crystals, including the thermodynamic variables (T, P), reagent composition and kinetic factors such as reaction time and cooling rate. NaCl/KCl, NaAs and KAs fluxes were used to grow *Ln*1111 crystals at pressure of 30 kbar. Crystals up to 300 mm in linear size were reproducibly obtained from NaCl/KCl flux [1-5]. Furthermore, millimeter-sized superconducting *Ln*1111 crystals were successfully grown from NaAs and KAs fluxes. These fluxes are at least three times more efficient in obtaining large size crystals, however, the phase formation and the chemical composition are more difficult to control. In addition to the substitution of F for O [1,2,3], superconductivity has also been studied by substituting Th for Sm, P for As, and Co for Fe [4,5]. Various experimental investigations of the crystal structure confirmed high structural quality, and show modifications due to substitutions, which are linked to superconducting properties.

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P2-82 OPTICAL PROPERTIES OF ALKALI-DOPED IRON ARSENIDE AND SELENIDE SUPERCONDUCTORS - ***A. Boris, A. Charnukha (Max Planck Institute for Solid State Research, Stuttgart)***

We show that the far-infrared conductivity of hole-doped Ba0.68K0.32Fe2As2 is accurately described by a strong-coupling Eliashberg model in the clean limit [1]. The same model in the dirty limit also accurately describes the optical conductivity of electron-doped 122 iron arsenides, which turned out to be dominated by impurity scattering. The difference between electron- and hole-doped compounds is a consequence of the doping mechanism, which involves substitution inside and out of the iron arsenide planes, respectively. Our data and analysis allows a universal understanding of the optical properties of this entire family of materials.

As an unusual complement to these results we observe a superconductivity-induced suppression of an absorption band at an energy of 2.5 eV, two orders of magnitude above the superconducting gap energy [2]. This band is assigned to transitions from As-p to Fe-d orbitals crossing the Fermi surface. This anomaly is explained as a consequence of redistribution of the occupation of the different bands below Tc, which can potentially enhance superconductivity in iron - pnictides.

We also report the complex dielectric function of a Rb2Fe4Se5 superconductor with Tc = 32 K [3] which displays a clear metallic response in the THz spectral range below 100 K with w_pl = 100 meV, which is partially suppressed in the superconducting state. Such a small charge carrier density suggests that the optical conductivity of Rb2Fe4Se5 represents an effective-medium response of two separate phases dominated by the magnetic semiconducting phase. Our recent results on apertureless near-field infrared microscopy indicate that the phases segregate on the nanoscale out of plane, reminiscent of a quasiregular heterostructure.

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P2-83 Thermal Conductivity of the Iron-Based Superconductor FeSe_{1-x}_Te_{x}_ - ***M. Ohno, T. Kawamata, T. Noji, M. Imaizumi, K. Naruse, T. Adachi, Y. Koike (Department of Applied Physics, Graduate School of Engineering, Tohoku University), T. Nishizaki, N. Kobayashi (Institute for Materials Research, Tohoku University)***

The iron-based superconductor $FeSe_{1-x}Te_x$, which has the simplest structure among all iron-based superconductors, is an ideal compound to investigate the origin of the superconductivity. We have found that the x range of $FeSe_{1-x}Te_x$ single crystals where bulk superconductivity appears is expanded by the vacuum-annealing [1], indicating that the superconductivity in $FeSe_{1-}$

$_x$Te$_x$ is strongly affected by the lattice distortion and by the homogeneity of the distribution of Se and Te atoms. The thermal conductivity is a suitable probe for detecting disorder of a long-range ordered state, because heat carriers are scattered by the disorder. Therefore, we have measured the thermal conductivity in the *ab*-plane, κ_{ab}, of as-grown and vacuum-annealed single crystals of $FeSe_{1-x}Te_x$ (x = 0.7, 1.0) in order to investigate the vacuum-annealing effects. It has been found that κ_{ab} of x = 1.0 decreases monotonically with decreasing temperature and exhibits a jump at ~60 K where both SDW and structural phase transitions occur, while κ_{ab} of x = 0.7 only decreases monotonically with decreasing temperature. Values of κ_{ab} slightly increase by the vacuum-annealing in both x = 0.7 and 1.0. The increase of κ_{ab} in x = 1.0 is guessed to be due to the removal of lattice distortions introduced during the crystal-growth process by the vacuum-annealing. In the case of x = 0.7, on the other hand, κ_{ab} increases by the homogenization of the distribution of Se and Te atoms in addition to the above effect. However, the slight increase of κ_{ab} by the vacuum-annealing implies that there remain disorders even after the vacuum-annealing. The disorders may be due to excess irons in x = 1.0 and due to the difference between the Se height and the Te height from the Fe plane, observed in EXAFS [2], in x = 0.7.

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P2-84 Impurity Effects on the Superconductivity in FeSe_{1-x}_Te_{x}_ - ***T. Inabe, T. Noji, M. Imaizumi, T. Kawamata, Y. Koike (Department of Applied Physics, Tohoku University)***

In iron-based superconductors, the symmetry of the superconducting order parameter related to the pairing mechanism is controversial. In the case that the sign of the order parameter in each Fermi surface is different from each other, Cooper pairs are broken by potential scattering so that the superconducting transition temperature, T_c, is markedly suppressed by impurity-doping. Therefore, we have investigated the T_c suppression through the substitution of M (M = Mn, Co, Ni, Cu, Zn, Ru) for Fe in $Fe_{1-y}M_ySe_{1-x}Te_x$ single crystals of good quality, which were grown using the Bridgman method and annealed in vacuum at 400 C for 200 h [1]. It has been found that T_c decreases nearly linearly with increasing y and that the residual resistivity in the normal state increases with increasing y. However, the rate of the T_c suppression with increasing residual resistivity is smaller than that calculated based on the Abrikosov-Gor'kov theory taking into account the pair-breaking due to potential scattering. Accordingly, it is concluded that the symmetry of the superconducting order parameter in $FeSe_{1-x}Te_x$ is S_{++} where the sign in each Fermi surface is the same.

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P2-85 Hydrogen-doped 1111-type Iron-pnictide Superconductors - ***H. Hosono, S. Iimura, T. Hanna, S. Matsuishi (Tokyo Institute of Technology)***

Iron pnictide superconductor was first discovered by electron-doping to Ln-1111 type compounds using partial substitution of the O^{2-} sites with F^- ion. However, since the upper doping level by this method is restricted to 10-15%, the phase diagram reported to date is insufficient for the Ln-1111 materials with the higher Tc as exemplified by no realization of the over-doped region. This situation originates from the low solubility of F^- into the O^{2-} sites. We found a more effective electron-doping method to overcome this difficulty, H^- doping in to the O^{2-} sites in place of F^-.

The bulk polycrystalline samples of $LnFeAsO_{1-x}H_x$ (Ln: lanthanide) were obtained up to x~0.5 utilizing high pressure synthesis. The chemical composition of the resulting phases by EPMA(for O) and TG-MAS (for H) and Rietvelt analysis of the powder neutron diffraction and synchrotron x-ray diffraction data on LnFeAsΘ1 x(D,H)x revealed that H substitutes the O-sites without the formation of noticeable amount of oxygen vacancy. It was concluded from DFT calculations and comparison with the superconducting dome of the fluorine-substituted systems that the charge state of the hydrogen substituting the oxygen sites was −1.

Bulk superconductivity was observed over a wide x range (0.1<x <~0.5) and the superconducting dome had a rather flat shape with a maximum *T*c = 47 K at x~0.25 for the Ce system or Tc=56K at x~0.37 for the Sm-system. It is worth noting that the optimal Tc remains almost unchanged over a wide x range (0.2-0.4) for both systems. Since the hole pocket athe zone center almost vanishes for 0.3< x, the Fermi surface nesting appears not to be the mechanism controlling superconductivity in the 1111 compounds with higher Tc.

P2-86 Microstructural analysis of the structural transition in 1111 oxy-pnictides and a new phase diagram for the SmFeAs(O1-xFx) system - ***a. Martinelli (SPIN-CNR, corso Perrone 24, 16152 Genova), A. Palenzona (Dept. of Chemistry and Industrial Chemistry, University of Genoa, via Dodecaneso 31, 16146 Genova), M. Putti (Dept. of Physics, University of Genoa, via Dodecaneso 33, 16146 Genova), C. Ferdeghini (SPIN-CNR, corso Perrone 24, 16152 Genova)***

The microstructural evolution throughout the first order tetragonal to orthorhombic structural transition was analyzed for two different systems belonging to the class of compounds referred to as 1111 oxy-pnictides: $(La_{1-y}Y_y)FeAsO$ and $SmFeAs(O_{1-x}F_x)$. Both systems are characterized by a similar behaviour: on cooling microstructural strain along the tetragonal *hh*0 direction takes place and increases as the temperature is decreased. Just above the structural transition strain reaches its maximum value and then is abruptly suppressed by symmetry breaking. No volume discontinuity throughout the transition is observed and a group-subgroup relationship holds between the tetragonal and the orthorhombic structures, thus suggesting that orbital ordering drives symmetry breaking. Microstrain reflects a distribution of lattice parameters in the tetragonal phase, explains the occurrence of anisotropic properties commonly attributed to nematic correlations and suggests the occurrence of a nematic orbital ordering.

In the $SmFeAs(O_{1-x}F_x)$ system the structural transition is slightly affected by F content and is retained for the superconducting samples, even at optimal doping. As a consequence a new phase diagram for this system has been drawn [1].

These findings relate the AFM transition on a different ground with respect to the structural one and suggests that orbital ordering could be the driving force for symmetry breaking.

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P2-87 Effect of nonmagnetic Zn impurity and its implication for pairing symmetry in iron-based arsenide superconductors - *Z. Xu, Y. Li, X. Lin, Q. Tao, G. Cao (Zhejiang University)*

It is well known that superconductivity with an s-wave pairing symmetry is robust to nonmagnetic impurity while significant pair breaking effect of nonmagnetic impurity has been observed in d-wave pairing cuprates and also proposed in s± wave pairing iron-based pnictides. Thus the study of the effect of nonmagnetic Zn impurity in iron-based arsenides can provide insights on the pairing symmetry. The partial substitution of Fe by Zn can suppress SDW order in the 1111 type parent compound LaFeAsO, but it does not affect superconductivity in the optimally doped LaFeAsO0.9F0.1. Further experiments revealed that the effect of Zn impurity on Tc also dependent on the F doping level. In the underdoped LaFeAsO0.95F0.05, Tc is even enhanced as Zn impurity is doped, meanwhile Tc drops severely with increasing Zn content in the overdoped LaFeAsO0.85F0.15. Our results indicated that the pairing symmetry may not be universal, i.e, it may change with the doping level as well as the electronic structure. Moreover, Zn impurity always causes severe pairing-breaking in the Co-doped LaFe1-xCoxAsO despite of the Co doping level. The results may be understood in a two-component superconducting model.

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P2-88 Sb doping effect in BaFe2-xCoxAs2 system - *C. Shen, Z. Xu, X. Yang, H. Zhai, G. Cao (Department of Physics, Zhejiang University)*

For both 1111 type and 122 type FeAs-based pnictides, superconductivity can be induced by P doping at As site due to the so-called chemical pressure effect. The mechanism of pressure induced superconductivity in pnictides is still under debate. The measurements of ARPES found that P doing can induce holes in the system. For comparison, we investigated the negative chemical pressure effect of Sb doping on the As site. We synthesized a series of Sb doped BaFe2-xCoxAs2 single crystals by self-flux method with the Co concentration in the range from underdoped to overdoped while Sb content is about 2%. We studied the physical properties of this system through XRD, resistivity measurements, thermal power and Hall Effect. The effect of Sb doping on superconductivity is discussed.

P2-89 Self-organized nanoscale quasi-heterostructurein an antiferromagnetic superconductor - *A. Charnukha, D. Proepper, B. Keimer, A. Boris (Max Planck Institute for Solid-State Research), A. Cvitkovic, N. Ocelic (NeaSpec GmbH), T. Prokscha, A. Suter, Z. Salman, E. Morenzoni (Paul Scherrer Institut), J. Deisenhofer, V. Tsurkan, A. Loidl (University Augsburg)*

The recent discovery of intercalated iron-selenide superconductors has stirred up the condensed-matter community accustomed to the proximity of the superconducting and magnetic phases in various cuprate and pnictide superconductors. Never before has a superconducting state with a transition temperature as high as 30 K been found to coexist with such exceptionally strong antiferromagnetism with Neel temperatures up to 550 K as in this new family of iron-selenide materials. Significant experimental evidence suggests, however, that the superconducting and antiferromagnetic phases are spatially separated. All the experimental effort notwithstanding, the microscopic scale of the phase separation and the domain order with a possible coupling between the phase order parameters remain unclear. Here we use a unique combination of scattering-type scanning near-field optical microscopy (s-SNOM) and low-energy muon spin rotation (LE-mSR) to shed light on microscopic character of the phase separation in superconducting Rb2Fe4Se5 (RFS) single crystals. We demonstrate that the phases segregate on the nanoscale out of plane, reminiscent of a quasiregular heterostructure, while the characteristic size of the paramagnetic domains in plane reaches 10 mm. By means of LE-mSR we further show that the antiferromagnetic semiconducting phase is strongly weakened near the sample surface. Self-organization in a chemically homogeneous structure indicates an intimate connection between the modulated superconducting and antiferromagnetic phases.

P2-90 Fe Vacancy Disorder Induced Recovery of Fermi Surface of KxFe2-ySe2 - *T. Berlijn, W. Ku (Brookhaven National Laboratory), P. Hirschfeld (University of Florida)*

One of the many remarkable features of the newly discovered ternary iron selenide superconductors is the presence of Fe vacancies and their ordering. Several ordering patterns have been observed by various experimental probes. However, if such orderings were to be strong and long ranged in nature it would inevitably induce a heavy reconstruction of the Fermi surface which does not agree with ARPES measurements and furthermore makes it hard to understand the superconductivity theoretically. To resolve this issue we perform first-principles calculations of the configuration-averaged spectral function [1] of KFe2Se2 with disordered K and Fe vacancies, from which we recover a Fermi surface with large well-defined pockets in better agreement with the ARPES results.

[1] T. Berlijn, D. Volja and W. Ku, Phys. Rev. Lett. 106, 077005 (2011) Work supported by DOE DE-AC02-98CH10886 and DOE CMCSN

P2-91 LATTICE EFFECTS ACROSS THE PHASE DIAGRAM IN PNICTIDES - ***E. LIAROKAPIS (Department of Physics, National Technical University of Athens, Athens 15780, Greece), M. CALAMIOTOU (2Department of Physics, University of Athens, Athens, Greece), N. ZHIGADLO, S. KATRYSH, J. KARPINSKI (Laboratory for Solid State Physics, ETH Zurich, 8093 Zurich, Switzerland)***

We have carried out systematic low temperature and hydrostatic pressure Raman and synchrotron structural XRD measurements on various pnictides in order to delineate the effect of lattice distortions on these compounds and their relation to superconductivity. In particular, we have chosen to study the 1111 series of iron-based pnictides, such as $RFeAsO_{1-x}F_x$, R=Sm, Nd with doping levels ranging from the non-superconducting state to the optimally doped one with maximum T_c. Hydrostatic pressure has been used to induce superconductivity in the low doping case or reduce T_c in the optimally doped systems. We have employed micro-Raman spectroscopy to measure the change of phonon modes at the superconducting transition and the antiferromagnetic ordering and study their evolution with doping and pressure. The relative variation of the bond lengths has been obtained from the analysis of synchrotron XRD spectra on powder samples. The results are compared with the relative studies on the cuprates, which have a very similar phase diagram with the pnictides with antiferromagnetic ordering at low doping and superconductivity in a range of doping level. The effect of the lattice distortions on superconductivity is examined in a large region of the phase diagram of these high T_c compounds providing some hint about the role of lattice to the unconventional superconductivity across the phase diagram.

P2-92 Thermodynamic Properties of Superconducting FeCrxSe Single Crystal - ***A. Yadav, C. Tomy (Indian Institute of Technology Bombay), A. Thakur (Indian Institute of Technology, Patna)***

Iron chalcogenide α-FeSe crystallizes in the hexagonal NiAs type crystal structure with *$P6_3/mmc$* space group, and is non-superconducting. A slight excess of Fe stabilizes the superconducting tetragonal phase β-$Fe_{1+x}Se$ (PbO type; space group *P4/nmm*) with a superconducting transition temperature (T_c) of ~8.5 K [1]. We have reported earlier the enhancement of T_c by the substitution of Cr instead of excess iron in polycrystalline $FeCr_xSe$ samples [2]. Here we report the detailed superconducting and transport properties in a single crystal of $FeCr_{0.02}Se$. The single crystal was synthesized by the self flux method followed by quenching in liquid N_2.The XRD and EDAX were performed to confirm the structure and elemental analysis. The crystals were found to be oriented along the (l01) direction of the tetragonal PbO type structure. The dc and ac magnetization studies show T_c ~10.5 K. Critical current density (J_c), calculated from the M-H loops for applied magnetic fields parallel and perpendicular to the (101) direction, was found to be weakly anisotropic which was further confirmed from the electrical transport measurements. Thermopower measurements show a pseudo gap at T_{PG} ~ 65 K. As the temperature is decreased, the Seebeck coefficient changes from positive to negative below ~190K, reaches a minimum (-30muV/K) and then increases to positive values as the temperature is further decreased, before falling to zero at the superconducting transition. The change in sign of the Seebeck coefficient indicates the presence of both types of charge carriers in the crystal, which is also corroborated via Hall effect measurements.

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P2-93 MuSR studies of superfluid density in the overdoped side of FeAs superconductors. - ***C. Arguello (Physics Department, Columbia University), T. Munsie, T. Williams, G. Luke (Department of Physics and Astronomy, McMaster University), K. Hemmi, T. Kobayashi, S. Miyasaka, S. Tajima (Department of Physics, Osaka University), H. Luo, S. Carr, P. Dai (Department of Physics, University of Tennessee), C. Jin (Institute of Physics, Chinese Academy of Science), J. Carlo, T. Goko, R. Fernandes, F. Ning, L. Liu, R. Chen, W. Chung, Y. Uemura (Physics Department, Columbia University)***

The superfluid density (n_s/m^*) of several overdoped (OD) cuprates, measured using MuSR (Muon Spin Relaxation), has been known to decrease with increasing doping concentration beyond optimal doping [1,2], with Tc decreasing as well. A coexistence / phase separation of normal and superconducting carriers in the OD region been proposed to explain this behavior [1]. In order to compare the effect of "overdoping" or "pressurizing" in cuprates and pnictide systems, we performed MuSR measurements of the superfluid density in Li1.1FeAs, Li0.9FeP, NdFe(PxAs1-x)(O0.9F0.1), NdOFeAs [3], LaOFeAs [3], LaOFeP [4] and KFe2As2. In all these cases, the superfluid density of the "overdoped / pressurized" systems has been comparable to or larger than those observed in the optimally-doped region with highest Tc in a given series. This behavior is in contrast to the tendency found for the electron doped 122-FeAs systems Ba(Fe1-xCox)2As2 and Sr(Fe1-xCox)2As2 [5] and in the ovedoped cuprates. We will present a summary of these results in FeAs systems, and discuss possible origin of the different responses of superfluid density on overdoping / pressurizing.

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P2-94 Interactions of magnetism and superconductivity in substituted EuFe2As2 single crystals - ***Z. Bukowski, V. Tran, A. Zaleski (Institute of Low Temperature and Structure Research, Polish Academy of Sciences, P. O. Box 1410, 50-422 Wroclaw, Poland), L. Tran (Institute of Low Temperature and Structure Research, Polish Academy of Sciences, P. O. Box, 50-422 Wroclaw, Poland)***

The iron-pnictide EuFe2As2 is a suitable object to study the interplay between superconductivity and magnetism. The strategy of our investigations was to suppress the SDW order of the iron sublattice and induce superconductivity by proper substitution of Fe with Co or Ir while Ca or La substitution for Eu was applied in order to tune magnetic ordering temperature of Eu and as a possible source of charge doping. Single crystals of doped EuFe2As2 were grown using Sn flux. The crystal structure was studied at room temperature using X-ray diffraction, and the low-temperature physical properties were determined by means of ac-magnetic susceptibility, magnetization, electrical transport, and heat capacity measurements down to 1.9 K and in magnetic fields up to 9 T.

We have found superconductivity in EuFe2-xCoxAs2 with zero-resistivity below Tc~5 K coexisting with a canted antiferromagnetic (C-AF) ordering of the Eu-sublattice. When the external magnetic field is applied perpendicular or parallel to the crystallographic c-axis, CAF ordering evolves towards field induced ferromagnetism (FI-F) and interesting, unconventional features are observed in this system. Particularly, in EuFe1.62Co0.38As2 single crystals when magnetic field is applied perpendicular to the c-axis, we have revealed a rare example of the field induced superconductivity (FI-SC). Based on the experimental data, the magnetic field-temperature phase diagrams are constructed for both field orientations. The fundamental parameters of the superconducting state, such as, the upper critical field, Hc2, coherence length, and penetration depth (lambda) are estimated.

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P2-95 Low-energy 3D-ARPES study on Li1+xFeAs - *T. Hajiri (Graduate School of Engineering, Nagoya University), B. Min, Y. Kwon (Department of Physics, Sungkyunkwan University), T. Ito, R. Niwa, S. Hirate (Graduate School of Engineering, Nagoya University), M. Matsunami, S. Kimura (UVSOR Facility, Institute for Molecular Science)*

An iron-based superconductor LiFeAs has attracted much attention because of its superconductivity (T_C = 18 K) without involving any structural phase and SDW/AFM transitions [1]. In pristine LiFeAs, we have demonstrated that the electronic structure can be fundamentally explained by LDA band structure calculation [2]. In this system, the excess or deficiency of Li-ions from the stoichiometry suppresses the superconductivity [3] and enlarges spin fluctuation [4]. To elucidate the effect of the Li excess or deficiency, we investigated the electronic structure of non-superconducting $Li_{1+x}FeAs$ by a polarization-dependent three-dimensional angle-resolved photoemission spectroscopy (3D-ARPES). As a result, we have clarified the difference in the low-energy electronic structure between pristine LiFeAs and $Li_{1+x}FeAs$. Furthermore, two kink features in the band dispersions have been identified near the center of the Brillouin zone, one located at about 20 meV originates from phonons, the other located at about 100 meV cannot be explained by phonons. The higher-energy kink may be related to magnetic excitations.

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P2-96 Study of Impurity physics in pnictide superconductors using a five orbital mean-field model - *S. Mukherjee, M. Navarro Gastiasoro, B. Andersen (Niels Bohr Institute, University of Copenhagen)*

A study of pnictide superconductors using a more general theory that includes effects of all five d- orbitals and additional correlation effects beyond the onsite Coulomb repulsion can lead to important differences in the electronic structure and superconducting properties compared to simplifying two orbital models. In this work we report the results of a Bogoliubov de-Gennes study of the full five-band Hamiltonian including all general Coulomb interaction terms relevant for the pnictides at the mean-field level. We investigate the effects on the local density of states from the detailed structure of the pairing kernel with the spin-fluctuation mediated superconductivity. We also study the local electronic structure and competing order effects near disorder sites, and address the role of ordered and disordered vacancies in the ternary iron selenides.

P2-97 Optical properties of BaFe2(As1-xPx)2 - *M. Nakajima (University of Tokyo), K. Kihou, C. Lee, A. Iyo, H. Eisaki (National Institute of Advanced Industrial Science and Technology), T. Tanaka, S. Ishida, T. Kakeshita, S. Uchida (University of Tokyo)*

The parent compound of iron-based superconductors, $BaFe_2As_2$, shows a magnetostructural ordered phase. Various elemental substitutions suppress this phase, and superconductivity emerges. Replacement of As for P, corresponding to an isovalent substitution, also suppresses the magnetostructural phase and induces superconductivity [1]. Interestingly, this substitution dramatically decreases the resistivity at high temperatures.

To investigate how the electronic structure evolves with P substitution, We studied in-plane optical properties of $BaFe_2(As_{1-x}P_x)_2$ for various P contents at room temperature. For x=0, the optical conductivity spectrum in the low-energy region can be decomposed into a narrow (coherent) and a broad (incoherent) Drude component [2]. The dc conductivity is dominated by the incoherent term. With increasing x, the narrow Drude component increases its weight, resulting in the increase in the dc conductivity, but the broad one does not change its weight so much. Consequently, the coherent Drude component becomes dominant to the dc conductivity, consistent with the decrease in the high-temperature resistivity. The integral of the conductivity merges at ~ 6000 cm^{-1}, indicating that P substitution surely works as the isovalent replacement without changing the carrier density. The main role of P substitution is to control the number of the coherent carriers.

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P2-98 Magnetic Granularity in Iron Based Superconductors: A Scanning Micro-Hall Probe Study - ***M. Eisterer, T. Baumgartner, J. Hecher, V. Mishev, W. Seeböck, H. Weber (Atominstitut, Vienna University of Technology, 1020 Vienna), K. Iida, F. Kurth, J. Hänisch, B. Holzapfel (Institute for Metallic Materials, IFW Dresden, D-01171 Dresden), A. Sala, A. Palenzona, M. Putti (University of Genova and CNR-SPIN, via Dodecaneso 33, 16146 Genova)***

Magnetic granularity results from a suppression of the intergranular currents with respect to the intragranular currents. It has severe consequences for the applicability of materials, because the capability of a material to transport loss free currents is reduced in this way. Intragranular currents can be tuned by optimizing the pinning strength; the limitation of the currents across grain boundaries can either be extrinsic as in magnesium diboride or intrinsic as in the cuprates, thus demanding different approaches for overcoming the suppression. The corresponding mechanism in the iron based superconductors is currently under debate. We report results of scanning micro-Hall probe measurements on different iron based compounds in order to clarify the actual limitations for the current flow in sintered bulk samples as well as in textured tapes. The local currents can be assessed at different fields and temperatures by this technique.

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P2-99 Magnetic penetration depth and flux flow resistivity of SrFe2(As,P)2 single crystals - ***Y. Imai, H. Takahashi, T. Okada, A. Maeda (Department of Basic Sciences, the University of Tokyo), K. Kitagawa, K. Matsubayashi, M. Takigawa, Y. Uwatoko (Institute for Solid State Physics, the University of Tokyo)***

Symmetry of the superconducting order parameter intimately related to the pairing interaction is an important problem for iron-based superconductors. While nodeless s±-wave symmetry mediated by antiferromagnetic spin fluctuation [1-4] has been considered to be a very likely candidate, other symmetries are also suggested in several compounds. It was reported that LaFePO [5] and $BaFe_2(As,P)_2$ [6] have line nodes in their superconducting gap function. Since the presence of the node in P substituted systems has been discussed in terms of the spin related mechanism, it is essentially important to check whether or not the presence of line nodes is common among P substituted systems. Thus, we measured the microwave surface impedances of superconducting $SrFe_2(As,P)_2$ single crystals (T_c~25K).

The imaginary part of surface impedance, which is proportional to the London penetration depth in the superconducting state, shows a power law with an exponent slightly smaller than 2. The power law indicates the presence of the low-energy quasiparticle excitation, and an exponent slightly smaller than 2 does not exclude the possibility of the existence of line nodes. We rather argue that this is a characteristic feature of the multiband systems with line nodes. Subsequently, we performed microwave surface impedance measurements under finite magnetic fields up to 8 Tesla. We will discuss the magnetic field dependence of flux flow resistivity in terms of the superconducting gap anisotropy and vortex dynamics.

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P2-100 Similarity and dispersion of the spin-wave gap in the NaFeAs and BaFe2As2 iron-pnictide parent compounds - ***G. Friemel (Max-Planck-Institut for Solid State Research), B. Min, Y. Kwon (Department of Physics, Sungkyunkwan University), A. Ivanov (Institut Laue-Langevin), V. Hinkov, B. Keimer (Max-Planck Institut for Solid State Research), J. Park, T. Loew, Y. Li, D. Inosov (Max-Planck-Institut for Solid State Research), D. Sun, C. Lin (Max-Planck-Institut of Solid State Research)***

We present a study of the spin wave excitation spectrum by inelastic neutron scattering in the iron pnictide parent compounds NaFeAs and BaFe_2As_2. We found that despite the different magnetic ordering temperature T_N and size of the magnetic moment [1,2], the anisotropy gap in the spectrum at the ordering wave vector Q_AFM is nearly equal, being approximately 12 meV for both compounds. Furthermore, we observed a sharp opening of the anisotropy gap below T_N, consistent with an order parameter-like behaviour. In the case of NaFeAs, we do not observe a precursor gap between structural and magnetic phase transition. Gapless paramagnetic excitations are observed immidiately above T_N. We also measured the dispersion of the spin wave gap vs. the out-of-plane-component q_z, which is of the order of 20 meV for the in-plane excitations (q_z=0). This is smaller than the previously estimated gap, that was derived from the fitting of the global spin wave dispersion with Heisenberg-type model [3], and can be explained with a smaller effective out-of-plane exchange interaction J_c.

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P2-101 Theory of quasiparticle vortex bound states in iron-based superconductors: Application to scanning tunneling spectroscopy of LiFeAs - ***Y. Wang (Department of Physics, University of Florida), I. Vekhter (Department of Physics and Astronomy, Louisiana State University), P. Hirschfeld (Department of Physics, University of Florida)***

The spectroscopy of vortex bound states can provide valuable information on the structure of the superconducting order parameter. Quasiparticle wave functions are expected to leak out in the directions of gap minima or nodes, if they exist, and scanning tunneling spectroscopy (STS) on these low-energy states should probe the momentum dependence of the gap. Anisotropy can also arise from band-structure effects, however. We perform a quasiclassical calculation of the density of states of a single vortex in an anisotropic superconductor, and show that if the gap itself is not highly anisotropic, the Fermi-surface anisotropy can dominate, preventing

direct observation of superconducting gap features. This serves as a cautionary message for the analysis of STS data on the vortex state on Fe-based superconductors, in particular, LiFeAs. For this case we also discuss possible rotations of the STS patterns with bias voltage. YW and PJH were supported by the DOE under DE-FG02-05ER46236, and I. V. under DE-FG02-08ER46492.
Phys. Rev. B 85, 020506(R)

P2-102 Evidence for a Josephson phase in the optical conductivity of the iron-selenide K0.8Fe2-ySe2 - *C. Homes, Z. Xu, J. Wen, G. Gu (Brookhaven National Laboratory)*

The reflectance of a cleaved single crystal of the iron-selenide superconductor $K_{0.8}Fe_{2-y}Se_2$ has been measured over a wide frequency range for light polarized in the *a-b* planes for a number of temperatures above and below the critical temperature T_c=31 K. The complex optical properties have been determined from a Kramers-Kronig analysis of the reflectance [1]. In the normal state, the conductivity is observed to be a flat and incoherent; however, just above T_c a coherent Drude-like response is observed. The highly-anisotropic nature of this material suggests that the transport should be described in terms of the sheet resistance $R_s=\rho_{dc}/d$, where ρ_{dc} is the dc resistivity and d is the separation between the Fe-Se sheets. The calculated sheet resistance $R_{s\square}$=320 kΩ just above T_c is well above the threshold for the superconductor-insulator transition at $R_s=h/4e^2\cong 6.9$ kΩ, suggesting that this material is not homogeneous. Below T_c the calculated superconducting plasma frequency of $\omega_{p,S}\cong 220\pm 20$ cm^{-1}, and the resulting superfluid density $\rho_{s0}\equiv(\omega_{p,S})^2$, are much smaller than what is observed in other iron-arsenic and iron-chalcogenide superconductors [2,3]. It has been pointed out that the iron-based superconductors fall on the general scaling relation observed in the cuprate superconductors [4]. Surprisingly $K_{0.8}Fe_{2-y}Se_2$ also falls on the scaling line; however, it does so in a region typically associated with Josephson coupling along the poorly-conducting *c* axis in the cuprates, suggesting that this material is inhomogeneous and that the superconductivity is due to Josephson coupling.
Supported by the U. S. DOE, Office of Basic Energy Sciences, under Contract No. DE-AC02-98CH10886.
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P2-103 Specific heat and magnetic penetration depth in the presence of Spin-Density-Wave in Iron-based superconductors - *M. Vavilov, D. Kuzmanovski, A. Chubukov (University of Wisconsin)*

Experiments reveal that in iron-based superconductors the jump of the specific heat at the superconducting transition is not proportional to the transition temperature, as expected within the BCS theory. Rather, the ratio of the jump of the specific heat to the transition temperature peaks near optimal doping and decreases at smaller and larger dopings [1,2]. Measurements of the magnetic penetration depth show that the penetration depth is minimal at the optimal doping [3]. We demonstrate that such non-monotonic behavior of the specific heat and the magnetic penetration depth on doping is a manifestation of the interplay between superconductivity and antiferromagnetism in the underdoped regime. We show that doping favors the superconducting state, either by breaking nesting between the Fermi surfaces or by increasing the strength of disorder, and drives the system from a Spin-Density wave phase to a superconducting phase through a mixed phase where the superconductivity and the antiferromagnetism coexist.
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P2-104 Novel Insulating Antiferromagnetism in Vacancy-Ordered K0.8Fe1.6Se2 Explained in the Unified Picture - *W. Yin, C. Lin, W. Ku (Condensed Matter Physics and Materials Science Department, Brookhaven National Laboratory, Upton, New York 11973, USA)*

We present a theoretical study of the novel insulating block checkerboard antiferromagnetism in vacancy-ordered $K_{0.8}Fe_{1.6}Se_2$, a parent compound of the $A_yFe_{2-x}Se_2$ family of iron-based superconductors (FeSCs). Our first-principles electronic structure analysis reveals its incompatibility with either the itinerant-electron model or the Mott insulator scenario. Instead, the spin-fermion model with coexisting itinerant and localized electronic states is found capable of unifying this insulating spin order with the metallic collinear and bicollinear spin orders observed in the parent compounds of vacancy-free FeSCs. We show that this magnetic diversity is driven by balancing three effects: (i) orbital degeneracy and anisotropy of the itinerant electrons, (ii) double-exchange ferromagnetism originating from Hund's rule coupling J_H between the itinerant electrons and the localized spins, and (iii) superexchange antiferromagnetism between the localized spins. We demonstrate that the three blocking mechanisms from J_H, orbital anisotropy, and vacancies work together to make $K_{0.8}Fe_{1.6}Se_2$such an insulator whose gap size is sensitive to the magnetic structure rather than local Coulomb interaction U, in sharp contrast with the Mott insulator. This renders $K_{0.8}Fe_{1.6}Se_2$ a novel Hund insulator. There results manifest that J_H is key to understand how electrons come to be correlated in FeSCs.
This work was supported by the U.S. Department of Energy (DOE), Office of Basic Energy Science, under Contract No. DE-AC02-98CH10886.
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P2-105 KFe2As2: Coexistence of Unconventional Superconductivity with Spin-Glass Phases - ***S. Drechsler, V. Grinenko, M. Abdel-Hafiez, S. Aswartham, S. Wurmehl, A. Wolter-Giraud, K. Nenkov, G. Fuchs, S. Johnston, C. Hess, B. Holzapfel, J. van den Brink, B. Buechner (IFW-Dresden), H. Rosner (MPI-CPFS Dresden), L. Boeri (MPI-FKF Stuttgart)***

High quality KFe_2As_2 (K122) single crystals have been studied by transport, magnetization and low-T specific heat measurements. The analysis of this data shows that unconventional superconductivity coexists with disordered magnetic phases (Griffith or spin-glass) which cause the observed non-Fermi liquid behavior in the low-T resistivity and contribute to the large phenomenological Sommerfeld coefficient in the electronic specific heat $gamma_{el}$ = 92 mJ / mol K^2. As a consequence the intrinsic itinerant $gamma_{el}$ = 56(9) mJ / mol K^2 is significantly reduced compared to the former value which leads to an enhanced jump of the specific heat Delta gamma_n/Tc of about 0.9 generic for *d*-wave or *p*-wave superconductivity and a *weak* total electron-boson coupling constant lambda less than 1 in accord with an Eliashberg analysis including also the penetration depth. The empirical value of the total electron-boson coupling constant as derived from normal state specific heat data exhibits only moderate changes in less strongly hole doped members in the 122-family, including also the optimally doped high-Tc systems which yields a strong constraint for the superconducting mechanism. Thereby a high-energy mass renormalization due to Coulomb and/or Hund's rule coupling of about 2.7 has to be taken into account. The Sommerfeld coefficient of the spin-glass phases in K122 is reduced by a factor of 2 in the superconducting state. Various possibilities for the microscopic origin of the spin-glass phases and available data for the sister compound RbFe2As2 are briefly discussed. The measured anisotropy of the upper critical field Hc2 near Tc of about five slightly exceeds the mass anisotropy of about 4.2 as derived from from LDA electronic structure calculations.

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P2-106 Hydrostatic High-pressure Measurements of the Superconducting Transition of Single-crystalline and Polycrystalline LnFePO (Ln = La, Pr, Nd) - ***N. Foroozani (Dept. of Physics, Washington University), J. Hamlin, R. Baumbach, I. Lum, D. Zocco, M. Maple (Dept. of Physics and Institute for Pure and Applied Physical Sciences, Univ. of California, San Diego), N. Hillier, J. Schilling (Dept. of Physics, Washington University)***

Since their discovery several years ago, the iron-based superconductors have attracted considerable attention. However, due to their slightly lower superconducting transition temperatures, the LnFePO (Ln = La, Pr, Nd, Sm, Gd) superconductors have not been studied quite as extensively. Earlier high pressure measurements by Hamlin *et al*. [1] and Takahashi *et a*l. [2] on LaFePO show that Tc initially increases with pressure before passing though a maximum and decreasing at higher pressures. To further understand this class of superconductors, ac susceptibility measurements were carried out on LnFePO (Ln = La, Pr, Nd) single crystals in a hydrostatic (He-gas) high pressure system to 0.8 GPa. Surprisingly, for all samples Tc initially decreases with pressure at a rate of approximately -2 to -3 K/GPa. This decrease is in stark contrast to the initial increase in Tc seen in the earlier measurements [1,2]. Further resistivity measurements on both single-crystalline and polycrystalline LaFePO show a similar decrease in Tc with He-gas pressure, indicating that the factors determining the pressure dependence of Tc are much more complicated than initially thought. A comparison of results of high pressure studies for both single-crystalline and polycrystalline LnFePO compounds in varying pressure media will be presented. The pressure dependence of Tc may depend sensitively on the degree of strain in the sample.

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High-pressure work at Washington University is supported by the NSF, and crystal growth at the University of California, San Diego is supported by the DOE.

P2-107 Annealing Effects on Fe(Te1-xSex) Single Crystals - ***Y. Sun, T. Taen, T. Prombood, Y. Tsuchiya, Y. Nakajima, T. Tamegai (Department of Applied Physics, The University of Tokyo)***

Annealing effects on $Fe(Te_{1-x}Se_x)$ single crystals are carefully studied by annealing under different conditions: vacuumed quartz tube or niobium tube, oxygen or Argon atmosphere, and pumping gas while annealing. By comparing the chemical inhomogeneities and superconducting properties before and after annealing, we find out that annealing with oxygen is the best. Then we quantitatively studied the relationship between transition temperature, T_c, and the amount of oxygen during annealing, which shows T_c first gradually increases with the amount of oxygen, after reaching the maximum value, then decreases with the oxygen content. Our results directly prove the effect of oxygen in annealing the $Fe(Te_{1-x}Se_x)$ single crystals. The introduced oxygen seems suppress harmful effects of excess Fe in the single crystal that is benefit to superconductivity, while too much oxygen damages the sample. Superconducting volume, as well as the critical current density also follows the same trend as T_c. Besides, some transport and magnetic properties before and after annealing are also compared and discussed in detail.

P2-108 Transport, magnetic and thermal properties of PrFeAsO oxypnictides - ***P. Mandal (Saha Institute of Nuclear Physics, 1/AF-Bidhannagar, Calcutta, 700 064), P. Choudhury (Centrl Glass and Ceramic Research Institute, Calcutta, 700 032), D. Bhoi (Saha Institute of Nuclear Physics, 1/AF-Bidhannagar, Calcutta, 700 064), V. Ganesan (UGC-DAE-CSR, University Campus, Khandwa Road 452 017, Indore), S. Pandya (UGC-DAE-CSR, University Campus, Khandwa Road, Indore, 452 017)***

We have studied the temperature dependence of resistivity (ρ), Hall coefficient (R_H), dc magnetization (M) and specific heat (C) of the nonsuperconducting PrFeAsO compound. Anomalies are clearly reflected at the structural transitions (T_S), AFM magnetic ordering of Fe (T_N) and Pr sub-lattices (TNPr) in the temperature dependence of resistivity, Hall coefficient, magnetization and specific heat data. Our study also shows a hitherto unobserved anomaly at T_{SR} in the resistivity and specific heat data which arises as a result of the interplay of antiferromagnetic (AFM) Pr and Fe sublattices [1]. The magnetic field does not affect the T_S and T_N. However, the resistivity, specific heat and magnetic transitions at low temperatures are significantly affected. We also observed an unusual *H* dependence of transverse magnetoresistance (MR). Below, the spin density wave transition MR is large, positive and increases with decreasing temperature. At low temperatures, MR increases linearly with *H* up to 14 T. For $T \leq 40$ K, MR vs *H* curve develops a weak curvature in the low-field region which indicates a crossover from *H* linear to H^2 dependence as $H \rightarrow 0$ [2]. The novel *H* linear MR originates from the Dirac cone states and has been explained by the quantum mechanical model proposed by Abrikosov [2,3].

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P2-109 Vortex Phase Diagram of PrFeAsO0.60F0.12 Superconductor - ***D. Bhoi (Saha Institute of Nuclear Physics, 1/AF-Bidhannagar, Calcutta, 700 064), P. Choudhury (Central Glass and Ceramic Research Institute, 196 Raja S. C. Mullick Road, Calcutta 700 032,), P. Mandal (Saha Institute of Nuclear Physics, 1/AF-Bidhannagar, Calcutta, 700 064), A. Banerjee (UGC-DAE-CSR, University Campus, Khandwa Road, Indore, 452 017), S. Dash (UGC-DAE-CSR, University Campus, Khandwa Road, Indore, 452 017)***

We have studied the resistivity, magnetization of the $PrFeAsO_{0.60}F_{0.12}$ sample as functions of temperature and magnetic field in the superconducting state. The zero-temperature upper critical field $H_{c2}(0)$ estimated by using the Ginzburg–Landau theory and the Werthamer–Helfand–Hohenberg equation exceeds 100 T. The activation energy U_0, determined from the Arrhenius plot of the resistivity, shows a power-law decrease ($U_0 \propto H^{-alpha}$) with magnetic field. The observed total magnetization is the sum of a superconducting irreversible magnetization and a paramagnetic magnetization. Analysis of dc susceptibility in the normal state shows that the paramagnetic component of magnetization comes from the Pr^{3+} magnetic moments. The field dependence of the supercurrent density *J(H)* displays a "second magnetization peak" (SMP) which shifts towards the high-field region with decreasing temperature. In the low-field region, a plateau up to a field *H** followed by a power law $H^{5/8}$ behavior of *J(H)* is the characteristic of the strong pinning. The dynamic magnetization relaxation rate *Q* is large which indicates a moderate vortex motion and relatively weak pinning energy. Data analysis based on the generalized inversion scheme suggests that the vortex dynamics can be described by collective pinning model. The temperature dependence of the critical current density is consistent with the [illegible]pinning. The strong temperature dependence of the $H_p(T)$ line in the *H-T* phase diagram suggests that the origin of SMP may be related to a vortex structural phase transition.

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P2-110 Angle and field dependent critical current density in Fe-based superconductors - ***C. Van Der Beek (Laboratoire des Solides Irradiés, CNRS UMR 7642, CEA - DSM - IRAMIS, Ecole Polytechnique, F 91128 Palaiseau cedex), H. Wen (Center for Superconducting Physics and Materials, National Laboratory of Solid State Microstructures and Department of Physics, Nanjing University, Nanjing 210093, China), B. Shen (Center for Superconducting Physics and Materials, National Laboratory of Solid State Microstructures and Department of Physics, Nanjing University, Nanjing 210093, China and), T. Shibauchi, Y. Matsuda (Department of Physics, Kyoto University, Sakyo-ku, Kyoto 606-8501, Japan), S. Demirdis, M. Konczykowski (Laboratoire des Solides Irradiés, CNRS UMR 7642 & CEA - DSM - IRAMIS, Ecole Polytechnique, F 91128 PALAISEAU cedex), S. Kasahara, T. Terashima (Research Center for Low Temperature and Materials Sciences, Kyoto University,Sakyo-ku, Kyoto 606-8501, Japan), R. Prozorov (The Ames Laboratory, Ames, Iowa 50011, USA Department of Physics & Astronomy, Iowa State University, Ames, Iowa 50011, USA)***

Recent data on the field-angle dependence of vortex pinning in iron-pnictide superconductors have revealed scaling behavior of the critical current density, reminiscent of the scaling of the upper critical field Hc2 [1]. Furthermore, non-trivial relations between the three possible independent critical current densities in these uniaxial anisotropic superconductors were revealed in Ref. [2]. This behavior has recently been shown to be due to the fact that the critical current anisotropy is intimately related to the coherence length-anisotropy, which, in multiband superconductors is, in general, different from the penetration depth anisotropy [3].

In this contribution, we explore the full field angle-dependence of the critical current in anisotropic multiband superconductors in the different regimes of strong- and weak pinning [4]. We relate the results to the field-angle dependence of the critical current density measured in LiFeAs, BaFe2(As1-xPx)2, and (Ba1-x,Kx)Fe2As2, using both Hall probe-array magnetometry and magneto-optical visualization of the magnetic flux density.

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P2-111 Probing the pairing symmetry in Na(Fe0.95Co0.05)As by scanning tunneling spectroscopy at individual Co impurity atoms - ***H. Yang, D. Fang, H. Wen (Center for Superconducting Physics and Materials, National Laboratory of Solid State Microstructures and Department of Physics, Nanjing University, Nanjing 210093), T. Kariyado, M. Ogata (Department of Physics, University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-0033 and JST, TRIP, Sanbancho, Chiyoda, Tokyo 102-0075), Z. Wang, G. Chen (National Laboratory for Superconductivity, Institute of Physics and National Laboratory for Condensed Matter Physics, Chinese Academy of Sciences, Beijing 100190)***

Since the discovery of high temperature superconductivity in the iron pnictides and chalcogenides in early 2008 almost four years have elapsed. The mechanism about the pairing that leads to the superconductivity remains unsettled yet. One of the widely perceived picture is that the binding force between the two electrons of the Cooper pair is established through exchanging the anti-ferromagnetic spin fluctuations, and consequently the electrons are scattered between the electron and hole pockets leading to an s-wave gap with opposite signs (the S± model). As far as we know, convincing evidence in supporting the S± model is still lacking. Furthermore, the discovery of superconductivity at 32 K in $K_xFe_{2-y}Se_2$ which is supposed to have no hole pockets challenges the very basis of the S± model. In the superconducting state, the impurities will generate a unique pattern of local density of states (LDOS) which is strongly dependent on the pairing gap structure and the features of the impurities, and can be regarded as the *finger prints* for the pairing mechanism. Here we show the spatially resolved scanning tunneling spectroscopy (STS) in Co-doped $Na(Fe_{0.95}Co_{0.05})As$. We successfully identified the Co-impurities and investigated the spatial distribution of LDOS at different energies. The absence of any in-gap bound states or spatially dependent patterns of LDOS for the non-magnetic Co-impurities put strong constraint on the theoretical models.

P2-112 Five-band model analysis of transport properties of Ba(FeAs)2 - ***K. Huynh (Department of Physics, Graduate School of Science, Tohoku University, Aramaki, Aoba, Sendai, 980-8578), T. Kida, M. Hagiwara (Center for Quantum Science and Technology under Extreme Conditions (Kyokugen) Osaka University, 1-3 Machikaneyama, Toyonaka, Osaka 560-8531), T. Urata, S. Heguri (Department of physics, Graduate school of science, Tohoku University, Aramaki, Aoba, Sendai, 980-8578), K. Tanigaki (Department of physics, Graduate school of science, Tohoku University, Aramaki, Aoba, Sendai, 980-8578 WPI-Advanced Institute for Materials Research (WPI-AIMR), Tohoku University, Katahira, Aoba-ku, Sendai 980-8577), Y. Tanabe (WPI-Advanced Institute for Materials Research (WPI-AIMR), Tohoku University, Katahira, Aoba, Sendai 980-8577)***

One of the distinct features of the superconductivity (SC) in iron pnictides is the multi Fermi surface (FS) energetic structure hosting spin density wave (SDW) instability in their parent materials. A SC phase, appearing in thevicinity of SDW by either carrier doping or high pressure applications, inherits significant features from both complex band structure and antiferromagne tic scattering in the parent phase [1]. Despite this scenario, these two issues have not well been understood, and therefore detailed transport properties are especially necessary.

In this report, we focus on the in-plane magnetotransport, namely, magnetoesistances (MR) and Hall resistances (R_H), of high quality $Ba(FeAs)_2$ single crystals. The sample ratio of residual resistance was improved to 25 viaannealing under BaAs vapor [2]. The conductivity tensor evaluated from MR and R_H reveals that the transport properties can be better understood in terms of a five carrier-type model. Due to the large differences in relaxation times, these carrier-types differentiate their features at different B regimes. In particular, the transports in the low B-regime ($B < 0.1$ T) is governed by the Dirac carriers with mobility as high as 20,000 $cm^2V^{-1}s^{-1}$ [3, 4]. Whereasthe other three electron-like and hole-like FS's play the main roles in the regime of medium B, the transport properties in high B are dominated by another hole-like FS with the larger carrier number and much lower mobility.These results unambiguously suggest the existence of large asymmetry in the relaxation times of hole-like and electron-like carriers in $Ba(FeAs)_2$. This could be the key evidence in understanding the important role of inter-bandantiferro-magnetic scatterings in the SC mechanism of iron pnictides.

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P2-113 Observation of anomalous magneto-resistance near the in-plane upper critical field in Sr(Fe,Ni)2As2 single crystals - ***S. Khim (Seoul National University), J. Shim (Pohang University of Science and Technology), B. Lee, K. Choi, K. Yoo, K. Kim (Seoul National University)***

The discovery of iron-based superconductors (SC) has triggered numerous researches to find high temperature SC as well as to understand pairing mechanisms in the unconventional SC. The upper critical field, H_{c2}, provides clues to understanding fundamental properties of SC such as coherence length, pair breaking mechanism and underlying electronic structures. We have investigated H_{c2} behaviors in various iron based SC including $Sr(Fe,Co)_2As_2$, Fe(Se,Te) and LiFeAs [1-3]. In this particular work, we measured the resistivity of $Sr(Fe,Ni)_2As_2$ up to 35 T and report our unexpected findings in the magneto-resistance just above the upper critical fields around the *H // ab* direction at low temperatures. Apart from the transition in *H // c* direction, in which the resistivity is saturated after abruptly appearing from the zero resistive superconducting state with increasing magnetic field, the resistivity gradually increases after it rapidly appears until it reaches the value saturated for the *H // c* direction. This can be interpreted as 1) the rate of superconducting pair breaking changes or 2) the normal state resistivity is suppressed with emerging an abnormal state with the strong magneto-resistance with the in-plane field component. We will discuss the origin of this anomalous magneto-transport behavior based on the band calculation result, in connection with the possible Fulde-Ferrel-Larkin-Ovchinnikov (FFLO) ground state or the competing ground state.

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P2-114 Back to small moments and the bad metal behavior in iron-pnictides - *G. Teitel'baum (Zavoiskii Institute for Technical Physics of the Russian Academy of Sciences), L. Gor'kov (National High Magnetic Field Laboratory, Florida State University)*

There is no consensus yet on basic physics in new FeAs-materials. We focus on stoichiometric pnictides, mainly of 1111 and 122 groups, near and above their temperatures of structural (CDW) and antiferromagnetic (SDW) transition, $T_{CDW} \approx T_{SDW}$ (~100-150K). We assume a magnetic origin for driving order parameter with SDW transition split into the two by magneto-striction [1].

The two views on the transition itself are: the itinerant SDW nesting scenario; in the other one exchange interactions order localized Fe moments. Metallic conductivity favors the notion of itinerant carriers. While rather large staggered Fe-moments support the picture of the Heisenberg spins, they seem to be too small (0.2-0.4μ_B); another inconsistency is that surprisingly high resistivity corresponds to the mean free path $k_F l$~1 at $T \geq T_{SDW}$. These facts signify [2] importance of electron-electron correlations that place iron-pnictides on the boundary between localized and itinerant behavior.
We consider a model with *all* d-electrons initially in itinerant bands so that the bare Fe ions are diamagnetic interacting virtually with the conduction band via the “s-d” exchange, $J(S\cdot s)$. Here S is the spin induced on the Fe site and s is the electronic spin. We consider S as a classical spin. At large enough J interactions result in formation of the electronic spin cloud on the Fe-sites. Such spin-polaronic effect is akin to formation of the two-well potential considered first for A15 in [3] and treated rigorously in [4] for CDW in transition-metal atoms dichalcogenides. At plausible choice of parameters one obtains S<1 and correct values for the scattering time of electrons on disordered spins.

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P2-115 Validity of and deviation from the rigid-band model in the electron-doped compounds Ba(Fe1-xTx)2As2 (T = Co, Ni, Cu, Zn) studied by angle-resolved photoemission spectroscopy - *S. Ideta (University of Tokyo), K. Kihou, Y. Tomioka, C. Lee, A. Iyo, H. Eisaki, T. Ito (AIST), M. Kubota, K. Ono, H. Kumigashira (KEK), M. Matsuo, T. Sasagawa (Tokyo Institute of Technology), T. Yoshida, A. Fujimori, I. Nishi, M. Nakajima, S. Uchida, R. Arita (University of Tokyo), Y. Hotani (University of Tokyo, ISSP)*

It has been unclear how the substitution of transition-metal atoms such as Co, Ni, and Cu for Fe affects the electronic structure and dopes electrons in the iron-based compounds. In the previous angle-resolved photoemission spectroscopy (ARPES) study on Ba(Fe1-*x*Co*x*)2As2, it has been reported that the chemical potential is shifted upwards in agreement with the rigid-band model (RBM) [1]. On the other hand, a density functional calculation has suggested that the *d* electrons doped by impurity atoms such as Co, Ni, Cu, and Zn are mostly located at the substituted site, suggesting of a violation of the RBM [2].
We have investigated the electronic structure of the electron-doped compounds Ba(Fe1-*xTx*)2As2 (*T* = Ni, Cu, Zn: *T*-Ba122) by ARPES in order to examine to what extent the RBM is applicable to or violated in these systems. The electron Fermi surface volumes estimated from the ARPES data for the same nominal doping level are found to decrease in going from Co-, Ni-, to Cu-Ba122 with the same nominal doping level, and the energy difference between the hole bands and electron bands increases. That is, the deviation from the RBM is enhanced in going from Co, Ni, to Cu-Ba122. The 3*d* bands of the Ni, Cu, and Zn are observed below the Fe 3*d* band and becomes deeper in going from Ni to Cu to Zn. The present result indicates that there is a correlation between the strength of the impurity potential and the non-rigid-band behavior.

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P2-116 SANS studies on 122 FeAs superconductors - *H. Kawano-Furukawa (Ochanomizu Univ.), K. Kihou, C. Lee, A. Iyo, H. Eisaki (AIST), T. Saito, H. Fukazawa, Y. Kohori (Chiba Univ.), C. Dewhurst (Institut Laue-Langevin), L. Debeer-Schmitt, K. Littrell (Oak Ridge National Laboratory), R. Ishii, H. Kikuchi, M. Ono (Ochanomizu Univ.), J. White, J. Gavilano, M. Zolliker (Paul Scherrer Institute), C. Bowell (Univ. of Cambridge), M. Nakajima, S. Uchida (Univ. of Tokyo), A. Cameron, E. Blackburn, E. Forgan, L. Lemberger (University of Birmingham),*

Small angle neutron scattering (SANS) experiments on superconducting vortex lattice (VL) states can provide essential information to determine superconducting gap structures and therefore superconducting symmetries. We recently succeeded in observing a well-ordered VL in both KFe2As2 and BaFe2(As,P)2, which have the same ThCr2Si2 structure[1,2]. With the magnetic field parallel to the c-axis, KFe2As2 shows a distorted hexagonal VL under all conditions studied, and no clear evidence of VL structural transitions was observed, but BaFe2(As,P)2 shows a square VL in the middle field range. The VL structure closely connects with the Fermi surface anisotropy, i.e. the distribution of Fermi velocity and gap structure. Using also the temperature dependence of VL diffraction intensities, we discuss the gap structures in these two systems.

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P2-118 Electronic, magnetic and thermodynamical properties of iron pnictides - ***E. Marino (UFRJ), C. Conceicao (UFF), M. Silva Neto, M. el Massalami (UFRJ)***

[1] We firstly study the magnetic spectrum of iron pnictides, starting from a J1-J2 model for the localized electrons and mapping it into a theory with two coupled nonlinear sigma fields. We obtain the magnon dispersion relation and show that it has two gapped branches, in agreement with neutron scattering experiments [2]. We then introduce the itinerant electrons, associated with doping, and analyze their coupling to the localized ones. We show that in the magnetically ordered background phase the electronic spectrum contains Dirac cones, thus confirming recent ARPES results [3]. We finally consider thermodynamical aspects of the system and derive an expression for the magnetic specific heat, which is in good agreement with the experimental data without any adjustment of parameters.

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P2-119 Low energy inelastic neutron scattering on LaFePO0.9 - ***M. Ishikado, R. Kajimoto (Comprehensive Research Organization for Science and Society, Tokai), H. Mutka (Institut Laue Langevin), M. Nakamura, Y. Inamura, M. Arai (J-PARC Center, Japan Atomic Energy Agency), A. Iyo, H. Eisaki (National Institute of Advanced Industrial Science and Technology), T. Hong (Oak Ridge National Laboratory), K. Kodama, S. Wakimoto, S. Shamoto (Quantum Beam Science Directorate, Japan Atomic Energy Agency)***

We have performed systematic researches about magnetic fluctuations on powder samples of LaFeAsO1-*x*F*x* and BaFe2(As0.65P0.35)2 by using inelastic neutron scattering on the chopper spectrometer 4SEASONS (J-PARC, MLF) and Triple Axis Spectrometer (TAS-1) at JRR-3 complementarily. According to the results, in superconducting sample of LaFeAsO1-*x*F*x* (*x*=5.7, 8.2%), spin fluctuation was observed at *Q*~1.2 $Å^{-1}$ corresponding to *G*-*M* point Fermi Surface (FS) nesting vector with same magnitude of spin fluctuation of parent material $LaFeASO_{1.0}$ [1]. On the contrary, spin fluctuation was not clearly observed on electron-overdped sample (*x*=15.8%, *Tc*~7K) whose T_c is highly suppressed [2]. Furthermore, we have observed same magnitude of spin fluctuation of LaFeAs(O1-*x*F*x*) on BaFe2(As0.65P0.35)2 with almost same *T*cmax(=30 K) value with LaFeAs(O1-*x*F*x*) [3]. In the session, we report results of inelastic neutron scattering measurement on powder sample of relatively low-T_c $LaFePO_{0.9}$ (*Tc*~5 K). Spin fluctuation arising from *G*-*M* point FS nesting was not clearly observed on LaFePO0.9. This feature is similar with LaFeAsO1-*x*F*x* (*x*=15.8%, *Tc*~7 K). Considering the fact that the magnetic fluctuation is also observed on high-T_c material of *x*=8.2% (*Tc*=29 K), it indicates strong correlation between magnetic fluctuation arising from *G*-*M* FS nesting and high-T_c. Furthermore, we also report recent experimental results performed by using CTAX (Triple Axis Spectrometer) at HFIR in ORNL and IN5 (chopper spectrometer) in ILL in order to see magnetic excitation and resonance mode at lower *Q*-*E* space and temperature region on LaFePO0.9.

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P2-120 THz Conductivity Measurements of Co-doped and La-doped BaFe2As2 Thin Films - ***F. Nabeshima, Y. Imai, A. Maeda (Department of Basic Science, the University of Tokyo), T. Katase, H. Hiramatsu, H. Hosono (Department of Materials Science and Engineering, Tokyo Institute of Technology), D. Nakamura (Institute for Solid State Physics International MegaGauss Science Laboratory, the University of Tokyo)***

Superconductivity in iron pnictide $BaFe_2As_2$ is induced by electron doping, which is realized by substituting Co for Fe[1] or by La substitution for Ba[2]. They are different in whether impurity dopants are introduced into the FeAs conducting layers or the insulating layers. In the latter case, impurity dopants are expected to have smaller effects on carrier conduction and on the superconducting properties. Thus a large difference in transport properties is expected between Co-doped and La-doped $BaFe_2As_2$. In addition, non-doped $BaFe_2As_2$ is theoretically expected to have Dirac dispersions in the spin density wave (SDW) state, which is observed by an ARPES measurement[3]. If they survive even in the underdoped region, where SDW coexists with superconductivity, there must be a characteristic behavior of the THz conductivity by the peculiar dispersion as observed in non-doped $BaFe_2As_2$[4]. Thus we have performed the THz conductivity measurement with optimally doped $Ba(Fe,Co)_2As_2$ and $(Ba,La)Fe_2As_2$ thin films, and also with underdoped $Ba(Fe,Co)_2As_2$ films. Optimally doped $Ba(Fe,Co)_2As_2$[5] shows the Drude-like frequency dependence of complex conductivity in the normal state. In the superconducting state rather large residual conductivity is observed in the low-frequency region. This may come from the introduction of impurity dopants in the conducting layers. In the presentation, we will also show the results in the other materials, and discuss these in a comparative manner.

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P2-121 Anisotropy of superconducting gap in the iron pnictide superconductor BaFe2(As1-xPx)2 studied by angle-resolved photoemission spectroscopy - ***T. Yoshida (University of Tokyo), K. Kihou, C. Lee, H. Eisaki (AIST), Y. Nakashima, H. Anzai, A. Ino, M. Arita, H. Namatame, M. Taniguchi (Hiroshima University), H. Kumigashira, K. Ono (KEK-PF), S. Kasahara, T. Shibauchi, T. Terashima, Y. Matsuda, H. Ikeda (Kyoto University), S. Ideta, A. Fujimori, T. Shimojima, W. Malaeb, S. Shin, M. Nakajima, S. Uchida, R. Arita (University of Tokyo)***

Most of experimental studies on the iron-pnictide superconductors have so far indicated that the superconducting gap is nodeless and opens on the entire Fermi surfaces in contrast to the *d*-wave superconducting gap in the high-T_c cuprate superconductors. However, the isovalent-substituted system $BaFe_2(As_{1-x}P_x)_2$ shows signatures of superconducting gaps with line nodes [1]. According to the spin-fluctuation-mediated pairing mechanism, a line node in the superconducting gap may appear in the strongly warped hole Fermi surface [2].Recent angle-resolved photoemission study (ARPES) [3] reported a line node in the outer hole Fermi surface around the Z point. However, this result is not consistent with a previous laser ARPES result [4], where Fermi-surface-independent gaps were observed around the Z point. Therefore, it is crucial to further investigate the superconducting gap of this system. We have investigated the anisotropy of the superconducting gaps of $BaFe_2(As_{1-x}P_x)_2$ for the electron and hole Fermi surfaces by ARPES. Unlike the previous study [3], we have observed a full gap opening around the Z point on the outer hole Fermi surface and anisotropic gaps on the electron Fermi surfaces. The present result implies that line nodes or at least strong anisotropy exist in the superconducting gaps on the electron Fermi surfaces like a "loop-like node" [5] rather than a "horizontal node" [2].

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P2-122 Orbital-independent superconducting gaps in optimally doped BaKFe2As2 and BaFe2(As,P)2 - ***T. Shimojima (University of Tokyo), K. Kiho, C. Lee, A. Iyo, H. Eisaki (AIST), C. Chen (Chinese academy of science), M. Arita, K. Shimada, H. Namatame, M. Taniguchi (Hiroshima university), S. Kasahara, T. Shibauchi, Y. Matsuda (Kyoto university), T. Kiss (Osaka university), A. Chainani (RIKEN), W. Malaeb, S. Watanabe, T. Yoshida, S. Ideta, A. Fujimori, K. Ohgushi, M. Nakajima, S. Uchida, K. Ishizaka, S. Shin (University of Tokyo)***

The origin of superconductivity in the iron pnictides[1] has been attributed to antiferromagnetic spin ordering that occurs in close combination with a structural transition. There are also proposals that link superconductivity to orbital ordering[2,3]. In this work, we used bulk-sensitive laser angle–resolved photoemission spectroscopy on optimally-doped $BaFe_2(As,P)_2$ and $BaKFe_2As_2$ to elucidate the role of orbital degrees of freedom on the electron-pairing mechanism. We found an orbital-independent superconducting gap magnitude in the hole Fermi surfaces of both materials[4]. Our result is not expected from the superconductivity associated with spin-fluctuations alone, but is better explained in terms of inter-orbital pairing interactions due to orbital fluctuations.

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P2-123 Fe-site substitution effect on superconducting LiFeAs single crystals - ***B. Lee, S. Khim, B. Jeon, K. Choi, K. Kim (CeNSCMR Department of Physics and Astronomy Seoul National University Seoul 151-747)***

Among the Fe-based superconductors, LiFeAs belongs to rather a unique class in the sense that the superconducting transition at T_c = 18 K occurs without any chemical doping while most of undoped Fe-based crystals do not exhibit superconductivity. To understand this peculiar property further, we have performed systematic study on the effect of chemical doping on the superconducting properties. As it was reported by ARPES study [1] that LiFeAs has a large electron-pocket, additional electron-doping such as Co doing is expected to reduce T_c as often observed in other over-doped compounds. On the other hand, the case for the hole-doping has not been explored yet. In the other 122 system such as $SrFe_2As_2$, Mn has been substituted for Fe to introduce hole-carriers into the system. It was, however, reported that Mn doping did not induce superconductivity but made the system insulating while it still suppressed the spin-density-wave transition [2]. In this respect, we have grown the single crystals of LiFeAs whose Fe-site is substituted with Co or Mn by the Sn-flux method as we reported in Ref. [3], and studied the doping dependence of these series. T_c is reduced while the doping level increases for both Co- and Mn-doped cases, but the tendency of the suppression is different from each other. We have also investigated the structure information and the transport properties to understand the difference between the Co- and Mn-doping.

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P2-124 One-Fe versus Two-Fe Brillouin Zone of Fe-Based Superconductors: Creation of the Electron Pockets via Translational Symmetry Breaking - ***C. Lin, T. Berlijn, L. Wang, C. Lee, W. Yin, W. Ku (Condensed Matter Physics and Materials Science Department, Brookhaven National Laboratory)***

We investigate the physical effects of translational symmetry breaking in Fe-based high-temperature superconductors due to alternating anion positions. [1] In the representative parent compounds, including the newly discovered Fe-vacancy-ordered K0.8Fe1.6Se2, an unusual change of orbital character is found across the one-Fe Brillouin zone upon unfolding the first-principles band structure and Fermi surfaces [2], suggesting that covering a larger one-Fe Brillouin zone is necessary in experiments. Most significantly, the electron pockets (critical to the magnetism and superconductivity) are found only created with the broken symmetry, advocating strongly its full inclusion in future studies, particularly on the debated nodal structures of the superconducting order parameter.

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P2-125 Role of Charge Carriers Density in Fe1+xSe superconductor - ***A. Yadav (Department of Physics, Indian Institute of Technology Bombay), C. Tomy (Indian Institute of Technology Bombay), A. Thakur (Indian Institute of Technology Patna)***

Iron based chalcogenides superconductors are very interesting from physics perspective and despite its simple structure, in β-$Fe_{1+x}Se$ (T_c ~8K) superconductivity is extremely sensitive to its stochiometry and phase stabilization [1]. Superconductivity can survive in this compound with doping of slight amount (x < 4%) of excess iron. The excess iron provides a magnetic coupling between the FeSe layers that creates appropriate environment for generation of superconductivity [2]. The localization of charge carriers from excess iron between the FeSe layers suggests the importance of charge carrier in describing the existence of superconductivity in this compound [3]. We reported earlier the enhancement of superconducting transition temperature with doping of excess chromium instead of iron in $FeCr_xSe$ (T_c ~ 11.2K) compounds [4]. Here we report the connection of superconductivity with changes in charge carrier density in $Fe_{1+x}Se$ superconductor upon transition metal doping in nominal amount in place of excess iron.

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P2-126 Electronic behavior of Ca1-xLaxFe2As2 - ***Y. Ding (Department of Materials Science and Engineering, The Ohio State University Depratment of Physics, Southeast University), Y. Sun, J. Zhuang, L. Cui (Department of Physics, Southeast University)***

Single crystals $Ca_{1-x}La_xFe_2As_2$ were successfully grown by self-flux method, and characterized by structural, component, transport measurements. Resistivity measurements show a systematic reduction of structural and antiferromagnetic spin-density-wave (SDW) transition with temperatures and a subsequent emergence of superconductivity upon La-doping. A interesting shaped superconducting phase is shown in a range of x, with the highest transition temperature T_c about 42 K locating near the end of SDW phase. EDX measurements show that actual content of the elements deviate the nominal content. The Hall coefficient was measured in different temperatures to investigate the property of charge carrier. The charge-carrier density as well as the effective mass were also obtained and discussed in detail.

P2-127 Two Different Superconducting Mechanisms in RFe(P, As)(O, F) [R = rare earth] - ***A. Takemori (Department of Physics, Graduate School of Science, Osaka University, Toyonaka, Osaka 560-0043, Japan), A. Nakao, H. Nakao, Y. Murakami (Condensed Matter Research Center and Photon Factory, Institute of Materials Structure Science, High Energy Accelerator Research Organization, Tsukuba, Ibaraki 305-0801, Japan), S. Miyasaka, S. Tajima (Department of Physics, Graduate School of Science, Osaka University, Toyonaka, Osaka 560-0043, Japan / JST, Transformative Research-Project on Iron Pnictides (TRIP), Chiyoda, Tokyo 102-0075, Japan), R. Kumai (JST, Transformative Research-Project on Iron Pnictides (TRIP), Chiyoda, Tokyo 102-0075, Japan / Condensed Matter Research Center and Photon Factory, Institute of Materials Structure Science, High Energy Accelerator Research Organization, Tsukuba, Ibaraki 305-0801, Japan / National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaraki 305-8568, Japan)***

We have studied RFeP1-xAsxO1-yFy (R=La, Pr, Nd), whose lattice parameters linearly increase with x, in order to clarify the relationship among crystal structure, Tc, and transport properties in the iron pnictide systems. In contrast to x-linear change of lattice parameters, Tc and transport properties show the different behaviors in the regions of x<0.6 and x>0.6. For x<0.6, Tc increases from ~5K to ~30K and the power (*n*) of temperature(T) in resistivity decreases from 2 to 1 with increasing x. This behavior suggests a strong antiferromagnetic (AF) fluctuation, which could cause the superconductivity. By contrast, for x>0.6, the change of Tc is dependent on R or y, and the power n slightly increases with x. A critical behavior at x~0.6 was also suggested by Hall coefficient. Considering another Tc-n relation for RFeAsO1-y reported previously[1], we conclude that the present results demonstrate a crossover at x~0.6 from the FeP-type to the FeAs-type electronic state. These two states have different Fermi surfaces (FSs) and different superconductivity mechanisms with different Tc and gap symmetry. For the FeP-type FS, the achieved maximum Tc is about 30K when n~1, while for the FeAs-type FS the maximum Tc reaches 55K also when n~1.

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P2-128 Magnetism and pairing symmetry in the multiorbital models of iron-based superconductors - ***D. Yao (Sun Yat-sen University and State Key Laboratory of Optoelectronic Materials and Technologies),***

Magnetism plays an important role in the high Tc superconductors. Superconductivity would emerge when the long-range magnetic order is suppressed. I will show how to estimate the exchange couplings from the neutron scattering data, especially in newly discovered 245-ferrochalcogenides (e.g., RbFeSe). The multiorbital nature of iron pnictides makes them

unique in many aspects compared to cuprate superconductors. We study a two-orbital quantum spin model to describe the stripe antiferromagnetism in the iron pnictides. By comparing with the neutron-scattering and angle-resolved photoemission experiments, we find the constraints on the range of values for the Hubbard U and Hund coupling in the mean-field approximation. The phase diagrams are provided within the mean field method. In addition, we study the pairing tendencies by using the random phase approximation. We notice that there is a strong competition between several states that belong to different pairing symmetries. The striped phase in the iron pnictides is found by using a real space Hartree-Fock approximation. The connection between neutron spin resonance peak and superconductivity will be discussed.
We thank the collaborators Elbio Dagotto, Adriana Moreo, Pengcheng Dai, Jiangping Hu, E. W. Carlson, A. W. Sandvik, Qinlong Luo, M. Daghofer, Weiqiang Yu, G. Martins, M. Wang, et al. Refs: [1] PRB 78, 052507 (2008), [2] Nat. Communications 2, 580(2011). [3] PRB 81, 180514R (2010). [4] PRB 83, 174513 (2011). [5] PRB 84, 140506R (2011). [6] ArXiv:1110.0761.

P2-129 Searching for superconductivity in the actinide based iron oxypnictide compounds: NpFeAsO and PuFeAsO - *T. Klimczuk (European Commission, JRC, Institute for Transuranium Elements, Postfach 2340, 76125 Karlsruhe, Germany), C. Eric (European Commission, JRC, Institute for Transuranium Elements, Postfach 2340, 76125 Karlsruhe), A. Schick, J. Griveau, D. BOUEXIERE, R. Eloirdi, P. Gaczynski, R. Caciuffo (European Commission, JRC, Institute for Transuranium Elements, Postfach 2340, 76125 Karlsruhe,), S. Kimber (European Synchrotron Radiation Facility, BP220, F-38043 Grenoble Cedex), C. Ritter (Institut Laue-Langevin, 38042 Grenoble Cedex), R. Springell (London Centre for Nanotechnology and Department of Physics and Astronomy,University College London, London WC1E 6BT), K. Gofryk (Los Alamos National Laboratory), H. Walker (Petra III at Hasylab, Deutsches Elektronen-Synchrotron, Notkestr 85, 22607 Hamburg, Germany), R. Cava (Princeton University, Princeton, NJ)*

We report on the synthesis of NpFeAsO and PuFeAsO, the first actinide based oxypnictides. These new compounds are isostructural to the *R*FeAsO system (*R*=Rare Earth), possessing lattice parameters, Fe-As interatomic distances, and Fe-As-Fe bond angles falling within the empirical 'optimum' for the observation of the highest superconducting transition temperatures.
A series of bulk measurements performed on the parent NpFeAsO compound, including susceptibility, heat capacity, Hall effect and resistivity, show no evidence for the expected spin density wave (SDW) formation, nor antiferromagnetic (AFM) ordering of the Fe sublattice. Instead, a distinct AFM ordering occurs at T_N =57 K, which is four times higher in temperature than the highest T_N observed in the RFeAsO (R=Pr) family.
^{237}Np Mossbauer spectroscopy and powder neutron diffraction clearly show that the Np moments order below 57 K and are aligned along the c-axis, with a FM coupling within the basal plane, and an AFM coupling between the planes. In contrast to all of the RFeAsO compounds, on cooling to 5 K no orthorhombic distortion was observed neither for NpFeAsO nor PuFeAsO.
We attempted to dope the iron and oxygen sites in NpFeAsO by cobalt and fluorine, respectively. There is no hint of a superconducting transition observable in the susceptibility or specific heat data for the F-doped or Co-doped NpFeAsO samples down to 2 K. This observation, together with the lack of both SDW and AFM ordering of the iron ions in the parent material, are in agreement with the scenario that the same magnetic interactions are responsible for both antiferromagnetism and superconductivity in the 1111 systems.
Np metal required for the fabrication of the compound was made available through a loan agreement between Lawrence Livermore National Laboratory and ITU, in the frame of a collaboration involving Lawrence Livermore National Laboratory, Los Alamos National Laboratory, and the US Department of Energy.

P2-130 Phase diagram and oxygen-annealing effect of FeTe1-xSex - *Y. Takano, Y. Kawasaki, H. Okazaki (National Institute for Materials Science (NIMS))*

The iron-chalcogenide FeTe1-xSex has the simplest crystal structure among the iron-based superconductors due to being composed of only superconducting layers. Thus, it is suitable to clarify the mechanism of iron-based superconductivity. However, it is known that the iron-chalcogenides include a small amount of excess Fe which are located between the superconducting layers. Therefore, it is difficult to synthesize the nominal composition of the material.
Recently, we discovered that oxygen-annealing induced the bulk superconductivity for FeTe1-xSex [1]. Furthermore, the phase diagrams of the samples before and after oxygen-annealing were established on the basis of magnetic susceptibility measurements. For the as-grown samples, weak superconductivity was observed in the range region from 0.1 to 0.4. Only the FeTe0.5Se0.5 sample was found to be a bulk superconductor. However, we observed the bulk superconductivity for oxygen-annealed samples with x more than 0.1. In the phase diagram, most importantly, bulk superconducting region was significantly spread down to x = 0.1 by oxygen-annealing. According to first-principles density functional calculations [2], the excess Fe are responsible for the suppression of superconductivity. We consider that oxygen-annealing might suppress the role of the excess Fe. Thus, the bulk superconductivity was probably observed in the range region x more than 0.1. We will report the phase diagrams of as-grown and oxygen-annealed samples and role of oxygen-annealing.
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P2-131 Ultrathin Film of FeTe_1-x_Se_x_ Fabricated by Scotch-Tape method - *H. Okazaki, T. Watanabe, T. Yamaguchi, Y. Kawasaki, K. Deguchi, S. Demura, T. Ozaki, H. Takeya, Y. Takano (National Institute for Materials Science), Y. Mizuguchi (Tokyo Metropolitan University)*

The Fe-based superconductor was discovered in 2008 [1], and has stimulated fundamental discussion on the mechanism of superconductivity. Recently, it was reported that T_c relates to the anion height from Fe layers which can be changed by high pressure and substitution of anion site [2]. Since the change of the anion height should change the electronic structure, it can be considered that the change of the electronic structure is the origin of the increase of T_c. We consider that the electronic structure is changed by ultra-thinning and its T_c increases. $FeTe_{1-x}Se_x$ is the simplest system with stacked only Fe-chalcogen layers without any insulating block layer among the Fe-based superconductors. Recently, it was reported that $FeTe_{1-x}S_x$ thin film can be fabricated by a scotch-tape method [31], which is a powerful method to easily prepare an ultrathin film such as a graphene [4]. Thus, $FeTe_{1-x}Se_x$ is an ideal candidate for a fabrication of a superconducting monolayer film by the scotch-tape method. In order to investigate the change of the superconductivity from bulk to ultra-thin film of $FeTe_{1-x}Se_x$, we fabricated the ultrathin film and measured the resistivity. We succeeded to fabricate ultra-thin film composed of 3 layers. The resistivity of thin film exhibits sharper superconducting-transition width and more isotropic superconductivity than the bulk. In the presentation, the result of fabrication of the ultrathin film and the resistivity will be discussed in detail.

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[4] K. S. Novoselov *et al.*, Science **306**, 5696 (2004).

P2-132 Evolution of the structural ordering and superconductor of the YBa2Cu3-xFexO7-d and Y3Ba5Cu8-xFexO18- d superconducting systems - ***D. Martinez Buitrago, F. Caicedo Mateus, C. Parra Vargas (Grupo de Física de Materiales, Universidad Pedagógica y Tecnológica de Colombia, Tunja, Colombia.), A. Rosales Rivera (Laboratorio de Magnetismo y Materiales Avanzados, Universidad Nacional de Colombia, Sede Manizalez, Colombia.), N. Salazar Henao (Laboratorio de Magnetismo y Materiales Avanzados, Universidad Nacional de Colombia, Sede Manizalez, Colombia.)***

Was produced the system $YBa_2Cu_{3-x}Fe_xO_{7-d}$ (Y:123) and the system $Y_3Ba_5Cu_{8-x}Fe_xO_{18-d}$ (Y:358) both with percentage variations (0.05975≤ x ≤ 0.1225) between (Δx = 0.006), through the technique of SSR solid state reaction, detecting the variations in doping elements Copper with iron (Fe) [1], affects the critical temperature T_C, obtained from the measurements of magnetization as a function of temperature, which remain similar to that the superconducting systems Y: 123. The crystal structure of the systems Y: 358 were analyzed by the technique of X-ray Diffraction (XRD) and Rietveld refinement method [3] which allowed deduce the structure of the system remains in either of the doping proposed, as in the system Y:123 a tetragonal phase (p4mmm)[2]; however, is shown as the percentage of iron present in the system, affect the structural parameters of the systems Y:123 and Y:358. Those were produced by solid state reaction following the similar thermal processes in the production of $YBa_2Cu_{3-x}Fe_xO_{7-d}$. Experimental results obtained by the technique of X-ray diffraction, and Rietveld analysis confirmed the expected crystalline structure. Magnetization measurements enabled the demonstration of superconducting response systems Y:123 and Y:358.

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P2-134 Electronic excitations and symmetry breaking in FeSe0.4Te0.6 - ***S. White, U. Singh, S. Schmaus, Y. Liu, C. Lin (Max-Planck-Institute for Solid State Research), V. Tsurkan, J. Deisenhofer, A. Loidl (University of Augsburg), P. Wahl (University of St Andrews)***

We present a spectroscopic imaging scanning tunneling microscopy (SI-STM) study of $FeSe_{0.4}Te_{0.6}$ and supplementary $Fe_{1+d}Se_xTe_{1-x}$ compositions. This structurally simple iron-chalcogenide superconductor crystallizes in a layered, tetragonal lattice, with orthorhombic and monoclinic distortions appearing at low temperatures at the extreme ends of the phase diagram [1]. In this study we investigate the electronic structure of this superconductor by spatially mapping the local density of states on cleaved samples with a superconducting transition temperature of about 14K. We determine sample stoichiometry from STM topographies and corroborate the results with energy-dispersive X-ray spectroscopy (EDX). Temperature dependent spectroscopic maps acquired between 1.6 and 16K reveal the superconducting gap, which we can fit with the Dynes equation. The gap structure is consistent with Hanaguri et al. [2]. A significant spatial inhomogeneity of the superconducting gap is observed. In the autocorrelation and Fourier transforms of the maps extracted from the temperature dependent data we observe evidence of dispersing electronic states, indicating the possible existence of nematicity in the compound. We discuss these findings and possible interpretations.

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[2] T. Hanaguri, S. Niitaka, K. Kuroki and H. Takagi, Science **328**, 474 (2010)

P2-135 Electrical transport Properties of BaFe2-xNixAs2 single crystals in magnetic fields - ***Y. Zhang (National Laboratory for Superconductivity, Institute of Physics and Beijing National Laboratory for Condensed Matter Physics,Chinese Academy of Sciences, Beijing 100190, China), C. Yang (1 National Laboratory for Superconductivity, Institute of Physics and Center for Condensed Matter Physics, Chinese Academy of Sciences, PO Box 603, 100190 Beijing, People's Republic of China. 2Academy of Materials Science and Engineering, University of Science and Technology, Beijing100083, China.), N. Chen (Academy of Materials Science and Engineering, University of Science and Technology, Beijing100083, China), L. Liu (Academy of Materials Science and Engineering, University of Science and Technology, Beijing100083, China), H. Luo, W. Huang, S. Jia (National Laboratory for Superconductivity, Institute of Physics and Center for Condensed Matter Physics, Chinese Academy of Sciences, PO Box 603, 100190 Beijing, People's Republic of China)***

Electrical transport measurements of a series of $BaFe_{2-x}Ni_xAs_2$ (from underdoped to overdoped) single crystals were studied with magnetic fields up to 9.0 T. By using these data, we studied (i) the doping phase diagram; (ii) the magnetic phase diagrams for several samples; (iii) characteristics of thermally activated flux flow; (iv) vortex glass transition temperature; (v) carrier density information. Furthermore, the relations between different doping and measurements are studied and discussed.

P2-136 Superconductivity of (Ca1-xNax)Fe2As2 system - ***Kan Zhao, Institute of Physics, Chinese Academy of Sciences, China; Qing Qing Liu, Institute of Physics, Chinese Academy of Sciences, China; Xian Cheng Wang, Institute of Physics, Chinese Academy of Sciences, China; Zheng Deng, Institute of Physics, Chinese Academy of Sciences, China; Yu Xi Lv, Institute of Physics, Chinese Academy of Sciences, China; Jin Long Zhu, Institute of Physics, Chinese Academy of Sciences, China; Feng Ying Li, Institute of Physics, Chinese Academy of Sciences, China; Chang Qing Jin, Institute of Physics, Chinese Academy of Sciences, China***

Since the discovery of iron arsenide based superconductor $LaFeAsO_{1-x}F_x$ with superconducting transition temperature (Tc) 26 K, a series of "1111", "122" or "111" type pnictide superconductors were synthesized.

The alkaline earth based AFe_2As_2 (where A is Ca, Sr or Ba) are the typical "122" parent compounds. The lower Tc (～10K) and the sensitivity to pressure condition of Ca122 under pressure is quite different from that of Ba122 and Sr122 , which exhibit superconductivity up to 29K between 28 Kbar and 60 Kbar. A pressure induced tetragonal to collapsed tetragonal transition was also observed above 0.35GPa at 50K in Ca122. Therefore Ca122 is somehow different from the Ba122 or Sr122.

The $Ba_{0.6}K_{0.4}Fe_2As_2$ is a superconductor with Tc up to 38K, with Tc ~35K for $Sr_{0.6}K_{0.4}Fe_2As_2$. But for Ca122 doping at Ca site resulted in superconducting transition with Tc 20K for $Ca_{0.5}Na_{0.5}Fe_2As_2$. We report that Tc above 33K can be obtained in $(Ca_{0.34}Na_{0.66})Fe_2As_2$ crystal. The anisotropy parameter $\gamma = H^{ab}{}_{c2}/ H^{c}{}_{c2} \approx 2$, indicating a low anisotropy.. Based on the structural, magnetic, transport, and heat capacity measurement, we can construct the phase diagrams of $(Ca_{1-x}Na_x)Fe_2As_2$ system. For 0.3 < x < 0.36, the SDW and the superconducting orders probably coexist, as the case in $(Ba_{1-x}K_x)Fe_2As_2$ system. Superconductivity appears for 0.3 < x < 0.66, higher Tc with more Na doping. With application of pressure, T_c decreases nearly linearly and disappears gradually above 2 GPa for $(Ca_{0.34}Na_{0.66})Fe_2As_2$ crystal. The disappearance of superconductivity is also companied with the recovery of FL behaviors of the normal-state. In high pressure synchrotron X-ray diffraction, between 2.3GPa and 3.1 GPa, there is a sharp increase in *a* axis and decrease in *c* axis, indicating the tetragonal to collapsed tetragonal transition.

P2-137 Transient spin density wave order in the normal state of BaFe2As2 induced by coherent phonon oscillations - ***C. Bernhard (University of Fribourg), K. Kim (Chungbuk National University), T. Wolf (Karlsruhe Institute of Technology), A. Pashkin, H. Schäfer, M. Beyer, J. Demsar, A. Leitenstorfer (University of Konstanz), M. Porer, R. Huber (University of Regensburg)***

A phase diagram with superconductivity emerging from a magnetic ground state has been observed in copper- and iron-based high-T_c superconductors. In particular, it has been suggested that antiferromagnetic spin fluctuations originating from the Fermi surface nesting in FeAs-based superconductors may play a key role in the pairing mechanism [1]. Since an antiferromagnetic spin density wave (SDW) ground state in these compounds is known to be accompanied by a structural distortion [2], unveiling the interplay between the lattice and magnetism in pnictides is crucial for an understanding of high-temperature superconductivity in this new class of materials.

Here, we employ broadband multi-THz pulses to resonantly probe the evolution of the SDW gap of $BaFe_2As_2$ following excitation with a femtosecond optical pulse. This material represents the undoped parent compound for a family of Ba-122 pnictide superconductors. Femtosecond optical excitation generates a pronounced coherent phonon oscillation which modulates multi-THz response in the real time. Very surprisingly, in the *normal* state above the transition temperature the spectral shape of the periodically modulated optical conductivity demonstrates a clear signature of the SDW gap suggesting that the transient SDW order quasi-adiabatically follows the coherent oscillation at a frequency as high as 5.5 THz. Our results attest to a pronounced spin-phonon coupling in pnictides that facilitates rapid development of a magnetic order upon small variation of the pnictogen height by vibrational lattice displacement [3].

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[3] K. W. Kim et al., Nature Mater. (2012), accepted.

P2-138 NERNST EFFECT OF IRON BASED SUPERCONDUCTORS - ***F. Caglieris, G. Lamura, I. Pallecchi, M. Tropeano (CNR-SPIN, Corso Perrone 24, 16151, Genova Italy), M. Putti (CNR-SPIN, University of Genova), U. Zeitler, A. Jost, S. Wiedmann (High Field Magnet Laboratory, Radboud University of Nijmegen NL- 6500 GL Nijmegen)***

The Nernst effect, defined as the transverse electric field in response to a longitudinal temperature gradient, in the presence of a perpendicular magnetic field H, is related to the thermal drift of quasiparticles shifted by the Lorenz force. The Nernst effect is usually small in metals but it is enhanced in compensated metal and exhibits a huge contribution in the mixed state of superconductors due to the motion of vortices.

We measure the Nernst effect of Fe-based superconductors and related parent compounds of the "11", (Fe(Te,Se) compounds), and "1111", (SmFeAs(O,F)compounds), families.

We observed different behaviours between the two families, both in the magnetic and superconduting regimes.

As for the superconducting samples, we explore the vortex regime below T_c and in we find an enhancement of the Nernst effect in the mixed state corresponding to the vortex motion in the 1111 phase that was not observed in the 11 compounds.

As for the parent compounds we explore the regime below the antiferromagnetic transition. We find an enhanced signal in the SmFeAsO compound whereas in the FeTe compound the Nernst signal change sign in correspondence of the transition. We interpret the curves in a framework of almost compensated metals and we suggest a possible relationship with the presence of Dirac cones in the band structure of the 1111 family, that are not been evidenced in the 11 phase.

P2-139 Anomaly in the evolution of the superconducting gap structure of K-Ba122 - ***R. Gordon (University of Sherbrooke), M. Tanatar (Ames Laboratory), H. Kim, R. Prozorov (Iowa State University and Ames Laboratory), H. Wen (Nanjing University), B. Shen (National Laboratory for Superconductivity, Institue of Physics and Beijing National Laboratory for Condensed Matter Physics, Chinese Academy of Sciences), J. Reid, X. Luo, H. Shakeripour, S. René de Cotret, A. Juneau-Fecteau, E. Hassinger, N. Doiron-Leyraud, J. Chang, L. Taillefer (University of Sherbrooke)***

The thermal conductivity κ of $Ba_{1-x}K_xFe_2As_2$ was measured down to 50 mK in magnetic fields up to 15 T, for a heat current both parallel and perpendicular to the tetragonal *c* axis, across a range of K concentrations from optimal doping (T_c = 38 K) down to T_c = 7 K [1], deep into the region of coexistence with antiferromagnetic order. From optimal doping down to T_c = 15 K, well into the coexistence region, there is no residual linear term in κ(T) as $T \rightarrow 0$, showing that there are no nodes in the superconducting gap anywhere on the Fermi surface. For concentrations in a narrow range such that 9 K < T_c < 13 K, a large residual linear term appears, signalling the onset of nodes in the superconducting gap, most likely vertical line nodes running along the *c* axis. For T_c < 9 K, the gap is again nodeless. We propose that these changes in the superconducting gap structure are triggered by changes in the Fermi surface as it is reconstructed by the growing antiferromagnetic order.

[1] J.-Ph. Reid *et al.*, arXiv:1105.2232.

P2-140 Absolute value and temperature dependence of the magnetic penetration depth in Ba(Co(0.074)Fe(0.926))2As2 - ***H. Saadaoui, E. Morenzoni (Paul Scherrer Institute, Laboratoryfor Muon Spin Spectroscopy, 5232 Villigen PSI), A. Thaler, R. Prozorov, P. Canfield (Ames Lab and Department of Physics and Astronomy, Iowa State University, Ames, IA 50011), M. Tanatar (Ames Lab and Department of Physics and Astronomy, Iowa State University, Ames, IA 50011,), G. Luke (Department of Physics and Astronomy, McMaster University), O. Ofer, M. Hossain, R. Kiefl, W. Hardy (Department of Physics and Astronomy,University of British Columbia), J. Baglo (Department of Physics and Astronomy,University of British Columbia,), Z. Salman, T. Prokscha, A. Suter, B. Wojek (Paul Scherrer Institute, Laboratoryfor Muon Spin Spectroscopy, 5232 Villigen PSI)***

The temperature dependence of the penetration depth, λ_{ab}, of an external magnetic field into a superconductor offers valuable information about the nature of the pairing symmetry of the Cooper pairs that give rise to superconductivity. Low-energy muon spin rotation (LE-μSR), which uses the muons to probe the magnetic field profile on a nanometer length scale near the surface of materials, can directly measure λ_{ab}. In this study, we present LE-μSR measurements of the absolute value and temperature dependence of λ_{ab} of single crystals Ba(Co$_{0.074}$Fe$_{0.926}$)$_2$As$_2$ [1]. The experiment is performed in the Meissner state, where the average internal field is studied as a function of a weak external field applied parallel to the surface of the crystals. Our results indicate the absence of any magnetism near the surface of the films and show an internal field well described by the London model. By combining the LE-μSR measurements of the absolute value of λ_{ab} with microwave measurements of its temperature dependence performed on the same sample we obtain an accurate determination of the temperature variation of the superfluid density, which can be well described over the entire temperature range by a two gap s-wave model.

[1] O. Ofer, to appear in Phys. Rev. B (R), 2012.

P2-141 Doping dependence of the specific heat of single crystal BaFe2(As1-xPx)2 - ***U. Welp, C. Chaparro, L. Fang, H. Claus, G. Crabtree, V. Stanev, W. Kwok (Argonne National Laboratory), A. Rydh (Stockholm University)***

Empirical relations expressing universal trends in the behavior of classes of materials have proven important in clarifying underlying physical mechanisms. Examples include the Kadowaki-Woods relation [1], and the Uemura plot [2] and Homes scaling [3]. Recently, Bud'ko, Ni and Canfield [4] observed that the specific heat anomaly at the superconducting transition of a series of $Ba(Fe_{1-x}Co_x)_2As_2$ and $Ba(Fe_{1-x}Ni_x)_2As_2$ crystals displayed an unexpected scaling of the form delta $C/T_c \sim T_c^2$ (BNC-scaling). Since, this scaling has been found to apply in a wide variety of Fe-pnictide and Fe-chalcogenide superconductors. However, a completely satisfying theoretical explanation is still lacking.

We present specific heat measurements on a series of $BaFe_2(As_{1-x}P_x)_2$ single crystals with phosphorous content ranging x = 0.3 to x = 0.55. In contrast to most other Fe-pnictide and Fe-chalcogenide superconductors, $BaFe_2(As_{1-x}P_x)_2$ can be grown with very high purity as evidenced by the low values of critical current density and residual resistivity. Our specific heat results reveal that $BaFe_2(As_{1-x}P_x)_2$ follows the BNC-scaling remarkably well [5]. The high purity of this material imposes new restraints on theories aimed at explaining the scaling since models based on specific electron scattering mechanisms appear to be inconsistent with our results. Furthermore, we find that the Ginzburg-Landau parameter k_c decreases significantly with doping, whereas the superconducting anisotropy is ~2.6, independent of doping, indicative of the dominating role of the electron Fermi surface sheets in forming the superconducting state.

Supported by the CES, an EFRC funded by the DoE – BES (CC, LF, WKK), and by DoE – BES (UW, HC, GWC) under # DE-AC02-06CH11357.

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P2-142 Concentration dependence of magnetic and transport characteristics in coexistence of superconductivity with magnetism in EuFe2As2-xPx (0?x?1.0) single crystals - *T. Ishikawa, T. Kashiwagi, A. Nozawa, K. Tashima, K. Kadowaki (Graduate school of Pure and Applied Science. Univ. of Tsukuba, WPI-MANA, CREST-JST)*

AFe_2As_2 systems with A = Ba, Sr, Ca, Eu crystallize the $ThCr_2Si_2$ structure and exhibit superconductivity with T_c values up to 38 K. The parent compound is known to have both phase transitions to the spin-density wave (SDW) and to the crystallographic structural transition almost simultaneously.

In the case of $EuFe_2As_2$, it undergoes the SDW transition of Fe spins at T_{SDW}=190 K and subsequently the magnetic order of Eu^{2+} moment at T_N=19 K. In addition to that, it shows superconductivity with the T_c value up to 28 K as As is substituted with the isovalent P[1]. We have studied magnetic and transport properties of the $EuFe_2As_{2-x}P_x$ single crystals grown by the self-flux method. From the magnetization measurements at 5 K, we observed a saturation of magnetization of Eu^{2+} at H_M ~ 1 T and a spin-flop like behavior at H_{sf} ~ 0.6 T for $H||ab$-plane. These fields seem to decrease as x is increased, indicating reduction of the exchange interaction and the uniaxial anisotropy. We also performed electron spin resonance measurements at X-band on single crystals of $EuFe_2As_{2-x}P_x$. The result shows that the resonance field increases with decreasing temperature towards to T_N=19 K below which a new line was observed. We will discuss these results including electron spin resonance experiments with emphasis on the phase diagram of magnetism and superconductivity in $EuFe_2As_{2-x}P_x$.

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P2-143 Effects of disordered Ru substitutions in BaFe2As2 - *L. Wang, T. Berlijn (Brookhaven National Laboratory), C. Lin, W. Ku (Brookhaven National Laboratory, Stony Brook University), Y. Wang, P. Hirschfeld (University of Florida)*

We clarify the currently debated issue concerning whether the isovalent Ru substitution in BaFe2As2 will influence the Fermi surface or the carrier density. Using the recently developed Wannier function based effective Hamiltonian method for disordered systems [1,2], we found the reduction of the carrier density and the density of states at the Fermi level with increasing of Ru concentration. Furthermore, the shape of the Fermi surface shows the enhanced three-dimension-like characteristic. Although the disordered Ru substitutions introduce strong scattering in the Fe bands, the Fermi surface remains amazingly coherent.

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Work supported by DOE DE-AC02-98CH10886 and DOE CMCSN

P2-144 Can Jc of Iron-Based Superconductors surpass that of High-Tc Cuprates? - *L. Fang, Y. Jia, G. Sheet, C. Chaparro, A. Koshelev, U. Welp, G. Crabtree, X. Zhu (Argonne National Laboratory), W. Kwok (Argonne National Laboratoy), H. Wen (Nanjing University), H. Hu, J. Zuo (University of Illinois Urbana Champaign)*

The recently discovered iron-based superconductors are distinguished by materials characteristics that make them very appealing for potential applications. Their reasonably high values of the superconducting transition temperature T_c, very high upper critical magnetic fields H_{c2}, and generally low intrinsic anisotropy enable operation in economically interesting temperature-field ranges and, at the same time, minimize detrimental effects due to grain boundaries and thermal fluctuations that have plagued the cuprate superconductors. However, the most important applied metric, the maximum loss-less electrical current, is ultimately determined by the vortex pinning that can be engineered into the material. Here we use irradiation with heavy-ions to produce pinning defects in a controlled fashion without the need for chemically modifying the material, and show that $Ba_{0.6}K_{0.4}Fe_2As_2$ with a critical temperature of T_c ? 37 K can accommodate a surprisingly large concentration of strong-pinning defects without suppression of T_c. Following irradiation with 1.4-GeV Pb-ions to a fluence of ~10^{12} 1/cm^2, we observe J_c ~ 5 MA/cm^2 which in a magnetic field of 7 T applied perpendicular to the superconducting FeAs-layers decreases by only 22%. The high-field J_c is comparable to that of $YBa_2Cu_3O_{7-\square}$based conductors. This excellent in-field behavior combined with the enhancement of the irreversibility field by a factor of ~2 to -3.2 T/K as compared to the un-irradiated material and the low intrinsic anisotropy makes $Ba_{0.6}K_{0.4}Fe_2As_2$ a promising candidate for applications in the 20-30 K range which has been envisioned for superconducting machinery such as light-weight generators, motors and transformers.

This work was supported by the EFRC funded by the US Department of Energy, Office of Basic Energy Sciences (LF, CC, GS, YJ, HFH, JMZ, WKK), irradiation was provided by the core research program of the DoE, Office of Basic Energy Sciences (UW, GWC),under Contract No. DE-AC02-06CH11357 and by the ATLAS accelerator at Argonne (SFZ).

P2-145 Model of collective modes in three-band superconductors with repulsive interband interactions - *V. Stanev (Materials Science Division, Argonne National Laboratory)*

I consider a simple model of a three-band superconductor with repulsive interband interactions. The frustration, associated with the odd number of bands, leads to the possible existence of intrinsically complex time-reversal symmetry breaking (TRSB) order parameter. In such state the fluctuations of the *different* gaps are strongly coupled, and this leads to the development of novel collective modes, which mix phase and amplitude oscillations. I study these fluctuations using a simple microscopic model and derive the dispersion for two physically distinct modes, which are gapped by energy less than twice the energy gap (and thus are true collective modes), and apparently present for all interband interactions.

This work was supported by the Center for Emergent Superconductivity, a DOE Energy Frontier Research Center, Grant No. DE-AC0298CH1088.

P2-146 Fermi-liquid behavior of quasiparticle scattering in the normal state of BaFe2(As1-xPx)2 - ***Y. Jia (Materials Science Division, Argonne National Laboratory), G. Crabtree (1.Materials Science Division, Argonne National Laboratory 2. Dept. of Physics, Electrical and Mechanical Engineering, University of Illinois at Chicago), L. Fang, U. Welp, A. Koshelev, W. Kwok (Materials Science Division, Argonne National Laboratory)***

Various models have been proposed to elucidate the normal state transport properties of iron-based superconductors, such as the temperature dependent Hall effect and resistivity, which does not follow the standard Bloch-Gruneisen dependence. Since the superconducting state emerges from an anti-ferromagnetic parent phase, a quantum critical point near optimal doping and scattering by spin fluctuations have been invoked to explain the unusual transport properties [1]. Alternatively, the coexistence of a dirty and clean band within an effective shunt model [2] can account for the observed temperature dependence of the normal state resistivity for many of the iron-based superconductors. Lastly, the thermal activation of carriers in a multiband semi-metal can also account for this behavior[3].

We present studies of galvanomagnetic effects of compensated BaFe2(As1-xPx)2 (x = 0.32 ~ 0.6) superconductors. The magnetoresistance follows the relaxed Kohler's scaling for all doping levels indicating that the underlying transport mechanism is the same for all compositions. Using a two-band model, we obtained the doping and temperature dependent scattering parameters m*/tau and the carrier density of the electron and hole bands. The temperature dependence of the carrier concentration reveals the semimetal properties of BaFe2(As1-xPx)2. The Fermi-liquid behavior, m*/tau ~ T^2 is observed from optimal doped x = 0.32 to over-doped x = 0.6 crystals, suggesting that the proximity of the SDW state does not play and important role in transport. Our analysis suggests that the anomalous normal state transport properties of BaFe2(As1-xPx)2 (x = 0.32 ~ 0.6) can be well understood in the framework of a compensated multi-band Fermi-liquid semimetal.

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Work supported by the CES-EFRC funded by the DoE-BES (YJ, LF, WKK, GWC), and by DoE-BES (UW, AEK) under # DE-AC02-06CH11357.

P2-147 New characteristic energy scales in the normal state of NaFeAs and BaFe2As2 Fe-based superconductor from directional transport measurements - ***M. Tanatar, S. Bud'ko, R. Prozorov (Ames Laboratory), K. Cho, P. Canfield (Ames Laboratory USDOE), N. Spyrison, E. Blomberg (Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011, USA), A. Thaler (Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011, USA 37996-1200, USA), C. Zhang, P. Dai (Department of Physics and Astronomy, The University of Tennessee, Knoxville, Tennessee 37996-1200, USA), H. Wen (National Laboratory of Solid State Microstructures and Department of Physics, Nanjing University, Nanjing 210093, P. R. China)***

Temperature dependent electrical resistivity was measured along three principal directions of conductivity tensor in electron- (e-), hole- (h-) and isoelectron- (i-) doped pnictide superconductors based BaFe2As2 (Ba122) parent compound and compared with measurements on self- (s-) doped stoichiometric LiFeAs and NaFeAs compounds. In addition to known features due to structural, magnetic and superconducting transitions, this study found existence of clear resistive signatures of a pseudogap [1]. An asymmetry in the behavior between h-doped (BaK122) and e- doped BaT122 (T = transition metal) is revealed [2,3]. The pseudogap temperature is almost doping independent on the h- side, drops rapidly on the e- side and shoots up with i-doping, leading to a dramatic difference in anisotropic resistivity temperature dependence between three types of dopings. Similarly strong variation of anisotropy is found in s-doped NaFeAs [4] and LiFeAs. Study of the doping evolution of pseudogap for various transition metal substitutions [2] suggests that pseudogap represents an independent energy scale in the phase diagram. Normal state in-plane anisotropy peaks on the e- side, gradually decreases and changes sign on the h- side.

Work at the Ames Laboratory was supported by the Department of Energy-Basic Energy Sciences under Contract No. DE-AC02-07CH11358.

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P2-150 Superconductivity and Oxygen Doping of FeTe and FeSe Films - ***B. Wells (University of Connecticut), G. Gu (Brookhaven National Laboratory), L. Narangammana, Y. Nie, J. Budnick (University of Connecticut)***

The iron-chalcogenide superconductors have an important place in the study of Fe-based superconductivity. One important aspect is that the parent compound FeTe can be doped to become a superconductor either by substitution of Se onto Te sites or the addition of excess oxygen, at least in film samples. The former method involves isoelectronic doping, and thus presumably superconductivity arises due to changes in the lattice. The latter method involves substantial hole doping and only a small change in the room temperature lattice. We are able to add oxygen to films of FeTe, $FeTe_{0.5}Se_{0.5}$ or FeSe. In each case there is substantial hole doping though the process kills superconductivity in FeSe. Films grown using a porous, unreacted Fe/Te target showed islanding, an open structure, and a strong c axis texture. Oxygen could be easily added or removed by low temperature anneals. Films grown using a dense, crystalline target and a short target-substrate distance had better epitaxy, and were dense, continuous and smooth. Post processing of oxygen on these films was difficult, but we were able to control oxygen concentration during growth and the oxygen concentration is more stable. We report on our latest results on the magnetism and electronic structure (heavy hole doping) in superconducting FeTeOx films as well as a study of a structural phase transition at Tc that might be the key to allowing superconductivity.

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Phys. Rev. B **82**, 020508 (2010) and http://arxiv.org/abs/1102.2155

Y.F. Nie now at Cornell University

P2-151 Measurements of Hall effect at atmospheric pressure and electrical resistivity under pressure on single crystals of the high Tc superconductor parent compound LaFeAsO - ***C. McElroy, J. Hamlin, D. Tutun, N. Kanchanavatee, Y. Heo, B. White, A. Ellington, M. Maple (University of California, San Diego)***

Among the recently discovered iron-based superconductors, the materials adopting the ZrCuSiAs-type crystal structure, such as RFeAsO (R = rare earth), exhibit the highest superconducting critical temperatures. We present measurements of electrical resistivity under hydrostatic pressure as well as magneto-resistivity and Hall effect measurements on single crystals of LaFeAsO. We track the evolution of the spin-density-wave feature with pressure. In contrast to earlier measurements on polycrystalline LaFeAsO, the transport signature of the spin-density-wave in single crystalline samples remains clear and sharp under applied pressure, allowing for a more accurate assessment of the pressure dependence of the ordering temperature. Results from transport and thermodynamic properties measurements of other 1111 parent compounds will also be discussed.

Materials synthesis and screening for superconductivity were performed under the auspices of AFOSR MURI, Grant FA9550-09-1-0603. Physical properties characterization was supported by DOE Grant DE-FG02-04-ER46105. Measurements under applied pressure were supported by DOE Grant No. DE-FG52-09NA29459.

P2-152 Search for superconductivity in noncentrosymmetric M2T12Pn7 (M = lanthanide or actinide, T = transition metal, Pn = P, As) - ***D. Tutun, S. Jang, J. Hamlin, R. Baumbach, M. Janoschek, I. Lum, B. White, M. Maple (University of California, San Diego)***

Superconducting materials with noncentrosymmetric crystal structure have attracted significant attention due to the possibility of observing an unconventional admixture of spin-singlet and spin-triplet pairing. Understanding this unusual superconducting state might contribute to the discovery of new superconducters with higher critical temperatures. The high incidence of anomalous properties we have found in members of the so-called “2-12-7” class of compounds, each possessing noncentrosymmetric crystal structures, suggests that this family of systems may represent a relatively unexplored reservoir of strongly correlated electron phenomena including possible superconductivity. One of the more interesting characteristics of these materials is that both the *M* and *T* sites can be tuned from magnetic to non-magnetic depending on the incorporated element. Systems with *T* = Co typically exhibit ferromagnetic ordering, whereas in the corresponding Fe and Ni analogues, the transition metal ions appear to be non-magnetic. We present results covering our study of these systems, focusing particularly on the pseudoternary systems $Yb_2(Fe_{1-x}Co_x)_{12}P_7$ and $Hf_2(Fe_{1-x}Co_x)_{12}P_7$. In these systems, we searched for superconductivity near the concentration at which ferromagnetic order is suppressed. While superconductivity has not yet been observed in any of the 2-12-7 systems we have synthesized, we continue to explore this intriguing class of materials in search of superconductivity.

Materials synthesis and screening for superconductivity were carried out under the auspices of AFOSR MURI, Grant FA9550-09-1-0603. Physical properties characterization was supported by US DOE Grant DE-FG02-04-ER46105. Low temperature measurements were supported by NSF Grant DMR-0802478.

P2-153 Effects of disorder on London penetration depth in single crystals of SrFe_2(As_0.65P_0.35)_2 - ***C. Strehlow (The Ames Laboratory, Ames, IA, & Iowa State University, Ames, IA), R. Prozorov, M. Tanatar, K. Cho (Ames Laboratory, Ames, IA)***

In a contrast to a fully-gapped chargedoped (Ba,K)Fe_2As_2 and Ba(Fe,T)_2As_2 [1], isoelectron - substituted BaFe_2(As,P)_2 exhibit nodal superconducting gap [2]. To explore possible universality of this e?ect, precision measurements of London penetration depth were performed in optimally - doped SrFe_2(As_0.65P_0.35)_2. Three single crystals used in this study were characterized by DC and RF magnetic susceptibility showing bulk superconducting transition at Tc=29 K. The low - temperature variation of the London penetration depth, ?(T), revealed notable deviations from the exponential temperature dependence, expected for a fully-gapped superconductors.Instead the data are best ?t with a power-law function, ? = AT^n. The analysis of the data below 1/3 Tc over a variable ?tting temperature range produced exponents n~=2 which suggests the presence of nodes in the superconducting gap, similar to the P - doped Ba122 compounds. The relevance of our results to the current theories of the pairing mechanisms in Fe-based superconductors will be discussed. [1]

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Crystals grown by: T. Dulguun, S. Miyasaka, S. Tajima, JST, TRIP, Chioda, Tokyo, Japan

P2-154 Spatially uniform nodeless two-gap superconductivity observed in scanning tunneling spectroscopy of LiFeAs - ***S. Chi (Department of Physics and Astronomy, University of British Columbia), S. Burke (Departme nt of Physics and Astronomy, University of British Columbia; Department of Chemistry, University of British Columbia), S. Grothe (Department of Physics and Astronomy, University of British Columbia), R. Liang, W. Hardy, D. Bonn, Y. Pennec (Department of Physics and Astronomy, University of British Columbia; Quantum Matter Institute, University of British Columbia)***

A particularly interesting member amongst the pnictides superconductors is LiFeAs[1]. This stoichiometric superconductor with non-polar, as-cleaved surfaces is very suitable for studying the superconducting mechanism of pnictides in the clean limit by scanning tunneling microscopy (STM) and spectroscopy (STS). Atomic resolution imaging reveals the as-cleaved surface has the lattice constants of the Li layer or As layer. Five different types of impurities have been detected with total density lower than 0.4% per unit cell. In addition, impurities tend to form clusters and leave large defect-free areas at length scales $\sim$ 30 nm.
Two nodeless gaps can be clearly resolved from STS measured at 2 K. By employing Dynes’ formula, the spectrum can be fitted to both a two-isotropic-gap model with $\Delta_{1}=5.34$ meV and $\Delta_{2}=2.50$ meV and a two-anisotropic-gap model with $\Delta_{1}(\theta)=5.33 (1+0.09cos(4\theta))$ meV and $\Delta_{2}(\theta)=2.53(1+0.20cos(4\theta))$ meV, suggesting no strong angle dependence of those two gaps. Normalized Superconducting STS reveals a clear dip-hump feature just above

the quasiparticle peaks, indicating collective modes coupling to the quasiparticles. Gap maps over 90 $\times$ 90 nm^2 area unambiguously demonstrate great homogeneity in the as cleaved surface of LiFeAs.

Temperature dependence of STS shows the superconducting gaps are fully closed at 17 K, which is the same as the onset of bulk T_c=17 K determined by a SQUID magnetometer, indicating the physical properties of as-cleaved surface represent the bulk properties very well. The closing of the superconducting gap Δ_{1} with temperature follows BCS theory.

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P2-155 Contrasts in the normal and superconducting state properties in LiFeP and LiFeAs superconductors - ***S. Kasahara (Research Center for Low Temperature and Materials Sciences, Kyoto University), K. Hashimoto, H. Ikeda, Y. Matsuda, T. Shibauchi (Department of Physics, Kyoto University), T. Terashima (Research Center for Low Temperature and Materials Sciences, Kyoto University)***

A central issue in the physics of iron-based superconductivity concerns the origin of the pairing interaction, in which the importance of the interband fluctuations associated with spin and orbital degrees of freedoms has been discussed [1]. Among various peculiar properties caused by the multiband electronic structure with good nesting between the hole and electron Fermi surface sheets, the non-universality of the superconducting gap structure is one of the outstanding features in this class of materials [2, 3]. Understanding what causes the nodal and nodeless superconducting gap is believed to be a key to the mechanism of this intriguing superconductivity. Here, based on our high-quality single crystals [4], we quantitatively compare the transport properties between LiFeP and LiFeAs superconductors with compensated electron and hole carriers. The low-temperature resistivity follows the Fermi-liquid AT^2 dependence with a factor of ~ 3 difference in the coefficient *A*. This highlights weaker electron correlations in LiFeP, which is consistent with its ~ 70 times lower upper critical field than that of LiFeAs. The recent observations of quantum oscillations at high fields also show the significant mass enhancement in LiFeAs as compared with LiFeP [5], which is fully consistent with our normal-state transport data. Our analysis of the magneto-transport data indicates that in LiFeP the electron carriers with lighter masses exhibit stronger temperature dependence of inelastic scattering rate than the holes, which is the opposite to the LiFeAs case. This stark difference in the band-dependent inelastic scattering may be relevant to the recently reported contrasting superconducting gap structures in these two superconductors [3].

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P2-156 Effect of gap anisotropy in near-vortex electronic structure of LiFeAs within self-consistent BdG - *E. Kim, K. Lee, F. Mark (Cornell University)*

A major question in Fe-based superconductors is whether the pairing is of an unconventional nature with a sign change. The near-vortex electronic structure in the presence of vortices can serve as a platform for phase sensitive measurements to answer this question. Through a microscopic self-consistent BdG calculation for LiFeAs in the presence of a perpendicular magnetic field, we calculated the energy-dependent local electronic structure near a vortex for different gap-symmetry possibilities. We found the low-energy local density of states (LDOS) to be dominated by the geometry of the Fermi surface and independent of gap-symmetry. However, the LDOS at energies of order of gap turned out to be sensitive to the gap symmetry. Hence in-field scanning tunneling spectroscopy can be used to study LDOS profile near a vortex to probe the gap symmetry. I will discuss the results and insight we gained from Ginzburg-Landau theory.

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P2-157 Point-Contact Andreev Reflection Study of Iron Pnictide Superconductor Ba-122 Single Crystals - ***C. Ren (National Laboratory for Superconductivity, Institute of Physics, CAS), H. Wen (Physics Department, Nanjing University), Z. Wang, Z. Wang, H. Luo, X. Lu, B. Shen, J. Zhu, X. Hou, J. Gong, C. Li, L. Shan (National Laboratory for Superconductivity, Institute of Physics, CAS), H. Yang (Physics Department, Nanjing University)***

Point-contact Andreev reflection (PCAR) spectroscopy has been adopted for probing the density of state (DOS) of superconductors with the high energy resolution. In addition, the capability of this technique to study the anisotropy and the temperature dependence of the superconducting gap make it a unique tool in providing invaluable information for various mechanisms of unconventional superconductivity. We report a systematic investigation on c-axis point-contact Andreev reflection (PCAR) in optimally doped hole type BaKFeAs and electron-type BaFeNiAs single crystals. For both cases the PCAR spectrum feature the structures of two superconducting gap and electron-boson coupling mode. In the s\pm scenario, quantitative analysis using a generalized Blonder-Tinkham-Klapwijk (BTK) formalism with two gaps: one isotropic and another angle dependent, suggest a nodeless state in strong-coupling limit with gap minima on the Fermi surfaces. The observed electron-boson mode shows a tendency of superconducting gap-T dependence with the energy scales strongly relating to spin resonance mode energy. These results are consistent with the calculations for the orbital dependent pair interaction mediated by the antiferromagnetic spin fluctuations.

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P2-158 Electronic and magnetic structure in Fe-based superconductors: from FeSe (11) to KFe2Se2 (122) - ***L. Simonelli (European Synchrotron Radiation Facility), N. Saini (Dip. di Fisica, Università di Roma "La Sapienza"), G. Monaco (European Synchrotron Radiation Facility)***

Although, FeSe (11)-type chalcogenides have been widely regarded as model systems to explore the basic electronic structure of Fe-based superconductors, they lack the spacer layers present in the RFeAsO (1111) and AFe_2As_2 (122)-type of pnictides. Recently FeSe layers have been successfully intercalated by alkaline atoms (K, Rb, Cs), with intercalated chalcogenides showing superconductivity at 30 K, unlike the (11)-type of chalcogenides (maximum T_c: 15 K).

In $A_xFe_{2-y}Se_2$ (11)-type chalcogenides superconductivity appears to occur only in Fe-deficient samples, where the alkali metals are intercalated between the FeSe layers. It has been demonstrated how the ordering of the Fe vacancies can be correlated to superconductivity and how it can be controlled by temperature treatments [1-5]. In particular the superconductivity can be tuned on a single sample from an insulating state by post-annealing and fast quenching, and it is tempting to conclude that the superconductivity is achieved when the Fe-vacancies are in a disordered state [5].

Here we report on the electronic and magnetic structure of $K_{0.8}Fe_{1.6}Se_2$ superconductor by x-ray emission and high resolution absorption spectroscopy. We report a study where the electronic and magnetic properties are investigated at the same time as a function of temperature in several consistent thermal cycles. We discuss the effects of ordered and disordered Fe vacancies on the electronic and magnetic structure, the existence of memory effects on thermal cycles, and the relation between electronic and magnetic properties and superconductivity. The results obtained are finally compared with the electronic and magnetic properties of (11)-type chalcogenides.

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P2-159 Inducement of superconductivity in Fe0.95Te0.85S0.15 composition using immersion in sulfuric acid - ***M. Nagao (University of Yamanashi), Y. Takano (National Institute for Materials Science), Y. Mizuguchi (Tokyo Metropolitan University), S. Watauchi, I. Tanaka (University of Yamanashi)***

Sulfuric acid treatment improved the superconducting properties of $Fe_{0.95}Te_{0.85}S_{0.15}$ composition. The $Fe_{0.95}Te_{0.85}S_{0.15}$ composition immersed in diluted sulfuric acid enhances the superconducting properties compared to pure water immersing. And, sulfuric acid treatment removes impurity iron from $Fe_{0.95}Te_{0.85}S_{0.15}$ composition. Sulfuric acid has the ability to induce superconductivity in Fe-Te-S compound.

P2-160 Pressure Effects on the Crystal Structure and Electronic Properties of the Iron Based Superconductors - ***G. Garbarino (European Synchrotron Radiation Facility (ESRF)), R. Weht (Comisión Nacional de Energía Atómica - Universidad Nacional de San Martín), M. Mezouar (ESRF), M. Nunez Regueiro (Institut Neel, CNRS), P. Bouvier (Laboratoire des Matériaux et du Génie Physique, CNRS & Grenoble Institute of Technology)***

The study of the pressure effects on the crystal and electronic structure is a powerful tool that helps to find clues to analyze the superconducting state. The new iron based superconductors is an excellent example, where there are still plenty of opened questions to be answered.

In this presentation, we will discuss the effect of structural parameters under pressure on the superconducting properties on compounds belonging to 1111, 111 and 11 Fe based family. In particular, we have observed a strong correlation of the crystal structure parameters on the T_C in (La,Sm)$FeAsO_{1-x}F_x$, LiFeAs and FeSe compounds [1,2,3,4]. We have analyzed in detail the pressure dependence of the inter(intra)layer distance, the angle Fe-As-Fe and its effect on the T_C. These results are of great importance for band structure calculations based on realistic atomic positions that permit to obtain a detailed microscopic interpretation of the subtle effects on the electronic properties, explaining the effects on the superconducting transition.

This is the approach that we use to explain the pressure evolution of superconducting transition in $SmFeAsO_{1-x}F_x$ and Sr_2VO_3FeAs [2,5]. We also studied the pressure evolution of the structural and spin density wave transition in the SmFeAsO compound and we will correlate it with the superconducting properties

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P2-161 Scanning Transmission Electron Microscopy Evidences of Interstitial and Substitutional Oxygen in MBE Grown Fe1+xTe Thin Films and Emergence of Superconductivity - ***H. Hu, M. Zheng, C. Zhang, J. Eckstein, J. Zuo (University of Illinois at Urbana-Champaign)***

Discovery of iron-based superconductors has attracted great interest since 2008 [1]. Among the iron-based superconductors, 11-type iron chalcogenide received special attention. Compared to bulk crystals, thin films of iron chalcogenide demonstrate a significant increase in T_c [2]. Particularly, superconductivity emerges in some $Fe_{1+x}Te$ thin films with incorporation of oxygen, but not in the bulk crystals. To better understand the role of oxygen in these thin films, atomic scale investigation of oxygen doping is performed by using scanning transmission electron microscopy (STEM) and electron energy loss spectroscopy (EELS).

Our $Fe_{1+x}Te$ films were grown by molecular beam epitaxy (MBE) under controlled oxygen exposure. The as-grown film has a T_c ~ 12 K. Atomic resolution dark field STEM images demonstrate a well-defined epitaxial interface. Blobs with dark contrast, starting to appearat 7~8 unit cells away from the interface where oxygen was turned on during growth, are observed. The atomic structure in those dark blobs is still preserved, which implies a decrease in the average atomic mass. EELS confirmed that the dark blobs contain higher oxygen content, suggesting substitution of Te by O. The O-K edge was also detected in the first 7~8 unit cells. line scan EELS in this region provides evidence of oxygen content modulation that is correlated with Fe-Te layers, which suggests oxygen occupies interstitial sites. Characterization of nonsuperconducting $Fe_{1+x}Te$ films revealed the presence of amorphous interfacial layers in these films.

Our results suggest that the epitaxial interface and possible interfacial electronic reconstruction, together with oxygen doping, provides the key to emergence of superconductivity in $Fe_{1+x}Te$ films.

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P2-162 Growth and oxygen doping of thin film FeTe by Molecular Beam Epitaxy - *M. Zheng (University of Illinois at Urbana-Champaign), U. Welp, Y. Jia, W. Kwok (Argonne National Laboratory), C. Zhang, H. Hu, J. Zuo, J. Eckstein (University of Illinois at Urbana-Champaign)*

FeTe is isomorphic to FeSe, a representative of the 11 family of iron based superconductors. While not a superconductor itself, FeTe in thin film form undergoes a superconducting transition when doped with oxygen. We will discuss the growth of FeTe by MBE and various schemes we used to dope the samples. The results of films grown under different doping conditions, combined with HR STEM and EELS studies, provide evidence that suggest that while partial oxygen substitution might happen during growth, the oxygen dopant responsible for superconductivity is the result of reversible diffusion into the crystal at very moderate temperatures, less than the growth temperature. We also have discovered films that remain non-superconducting for months in air. STEM data hint that epitaxy may also be an ingredient in making FeTe films superconducting. This could provide an explanation for why oxygen induced superconductivity in FeTe is only observed in thin film form thus far. Magnetotransport studies of FeTe films reveal a switching of the carrier sign around 35K, as well as a small but negative magneto-resistance.

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P2-163 Magnetic penetration depth in Ba0.6K 0.4Fe2As2 superconducting crystals - *N. Salovich (University of Illinois at Urbana-Champaign), W. Kwok, U. Welp (Argonne National Laboratory), A. Ghosh (Jadavpur University), B. Shen (Nanjing University), H. Wen (Nanjing University, Nanjing 210093, China), R. Giannetta (University of Illinois at Urbana-Champaign)*

Using a tunnel diode oscillator, the magnetic penetration depth has been measured in both heavy ion- irradiated and non-irradiated crystals of $Ba_{0.6}K_{0.4}Fe_2As_2$. The low temperature behavior of the penetration depth is consistent with a finite energy gap with no additional midgap states introduced by irradiation. By cooling in a magnetic field we determined the Campbell penetration depth due to vortex motion. The “equilibrium” critical current is derived from the field and temperature dependence of the Campbell depth. Irradiation significantly increases the vortex pinning and critical current.

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P2-164 Search for new superconductors on the basis of Y-Fe-Si ternary system - *S. Noguchi (Department of Physics and Electronics, Graduate School of Engineering, Osaka Prefecture University), H. Fujiwara (Department of Chemistry, Graduate School of Science, Osaka Prefecture University), K. Fujita, H. Shishido, T. Ishida (Department of Physics and Electronics, Graduate School of Engineering, Osaka Prefecture University)*

We search for a new superconductor in the ternary Y-Fe-Si system by partly substituting B and C for Fe. Two samples of the nominal composition with $Y_2Fe_3Si_4X$ (X = B, C) were prepared by the Czochralski pulling method in a tri-arc furnace, and were checked to be a single phase of $Y(Fe_{0.75}B_{0.25})_2Si_2$ and $Y(Fe_{0.75}C_{0.25})_2Si_2$ with the $ThCr_2Si_2$-type by X-ray measurements. The lattice parameters were a = 0.3927 nm and c = 0.9945 nm for $Y(Fe_{0.75}B_{0.25})_2Si_2$, and a = 0.3926 nm and c = 0.9962 nm for $Y(Fe_{0.75}C_{0.25})_2Si_2$. Magneticsusceptibility in field after cooled in zero fields was measured upon warming by a SQUID magnetometer for $Y(Fe_{0.75}B_{0.25})_2Si_2$ and $Y(Fe_{0.75}C_{0.25})_2Si_2$ under an ambient pressure and 1 GPa. Clear diamagnetic behaviors were observed at low temperatures. We estimate from the measurements the superconducting transition temperatures to be T_c = 4.2 K for $Y(Fe_{0.75}B_{0.25})_2Si_2$ and T_c = 3.8 K for $Y(Fe_{0.75}C_{0.25})_2Si_2$. No appreciable pressure dependence of T_c was observed for both samples. The volume fraction of the superconductivity is estimated to be a few percent which is much smaller than the perfect diamagnetism.

In the stoichiometric Y-Fe-Si system, it has been reported that only the $Y_2Fe_3Si_5$ compound shows superconductivity at 2.4 K [1]. We confirmed the stoichiometric YFe_2Si_2 showed no superconductivity above 0.4 K under an ambient pressure and above 1.8 K at 1 GPa. Non-stoichiometric disorder in Fe sites [2] and substitution of Fe sites by light elements (B, C) cause the superconductivity in this system although a superconducting volume fraction is still small at this moment.

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P2-165 Pressure effect on Tc and crystal structure of CeFe0.95Co0.05AsO0.9F0.1 - ***R. Kumar (High Pressure Science and Engineering Center (HiPSEC) and Department of Physics and Astronomy, University of Nevada Las Vegas, Nevada 89154 USA), K. M (Bharathidasan University, Trichy), A. Sonachalam (Center for High Pressure Research, School of Physics, Bharathidasan University, Tiruchirapalli 620024 India), P. Jai, G. Thakur, A. Ganguli (Department of Chemistry, Indian Institute of Technology, New Delhi, 110016 India), D. Antonio, J. Baker, A. Cornelius, Y. Zhao (High Pressure Science and Engineering Center (HiPSEC) and Department of Physics and Astronomy, University of Nevada Las Vegas, Nevada 89154 USA)***

We have investigated the superconducting transition temperature of the oxyarsenide compound $CeFe_{0.95}Co_{0.05}AsO_{0.9}F_{0.1}$ (T_c onset ≈ 26.2 K) as a function of quasihydrostatic pressures up to 1 GPa using the four probe resistivity technique in a piston cylinder cell. Application of pressure significantly enhances the onset transition from 26.2 K to 28 K. The compressibility of the compound has been studied up to 50 GPa using a diamond anvil cell and Ne pressure medium with synchrotron powder x-ray diffraction technique. Even though there is no apparent pressure induced phase transition in the lower pressure range; the lattice parameters show large anisotropic compression. The equation of state and pressure effect on superconducting transition temperature will be discussed.

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P2-166 Competing antiferromagnetic states in the pnictides - ***P. Brydon, J. Schmiedt, C. Timm (Technische Universität Dresden)***

Motivated by the complicated nesting properties of the Fermi surface of the pnictide parent compounds [1], we study the competition of the observed antiferromagnetic stripe order with other commensurate and incommensurate states. Starting from a phenomenological microscopic model, we derive the mean-field Ginzburg-Landau free energy, and systematically construct the magnetic phase diagram as a function of the doping and key band structure parameters [2]. We show that the number, location, and relative size of the hole pockets crucially controls the magnetic state, which we explain in terms of the competition between different nesting instabilities. We discuss the implications for electronic-only models of the magnetic order.

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This work was partially funded by the DPG Priority Programme 1458.

P2-167 Evidence for Interface-Induced Tc-Enhancement in Fe-Pnictide and -Chalcogenide Superconductors and Others - ***C. Chu (Department of Physics and Texas Center for Superconductivity, University of Houston; Lawrence Berkeley National Laboratory), J. Meen (Department of Chemistry and Texas Center for Superconductivity, University of Houston), B. Lv, M. Gooch, L. Deng, Y. Xue, B. Lorenz (Department of Physics and Texas Center for Superconductivity, University of Houston), F. Wei (Texas Center for Superconductivity, University of Houston)***

Recently, a T_c of 42–49 K has been reported in rare-earth doped $CaFe_2As_2$ at ambient[1], in $K_xFe_2Se_2$ over a narrow pressure range around 12 GPa[2], and in single unit-cell FeSe-layer at ambient[3]. Such a T_c is the highest in known materials directly derivable from the above three respective examples. An extensive study has been carried out by us on single-crystalline $CaFe_2As_2$ (Ca122) slightly doped with La, Ce, Pr, and Nd. Two superconducting states characterized by two distinct critical fields are detected below ~ 49 K and ~ 20 K, respectively. For instance, 300 Oe is sufficient to suppress completely the 49 K-magnetic transition. No calorimetric anomaly was detected at either of the two transition temperatures. The magnetic anisotropy reaches ~ 30 and experiences a sudden drop to ~ 20 at ~ 20 K, consistent with the two transition suggestions. The large magnetic anisotropy observed is in contrast to that of ~ 5 arising from the sample geometry. The measured dependences of the magnetic anisotropy on the externally applied field and temperature enable us to determine qualitatively that superconductivity is confined to nanoscale-regions. In addition, the T_c ~ 40s K detected appears to depend more on the physical conditions of the samples than the chemical condition. We have therefore ascribed the T_c-enhancement observed in doped $CaFe_2As_2$ single crystals to the interface mechanism, and also in the other two cases mentioned above in view of the similarities of the results. A review on enhanced superconductivity in single crystals of un-doped Ca122, Sr122, Ba122, Sr_2RuO_4, alpha-U, the cuprate layer superconductors, etc. suggests that interface-induced T_c-enhancement may be ubiquitous and may provide a new paradigm for higher T_c.

Supported in part by AFOSR, DoE, TCSUH, T. L. L. Temple Endowment, and John J. and Rebecca Moores Endowment.
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2. L. L. Sun et al., Nature, 22 Feb. 2012.
3. Q. Y. Wang et al., arXiv:1201.5694v1 [cond-mat.supr-con] (2012).

P2-168 Signature of Coherent Polarons in Antiferromagnetic Ordered Fe1.02Te Observed by Photoemission - ***Z. Liu (Stanford University), R. He, S. Mo, Z. Hussain (Lawrence Berkeley National Laboratory), D. Lu, Y. Chen, M. Hashimoto, R. Moore, T. Devereaux (SLAC National Accelerator Laboratory), M. Yi, Z. Shen (Stanford University), J. Hu, Z. Mao (Tulane University)***

The role of many-body effects is one of the central questions for unconventional superconductivity. For the recently discovered iron-based superconductors, the strength of electronic correlations is still an unsettled issue. For one of them, iron chalcogenides, a strong correlation scenario has both been proposed by theory and suggested by experiments. However, the metallic behavior in the antiferromagnetic ordered state seems to deviate from such scenario. Our discovery of signatures of coherent polarons in electronic bandstructure probed by angle resolved photoemission (ARPES) reconciles this contrast. Our finding also highlights the non-trivial enrichment of many-body effects when multiple ingredients of interactions reinforce each other.

P2-169 Theoretical explanation of resistivity of iron-based superconductors La [O1-xFx] FeAs: Spin fluctuation mechanism - *D. Prasad (Shri Vaishnav Institute of Technology and Science)*

Temperature-dependant resistivity of Iron-Based superconductors $La[O_{1-x}F_x]FeAs$ (for x = 0.12) is theoretically analysed by considering the strong spin fluctuations effect. In addition to the spin fluctuation-induced contribution the electron–phonon $\rho_{e-ph}(T) = AT$, and electron–electron $\rho_{e-e}(T) = BT^2$ contributions are also incorporated for complete understanding of experimental data.

For realistic calculation of temperature dependence resistivity of $La[O_{0.88}F_{0.12}]FeAs$ we use the value of some physical parameters as $A = 2.6\times10^{-6}$ W cm/K, $B = 3.16\times10^{-8}$ Wcm/K^2, $E_F = 0.4$ eV and $w_p = 2.3$ eV. Our numerical results on temperature dependence of resistivity are plotted in figure 1 along with the single crystal data [3]. We have noticed from the plot that the estimated *r* using quadratic electron-electron, linear electron-phonon and spin fluctuation contributions can successfully revels the experimental data on temperature dependence resistivity of iron based superconductors. The pessimism with respect to the role of electron–phonon interaction mentioned above, as well as the closeness of superconducting phase to antiferromagnetic on the phase diagram of new superconductors, has lead to the growth of popularity of pairing models based upon the decisive role of spin fluctuations, in many respects similar to those already considered for HTSC cuprates. Although, the electron-phonon contribution is not responsible for superconductivity but phonon scattering play a significant role in electrical resistivity, which shows conventional linear temperature dependence along with spin fluctuation and electron-electron contributions.

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P2-171 ARPES study of symmetry breaking orbital anisotropy in detwinned iron-pnictides - *D. Lu (SSRL, SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025), K. Kihou, C. Lee, A. Iyo, H. Eisaki (AIST, Tsukuba, Ibaraki 305-8568, Japan), S. Mo, Z. Hussain (ALS, Lawrence Berkeley National Lab, Berkeley, CA 94720), T. Yoshida, A. Fujimori (Department of Physics, University of Tokyo, Hongo, Tokyo 113-0033, Japan), M. Yi, J. Chu, J. Analytis, A. Sorini, A. Kemper, B. Moritz, R. Moore, W. Lee, T. Devereaux, I. Fisher, Z. Shen (SIMES, SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025), M. Hashimoto (SSRL, SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025)*

High-temperature superconductivity often emerges in the proximity of a symmetry-breaking competing phase. In the case of iron-pnictide superconductors, a tetragonal to orthorhombic structural transition and paramagnetic to collinear SDW transition are present in the underdoped region, with both transitions breaking the C4 rotational symmetry. Evidence for strong in-plane anisotropy in the SDW state has been reported by neutron scattering, STM and transport measurements. We use angle-resolved photoemission spectroscopy to study twinned and detwinned iron pnictides Ba(Fe1-xCox)2As2 [1] and NaFeAs [2]. Distinct signatures of electronic reconstruction associated with the structural (Ts) and magnetic (Tsdw) transitions have been observed. At Ts, C4 rotational symmetry is broken in the form of an anisotropic shift of the orthogonal dxz and dyz bands. The magnitude of this orbital anisotropy rapidly develops to near completion upon approaching Tsdw, at which temperature band folding occurs via the antiferromagnetic ordering wave vector. Interestingly, the anisotropic band shift onsetting at Ts develops in such a way to enhance the nesting conditions in the C2 symmetric state, hence is intimately correlated with the long range collinear AFM order. Furthermore, the band splitting is observed slightly above Ts for unstressed crystals, whereas for stressed crystals it occurs at considerably higher temperatures, revealing the presence of a surprisingly large in-plane electronic nematic susceptibility in the electronic structure. These observations suggest that the orbital fluctuations may play an important role in determining the ground state properties in iron-based supcerconductors.

This work is supported by DOE Office of Basic Energy Science, Division of Materials Science and Engineering, under contract DE-AC02-76SF00515.

[1] M. Yi *et al.*, PNAS 108, 6878 (2011).
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P2-172 Low-Energy Quasiparticles Probed by Heat Transport in the Iron Based Superconductor LaFePO - *R. Hill (University of Waterloo), J. Analytis, I. Fisher (Stanford University), M. Sutherland, E. O'Farrell (University of Cambridge), W. Toews, J. Dunn (University of Waterloo)*

We have measured the thermal conductivity of the iron pnictide superconductor LaFePO down to temperatures as low as T=60mK and in magnetic fields up to 5 T. The data shows a large residual contribution that is linear in temperature, consistent with the presence of low energy electronic quasiparticles. We interpret the magnitude of the linear term, as well as the field and temperature dependence of thermal transport in several pairing scenarios. The presence of an unusual super-linear temperature dependence of the electronic thermal conductivity in zero magnetic field, and a high scattering rate with minimal Tc suppression argues for a sign-changing nodal s+/- state.

This research was supported by NSERC of Canada and the Royal Society. Work at Stanford University was supported by the Department of Energy, Office of Basic Energy Sciences under contract DE-AC02-76SF00515.

P2-173 In-plane Structural and Electronic Anisotropy of the Iron-based Superconductors - ***Erick Christopher Blomberg, The Ames Laboratory and Iowa State University, Grad Student; Makariy Tanatar, The Ames Laboratory and Iowa State University, United States of America; Ruslan Prozorov, The Ames Laboratory and Iowa State University, United States of America; Paul Canfield, The Ames Laboratory and Iowa State University, United States of America; Sergey Bud'ko, The Ames Laboratory and Iowa State University, United States of America; Alex Thaler, The Ames Laboratory and Iowa State University, United States of America; Ni Ni, Los Alamos National Lab, United States of America; Bing Shen, Institute of Physics, Chinese Academy of Sciences, China; Hai-Hu Wen, Chinese Academy of Sciences, China***

Upon cooling, the parent compounds of iron-arsenide superconductors, AFe_2As_2 (A=Ba, Ca, Sr), undergo a structural transition from a tetragonal to orthorhombic crystal symmetry, at a characteristic temperature T_{TO}, as well as long range magnetic ordering into an antiferromagnetic stripe phase at T_N. The symmetry lowering at the structural transition leads to formation of four degenerate "twin" domains, which are crystallographically identical, but have different orientations within the orthorhombic ab-plane. The crystal becomes equally populated with each domain orientation masking any direct measurement of in-plane anisotropy.

The application of uniaxial mechanical stress or strain can make one domain orientation far more energetically favorable than the others. Therefore a crystal can "de-twinned " into a state where the dominant domain occupies more than 90 percent of the crystal's volume fraction allowing for the study of in-plane anisotropy measurements.

Here, we will describe the process of mechanical de-twinning and report the major results of our studies of in-plane anisotropic properties in iron-arsenide superconductors.

Work at Ames Laboratory was supported by the U. S. Department of Energy, Basic Energy Sciences, under Contract No. DE-AC02-07CH11358.

P2-174 Observation of temperature-induced orbital-selective Mott transition in iron selenide superconductors - ***M. Yi (Department of Physics and Stanford Institute of Materials and Energy Sciences, Stanford University), S. Mo, Z. Hussain (Advanced Light Source, Lawrence Berkeley National Lab, Berkeley), R. Yu, Q. Si (Department of Physics and Astronomy, Rice University), B. Lv, C. Chu (Department of Physics, University of Houston), S. Riggs, J. Chu, Z. Liu, M. Lu, Y. Cui, I. Fisher, Z. Shen (Stanford Institute of Materials and Energy Sciences, Stanford University), D. Lu, M. Hashimoto (Stanford Synchrotron Radiation Lightsource, SLAC National Accelerator Laboratory)***

Electron correlation strength is an issue of fundamental importance in the study of high temperature superconductors—the cuprates and iron-based superconductors (FeSC)—as it sets the basis for theoretical understanding. The cuprates are strongly correlated as superconductivity is understood to emerge by doping a Mott insulator. In contrast, the bad metal behavior of most FeSC seems to suggest weaker correlation, as confirmed by early experiments. Recently, a new family of iron selenide superconductors (FeSeSC)—$A_xFe_{2-y}Se_2$ (A=K, Cs, Rb)—was discovered, as the first FeSC with insulating behavior in the phase diagram. Theoretical calculations have suggested stronger correlation in this family, in proximity to Mott insulating phase, in particular an orbital-selective Mott phase. Here, we present angle-resolved photoemission spectroscopy (ARPES) studies of superconducting $A_xFe_{2-y}Se_2$ (A=K, Rb), in which we observe for the first time a temperature-induced orbital-selective Mott transition: the d_{xy} band undergoes a Mott transition with vanished spectral weight at the Fermi level while d_{xz}/d_{yz} bands remain metallic. Our theoretical calculations show that for such a temperature-induced transition to occur, the strengths of Hund's coupling and Coulomb repulsion in these FeSeSC are such that their low temperature ground state is very near the boundary of an orbital-selective Mott phase.

This work is supported by DOE Office of Basic Energy Science, Division of Materials Science and Engineering, under contract DE-AC02-76SF00515.

P2-175 Entanglement Spectrum of Iron-based Superconductors - ***N. Bray-Ali (Joint Quantum Institute, Univ. of Maryland and NIST)***

The entanglement spectrum of iron-based superconductors provides insight into their pairing symmetry, Andreev surface states, and pairing mechanism. We calculate the entanglement spectrum for pnictides and chalcogenides, including the recently discovered selenides, using a slave-particle approach. We find topologically protected Andreev surface states for a number of compounds and evidence for unconventional pairing symmetry. We comment on recent experiments and various proposals for the pairing mechanism of iron-based superconductors.

This work was generously supported by a grant from the National Research Council Postdoctoral Research Associateship Program.

P2-176 Complex magnetic order in (R)FeAsO single crystals at low temperatures - ***A. Kreyssig (Ames Laboratory & Iowa State University), B. Jensen, K. Dennis, T. Lograsso, J. Zarestky (Ames Laboratory), M. Kim (Ames Laboratory & Iowa State University), R. McCallum, R. McQueeney, A. Goldman (Ames Laboratory and Iowa State University), J. Kim (APS, ANL), S. Nandi (JCNS, Juelich, Germany; Ames Laboratory & Iowa State University), W. Ratcliff II (NCNR, NIST Gaithersburg), J. Lynn (NCNR, NIST Gaithersburg), W. Tian (NScD, ORNL and Ames Laboratory), J. Yan (ORNL and Ames Laboratory)***

In iron-based high-temperature superconductors, magnetic fluctuations and magneto-elastic effects are believed to be important for the superconducting electron pairing mechanism. To gain insight into the interplay between the different ordering phenomena and the underlying couplings we studied the magnetic order and lattice distortion on (R)FeAsO single crystals by neutron and x-ray diffraction. The onset of rare earth [(R) = Nd, Pr] magnetic order is coupled to changes in the iron magnetic structure without affecting the lattice distortion. High-resolution neutron and x-ray resonant magnetic scattering measurements down to 0.4 K revealed complex magnetic structures with multiple propagation vectors.

P2-177 Consistent theory of magnetism and superconductivity in iron superconductors - *V. Antropov, L. Ke (Ames Laboratory USDOE), M. van Schilfgaarde (King's College), M. Katsnelson (Radboud University)*

Crucial questions in understandings of newly discovered iron superconductors are related with a nature of superconducting pairing and specific features of these materials in a normal state that lead to the existence and stabilization of superconductivity. We argue that all iron superconductors belong to the specific class of highly responsive materials with strong spin quantum fluctuations. These fluctuations are essentially non-linear and highly anharmonic. They result in both the observed magnetic properties of a normal state and the appearance of strong spin-electron interaction, responsible for the spin-fluctuation induced superconductivity. Thus, we identify a type of spin fluctuations which make these materials so peculiar, show why they appear in these materials, and suggest a way for an experimental search of new similar materials.

P2-178 Metal-to-Insulator Transition in Multi-Orbital Models for AxFeySe2 - *R. Yu (Department of Physics, Rice University*

The degree of electron correlations remains a central issue in the area of iron-based superconductors. Compared to other compounds, the newly discovered $A_xFe_ySe_2$ family have some striking features. The Fermi surface consists of only electron pockets, while Tc is as high as their pnictides counterparts. Furthermore, the superconducting compound is close to an antiferromagnetically insulating phase with a large magnetic moment, suggesting that the electron correlations here are stronger than the case of the pnictides. To investigate the correlation effects in $A_xFe_ySe_2$, I will present a study of the metal-to-insulator transition in multi-orbital models for this system using a slave-spin method. I will show that when electron correlations are tuned, the system undergoes a metal-to-Mott-insulator transition at electron fillings of the parent compounds (Fe+2), with or without ordered vacancies. The Mott insulator is close to an orbital-selective Mott phase (OSMP) in the phase diagram. In the doped systems, I will demonstrate a temperature induced transition to an OSMP. I will compare our theoretical results with recent ARPES experiments in superconducting $A_xFe_ySe_2$, and conclude with a discussion of the implications of our results for magnetism and superconductivity in $A_xFe_ySe_2$ and other Fe-based compounds.
Work done in collaboration with Q. Si, J.-X. Zhu, M. Yi, D.-H. Lu, and Z.-X. Shen.

P2-179 FeSe0.5Te0.5 thin films with critical current density above 1MA/cm2 - *W. Si, X. Shi, I. Dimitrov, Q. Li (Condensed Matter Physics and Material Science Dept., Brookhaven National Laboratory)*

High quality $FeSe_{0.5}Te_{0.5}$ thin films have been prepared on various substrates, such as $SrTiO_3$, $LaAlO_3$ and YSZ, some with buffer layers. T_c's as high as 20K with superconducting transition widths of about 1K were obtained. These T_c's are much higher than those of bulk $FeSe_{0.5}Te_{0.5}$ (~15K). Our films carry high critical current densities J_c's (above 1MA/cm^2) at liquid helium temperature. These films hold J_c's on the order of 1×10^5A/cm^2 and very low J_c anisotropies (< 3) under magnetic fields as high as 30T at 4.2K. We have also prepared textured $FeSe_{0.5}Te_{0.5}$ thin films on buffered metal templates such as IBAD and RABiTS coated conductor substrates, which were developed for high T_c cuprates, with results similar to the ones on single crystalline substrates. This shows that iron chalcogenides have a very promising future for high-field applications at liquid helium temperatures. Pinning force analysis indicates the presence of a point defect flux-pinning mechanism, suggesting a straightforward approach to conductor optimization.

Invited Sessions

I6 - Fermiology of Underdoped Cuprates
Regency, 3:30 PM to 6:00 PM
Session Chair: Bernhard Keimer

I6-01 Fermi surface reconstruction by stripe order in cuprates - *C. Proust (Laboratoire National des Champs Magnétiques Intenses - Toulouse)*

25 years after the discovery of high temperature cuprate superconductors, the observation of quantum oscillations has deeply changed the theoretical landscape relevant to these materials. The measurements of quantum oscillations on both sides of the phase diagram of cuprates confirm the existence of a Fermi surface with sharply defined excitations on the overdoped side but also show that the Fermi surface has suffered a drastic modification on the underdoped side. The small Fermi pocket inferred from quantum oscillations in the underdoped regime combined with the negative Hall and Seebeck coefficients pointing to an electron pocket, demonstrate that the Fermi surface of $YBa_2Cu_3O_y$ undergoes a reconstruction because the translational symmetry of its lattice is broken at low temperature.
This order has recently been identified as an unidirectional 4a-periodic stripe modulation using NMR measurements in high magnetic fields. In this talk, I will discuss the impact of this charge order in some transport properties, e.g. Hall effect, Seebeck coefficient and *c*-axis transport. More information on this charge order has been obtained with sound velocity measurements. I will show that sound velocity is an unique thermodynamic probe that allows to observe the competition at low temperature between charge order and superconductivity.

I6-02 specific heat through the resistive transition to 45T in an underdoped cuprate - ***S. Riggs (Stanford University), J. Betts, A. Migliori, F. Balakirev (LANL, MagLab), O. Vafek, J. Kemper, G. Boebinger (MagLab, FSU), W. Hardy, D. Bonn, R. Liang (UBC)***

The upper critical field in a superconductor, Hc2, is *defined* as the applied magnetic field needed to destroy the superconducting gap. In electrical transport measurements, Hc2 is usually *determined* as the point where the magnetic-field-induced resistivity maps onto the zero field resistivity at temperatures above the superconducting transition temperature. When this happens the superconducting system is in a state referred to as the magnetic-field-induced-"normal"-state. Recent heat capacity measurements on YBa2Cu3O_{6.56} have shown that the application of magnetic field up to 45T does very little to suppress the d-wave superconducting gap, as evidenced by a sqrt{H} dependence on the quasi-particle density of states [1]. However, transport measurements, over this same magnetic field regime report a "normal"-state resistivity value once the magnetic field destroys the zero resistance state [2]. If the YBa2Cu3O_{6.56} system has a well defined d-wave quasi-particle density of states and a "normal"-state resistivity value, what implications does this have for models of superconductivity in the High-Tc cuprates? We discuss possible interpretations in the context of proposed Fermi surface reconstruction scenarios [3].

[1] Scott C. Riggs, et al., *Nature Physics* **7**, 332-335 (2011).
[2] N. Doiron-Leyraud, et al., *Nature* **447**, 565–568 (2007).
[3] S. E. Sebastian, et al., *Nature* **454**, 200–203 (2008).

I6-03 Nodal pocket yielding multiple quantum oscillation frequencies in the underdoped cuprate superconductor YBa2Cu3O6+x - ***S. Sebastian (University of Cambridge), C. Mielke (National High Magnetic Field Laboratory, Los Alamos), N. Harrison, M. Altarawneh (National High Magnetic Laboratory, Los Alamos), R. Liang, W. Hardy, D. Bonn (University of British Columbia), G. Lonzarich (University of Cambridge)***

Quantum oscillations have proved a vital tool in uncovering the electronic structure underlying the normal state of the underdoped cuprates. Our experiments have established that quasiparticles in this regime are governed by fermi dirac statistics, yet a comprehensive description of the fermi surface geometry remains elusive. The location, carrier type, and multiplicity of fermi pockets that constitute the electronic structure are still the subject of intense debate, with complementary experiments and techniques yielding seemingly dichotomous interpretations. We use an array of quantum oscillation measurements in the underdoped cuprate YBa2Cu3O6+x in tandem with results from complementary experimental techniques to distinguish between alternative Fermi surface possibilities; evidence strongly points to a Fermi surface comprising a nodal pocket, giving rise to the multiple observed quantum oscillation frequencies.

S. E. Sebastian et al., Nature Communications 2, Article number: 471

I6-04 Magnetic quantum oscillations in electron-doped cuprate superconductors - ***M. Kartsovnik (Walther-Meissner-Institut), E. Kampert, J. Wosnitza (Hochfeld-Magnetlabor Dresden), S. Lepault, C. Proust (Laboratoire National des Champs Magnétiques Intenses, CNRS), A. Kiswandhi, E. Choi, J. Brooks (National High Magnetic Field Laboratory), C. Putzke (University of Bristol), T. Helm, W. Biberacher, A. Erb, R. Gross (Walther-Meissner-Institut)***

We present the current status of the Fermi surface studies in the bulk of electron-doped cuprate superconductor $Nd_{2-x}Ce_xCuO_4$ by means of magnetic quantum oscillations of magnetoresistance (Shubnikov-de Haas effect). The oscillations are observed for Ce concentrations *x* starting from 0.145 (optimal doping) up to 0.17 (strongly overdoped composition). The data give evidence of a weak (*p*/*a*,*p*/*a*)-superlattice potential persisting over the whole overdoped range available for bulk crystals. The dependence of the oscillation amplitude on the field orientation indicates a magnetic nature of the relevant ordering. The superlattice energy gap is very small, ~ 10^{-2} eV; it is gradually suppressed at increasing the doping level, extrapolating to zero right at the edge of the superconducting dome, *x* » 0.175. This suggests a close relation between superconductivity and the competing ordering instability.

Decreasing the doping below the optimal level leads to a dramatic suppression of the oscillation amplitude and a considerable increase of the effective cyclotron mass. A possibility of a quantum phase transition leading to a collapse of the classical cyclotron orbits on a closed Fermi surface just slightly below optimal doping is corroborated by dramatic changes in the nonoscillating component of magnetoresistance and Hall coefficient as well as by the behavior of the quantum oscillations in the sister compound $Pr_{2-x}Ce_xCuO_4$.

This work was supported by the German Research Foundation via the Research Unit FOR 538 and Grant No. GR 1132/15, EuroMagNET II under the EC Contract No. 228043 as well as by the German Excellence Initiative via NIM.

I6-05 Contrasting quantum oscillations in n- and p-doped cuprates - ***S. Chakravarty (University of California Los Angeles)***

We consider quantum oscillation experiments in cuprates from both a commensurate (period-2) as well as an incommensurate (period-8) d-density wave order using an exact transfer matrix method and the Pichard-Landauer formula for the conductivity. While the electron-doped materials can be understood in detail using the commensurate choice, including magnetic breakdown effects, the hole-doped case is better understood using period-8 order in which the current density is unidirectionally modulated, similar to stripes. This current modulation is accompanied by a period-4 site charge modulation, as allowed by Landau theory, which is consistent with a recent magnetic resonance experiment, with approximately the observed magnitude of the modulation. Our work provides a natural explanation why in hole-doped cuprates only oscillations from a single electron pocket is observed, and a hole pocket of roughly twice the frequency, as dictated by period-2 order and concomitant Luttinger sum rule, is not seen. The reason is that for period-8 order the hole pocket frequency is too small, and magnetic fields necessary to observe it are at the borderline of what is achievable. Clearly at least a few such oscillations have to be resolved. However, the very coexistence of the hole pocket, however small, provides a simple reason for the oscillations of the Hall

coefficient. The advantage of d-density wave is that it is effectively hidden, as compared to spin density wave, which is not present in the relevant range of parameters. We also find that the linear coefficient of the specific heat is within a factor of 2 of the observed value at about 45 T.
This work is supported by NSF under the Grant DMR-1004520 and is based on collaborations with J. Eun, Z. Wang, and X. Jia.
References: Science 319, 735 (2008); Phys. Rev. B 84, 094506 (2011); Phys. Rev. B 82, 094515 (2010); manuscript in preparation.

I6-06 Stripes, fractionalized Fermi liquids, and the cuprate pseudogap - *M. Vojta (Technische Universitaet Dresden)*

I will discuss aspects of hole-doped cuprate superconductors, with an attempt to connect stripe order, pseudogap formation, and the existence of small Fermi pockets as deduced from quantum-oscillation measurements. I will follow the idea that the pseudogap regime is properly described as a hole-doped spin liquid, which emerges as a result of doping a Mott insulator. This connects to the concepts of selective Mott phases and fractionalized Fermi liquids, originally developed to describe non-Fermi liquid behavior in multi-band systems. Concrete results will be presented for stripe-ordered fractionalized Fermi liquids, which will be confronted with experimental data.

I7 - Properties of 245 Pnictide Compounds
Palladian, 3:30 PM to 6:00 PM
Session Chair: Paul Canfield

I7-01 ARPES measurements on the superconducting gap in AxFe2-ySe2 - *H. Ding (Institute of Physics, CAS)*

In this talk, I will present our recent ARPES results on the AxFe2-ySe2 (A = Tl, K), mainly focusing on high-resolution measurements of the superconducting gap. Our results clearly suggest that there is no node in the superconducting gap, indicating that its pairing mechanism is likely to be driven by strong-coupling local antiferromagnetic exchange interactions.

I7-02 Neutron Scattering Study on the Fe-based Superconductors - *W. Bao (Renmin Univ. of China)*

Iron-based superconductors in several related structure families with Tc as high as 56 K have generated much excitement in the last three years, and new discovery continues to appear. Using neutron scattering technique, we have determined crystal and magnetic structure of several families of the new Fe superconductors and their sample composition [1-3], which provide solid foundation for further investigation on electronic structure and processes. Structural and magnetic transitions have been investigated to yield phase-diagrams which show a rich variety of relationship between superconducting and antiferromagnetic orders [4]. Such investigation also reveals the shortcoming of widely accepted spin-density-wave theoretic scenario and provides first experimental indication of important role played by the orbital order [2]. The symmetry of superconducting order parameter has strong signature in magnetic excitation spectrum. We observed with inelastic neutron scattering method the telltale spin resonance mode of the unconventional s+/- symmetry in the superconducting state of the 11 superconductor [5]. The normal state was shown to exhibit the single-lobed incommensurate excitation continuum of a typical itinerant antiferromagnet, in contrast to spin-wave cone of a localized antiferromagnet [6], supporting a Fermi liquid description of the normal state.

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[4] H. Chen et al., EPL. 85, 17006 (2009); T.J. Liu et al., Nat. Materials 9, 718 (2010); W. Bao et al., arXiv:1102.3674 (2011).
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I7-03 Magnetic Resonant Mode in the Superconducting Phase of A(x)Fe(2-y)Se(2) (A = K, Rb) Single Crystals - *D. Inosov (Max-Planck-Institut für Festkörperforschung, Stuttgart), V. Tsurkan, J. Deisenhofer, A. Loidl (Center for Electronic Correlations and Magnetism, Institute of Physics, Augsburg University), A. Ivanov (Institut Laue-Langevin, Grenoble), G. Friemel, J. Park, B. Keimer (Max-Planck-Institut für Festkörperforschung, Stuttgart)*

We employ inelastic neutron scattering to study the reciprocal-space structure and dispersion of magnetic excitations in the normal and superconducting states of single-crystalline $Rb_{0.8}Fe_{1.6}Se_2$ and $K_{0.8}Fe_{1.8}Se_2$. In the superconducting state of both samples, we observe a magnetic resonant mode centered at an energy of $h\omega_{res}$ = 14 meV near the commensurate wave vector (1/2 1/4 1/2) in the unfolded Fe-sublattice notation, which differs from the ones characterizing magnetic resonant modes in other iron-based superconductors. Our finding suggests that the 245-iron-selenides are unconventional superconductors with a sign-changing order parameter, in which bulk superconductivity coexists with the √5 × √5 magnetic superstructure. The estimated ratios of $h\omega_{res} / k_B T_c$ = 5.1±0.4 and $h\omega_{res} / 2\Delta$ = 0.7±0.1, where Δ is the superconducting gap, indicate moderate pairing strength in this compound, similar to that in optimally doped 1111- and 122-pnictides [1]. We also found that the magnetic resonant mode has a quasi-two-dimensional character, similar to overdoped iron-pnictide superconductors. Moreover, it exhibits a rich in-plane structure that is dominated by four elliptical peaks, symmetrically surrounding the Brillouin zone corner (Fig. 1), without the √5 × √5 reconstruction. We also present evidence for the dispersion of the resonance peak, as its position in momentum space depends on energy. Comparison of our findings with the results of band structure calculations provides strong support for the itinerant origin of the observed signal. It can be traced back to the nesting of electronlike Fermi pockets in the doped metallic phase of the sample in the absence of iron-vacancy ordering [2].

[1] J. T. Park, et al., Phys. Rev. Lett. 107, 177005 (2011).
[2] G. Friemel et al., arXiv:1112.1636.

I7-04 Re-emergence of superconductivity at 48 K in iron chalcogenides - ***L. Sun (Institute of Physics, CAS), H. Wang, M. Fang (Department of Physics, Zhejiang University), X. Chen, H. Mao (Geophysical Laboratory, Carnegie Institution of Washington), L. Wang (HPSynC, Geophysical Laboratory, Carnegie Institution of Washington), J. Guo, P. Gao, X. Chen, G. Chen, Q. Wu, C. Zhang, D. Gu, X. Dong, X. Dai, Z. Zhao (Institute of Physics, CAS), Q. Huang (NIST Center for Neutron Research, National Institute of Standards and Technology), K. Yang (Shanghai Synchrotron Radiation Facilities), A. Li (yangke@sinap.ac.cn)***

Pressure plays an essential role in the induction1 and control2,3 of superconductivity in iron-based superconductors. Substitution of a large cation by a smaller rare-earth ion to simulate the pressure effects has raised the superconducting transition temperature TC to a record high of 55 K in these materials4,5. Analogous to the bell-shaped curve of TC dependence on chemical doping, pressure-tuned TC typically drops monotonically after passing the optimal pressure 1-3. Here we show the observations of an unexpected phenomenon in superconducting iron chalcogenides that after the TC dropped from the maximum of 32 K at 1 GPa and vanished (< 4 K) above 9.5 GPa, a second superconducting phase with considerably higher TC than the first maximum suddenly reemerged above 11.5 GPa. We find that the maximum TC of the reemerging superconducting phase reaches 48 - 48.7 K for Tl0.6Rb0.4Fe1.67Se2, K0.8Fe1.7Se2 and K0.8Fe1.78Se2, setting a new TC record for iron chalcogenide superconductors.

1.. M.S. Torikachvili, S.L.Bud'ko, N. Ni, P.C. Canfield, Phys. Rev. Lett. 101, 057006 (2008). 2. H. Takahashi et al. Nature 453, 376-378 (2008). 3. S. Medvedev et al. Nature Mater. 8, 630-633 (2010). 4. X.H. Chen, X. H. et al. Nature 453, 761-762 (2008). 5. Z.A. Ren et al. Chin. Phys. Lett. 25, 2215-2216 (2008).

I7-05 Optical spectroscopy study on Fe-chalcogenides AxFe2-ySe2 (A=K, Rb, Cs) - ***N. Wang (Institute of Physics, Chinese Academy of Sciences, Beijing 100190)***

I present our optical spectroscopic measurements on single crystals of iron-selenides $A_xFe_{2-y}Se_2$ (A=K, Rb, Cs). We show that the superconductivity develops from a small energy gap semiconductor with an indirect gap E_g~30 meV. The major spectral features are found to be distinctly different from all other Fe-based superconductors. For both semiconducting and superconducting compounds, we observed two peculiar spectral features in optical conductivity: a double peak structure between 4000-6000 cm^{-1} and abundant phonon modes much more than those expected for a 122 structure. We elaborate that those features could be naturally explained from the blocked antiferromagnetic structure due to the presence of Fe vacancy ordering as determined by neutron diffraction experiments. For the superconducting $K_{0.75}Fe_{1.75}Se_2$compound, our measurement revealed the development of a sharp reflectance edge below T_c at frequency much smaller than the superconducting energy gap on a relatively incoherent electronic background. Furthermore, the feature could be noticeably suppressed and shifted to lower frequency by a moderate magnetic field. Our analysis indicates that this edge structure arises from the development of a Josephson-coupling plasmon in the superconducting condensate. Together with the transmission electron microscopy analysis, our study yields compelling evidence for the presence of nanoscale phase separation between superconductivity and magnetism.

Work done with R. H. Yuan, Z. G. Chen, T. Dong, P. Zheng, J. Q. Li

I7-06 Critical magnetic fluctuation in the superconducting ferropnictidesn-based superconductors - ***T. Xiang (Institute of Physics/Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190)***

In this talk, I will discuss about the effect of quantum critical magnetic fluctuations on the superconducting state of iron pnictides. The effective mass of quasiparticle is shown to be strongly enhanced close to the critical point. This leads to a suppression of the superfluid density in the critical regime, consistent with experimental observation. The influence of quantum critical fluctuation on the neutron scattering spectra and other physical quantities will be also discussed.

I8 - Theory of Pairing in Pnictides
Diplomat, 3:30 PM to 6:00 PM
Session Chair: Igor Mazin

I8-01 Theory of gap structure and pairing symmetry in iron-pnictide superconductors - ***A. Chubukov (University of Wisconsin)***

I discuss the pairing mechanism and the symmetry of the superconducting gap in Fe-based superconductors (FeSCs) with only hole or only electron pockets. I argue that the gap in FeScs with only hole pockets is an s-wave, whose structure is determined by the interplay between intra-pocket and inter-pocket interactions between the two nearly identical hole pockets. The gap changes sign between these hole pockets and has strong 4-fold angular variation and accidental nodes on one or several hole pockets. The strong angle dependence is the consequence of near-degeneracy between inter-pocket and intra-pocket interactions involving the two hole pockets. For FeSCs with only electron pockets, like KFe2Se2, the situation is more complex as the pairing condensate itself contains intra-pocket and inter-pocket components, the latter is made out of fermions belonging to different electron pockets. I discuss the interplay between intra-pocket and inter-pocket pairing, depending on the ellipticity of electron pockets and the strength of their hybridization, and show hat with increasing hybridization the system undergoes a transition from a d-wave state to an s-wave state, in which the gap changes sign between hybridized pockets. Such an s-wave state has the full gap and at the same time supports spin resonance, in agreement with the data. Near the boundary between d and s- states there is region of an s+id state which breaks time-reversal symmetry. I also discuss the gap structure in the underdoped region, where superconductivity emerges from a pre-existing spin-density-wave state which reconstructs hole and electron pockets. I argue that the reconstruction induces additional angle dependence of the interaction which may give rise to accidental nodes.

S. Maiti, M. M. Korshunov, T. A. Maier, P. J. Hirschfeld, and A. V. Chubukov, Phys. Rev. B **84**, 224505 (2011); S. Maiti, M. M. Korshunov, and A. V. Chubukov, Phys. Rev. B **85**, 014511 (2012); S. Maiti, R.M. Fernandes, and A. V. Chubukov, arXiv:1203.0991; M. Khodas and A.V. Chubukov, arXiv:1202.5563. This work was supported by NSF-DMR-0906953.

I8-02 Orbital Fluctuation Mediated Superconductivity and Structure Transition in Iron-Based Superconductors - *H. Kontani, S. Onari (Nagoya University)*

Since the discovery of iron-based superconductors, both the spin-fluctuation-mediated s+- state (with sign reversal) [1] and the orbital-fluctuation-mediated s++ state (without sign reversal) [2] had been proposed. The latter scenario is supported by the robustness of Tc against impurities in many iron-pnictides [3] and orbital-independent gap observed in $BaFe_2(As,P)_2$ and $(K,Ba)Fe_2As_2$ by laser ARPES measurement [4]. Theoretically, impurity-induced crossover from s+- state to s++ state had been discussed [2].

Possible origin of orbital order or fluctuation had been actively discussed, mainly based on the multiorbital Hubbard model with U=U'+2J and J>0. In the random-phase-approximation (RPA), the spin susceptibility is always larger than the orbital susceptibilities. Thus, the RPA fail to explain experimental ``nonmagnetic'' structure transition.

In Ref. [2], we had introduced the "charge quadrupole interaction" caused by e-ph interaction due to Fe-ion oscillation [2]. Recently, we have shown that this interaction term is also induced by the Coulomb interaction, due to the Azlamasov-Larkin type vertex correction (VC) that is absent in the RPA [5]. The induced AF-orbital fluctuations give the s++ wave superconducting state with “orbital independent gap function” [4]. In addition, the VC also produces the strong ferro-orbital (O_{x2-y2} ~ n_{xz}-n_{yz}) susceptibility, which causes the orthorhombic structure transition and the softening of shear modulus C66 [6].

In this talk, we show that the self-consistent-VC analysis for the multiorbital Hubbard model [5] predicts the development of strong ferro- and AF-orbital fluctuations, which offers a unified explanation for both the s++ -wave state and the structure transition.

1. I. I. Mazin et al., PRL 101, 057003 (2008); K. Kuroki et al., PRL 101, 087004 (2008).
2. H. Kontani and S. Onari, PRL 104, 157001 (2010).
3. S. Onari and H. Kontani, PRL 103, 177001 (2009).
4. T. Saito et al., PRB 82, 144510 (2010).
5. S. Onari and H. Kontani, arXiv: 1203.2874.
6. H. Kontani et al., PRB 84, 024528 (2011).

I8-03 Iron-Based Superconductors: S_4 symmetry Superconductors - *J. Hu (Institute of Physics, CAS, Beijing, China and Dept of Physics, Purdue University, West Lafayette, IN)*

I show the underlining electronic structure in iron-based superconductors is an almost decoupled two-orbital model governed by S_4 symmetry. For each orbital, the doping level is near half filling. In the presence of repulsive interaction or next nearest neighbour antiferromagnetism, the A_{1g} s-wave pairing is favored in superconducting state. The s-wave pairing can be mapped to a d-wave pairing in a different gauge setting, which indicates the s-wave is equivalent to the d-wave in cuprates. This model unifies iron-pnictides and iron-chalcogenides. The S_4 symmetry also brings a new symmetry classification of the SC state. Even in A_{1g} s-wave pairing, there are two different phases. A sign-change between up and bottom AS(Se) layer along c-axis in a single fe-as(se) layer is expected in one of the phase.

1. Kangjun Seo, et al, *Phys. Rev. Lett*., 101, 206404 (2008).
2. Jiangping Hu, Hong Ding, Arxiv:1107.1334
3. Jiangping Hu and Ningning Hao arXiv: 1202.5881
4. Jiangping Hu, unpublished

I8-04 d-wave vs s-wave in iron-based superconductors: review of functional RG approach - *R. Thomale (Department of Physics, Stanford University)*

Iron-based superconductors such as pnictides and chalcogenides have created substantial interest in investigating their superconducting order parameter symmetries. In addition to various symmetry classes such as s-wave and d-wave, the multi-orbital character of these compounds and the gap anisotropy following from there plays a crucial role in determining the nature of superconducting pairing.

This class of superconductors hence represents an arena where material-dependent details of the microscopic orbital energy scales such as intra/interorbital, Hund, and pair hopping coupling admix with universal aspects of the pairing formation. We develop the functional renormalization group (FRG) to connect the orbital energy scales with the collective energy scales where superconductivity emerges. We give a survey of the materials classes 1111, 122, 111, and 11 to show which universal aspects of the superconducting pairing are found from the viewpoint of FRG, and compare them with experimental findings.

I acknowledge support by an SITP fellowship of Stanford university and grant support from DFG-SPP 1458/1 on iron based superconductors. Selected references: Thomale et al., Phys. Rev. B **80**, 180505 (2009); Phys. Rev. Lett. **106**, 187003 (2011); Phys. Rev. Lett. **107**, 117001 (2011); Platt et al., Phys. Rev. B **84**, 235121 (2011).

I8-05 Review of RPA approach in iron-based superconductors - *T. Maier (Oak Ridge National Laboratory)*

A multi-orbital Hubbard model random-phase approximation (RPA) framework has been extensively used to understand the type of pairing and the various gap structures that have been observed in the multi-Fermi surface iron-based superconductors. In this talk, I will review the main predictions of these calculations and discuss what they tell us about the sensitivity of the superconducting state to key aspects of the electronic structure. In particular, I will describe how the Fermi surface topology, its orbital character and the magnitude of the interaction parameters determine the symmetry of the superconducting gap, the degree of anisotropy and the presence or absence of nodes.

I8-06 The electron pairing mechanism for iron-based superconductors: FRG methods - *D. Lee (University of California, Berkeley), F. Wang (Massachusetts Institute of Technology)*

Trailing behind the cuprates, the iron-based compounds are the second–highest-temperature superconducting material family known to date. Despite the marked differences in the chemical composition, these materials share many properties with the cuprates and offer the hope of finally unveiling the secret of high-temperature superconductivity. The purpose of this talk is to review our results obtained using the functional renormalization group method in computing the effective interaction responsible for Cooper pairing in these novel materals[1,2,3].

1. F. Wang, H. Zhai, Y. Ran, A. Vishwanath, and D.-H. Lee, Phys. Rev. Lett. 102, 047005 (2009).
2. H. Zhai, F. Wang, and D.-H. Lee, Phys. Rev. B 80, 064517 (2009).
3. F. Wang and D.-H. Lee, Science 332, 200 (2011).

I9 - Interface and E-field Induced Superconductivity
Empire, 3:30 PM to 6:00 PM
Session Chair: Jean-Marc Triscone

I9-01 Direct imaging of the coexistence of ferromagnetism and superconductivity at the LaAlO3-SrTiO3 interface - *K. Moler (Stanford University)*

LaAlO3 (LAO) and SrTiO3 (STO) are both nonmagnetic band insulators, yet previous experimental and theoretical work has indicated a superconducting state at the interface, and suggested the possibility of ferromagnetism. We use scanning SQUID microscopy to image the magnetic behavior on micron length scales, mapping both patches of ferromagnetism and the local diamagnetic response of the superconductor. The variety of details in reports of magnetism, including our observation of a landscape (rather than a homogeneous phase) and a critical thickness similar to that for conductivity indicate that an interface reconstruction is necessary for the formation of magnetism but that local disorder is likely needed to induce magnetism in a population of the interface carriers. We also present local magnetic susceptibility measurements taken as a function of temperature and gate voltage as well as position. We show that by normalizing our superfluid density vs. temperature, curves taken at different gate voltages collapse to a single curve that is consistent with a full superconducting gap.

Collaborators: Christopher Bell, Julie A. Bert, Yasuyuki Hikita, Masayuki Hosoda, Harold Y. Hwang, Beena Kalisky, Minu Kim, Hilary Noad, Katja Nowack, Hiroki K. Sato, Yanwu Xie

I9-02 Anisotropic magneto-transport properties of SrTiO3/LaAlO3 interfaces - *Y. Dagan, M. Ben Shalom (School of Physics and Astronomy Tel Aviv University), E. Flekser (School of Physics and Astronomy, Tel Aviv University)*

Interfaces between oxides can host variety of phenomena that do not exist in their constituting materials. For example superconductivity coexisting with magnetism has been reported at the interface between the non-magnetic insulators $LaAlO_3$ and $SrTiO_3$. The superconducting transition temperature can be modified by varying carrier concentration.

We report on magneto-transport measurements as a function of gate voltage. We find the magnetoresistance (MR) to be strongly anisotropic. While the out of plane MR is dominated by orbital effects (quantum and classical), the in plane conductance is dominated by spin scattering processes. The latter is strongly anisotropic and depends on the angle between current and magnetic field. These results are consistent with magnetic ordering appearing below ~30K together with gate dependent strong spin-orbit interaction.

In the superconducting state the upper critical field parallel to the interface exceeds the Clogston- Chandrasekhar limit. Consistent with the large spin-orbit interaction found from the normal state transport.

Support from the Israel Science Foundation under grant No. 1421/08 and from the Ministry of Science is Acknowledged. A portion of this work was performed at the National High Magnetic Field Laboratory, which is supported by NSF Cooperative Agreement No. DMR-0654118, by the State of Florida, and by the DOE.

I9-03 liquid-gated interface superconductivity - *Y. Iwasa (University of Tokyo and RIKEN)*

Electric double layer (EDL) at electrochemical interfaces is an electrochemical concept proposed by Helmholtz 150 year ago. It is emphasized that the electric field at EDLs can be as large as 50 MV/cm, and thus accumulate two dimensional electron systems with the carrier density of more than one order of magnitude larger than what is realized in all solid devices. Electric double layer transistor (EDLT), which has a device configuration equivalent to the field effect transistors, is extremely powerful to control the state of two dimensional electron systems. We applied this technique to a variety of materials to establish a new paradigm of materials science at ultrahigh electric fields. One of the peculiar features is the electrical phase control beyond the simple current switching function in conventional field effect transistors. We have so far demonstrated electric field induced metal insulator superconductivity, ferromagnetism.

In this presentation, we discuss on the gate tuning of electronic states in several transition metal dichalcogenides, using a double gate structure. The devices are composed of channel materials with nanometer thickness made by a Scotch-tape technique, and top (liquid) and bottom (solid) gate materials, which are for course and fine tuning of carrier density, respectively. In particular, electric field effect can produce a high precision phase diagram, accessing a low carrier density region which have not been investigated in the conventional bulk synthesis.

This work has been made in collaboration with J. T. Ye, Y. Kasahara, H. T. Yuan, Y. J. Zhang, M. Nakano, T. Hatano, S. Shimizu, S. Shimizu, M. Kawasaki, and Y. Tokura. This work has been supported by Grant-in-Aid for Scientific Research (S) (No. 21224009) and FIRST Program from JSPS, and also by SICORP from JST.

I9-04 Electrostatic-doping into an organic Mott-insulator - *H. Yamamoto (Institute for Molecular Sciece), M. Nakano, Y. Iwasa, M. Kawasaki, R. Kato (RIKEN)*

Kappa-type BEDT-TTF system is an organic Mott-insulator with 1/2-bandfilling. It exhibits a d-wave superconducting phase at low temperature when it is pressurized to evoke Mott transition in its T vs. U/W (Temperature vs. Electron correlation) phase diagram by bandwidth-control. We have been investigating an organic Mott-FET, or field effect transistor with kappa-BEDT-TTF, to achieve 'band-filling-controlled' Mott

transition and superconductivity at an organic interface. By forcing kappa-BEDT-TTF to stay at the vicinity of insulator-metal or metal-superconductor transitions boundary by a strain effect from the FET substrate, it has become possible to observe electric-field induced superconductivity at low temperature. Either n-dope or p-dope can be observed in the superconducting FET behavior. In addition, a seamless connection between the bandwidth-controlled superconductivity and bandfilling-controlled superconductivity was observed.

[ref.] Y. Kawasugi, H. M. Yamamoto, et al, Phys. Rev. B, 84, 125129/1-125129/9 (2011).

I9-05 Coexistence of magnetic order and two-dimensional superconductivity at LaAlO3/SrTiO3 interfaces - *J. Mannhart (Max Planck Institute for Solid State Research, Stuttgart), F. Loder (Augsburg University, Augsburg), C. Richter, H. Boschker, W. Dietsche (Max Planck Institute for Solid State Research, Stuttgart)*

The LaAlO3/SrTiO3 interface provides an intriguing 2-dimensional electron system in which the coexistence of superconductivity and magnetism has been observed [1-3].

It has been suggested that the superconductivity and the magnetism are spatially separated: scanning SQUID microscopy measurements showed ferromagnetic domains surrounded by superconducting regions. Further, a separation of the two states between different bands has been proposed as well, such that the magnetism is due to localized electrons in the dxy derived band of the interface Ti, while the superconductivity occurs in the dxz and dyz derived bands. Yet, it is also possible that the groundstate of the LaAlO3/SrTiO3 interface is an unconventional superconductor that is intimately connected to the magnetism.

To clarify this issue, we will present detailed experiments.

[1] Li, L. et al., Nature Physics 7, 762 (2011).
[2] Bert, J.A. et al., Nature Physics 7, 767 (2011).
[3] Dikin, D.A. et al., Physical Review Letters 107, 056802 (2011)

I9-06 Superconductor-Insulator transition in the two-dimensional electron gas at the Mott-Insulator/Band-Insulator LaTiO3/SrTiO3 interface. - *J. Lesueur (LPEM ESPCI-CNRS-UPMC, Paris), S. Caprara, M. Grilli (Dipartimento di Fisica Universita di Roma "La Sapienza"), A. Rastogi, R. Budhani (Dpt of Physics, Indian Institut of Technology, Kanpur), D. Leboeuf, C. Proust (Laboratoire National des Champs Magnétiques Intenses, Toulouse), J. Biscaras, N. Bergeal, S. Hurand, C. Grossetete (LPEM ESPCI-CNRS-UPMC, Paris)*

Transition metal oxides display a great variety of quantum electronic behaviors where correlations often play an important role. The achievement of high quality epitaxial interfaces involving such materials gives a unique opportunity to engineer artificial materials where new electronic orders take place. It has been shown recently that a two-dimensional electron gas 2DEG could form at the interface of two insulators such as $LaAlO_3$ and $SrTiO_3$ [1], or $LaTiO_3$ (a Mott insulator) and $SrTiO_3$ [2].

We present low temperature transport and magneto-transport measurements up to 45 T on $LaTiO_3/SrTiO_3$ hetero-structures, whose properties can be modulated by field effect using a metallic gate on the back of the substrate. The corresponding phase diagram has been investigated, and superconductivity evidenced for the first time in this system[3], which is triggered by the appearance of high mobility carriers at the edge of the 2DEG[4]. A model has been developed to account for this observation, based on a coupling in the reciprocal space. Finally, we will discuss the quantum phase transition from a superconducting to insulating state.

[1] N. Reyren et al, Science 317, 1196 (2007)
[2] A. Ohtomo et al, Nature 419, 378 (2002)
[3] J. Biscaras et al, Nature Communications 1,89 (2010)
[4] J. Biscaras et al, arXiv:1112.2633

I10 - Vortex-related Superconductivity
Congressional, 3:30 PM to 6:00 PM
Session Chair: Wai-Kwong Kwok

I10-01 Comparative analysis of vortex pinning and dynamics in oxide, iron-based and MgB2 superconductors - ***L. Civale (Los Alamos National Laboratory)***

Vortex physics has been a topic of interest since the discovery of the oxide high temperature superconductors (HTS). The complex vortex phenomena in these materials arise from the strong influence of thermal fluctuations, which is a consequence of the small superconducting coherence length (x) and the large crystalline anisotropy (g). Although this behavior contrasts with the simpler physics in conventional low temperature superconductors, according to the present understanding there is no sharp boundary between them. It should be noted, however, that modern vortex matter models have been developed to describe the oxide HTS, thus it is important to test them in different systems. The discovery of the iron-based superconductors provides a chance to "bridge the gap" and check the validity of vortex matter theories in a new family of materials with broad ranges of T_c and g, where the small x in some of them results in large fluctuation effects similar to those in the oxide HTS. On the other hand, the multi-band superconductivity in the Fe-based compounds introduces a new level of complexity, requiring a re-evaluation of the concept of anisotropy in the vortex behavior. Valuable information can also be obtained from MgB_2, a chemically simpler two-band superconductor where x and g can be modified by doping. I will present an overview of vortex pinning mechanisms in oxide, iron-based and MgB_2 superconductors, which may arise from correlated or uncorrelated disorder, or from mixed pinning landscapes with combinations of both. Then I will discuss our recent studies of vortex matter in thin films and single crystals of these materials. I will present a comparative analysis of the vortex dynamics and the characteristics of the depinning excitations.

Research supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering

I10-02 Observation of Giant Vortex and Super-Dense Vortex Clusters in Nanometer-Scale Superconductors by Scanning Tunneling Spectroscopy - *D. Roditchev, T. Cren, L. Serrier-Garcia, C. Brun, F. Debontridder (Institut des Nanosciences de Paris, Universite Pierre et Marie Curie Paris 6 and C.N.R.S.-UMR 7588, 4 place Jussieu, 75252 Paris)*

When put in rotation, macroscopic quantum condensates develop a very peculiar collective response: Instead of rotating as a whole, they split in a huge number of small quantum tornados - vortices - that organize in a regular lattice [1]. The vortex currents circulate owing to the gradient of the condensate wave function that accumulates exactly 2Pi phase difference around each vortex core - the eye of the cyclone - where the wave function vanishes. This general quantum phenomenon was observed in superconductors, superfluids, Bose-Einstein condensates of ultra-cold atoms [2]. The confinement of quantum condensates to the scales comparable to their characteristic coherence length should modify the vortex lattice, leading to novel configurations [3]. Despite of 45 years of theoretical efforts, till recently there have not been relevant experiments on this topic. Owing our home-made UHV STM/STS working down to 0.3K in magnetic fields up to 10T we succeeded to visualize the vortex phases strongly confined in individual superconducting nano-crystals of Pb deposited in-situ onto Si(111)-7x7 [4]. Starting from the simplest case of a single vortex confined in a superconducting box, in our lecture we will show how the confinement influences the vortex lattice leading to novel ultra-dense vortex configurations, impossible in bulk superconductors. At even higher confinement the Giant Vortices - quantum tornados characterized by a multiple phase accumulation L x 2p, L = 2; 3; 4 - are experimentally revealed by STS for the first time; their unusual cores will be discussed.

[1] Abrikosov, A. A. Sov. Physics JETP 5, 1174 (1957). [2] Essmann, U. & Trauble, H. Physics Letters 24A, 526 (1967); Yarmchuk et al. Phys. Rev. Lett. 43, 214217 (1979); Abo-Shaeer et al. Science 292, 476 (2001). [3] Saint-James, Phys. Lett. 15, 1 13 (1965). [4] Cren, T. et al. Phys. Rev. Lett. 107, 097202 (2011).

I10-03 Role of the vortex-core energy in the Beresinskii-Kosterlitz-Thouless transition - ***L. Benfatto (ISC-CNR and Department of Physics, Sapienza University of Rome, P.le A. Moro 2, 00185 Rome), C. Castellani (Department of Physics, Sapienza University of Rome, P.le A. Moro 2,00185 Rome), T. Giamarchi (DPMC- MaNEP University of Geneva, 24 Quai Ernest-Ansermet CH-1211, Geneva)***

The experimental advances made in the last decade in the investigation of superconducting phenomena in low-dimensional correlated electronic systems raised new questions on the nature of the Beresinskii-Kosterlitz-Thouless (BKT) transition in quasi-two-dimensional superconductors. A general issue concerns the possible limitations of theoretical predictions based on the *XY* model, that was studied as a paradigmatic example in the original formulation. Motivated by several issues connected to the physics of both high-temperature and low-temperature superconductors we revisited in the last few years the nature of the BKT transition within the general framework provided by the mapping into the sine-Gordon model [1]. While this mapping was already known since long, we recently emphasized the advantages on such an approach to account for new variables in the BKT physics. One such variable is the energy needed to create the core of the vortex, that is fixed within the *XY* model, while it attains substantially different values in real materials. This has interesting observable consequences, especially in the case when additional relevant perturbations are present, as a coupling between stacked two-dimensional superconducting layers [2,3], a finite magnetic field[4] or strong disorder[5].

[1] L.Benfatto, C.Castellani and T.Giamarchi arXiv:1201.2307
[2] L.Benfatto, C.Castellani and T.Giamarchi Phys. Rev.Lett. 98, 117008 (07)
[3] L.Benfatto, C.Castellani and T.Giamarchi Phys. Rev. B 77, 100506(R) (08)

[4] L.Benfatto, C.Castellani and T.Giamarchi Phys. Rev. Lett. 99, 207002 (07)
[5] M.Mondal et al Phys. Rev. Lett. 107, 217003 (11)

I10-04 The 2D vortex lattice viewed by very low temperature scanning tunneling microscopy and spectroscopy - ***H. Suderow (Laboratorio de Bajas Temperaturas, Departamento de Fisica de la Materia Condensada, Instituto Nicolas Cabrera, Facultad de Ciencias, Universidad Autonoma de Madrid), I. Guillamon (H.?H. Wills Physics Laboratory, University of Bristol, United Kingdom), R. Cordoba (Instituto de Nanociencia de Aragon, Universidad de Zaragoza, Zaragoza, 50009, Spain), J. Sesé, R. Ibarra (Instituto de Nanociencia de Aragon, Universidad de Zaragoza, Zaragoza, 50009, Spain; Departamento de Fisica de la Materia Condensada, Universidad de Zaragoza, 50009 Zaragoza, Spain), J. De Teresa (Instituto de Nanociencia de Aragon, Universidad de Zaragoza, Zaragoza, 50009, Spain; Instituto de Ciencia de Materiales de Aragon, Universidad de Zaragoza-CSIC, Facultad de Ciencias, Zaragoza, 50009, Spain), J. Galvis, A. Maldonado, P. Kulkarni, J. Rodrigo (Laboratorio de Bajas Temperaturas, Departamento de Física de la Materia Condensada, Instituto de Ciencia de Materiales Nicolás Cabrera, Universidad Autónoma de Madrid, E-28049 Madrid, Spain), S. Vieira (Laboratorio de Bajas Temperaturas, Departamento de Fisica de la Materia Condensada, Instituto Nicolas Cabrera, Facultad de Ciencias, Universidad Autonoma de Madrid)***

Scanning Tunneling Microscopy and Spectroscopy measurements in superconductors from down to 100mK up to the critical temperatures and magnetic fields have recently revealed insight into several aspects of vortex physics. Here I will present results on the vortex lattice in an amorphous focused ion beam deposited thin film hosting a two-dimensional vortex lattice. We have followed the vortex lattice compression at 100 mK in an area showing 3 vortices at low fields up to several thousands close to the critical field. Vortex pinning arises only due to small, nanometer size, modulations of the thickness, produced during the deposition when sweeping the focused ion beam. These modulations appear as lines in the topographic imaging and produce vortex re-orientations, which cease when the vortex density in between lines becomes large, above some hundreds of millitesla. Perfect topological order with decreasing positional correlation is then observed. When further increasing the magnetic field we first observe the appearance of isolated bound dislocation pairs.Then, their subsequent unbinding and proliferation produces a continuous depletion of the topological order and leads to a fully disordered vortex lattice at high fields. This zero-temperature transition follows closely Berezinskii Kosterlitz Thouless (BKT) theory for 2D melting, demonstrating that BKT scenario describes non-thermal phase transitions in 2D systems. Further, I will briefly present recent results about purely 2D superconductivity in transition metal dichalcogenides.

Guillamón et al., Nature Physics, 9, 651 (2009).
I. Guillamón et al., Phys. Rev. Lett., 106, 077001 (2011).

I10-05 Metastable and Ground State Vortex Lattice Phases in MgB2 - ***M. Eskildsen (Dept. of Physics, University of Notre Dame), N. Zhigadlo, J. Karpinski (ETH Zurich), C. Dewhurst (Institut Laue-Langevin), W. Gannon (Northwestern University), L. DeBeer-Schmitt (Oak Ridge National Laboratory), C. Rastovski, P. Das, K. Schlesinger, T. O'Brien (University of Notre Dame)***

Metastable phases of matter are well-known, with famous examples including supercooling and superheating of liquids and diamond which is one of the many allotropes of carbon. Metastability is almost exclusively observed in connection with first-order transitions, and is often found in frustrated systems where the energy difference between the states is small.

The vortex lattice (VL) symmetry and orientation in clean type-II superconductors depends sensitively on the host material anisotropy, vortex density and temperature, frequently leading to rich phase diagrams. Typically, a well-ordered VL is taken to imply a ground state configuration for the vortex-vortex interaction. Using small-angle neutron scattering we studied the VL in MgB_2 for a number of field-temperature histories, discovering an unprecedented degree of metastability in connection with a known, second-order rotation transition. This allows, for the first time, structural studies of a well-ordered, non-equilibrium VL.

Further studies to determine the mechanism responsible for the longevity of the metastable VL states show that these are not due to vortex pinning, suggesting instead a jamming of the VL domains which prevent a rotation to the ground state orientation. This is further supported by measurements using a transverse AC field to drive the VL into the ground state, showing the population having a logarithmic dependence upon the number of applied cycles indicative of glassy dynamics.

This work is supported by the US DOE Office of Basic Energy Science award no. DE-FG02-10ER46783.

I10-06 Dissipation-Free State in Nanopatterned Superconducting Systems - ***V. Vinokur (Argonne National Laboratory), T. Baturina, A. Mironov, D. Nasimov, A. Gutakovskii, A. Latyshev (A.V.Rzhanov Institute of Semiconductor Physics SB RAS, 13 Lavrentjev Avenue, Novosibirsk, 630090 Russia), J. Palacios (Departamento de Fisica de la Materia Condensada, Instituto de Ciencia de Materiales NicolasCabrera, Facultad de Ciencias, Universidad Aut´onoma de Madrid, E-28049 Madrid, Spain), I. Guillamon (H H Wills Physics Laboratory, University of Bristol, Tyndall Avenue,Bristol BS8 1TL, UK), M. Baklanov (IMEC Kapeldreef 75, B-3001 Leuven, Belgium), J. De Teresa (Instituto de Ciencia de Materiales de Aragon, Universidad de Zaragoza-CSIC, Facultad de Ciencias, Zaragoza, 50009, Spain), R. Cordoba (Instituto de Nanociencia de Aragon, Universidad de Zaragoza), J. Sese (Instituto de Nanociencia de Aragon, Universidad de Zaragoza, Zaragoza), R. Ibarra (Instituto de Nanociencia de Aragon, Universidad de Zaragoza, Zaragoza, 50018, Spain), S. Viera (Laboratorio de Bajas Temperaturas, Departamento de Fisica de la Materia Condensada, Instituto de Ciencia de Materiales Nicolas Cabrera, Facultad de Ciencias, Universidad Autonoma deMadrid, E-28049 Madrid, Spain), H. Suderow (Laboratorio de Bajas Temperaturas, Departamento de Fisica de la Materia Condensada, Instituto de Ciencia de Materiales Nicolas Cabrera, Facultad de Ciencias, Universidad Autonoma deMadrid, E-28049 Madrid, Spain8)***

Magnetic field penetrates type II superconductors in a form of Abrikosov vortices, which under the applied current move and dissipate energy, driving superconductors into a resistive state. Thus, the problem of immobilizing (pinning) vortices has become one of the major directions of superconducting studies during the past decades. The artificially engineered patterning, such as nanohole arrays, utilizing the geometric correspondence to arrays of vortices, the so-called vortex matching effects, holds highest promise for enhancing pinning and improving the performance of superconductors. Yet these effects are usually restricted to certain values of the magnetic field, where the vortex lattice and the nanopattern become commensurate which diminishes the usefulness of vortex matching phenomena for applications. Here we demonstrate that by the specific design of a nanopattern, confining vortices within the narrow superconducting constrictions, one can achieve a remarkably large, covering a wide magnetic field range, dissipation-free region within the domain of the resistive behavior. The underlying mechanism for the dissipation-free state is the confluence of surface superconductivity forming a sheath of superconducting channels, short-circuiting the resistance, and the aggregation of the individual vortices into giant vortex molecules (or hypervortices) with the extended vortex cores, which stabilize edge superconducting channels against the phase slips. Our results herald new understanding of the effects of magnetic field in low-dimensional superconductors and break the ground for the design of novel materials with the significantly enhanced superconducting performance.
This work supported by the Spanish MICINN and MEC
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FIS2011-23488 and ACI-2009-0905), by the Comunidad de
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of Energy Office of Science under the Contract No. DEAC02-
06CH11357.

S2 - ICAM / I2CAM Sponsored Public Lecture - From the Quantum to the Micron: The Mind-blowing Quest to Understand Matter and Life between the Angstrom and the Micron
Regency, 8:00 PM to 9:00 PM
Session Chair: Laura Greene

From the Quantum to the Micron: The Mind-blowing Quest to Understand Matter and Life between the Angstrom and the Micron - ***P. Coleman (Center for Materials Theory, Department of Physics and Astronomy, Rutgers, the State University of New Jersey)***

The Hitchhiker's guide to the Galaxy famously features a supercomputer, Deep Thought, that after millions of years spent calculating "the answer to the ultimate question of life, the Universe and everything else", reveals it to be 42! Douglas Adams cruel parody of our quest to understand our world, holds a certain sway today, for while we have most of the equations that govern matter on microscopic scales we can not trace their consequences out to human scales. The quest to make the leap of understanding from the Angstrom is one of the most wonderful frontiers of modern science, and it is one we will talk about, with demonstrations, in the public lecture today.

Wednesday, August 1, 2012

Plenary 6 - Cuprates and Iron-based Superconductors: A Dynamical Mean-field Theory Perspective

A. Georges (College de France, Paris)

Regency, 8:30 AM to 9:15 AM

Session Chair: Gabriel Kotliar

In this talk, I will review the insights that have been gained from dynamical mean-field theory into the physics of two classes of unconventional superconductors - copper oxides, and iron pnictides and chalcogenides. Both materials display hallmarks of strong electronic correlations, although of a very different nature. Mott physics is crucial to the physics of
hole-doped cuprates. The metallic state emerges out of the Mott insulator in a remarkable manner, characterized by a strong dichotomy between nodal regions with well-defined quasiparticles, and antinodal regions where a pseudogap opens. Cluster extensions of dynamical mean-field theory provide an understanding of this phenomenon as a `momentum-selective' Mott transition. The possible distinct origin of the pseudogap and superconducting gap will also be addressed, as well as some progress in understanding materials trends in relation to superconducting properties. In contrast, the iron-based
superconductors, along with some 4d oxides such as ruthenates, can be characterized as `Hund's metals', with electronic correlations due to the influence of the Hund's rule coupling and not to the proximity of a Mott state.

Collaborations with: M.Aichhorn, D.Basov, S.Biermann, M.Capone, M. Civelli, P.Cornaglia, D.Colson, L. 'de Medici, M.Ferrero, Y. Gallais, E.Gull, M.Imada, K.Haule, G.Kotliar, M. Le Tacon, A.J.Millis, T.Miyake, J.Mravlje, O.Parcollet, L. Pourovskii, A.Sacuto, T.Stanescu and V.Vildosola are gratefully acknowledged.

Plenary 7 - Overview of Research on Superconductivity at Oxide and Other Interfaces

I. Bozovic (Brookhaven National Laboratory)

Regency, 9:15 AM to 10:00 AM

Session Chair: Gabriel Kotliar

Interface Superconductivity was envisioned by V. L. Ginzburg and P.-G. De Gennes almost 50 years ago. However, only in recent years has it been propelled to the forefront of superconductivity research, with a number of groups currently active worldwide. From the materials and mechanisms viewpoint, the key results so far are as follows.

1. *Interface superconductivity* has been observed unambiguously at the border between two insulators (e.g. $LaAlO_3$ and $SrTiO_3$), or between a metal and an insulator (e.g., $La_{1.55}Sr_{0.45}CuO_4$ and La_2CuO_4)
2. *Interface-enhanced superconductivity* has been discovered in bilayers where one or both constituent materials are superconducting, while T_c of the bilayer is significantly higher than in either of the components. Examples include $La_{1.84}Sr_{0.16}CuO_4$-La_2CuO_{4+d} (25% enhancement in T_c), $SrTiO_3$-FeSe (> 400 %) and PbTe-PbS (> 700 %).
3. *Electric-field-induced superconductivity* has been realized at the electrolyte-solid interface in $SrTiO_3$, LSCO, YBCO, ZrNCl, and $KTaO_3$. (NB: superconductivity has never been achieved in $KTaO_3$ by chemical doping.)
4. *Anomalous proximity effects* have been discovered between optimally doped and underdoped LSCO layers, between YBCO and $La_{2/3}Sr_{1/3}MnO_3$, etc.
5. *HTS in nickelate heterostructures* (e.g. $LaNiO_3$-$LaMnO_3$) has been predicted theoretically. However, it has not been observed yet, despite extensive experimental efforts.

Some of these studies were specifically aimed at interrogating the mechanism(s) of superconductivity in the respective materials. Important new insights have been gained, and will be highlighted.

Finally, an outlook will be offered of prospects, conjectures, and key open problems for the coming years.

Supported by the U.S. Department of Energy, Basic Energy Sciences, Materials Sciences and Engineering Division, and by the Center for Emergent Superconductivity, an Energy Frontier Research Center funded by the US Department of Energy.

K4 - Cuprate Experiment
Regency, 10:30 AM to 12:00 PM
Session Chair: Aharon Kapitulnik

K4-01 Spin and charge correlations in cuprate superconductors - ***B. Keimer (Max Planck Institute for Solid State Research)***

I will present recent inelastic neutron scattering and resonant inelastic x-ray scattering (RIXS) data that throw new light on the role of low-energy spin and charge fluctuations in the mechanism of high-temperature superconductivity and its interplay with competing spin- and charge-density-wave order.

M. Le Tacon, G. Ghiringhelli, J. Chaloupka, M. Moretti Sala, V. Hinkov, M.W. Haverkort, M. Minola, M. Bakr, K. J. Zhou, S. Blanco-Canosa, C. Monney, Y. T. Song, G. L. Sun, C. T. Lin, G. M. De Luca, M. Salluzzo, G. Khaliullin, T. Schmitt, L. Braicovich and B. Keimer, Nature Physics 7, 725 (2011).

K4-02 Photoemission studies of the High Tc Cuprate phase diagram - ***P. Johnson (Brookhaven National Laboratory)***

High Tc Superconductivity presents some of the biggest challenges in condensed matter physics. In the cuprates, the superconducting state evolves from a Mott insulating state with doping . In the under-doped or pseudo-gap phase, a significant portion of the Fermi surface is still gapped at temperatures above the transition temperature Tc. Further instead of a closed Fermi surface, the low-energy electronic excitations in the normal state appear to form Fermi arcs separated by the gapped regions. Here we use high resolution angle resolved photoemission to examine in detail these complex phenomena. We show that the Fermi arcs may in fact be one side of Fermi pockets, consistent with the underlying nature of the spin liquids in these materials and the proximity to the Mott insulating state. It appears that the areas of these hole pockets scale approximately with the doping level. A particle-hole asymmetry observed in the nodal region is clear evidence that electron pairing does not originate from the Fermi arcs in the normal state. However in contrast the particle-hole symmetry observed in the anti-nodal region is interpreted as evidence for singlet pairs forming along the copper-oxygen bond directions at temperatures above the superconducting transition temperature Tc. These studies are extended to the overdoped regime where the pockets evolve into the large Fermi surface that characterizes the more Fermi liquid like state. We report the search for evidence of a critical point associated with this crossover.

K4-03 Fundamental Elements of Electronic Structure in Copper-based and Iron-based Superconductors from Spectroscopic Imaging STM - ***J. Davis (Cornell University / Brookhaven National Lab. / St. Andrews University)***

We review the key common features of electronic structure in copper-based and iron-based high temperature superconductors from the point of view of spectroscopic imaging scanning tunneling microscopy (SI-STM). High temperature superconductivity emerges in both cases upon the suppression of a commensurate antiferromagnetic ordered state, which is itself primarily generated by strong on-site correlations at the transition metal atoms. For both systems, we use SI-STM to visualize the atomic-scale electronic structure of the 'parent' state, the bizarre effects occurring in the intermediate state during suppression of the antiferromagnetism, and the Bogoliubov band-structure and anisotropic energy gaps of the eventual unconventional superconducting state. Searches for a representation of the Cooper pairing processes in these materials as mediated by a bosonic field, reveal intense electron-boson interactions. But whether and how these contribute to the pairing mechanisms has so far been inconclusive. Here we compare relevant electron-boson interaction phenomena for copper-based and iron-based high temperature superconductors and discuss the challenge of direct determination of a spin-fluctuation mediated pairing mechanism.

K5 - Organic, Topological and Spin Liquid Superconductivity
Palladian, 10:30 AM to 12:00 PM
Session Chair: Kazushi Kanoda

K5-01 Hydrocarbon superconductors : Superconductivity in (K, Rb, Ba, Sr, La, Sm)-doped phenanthrene - ***X. Chen (University of Science and Technology of China)***

Organic materials are believed to be potential superconductor with high transition temperature. Organic superconductors mainly belong to one of the two families: the quasi-one dimensional $(TMTSF)_2X$ and two dimensional $(BEDT\text{-}TTF)_2X$[1,2], in which TMTSF is tetramethyltetraselenafulvalene ($C_{10}H_{12}Se_4$) and BEDT-TTF or "ET" is bis(ethylenedithio)tetrathiafulvalene ($C_{10}H_8S_8$). We will give overview on the progress of hydrocarbon superconductors in this talk. Recently, superconductivity up to 18 K in alkali-metal doped picene with π-electron networks was reported[3]. We have discovered superconductivity at 5 K in alkali-metal-doped phenanthrene[4], 5.5 K in (Ba, Sr)-doped phenanthrene[5] and 6.1 K in (La, Sm) -doped phenanthrene. A 1-GPa pressure leads to a 20% increase of Tc for all the samples, suggesting that this class of materials shows unconventional superconductivity. The Raman spectra of all the superconducting samples show about 7 cm^{-1} electron downshifts generated by charge transfer, which is similar to A_3C_{60} (A = K and Rb). The shielding fraction of $Ba_{1.5}$phenanthrene can reach to 100%, it makes the investigation of the intrinsic physical properties and superconductivity mechanism in these organic,π-molecular materials possible. We successfully measure specific heat of $Ba_{1.5}$phenanthrene and discuss the superconducting pairing symmetry in this newly found organic superconductor. The result of specific heat suggests that $Ba_{1.5}$phenanthrene has s-wave superconducting gap.

[1] Ishiguro, T., Yamaji, K. & Saito, G. in Organic Superconductors, 2nd edn (Springer-Verlag, 1997).
[2] Singleton, J. Rep. Prog. Phys. 63, 1111–1207 (2000).
[3]Ryoji Mitsuhashi *et al. Nature*, **464**, 76 (2010).
[4] X. F. Wang *et al*. *Nature Communication*s **2**, 507 (2011) (2011).
[5] X. F. Wang *et al*. *Phys. Rev. B* **84**, 214523 (2011)

K5-02 From spin liquid to HiTc: a bird's eye view of the pseudo-gap - *P. Lee (MIT)*

I shall present a broad overview of the pseudo-gap state from the viewpoint of spin singlet formation following the RVB picture. I shall argue that recent discoveries of real materials that exhibit spin liquid behavior and show evidence of Fermionic spinons bolster this point of view. Instead of competing order, the notion of "derivative order" is more appropriate to describe the variety of ordered states which appear at low temperatures.

K5-03 Experiments Toward Identifying a Topological Superconductor - *Y. Ando (Institute of Scientific and Industrial Research, Osaka University)*

Topological superconductors (TSCs) are novel quantum states of matter that are characterized by nontrivial topological structures of the Hilbert space of their wavefunctions. Due to the so-called bulk-edge correspondence, topologically nontrivial bulk states are always accompanied by gapless edge states. In the case of TSCs, gapless Andreev bound states appear on the edges due to this topological principle, and they often consist of Majorana fermions, which are exotic charge-neutral particles that are their own antiparticles. Topological superconductors are either time-reversal breaking (TRB) or time-reversal invariant (TRI); theoretically, it has been elucidated that TRB-TSCs can exist only in 1D and 2D, but TRI-TSCs can exist also in 3D. A strong candidate of a quasi-2D TRB-TSC is Sr_2RuO_4, and the B-phase of superfluid helium-3 is considered to be a superfluid analogue of a 3D TRI-TSC. Recently, we have elucidated that $Cu_xBi_2Se_3$ superconductor is the first concrete example of a 3D TRI-TSC [1]. This material is a doped topological insulator, and we developed a new synthesis method that made it possible to characterize its detailed superconducting properties [2]. Most importantly, our point-contact spectroscopy experiments on this material found evidence for the existence of surface Andreev bound states (ABS). While ABS can be found in unconventional superconductors of non-topological variety, in the case of $Cu_xBi_2Se_3$, thanks to its peculiar band structure, it can be shown that an unconventional superconducting state in this material can only be topological. It follows that the observed ABS consist of helical Majorana fermions, and $Cu_xBi_2Se_3$ offers a playground for studying these exotic quasiparticles.

This work was done in collaboration with S. Sasaki, M. Kriener, K. Segawa, K. Yada, Y. Tanaka, and M. Sato, and was supported by JSPS (NEXT Program), MEXT (Innovative Area "Topological Quantum Phenomena" KAKENHI), and AFOSR (AOARD 104103 and 124038).

[1] S. Sasaki *et al*., PRL **107**, 217001 (2011).
[2] M. Kriener *et al*., PRL **106**, 127004 (2011).

K6 - Holographic Superconductivity
Diplomat, 10:30 AM to 12:00 PM
Session Chair: Subir Sachdev

K6-01 Mottness and Holography: A Discrete Marriage - *P. Phillips, K. Lo, R. Leigh, S. Hong (University of Illinois), M. Edalati (University of Texas)*

Superconductivity in the cuprates remains controversial because physics at strong coupling has proven to be quite intractable. The inherent problem is that there is a disconnect between the degrees of freedom which appear in the UV complete theory and those that propagate at low energies. A recent advance in string theory, the gauge-gravity duality, has offered a possible way out. The key claim here is that strongly coupled quantum mechanical systems live at the boundary of a spacetime which is asymptotically hyperbolic. I will show how a space-time consisting of a charged black hole and a bulk Pauli coupling corresponds to a boundary theory with a dynamically generated gap (with no symmetry breaking) and a massive rearrangement of the spectral weight as in classic Mott systems such as VO_2. In this holographic set-up, the gap opens only when the discrete scale invariance is present. The standard way of understanding discrete scale invariance is through a heirarchy of Efimov bound states. By integrating out the high-energy states in the Hubbard model, I will show how a possible candidate bound state arises which can give rise to the Fermi arc structure in the underdoped cuprates.

We also acknowledge nancial support from the NSF-DMR-0940992 and DMR-1104909.

K6-02 Quantum criticality, superconductivity and the AdS/CFT correspondence. - ***J. Zaanen (Instituut-Lorentz for Theoretical Physics, Leiden University)***

The understanding of non-Fermi liquids and their habit to turn into superconductors is severely hampered by the inability to describe systems of strongly interactng fermions with the methods of quantum field theory. Remarkably, the AdS/CFT duality of string theory might be the magic bullit. This dualizes the physics of strongly interacting quantum matter into (semi) classical gravitational physics where typically the phenomenological, highly emergent properties of the former are in correspondence with generic properties of special black holes. The highlight is the "AdS2 metal", a non-Fermi-liquid state characterized by local quantum criticality and algebraic pseudogap behavior, dual to a charged black hole [1]. Fermi-liquids are found as instabilities of such metals [2], but also "holographic superconductors" via a mechanism which is a generalization of BCS. This can be tested in the laboratory through a measurement of the pair susceptibility exploiting the second order Jospehson effect [3]. Very recently we discovered that the AdS2 metal reacts in a peculiar way to static periodic potentials [4]. The effect of nesting is to reshuffle the incoherence in the single electron spectral functions, in a way that has a fascinating resemblance to the "nodal-antinodal dichotomy" puzzle in underdoped cuprates.

[1] M. Cubrovic, J. Zaanen and K.Schalm, Science **325**, 439 (2009).
[2] M. Cubrovic, Y. Liu, K.Schalm, Y.W, Sun and J. Zaanen, Phys. Rev. D**84**, 086002 (2011).
[3] J.H. She, et al., Phys. Rev. B**84**, 144527 (2011).
[4] Y.Liu, K. Schalm, Y.W. Sun and J. Zaanen, preprint.

K6-03 Holographic Superconductivity - ***S. Hartnoll (Stanford University)***

Holographic duality is a theoretical framework that allows for a controlled description of certain strongly interacting quantum critical fractionalized phases of matter. Holographic superconductivity is a mechanism for superconductivity that appears naturally in this framework. The onset of superconductivity is dually described by a black hole spontaneously losing its charge in the form of a Bose-Einstein condensate outside the event horizon. I will present some new and old results on the phenomenology of holographic superconductivity and in particular on the interplay of superconductivity with the exotic `normal' state out of which the superconductivity emerges.

Poster Session - Hotel Exhibit Hall, 1:30 PM to 3:30 PM

P3 - Applications, Vortex Phenomena, Phenomenology and Light-element Superconductors

P3-01 DOPED CARBON NANOTUBE SUPERCONDUCTORS - ***R. Gill (Apex Institute Of Technology), P. Singh (Physics Department,Addis Ababa University)***

Carbon Nanotubes (CNT's) have attracted a lot of attention from all over the world because of their nano size and amazing properties in the various fields of interest. CNT's are very thin and light weight tubes made up of carbon and are invisible to naked eye and can be used as powerful yet tiny logic chips in computers and have high potency as compared to conventional silicon chips. These tubes usually superconduct at 15 K and 20 K but it has been found recently [1] that if carbon nanotubes doped with transition metals, then there is a strong indication of finding superconductivity even at room temperature which is perhaps due to the hybridization of delocalized electrons of transition metals atoms with the atoms of carbon that increases the interaction between electrons and excitations responsible for cooper pairing in doped CNT superconductors. In this paper, we have considered a model Hamiltonian for the doped CNT's and by using Quantum field theory green function [2] formalism, we have obtained the expressions for superconducting order parameter and transition temperature and it is theoretically found that the transition temperatures as high as 270 K can be reached which essentially means that the room temperature superconductivity can be realized with doped CNTs.

[1] C. Nirmala Louis et. al. "Band Structure, Density of States and Superconductivity of adsorbed Titanium Chains on (8,8) and (14,0) Carbon Nanotubes," Materials Physics and Mechanics 10,72-81(2010).
[2]D. N. Zubarev, "Double-Time Green Functions in Statistical Physics," Sov.Phys.Usp.3, 320(1960).

P3-02 Thermodynamic investigation of the Electronic States of Expanded Fullerides - ***Y. Kasahara (Quantum-Phase Electronics Center, School of Engineering, The University of Tokyo), R. Zadik, Y. Takabayashi, K. Prassides (Department of Chemistry, Durham University), A. Ganin, M. Rosseinsky (Department of Chemistry, University of Liverpool), Y. Takeuchi, Y. Iwasa (Quantum-Phase Electronics Center and Department of Applied Physics, University of Tokyo)***

Recent observation of a transition from an antiferromagnetic insulator to a superconducting metal with applying pressure in Cs_3C_{60} compounds shed light on the physics in alkali-metal-doped fullerides, A_3C_{60} (A: alkali metal). Superconductivity emerging out of the antiferromagnetic phase and the observed dome-like dependence of the superconducting transition temperature, T_c, as a function of pressure (or lattice volume) are reminiscent of non-BCS mechanism of superconductivity and highlight the importance of electron correlation and Mott physics in the fulleride superconductors.

We here report systematic measurements of the specific heat at ambient pressure in A_3C_{60} (A: alkali metal) with various compositions of A. To understand the electronic properties of expanded fullerides, measurements of specific heat are fundamental and highly important. However, due to the extreme air-sensitivity of the materials, specific heat in A_3C_{60} has been reported only for K_3C_{60} in the last 20 years. Using careful handling of the materials against air-exposure, we have now observed clear specific heat anomalies associated with both superconducting and antiferromagnetic transitions in several A_3C_{60} compounds. The variation of specific heat in a wide range of lattice volume will be presented.

P3-03 Synthesis of the perovskite-type APdH3 (A = Ca, Sr, Ba) - *H. Yagyu, S. Ayukawa, T. Takamatsu, M. Kato, T. Noji, Y. Koike (Tohoku University)*

Hydrides have attracted much interest as possible superconductors with high transition temperatures, T_c's, owing to their optical phonons with high frequencies due to the small mass of hydrogen. It is known that optical phonons with high frequencies have an important role in the appearance of superconductivity in PdH with T_c = 9 K. However, there are few reports on hydride superconductors except for PdH. Then, we have focused on perovskite-type $APdH_3$ (A = Ca, Sr, Ba) in which the electronic configuration of Pd is same as that in PdH. Here, we report on the synthesis of $APdH_3$ and the investigation of its superconductivity.

Polycrystalline samples of $APdH_3$ were synthesized by hydrogenation of a *A*Pd alloy as follows. First, starting materials of *A* granules and Pd powder were mixed in a He-filled glove box. The *A*Pd alloy was prepared through the induction melting of the mixture. Next, the hydrogenation of *A*Pd was performed in a pressure below 2 MPa of H_2 at room temperature for 24 h by two kinds of method. One is a conventional method using an autoclave connected to a hydrogen-gas cylinder. The other is a new method using hydrogen gas generated by the reaction of CaH_2 with CuO. That is, the *A*Pd alloy was placed in an evacuated glass tube separately from the mixture of CaH_2 and CuO. Then, only the mixture of CaH_2 and CuO was heated at ~250°C. At present, no superconductivity has appeared in the magnetic-susceptibility measurements.

P3-04 Low-temperature specific heat and upper critical field in two-gap superconductor Lu2Fe3Si5 - *Y. Nakajima (the University of Tokyo), T. Nishizaki, T. Sasaki, N. Kobayashi (Institute for Materials Research, Tohoku University), H. Hidaka, T. Nakagawa, T. Tamegai (the University of Tokyo)*

The recent discovery of iron-pnictide superconductors has attracted much interest because of their high transition temperature. One of the remarkable features in this system is the multiband superconductivity, which is in sharp contrast to the high temperature cuprate superconductors, and the multiband nature could be indispensable for the superconducting pairing mechanism.

The ternary iron-silicide $Lu_2Fe_3Si_5$ with T_c ~ 6 K, which has the highest transition temperature among the iron-based compounds other than the iron pnictides, can be another candidate for the canonical multigap superconductor. The multigap superconductivity in $Lu_2Fe_3Si_5$ has been revealed by the detailed study of low temperature specific heat [1]. To clarify the multiband nature of $Lu_2Fe_3Si_5$ in more detail, we investigate the low-temperature specific heat under magnetic field and the upper critical field. The anisotropy of upper critical field indicates that the active band has a weakly one-dimensional anisotropy. The low-temperature specific heat in magnetic field reveals that the virtual H_{c2} in the passive band is almost isotropic. These results suggest that the two bands have two different anisotropies, very similar to the typical two-band superconductor MgB_2.

[1] Y. Nakajima *et al*., Phys. Rev. Lett. 100, 157001 (2008)

P3-05 Influence of doping and scattering on anisotropic properties of MgB2 substituted with Li, Al, and C -*K. Rogacki, K. Oganisian (Institute of Low Temperature and Structure Research, Polish Academy of Sciences, Wroclaw), N. Zhigadlo, S. Katrych, J. Karpinski (Laboratory for Solid State Physics, ETH Zurich)*

In this work we examine the temperature dependence of the in-plane (S_{ab}) and out-of-plane (S_c) thermopower and the in-field measured resistivity of MgB_2 crystals doped with holes and electrons by partial substitution of Li, Al, and C. For unsubstituted crystals, the thermopower anisotropy g_S = 3 has been obtained at room temperature. Substitution of Li for Mg, which dopes MgB_2 with holes, increases the intraband scattering in the *pi*-band and results in a moderate decrease of both S_{ab} and S_c without any influence on g_S. For this substitution, the upper critical field anisotropy, $g_H = H_{c2}^{ab}/H_{c2}^{c}$ (~5 for unsubstituted MgB_2), is only slightly lowered confirming that the interband scattering is not affected. Substitution of Al for Mg, which dopes with electrons the *pi*-band and possible also the *sigma*-band, decreases S_{ab} and S_c with a rate |d*S*|**/**%Al much larger than |d*S*|**/**%Li, most likely due to the charge doping and the enhanced scattering mainly in the *pi*-band. This substitution reduces g_S from 3 to about 2, due to the notable increase of the interband scattering, consistently with the behaviour of g_H. Substitution of C for B, which donates electrons to the *sigma*-band, decreases strongly both S_{ab} and S_c, owing to the increased scattering in the both bands, *sigma* and *pi*. This substitution substantially reduces g_S (from 3 to 1) and g_H (from 5 to 2), suggesting that the interband scattering is enhanced in this case. It seems to be possible to increase H_{c2} toward the strong-coupling paramagnetic limit by selective substitutions on Mg or B sites. Thus, understanding the mechanism of the intra- and interband scattering and the competition between scattering and charge doping effects is important to obtain material still more interesting for large scale applications.

P3-06 Pressure-induced Superconductivity in Li(Mg) Alloys - *N. Hillier, N. Foroozani, J. Schilling (Dept. of Physics, Washington University)*

Under extreme pressures Li shows a marked deviation from free-electron behavior [1], leading to a superconducting transition temperature that is among the highest of all elemental superconductors. However, superconductivity in Li vanishes at 67 GPa [2], which is related to a metal-to-semiconductor transition later observed by Matsuoka and Shimizu above 70 GPa [3]. Although Mg itself has not yet been found to be superconducting, the alloy Li(Mg10%) has been found to become superconducting between 30 and 47 GPa, the highest pressure studied [4]. The substitution of divalent Mg for monovalent Li in the alloy increases the electron concentration. Here we present the results of further experiments on Li(Mg) alloys to much higher pressures to explore the effect of increasing electron concentration on the superconducting phase diagram Tc(P).

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High pressure work at Washington University is supported the NSF, DMR-0703896.

P3-07 Strong-coupling superconductivity of YB_{6} - ***J. Kacmarcík (Institute of Experimental Physics, Slovak Academy of Sciences, Watsonova47, SK-04001 Košice), T. Mori (Advanced Materials Laboratory, National Institute for Materials Science, Tsukuba, Ibaraki 305-0044), P. Szabó, J. Girovský, Z. Pribulová, S. Gabáni, G. Pristáš, I. Takácová, K. Flacbart, P. Samuely (Institute of Experimental Physics, Slovak Academy of Sciences, Watsonova47, SK-04001 Košice)***

Comprehensive experimental studies of YB_6 via point-contact spectroscopy, ac-calorimetry and high-pressure transport measurements were carried out. The point-contact spectra have directly revealed a strong superconducting coupling in the system. Namely, the single s-wave superconducting energy gap has a reduced value of 2"Delta"/kT_c close to 4. Moreover, a significant electron-phonon-interaction structure has been directly observed in the point-contact spectra above the superconducting energy gap suggesting that the superconductivity is mediated by the low energy phonon mode near 7.5 meV, in agreement with the previous suggestion of Lortz *et al.* [1] made by their specific heat measurements. The strong coupling is consistently revealed in our specific heat evidenced by the height of the jump at T_c as well as by the overall temperature dependence as compared to the alpha-model. Resistivity measurements were performed under hydrostatic pressure in both piston cylinder cell and in diamond anvil cell up to 22 kbar and 47 kbar respectively. The critical temperature and the upper critical magnetic field both decrease linearly with increasing pressure.

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P3-08 Influence of Ni, Co and Fe nanoparticles on superconductivity of MgB2 - ***N. Novosel, S. Galic, D. Pajic, E. Babic, K. Zadro (University of Zagreb, Faculty of Science, Physics Department)***

As a part of systematic investigation of the influence of magnetic nanoparticles (NP) [1] on superconducting parameters of MgB2 we studied the effects of pure Ni, Co and Fe NPs (average size 20-28 nm) on superconducting transition Tc, the irreversibility field Birr, the upper critical field Bc2 and the critical current density Jc of in-situ prepared MgB2/Fe wires. All NPs (NanoAmor, Inc., USA) had crystalline core and thin (~3 nm) carbon coating. The synergistic action of magnetic pinning on NPs and of carbon doping was expected to produce strong improvement in Birr, Bc2 and Jc(B) of wires.

At present, single doping level: Mg0.98NP0.02B2 (corresponds to ~2.5 wt.% of NPs) was used for all three types of NPs. Doping caused strong suppresion of Tc (3.3, 1.5 and 1.4 K per wt.% of Fe, Co and Ni, respectively), as well as the reduction of connectivity ratio, AF. Accordingly, Birr and Bc2 of doped wires were lower than that of undoped one. In particular, Birr(5K) were 8, 14, 15 and 16 T for wires doped with Fe, Co, Ni and undoped one, respectively. However, the rates of increase of Birr on lowering temperature were for Co and Ni doped wires the same as that for undoped one. The magnetic effect (suppresion of Tc) also effected Jc. Jc(20K) for doped wires was lower than that of undoped one at all fields and the reduction in Jc followed that in Tc (Fe->Co->Ni). However, at 5K Jc of Ni doped wire surpassed that for undoped one for B>6T. In particular, Jc(5K,10T) was 3500 and 1400 A/cm2 for Ni doped and undoped wire, respectively. Thus, like in case of Nb-Ti [2] nanosize Ni has the potential for improving Jc(B) of MgB2.

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P3-09 Superconducting heavily boron doped diamond (111) thin film with Tc(offset) above 10K and its anisotropic effect due to the uniaxial strain - ***S. Kurihara (Waseda university), T. Yamaguchi, Y. Takano (National Institute for Materials Science), R. Kanomata, H. Tsuboi, D. Utsunomiya, H. Kawarada (Waseda university)***

After superconducting diamond was obtained by high pressure method [1],the type II superconducting properties have been reproduced by CVD diamond films and the Tc(offset) (critical temperature for zero resistivity) were less than 5K[2,3] These film samples are thicker than 1um and have a lot of crystal defects such as misfit dislocations and/or grain boundaries leading to the lower Tc(offset). Using thinner films with scarce crystal defects we have succeed in realizing Tc(offset) >10K. These homo epitaxial diamond films are formed on (111) diamond substrate in less than 500nm thick with boron doping of $8\times10^{21}cm^{-3}$ (~5% in atomic concentration) [4].

Boron doped diamond leads to a lattice expansion because of difference in atomic diameter of carbon and boron. The amount of expansion is 0.5 % in 5 atomic percent of boron. (111) homo epitaxial layers below 500nm thick have a high perpendicular lattice expansion and very low in-plane lattice expansion because of a commensurate interface between boron doped and undoped films. The sample with Tc (offset) above 10K exhibits the highest uniaxial expansion (=0.6~0.7%), which might have a positive effect on Tc increase.

In general, the anisotropic lattice deformation has a great effect on electric state of degenerate semiconductors. In case of thinner film below 20nm, anisotropic upper critical field (H_{c2}) was observed clearly. The perpendicular coherent length of superconducting diamond with 20nm thickness is longer than in-plane one. In thin film below 20nm, angular and temperature dependence of H_{c2} was fitted well by 2D Tinkham theory and deviated from 3D Ginzburg Landau theory [5]. The 2D anisotropic effect was observed clearly at biaxial compressed ultrathin film.

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P3-10 Momentum-dependent energy gap distributions of MgB2 studied by electron tunneling spectra using MgB2/I/Pb tunnel junctions - ***W. Dai, Q. Li (Department of Physics, Pennsylvania State University, University Park, PA 16802), K. Chen, X. Xi (Department of Physics, Temple University, Philadelphia, PA 19122)***

We have fabricated MgB_2/native oxide/Pb planar tunnel junctions using MgB_2 films grown by the hybrid physical-chemical vapor deposition (HPCVD) technique. Both π (1.8~2.3 meV) and σ (6.8~7.9 meV) gaps were observed in tunneling spectra on MgB_2 films on MgO (211) and rough SiC (0001) substrates. We observed a distribution of energy gap values of both π and σ bands due to anisotropic electron-phonon interaction in clean MgB_2 films [Nature Communications, 3, 619 (2012)], in agreement with first-principles calculation [Nature, 418, 758 (2002)]. When adding impurities during MgB_2 film growth or using thinner MgB_2 films so as to reduce the electron mean free path, both π and σ gap distribution peaks became narrower as the intraband scatterings smear out the distribution of the gaps. On the other hand, increasing junction normal resistances by measuring one junction as it aged also resulted in smeared gap peaks due to scattering from the junction interface. For junctions made on degraded MgB_2 surfaces, we observed increased π gap with a broader peak, suggesting a gap merging effect due to interband scattering. Finally, we found the σ gap value is larger for MgB_2 films on SiC substrates (higher T_c) than on MgO substrates whereas the π gap value is similar, which agrees with the theory that the T_c of MgB_2 is determined by the σ gap.

P3-11 Results of Superconducting-to-Normal Switching Experiments in MgB2/I/Pb Josephson Junctions: Distinctive Features of a Multi-Gap Superconductor - ***S. Carabello (Drexel University, Penn State Harrisburg), J. Lambert (Drexel University), R. Ramos (Indiana Wesleyan University), W. Dai, Q. Li (Penn State University), C. Zhuang (Penn State University, Temple University), D. Cunnane, Y. Shen, K. Chen, X. Xi (Temple University)***

Superconducting-to-normal switching experiments, with and without microwave excitation, are useful for exploring resonances and other features of the washboard potential of a Josephson junction. A heterojunction, using the dual-gap MgB2 and single-gap Pb as its superconducting electrodes, provides a system well-suited for exploring the unique properties of MgB2, by exhibiting multiple tunneling channels. We present results of switching experiments on MgB2/I/Pb Josephson tunnel junctions incorporating high-quality MgB2 thin films on a SiC substrate, at temperatures as low as 25mK. These results, including escape rates and microwave resonant activation, indicate the presence of multiple resonances, and appear to be consistent with recent theoretical work on macroscopic quantum tunneling in multi-gap superconductors.

P3-12 Electrical characteristic evaluation of SNS junction by heavlily and lightly Boron-doped diamonds - ***R. Kanomata (Waseda university), T. Yamaguchi, Y. Takano (NIMS), S. Kurihara, D. Utsunomiya, H. Tsuboi, H. Kawarada (Waseda university)***

In this research, we applied the controllability of dopant concentration to fabricate heavily and lightly doped region for Superconductor($8x10^{21}$[cm^{-3}])-Normalconductor($2\text{-}6x10^{21}$[cm^{-3}])-Superconductor (SNS) junction entirely made by diamond. Our previous research shows that boron-doped diamond's transition temperature can be controlled by its boron density[1]. All boron doped diamond SNS junction has barrierless interface. We have fabricated lateral and vertical SNS Josephson junction.

Lateral SNS Josephson junction was fabricated using the difference in doping incorporation ratio in [111] and [001] directions. The boron concentration is 10-100 times higher in [111] growth. Using a step structure, two S layers are formed on two (111) terraces and one N layer in the middle is grown at (001) step surface. The performance of Josephson junction has been certificated by Shapiro steps and Fraunhofer-pattern.

In fabrication of vertical SNS Josephson junction consisting entirely of boron-doped diamond were fabricated by alternately synthesizing heavily doped and lightly doped diamond film. In evaluation of superconducting current, our experimental data are fitted to Likhare's theory of SNS weak-link junctions [2]. When the normal-state-diamond thickness is much larger than the coherent length in the normal conductor diamond (N), the exponential temperature dependence of normalized critical current [3] was observed indicating a proximity effect.

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P3-13 Search for Superconductivity in Doped Amorphous Carbon Thin Films - ***T. Haugan, B. Pierce (Air Force Research Laboratory, AFRL/RZPG), D. Vier (University of California San Diego), J. Burke, L. Brunke (University of Dayton Research Institute)***

There have been significant studies to induce superconductivity and increase transition temperatures (T_c) in the different allotropic forms of carbon[1-3]. Doping of diamond films with boron = 0.5–5 Vol% achieved T_c up to 7K[2], and superconductivity was achieved in A_3C_{60}'buckyballs' with a maximum T_c of 38K for A = cesium[1]. Doping of amorphous carbon powder with sulfur showed evidence of T_c ~ 37K. However so far T_c > 20K has not been measured resistively in any form of carbon, which is needed for wire applications. Herein we attempt to achieve a high T_c measured resistively in amorphous carbon thin films, doped with promising elements including P, B, S and Cs. Carbon films with varying thickness were prepared by pulsed laser deposition (PLD) on R-cut sapphire and amorphous SiO_2-buffered Si substrates. Doping was achieved by depositing from ($C_{1-x}A_x$) single-targets, and ion implantation was used to incorporate gaseous A dopants difficult to deposit by PLD, such as sulfur. Different ion implantation energies and dosing times were used to achieve varying doping levels up to 5 Vol% and different implantation depths. Initial results with phosphorus implantation show a dramatic decrease of resistivity by a factor of 10^5 at T < 50K, and also changing the carbon film from semi-conducting to metallic. There is some evidence of bulk superconductivity being achieved in a small volume fraction, as detected by modulated magnetic field microwave absorption (MMFMA).

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Air Force Office of Scientific Research and Propulsion Directorate

P3-14 Search for Superconductivity in RE-M-C-O Oxy-carbonate Compounds - ***T. Haugan, J. Reichart (Air Force Research Laboratory, AFRL/RZPG), P. Barnes (Army Research Laboratory), E. Morosan (Rice University Dept. of Physics), M. Sumption (The Ohio State University), D. Vier (Univeirisity of California San Deigo Dept..of Physics), J. Burke, C. Ebbing (University of Dayton Research Institute)***

The main families of high transition temperature (T_c) superconductors discovered so far are the Cu-oxides and Fe-As pnictides with maximum T_c's of 135K and 57K, respectively. The active superconducting block elements of these families are $M^{\pm2}$ = [$Cu^{+2}O^{-2}$] for the Cu-oxides and $M^{\pm2,3}$ = [$(Fe,As)^{\pm2,3}O^{-2}$] for the Fe-As pnictides. We believe a new class of materials to search for superconductors would be compounds with different active balanced valence states of $M^{\pm1}$ or $M^{\pm4}$, with a possible trend of T_c > 100K for $M^{\pm1}$ and T_c < 50K for $M^{\pm4}$. For this paper, we are searching for superconductivity in compounds with active balanced valence states of $M^{\pm4}$, and specifically for RE-M-C-(O,F) oxy-carbonates with $M^{\pm2,3,4,5}$ = Ti, Zr, Hf, Pr, Ru,V and other elements, $RE^{\pm3,4}$ = rare-earth, lanthanides, $C^{\pm2,\mathbf{4}}$ = carbon, and $O^{-2}F^{-1}$ = oxygen, fluorine. The four-element compounds are being synthesized by solid-state reaction of pressed pellets made of RE_2O_3 oxides, MO_x oxides or M metals, and carbon nanopowder. An ultra-pure Ar flowing-gas atmosphere is used for processing, and annealing is being studied at temperatures of 1200°C-1500°C. The samples are characterized by X-ray diffraction for phase assemblage and purity, and tests for superconductivity are done with modulating magnetic field microwave absorption (MMFMA), zero-field cooled (ZFC) and field-cooled (FC) vibrating sample magnetometry (VSM), specific heat measurements, and four-probe resistive measurements on solid-annealed pellets.

P3-15 Optimization of Processing Conditions for the High Trapped Field in MgB2 - ***M. Miryala (Railway Technical Research Institute (RTRI), Applied Superconductivity, Materials Technology Division, 2-8-38, Hikari-cho, Kokubuni-shi, Tokyo 185-8540, JAPAN), Y. Akiyasu (Graduate School of Information Science and Technology, Eng. Bldg. 2, 7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan.), A. Ishihara, M. Tomita (Railway Technical Research Institute (RTRI), Applied Superconductivity, Materials Technology Division, 2-8-38, Hikari-cho, Kokubuni-shi, Tokyo 185-8540, JAPAN)***

Superconducting MgB_2 magnets have a wide variety of commercial and industrial applications, especially in medical field for MRI instruments. MgB_2 material has high critical temperature (39 K), high critical current density (10^5-10^6 at 4.2K), and high Hc_2values compared to the conventional low temperature superconductors made of Nb_3Sn or NbTi. Furthermore, the bulk MgB_2 materials are more attractive because of their low fabrication cost, and these materials can be used at liquid hydrogen temperature (20 K). These two key factors cost and functionality at 20 K can drive lower the overall cost of medical systems. Therefore, further improvement of the critical current density and optimization of the processing conditions for highest trapped field "TF" is essential. The present investigation focuses on methods to improve the trapped field values of disk shape MgB_2 bulk superconductor by optimizing the processing condition. Series of samples are prepared in varying temperatures in pure argon atmosphere. Scanning electron microscopy (SEM) and x-ray diffraction results indicated that single phase and homogenous MgB_2 bulks are produced. The trapped field results showed that processing temperature is the key parameter to improve the highest TF. Samples of 20 mm in diameter and 7 mm in thick, prepared with optimized processing temperature, demonstrated a field of 1.5 T, at 20 K. Further, the TF values are improved dramatically with increasing the size and thickness of the MgB_2 bulk. The correlation between the processing and microstructure control and their implications on the trapped field will be discussed.

P3-16 Development of high critical current density MgB2 conductors by pressure-less densification - ***A. Yamamoto (University of Tokyo, JST-PRESTO), H. Tanaka, A. Ito, J. Shimoyama, H. Ogino, K. Kishio (University of Tokyo)***

We have studied the microstructure, electrical connectivity and critical current density J_c of polycrystalline MgB_2 samples prepared by various pressure-less routes. It is known that transport current in polycrystalline MgB_2 is rather suppressed due to poor electrical connectivity, the effective current-carrying cross-sectional area of a sample [1]. The low bulk density (~50% for conventional *in-situ* technique) is suggested to be the main cause of the poor connectivity [2]. In the present study, *ex-situ* and modified *in-situ* techniques were applied to obtain MgB_2samples with higher bulk density under ambient pressure. The *ex-situ* MgB_2 bulks heated at high-temperatures of ~900°C for a long period showed an increased bulk density, a larger inter-grain contact area and a significantly improved connectivity, all of which indicate the self-sintering of MgB_2 [3]. The sintered *ex-situ* bulks showed largely enhanced connectivity of 28% and J_c exceeding 0.4 MA/cm^2 at 20 K. Secondly, we focused on a different synthesis route of *in-situ* reaction, *i.e.* 1/2Mg + 1/2MgB_4 -> MgB_2. The route can reduce the amount of Mg grains, which are the origin of low bulk density, to be half compared to the conventional *in-situ* route. Microstructural analyses showed the MgB_2 bulks using MgB_4 precursor have smaller number of voids and bulk density is improved ~30% compared to the conventional *in-situ*route. Consequently, both the connectivity and J_c were enhanced owing to their higher bulk density.

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P3-17 OBSERVATION OF HOFSTADTER SPECTRUM IN SUPERCONDUCTING FILM - ***M. Kamran (COMSATS Institute of IT), Q. Xianggang (Condessed Matter Lab.)***

A uniform applied magnetic field was studied theoretically three decades ago by Hofstadter [1], who obtained a fractal energy spectrum composed of energy gaps called the Hofstadter butterfly. Although different approaches have been utilized to study the physics associated with the Hofstadter butterfly, no details about the results have yet been revealed. Here, we report that, by taking advantage of the similarity between Bloch electrons under an applied magnetic field and superconducting thin films perforated with periodic hole (anti-dot) arrays in the superconducting state, we have discovered an approach capable of revealing the characteristics of the Hofstadter butterfly. We demonstrate that when the parameters such as the diameter and the period of the hole array are carefully chosen, several characteristics of the Hofstadter butterfly can be observed. Because the required magnetic field for these experiments is several hundred Gauss rather than several hundreds Tesla, our approach opens a way to study the Hofstadter butterfly and related physics using conventional laboratory facilities.

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P3-18 Enhanced Fractional matching effect in superconducting NbN/MgO thin film - ***M. Kamran (COMSATS Institute of IT), Q. XIanggang (National Lab of Superconductivity, Institute of Physics, GUCAS, Beijing, China)***

Type-II superconducting thin films having a periodic array of artificial pinning centers have been of great interest due to their excellence for the studies of the vortex pinning mechanisms. Square hole array has been fabricated 60mm×60mm of NbN thin film by electron beam lithography superconducting thin film by e-beam lithography and lead to vortex matching phenomena at commensurate fields. The strength of the vortex pinning depends on the geometrical characteristics of the antidote lattice, coherence length and penetration depth. In this experiment there are two scenarios, multi integer and enhanced fractional matching fields. These integer and fractional matching fields are temperature and current dependent. Sharp peaks are observed at integer matching fields, 1^{st} to 6^{th} order and enhanced fractional matching fields, including 1/2, 1/3, 2/3, 3/2, 4/3, 5/3….etc. We present our experimental results on superconducting NbN thin film with square array of antidots.

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P3-19 Magnetic domain induced vortex confinement in superconductor-ferromagnet bilayer - ***M. Cieplak (Institute of Physics, Polish Academy of Sciences, 02668 Warsaw), X. Cheng, C. Chien (Dept. of Physics and Astronomy, The Johns Hopkins University, Baltimore, Md 21218), L. Zhu (Dept. of Physics and Astronomy, The Johns Hopkins University, Baltimore, Md 21218, and Materials Science Division, Argonne National Laboratory, Argonne, IL 60439), Z. Adamus (Institute of Physics, Polish Academy of Sciences, 02668 Warsaw), M. Konczykowski (Laboratoire des Solides Irradies, Ecole Polytechnique, 91128 Palaiseau)***

Superconductor-ferromagnet hybrids are important model systems to study the rich interplay between two seemingly incompatible collective phenomena. In this work we show interesting examples of the confinement of vortices by magnetic domains in a superconductor-ferromagnet bilayer. We use a line of miniature Hall sensors to study the flux penetration in a niobium film deposited on a ferromagnetic Co/Pt multilayer with perpendicular magnetic anisotropy, with the insulating layer in-between to eliminate proximity effect. Using a special magnetization procedure we reversibly define and erase the magnetic domain patterns of various geometries in a single tunable sample. The analysis of flux penetration shows that vortices are trapped above domains forming distinct patterns, including single or double vortex chains or Abrikosov lattice, depending on domain geometry and domain-domain distances. The most striking is the strong confinement of vortices by narrow and well isolated domains, which produce vortex-vortex distances comparable to the magnetic penetration depth.

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P3-20 The flux line lattice of neutron irradiated NbSe2 in the fishtail region measured by STM - ***M. Zehetmayer, J. Hecher, H. Weber (Atominstitut, Vienna University of Technology, 1020 Vienna, Austria)***

We report on a detailed study of the flux line lattice in superconducting NbSe2 single crystals by scanning tunneling spectroscopy. The superconducting magnetization of the pristine sample is reversible except for very low magnetic fields (< 0.2 T). By neutron irradiation artificial defects capable of pinning flux lines are introduced, which lead to a pronounced second peak (fishtail) in the magnetization and the critical current at high magnetic fields. We compare the vortex lattice of the pristine sample with that of the irradiated crystal in the reversible regime (i.e. at fields from about 0.2 to 0.8 T) and in the second peak region (i.e. above 0.8 T). Recording up to 2400 vortices per STM-image allows us to provide well founded statistical data on several quantities of interest such as the order parameters, the correlation lengths, or the dislocation density in the lattice. The results are compared with the macroscopic current density acquired on the same samples. For instance, we found a significant change in the parameters related to the translational or orientational order of the lattice at the onset of the second peak, which indicates the occurrence of an order disorder transition in this region.

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P3-21 Josephson effect involving magnetic domain wall motion - ***M. Mori, S. Maekawa (Japan Atomic Energy Agency), S. Hikino, W. Koshibae (RIKEN)***

Nano-scale magnetic materials for spintronics devices are extensively studied due to many advantages such as enhanced operation speed, low power consumption, and high integration of memory cell. Non-volatile memory using a magnetic domain wall (DW) is one example of such devices, and many studies are devoted to control DW. Among those studies, the oscillatory

DW is experimentally observed and is examined toward applications, e.g. high sensitive magnetic sensor, nano-scale telecommunication, rf-assisted writing of magnetic bit, and microwave generator. Once such devices are realized in a microscopic circuit, one needs to measure the DW frequency more precisely.
We theoretically propose a principle for precise measurement of oscillatory domain wall (DW) by a ferromagnetic Josephson junction, which is composed of a ferromagnetic wire with DW and two superconducting electrodes. The current-voltage curve exhibits stepwise structures, only when DW oscillates in the ferromagnetic wire. The voltage step appears at V=n(h/2e)f with the fundamental constant h/e, integer number n, and the DW frequency f. Since V can be determined in the order of 10^{-9} accuracy, the oscillatory DW will be measured more precisely than present status by conventional method.
The authors would like to thank Dr. J. Ieda for useful comments and discussions. This work is partly supported by Grants-in-Aid for Scientific Research from MEXT (Grant No. 19204035, No. 21360043, No. 22102501), the "K" computer project of Nanoscience Program, JST-CREST, and FIRST-Program.

P3-22 Expulsion of parallel vortices and field tuning of perpendicular vortex hopping - ***M. Kunchur (University of South Carolina), A. Gurevich (Old Dominion University), M. Liang (University of South Carolina)***

We have observed a transition in the mixed-state transport response of molybdenum-germanium films in parallel magnetic fields, which seems to correspond to the Likharev vortex core explosion that occurs above the temperatures at which the film thickness becomes smaller than 4.4 times the coherence length. Above the transition temperature the parallel vortices disappear and the dissipation seems to arise due to activated hopping of perpendicular vortices across the width of the film. The parallel field, while not providing a source of vortices in this regime, can be used to tune the resistive state through its pair breaking action in reducing the superfluid density.
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P3-23 Vortex structures in nano-sized two (electron and hole) band superconductor - ***Y. Niwa (Osaka Prefecture University), M. Kato (Department of Mathematical Sciences, Osaka Prefecture University)***

Generally the vortex-vortex interaction is repulsive and vortices form the Abrikosov lattice in type-II superconductors, but V. V. Moshchalkov et al. observed that the vortex configuration has an inhomogeneous spatial distribution in a two-band superconductor MgB_2 [1]. They argued that the vortex-vortex interaction in MgB_2 has short-range repulsion and long-range attraction parts, because there are type-II superconducting hole band and type-I superconducting electron band in MgB_2. And they reproduced the experimental vortex structures by the phenomenological numerical simulations.
In this study, we study the vortex state in nano-sized two (electron and hole) band superconductor microscopically. Suematsu et al. solved the Bogoliubov-de Gennes equation with the finite element method and studied vortex state in nano-sized *s*-wave superconductors [2]. We extended this method for two-band superconductors and studied the vortex structures.
We found that the vortex structures are affected by the type-I superconducting component. For example, vortices incline to be close to the edge of the superconductors, because type-I superconducting component avoids forming isolated vortices.

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P3-24 Transition temperature of nano-structured superconductors - ***M. Kato (Department of Mathematical Sciences, Osaka Prefecture University), O. Sato (Osaka Prefecture University College of Technology)***

In nano-sized superconductors, electrons and vortices are confined in a small region, and they show peculiar properties. For example, vortices are not only singly quantized vortices, but also giant vortices or anti vortices and their structures are different from the Abrikosov- triangular lattice. Confined superconducting electrons also show peculiar properties. The energy level of the electrons are discretized and if the energy level distance between adjacent two levels is bigger than the superconducting energy gap then the superconductivity is destroyed. Also parity of number of superconducting electrons affects the superconductivity.
Especially the transition temperature varies with the size of superconductor. For superconducting thin films, it is found experimentally that the transition temperature oscillates with the thickness of the film [1]. For metal clusters, it is predicted that the transition temperature increases for a closed shell structure [2]. We also found that the transition temperature of superconducting square plate becomes 1.5 times of that of the bulk superconductor [3].
In this study, we investigate how transition temperature changes with the nano-structures of superconductors using the Bogoliubov-de Gennes equations or Gor'kov equation and the finite element method. We find that the transition temperature oscillates with the size of the superconductors and is enhanced when the size is comparable to the coherence length. Furthermore, we argue that how thermal and quantum fluctuations affect the enhancement of the transition temperature.
This work is partly supported by ''The Faculty Innovation Research Project'' of Osaka Prefecture University.
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P3-25 Critical exponents and glass transition in superconducting hybrid systems with magnetic and non-magnetic periodic pinning potentials - ***J. Vicent (Dpto. Fisica Materiales, Facultad CC. Fisicas, Universidad Complutense), A. Gomez (Depto. Fisica Materiales, Facultad CC. Fisicas, Universidad Complutense), J. del Valle, E. Gonzalez (Dpto. Fisica Materiales, Facultad CC. Fisicas, Universidad Complutense)***

Superconducting Nb thin films have been fabricated on top of arrays of magnetic and nonmagnetic nanocenters using electron beam lithography and etching techniques. In these hybrid systems vortex lattice dynamics is studied by mean of magnetotransport measurements close to the superconducting critical temperature, in the regime where the array periodic pinning overcomes the random intrinsic pinning. In this work, we explore the effect of this periodic pinning in the vortex glass vs. vortex liquid second order transition. We have focused on the critical exponents and glassy transition temperatures dependence taking into account the magnetic and nonmagnetic behavior of the pinning potentials. An enhancement of the pinning behavior is found in the hybrids with magnetic arrays and the effect on the transition critical exponents will be analyzed.
We want to thank Spanish Ministerio de Economia y Competitividad, Comunidad de Madrid and Santander-UCM grants.

P3-27 Numerical simulation of vortex dynamics with retarded vortex-vortex interaction and heat conduction in superconductors - ***D. Fujibayashi, M. Kato (Department of Mathematical Sciences, Osaka Prefecture University)***

We develop numerical simulation method to investigate the dynamics of vortices with retarded vortex-vortex interaction in superconductors using molecular dynamics simulations and heat conduction simulations.

Vortices feel an attractive force in trace of other vortices.This is due to the inhomogeneity of the spatial structure of the order parameter that occurs while the order parameter of the trail of the other vortices recover. This is the retarded interaction. This retarded interaction is of great importance when considering moving vortex matter.[1]

Furthermore, in nano-structured superconductors such as Corbino disks, there is a inhomogeneity of temperature due to nonuniform motion of vortices. [2]Therefor, we perform heat conduction simulations to consider thermal forces due to thermal gradients in the system of our molecular dynamics simulations.

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P3-28 Detecting jumps in magnetization associated with re-entrant vortex melting in a BSCCO single crystal - ***S. Banerjee (Department of Physics, Indian Institute of Technology, Kanpur-208016, U. P., India), T. Tamegai (Department of Applied Physics, The University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan), G. Shaw, P. Mandal (Department of Physics, Indian Institute of Technology, Kanpur-208016, U. P., India)***

Theoretically, the vortex state in superconductors is soft at low and high magnetic fields, and therefore vortex melting is expected to be re-entrant. However detection of the low field re-entrant leg of the vortex melting line have remained elusive[1]. Using high sensitivity differential magneto-optical imaging (MOI) we detect a jump[2] in local magnetic field ~ 0.2 G at low magnetic fields, which corresponds to a jump in local vortex density in a single crystal of $Bi_2Sr_2CaCu_2O_8$. We trace the evolution of this jump in magnetization across different regions of the sample as the magnetic field is increased to beyond the lower critical field at a fixed temperature. A locus of the field - temperature values at which the jumps in magnetization occur reveals the presence of a dilute vortex phase transition boundary located just above the lower critical field of the superconductor. Investigation of the shielding current distribution in regions of the sample where the jump has already occurred, shows that the melting gives way to forming a a vortex solid with low field gradients. The low-field melting phase boundary fits the theoretically predicted, re-entrant vortex melting curve. By using MOI we also spatially resolve the relaxation[3] of remnant magnetization to uncover the nature of the pinning landscape in the sample. We correlate the spatial variations of the jump in magnetization with the variations in the pinning landscape. We modify the theoretical fit by keeping the Lindemann number as a fitting parameter to investigate how the re-entrant vortex melting is affected by pinning. We estimate a change in entropy ~ 0.05 k_B per vortex per CuO layer associated with the re-entrant vortex melting.

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P3-29 Jamming - Unjamming transition and critical behavior in driven vortex matter in 2H-NbS2 - ***S. Banerjee (Department of Physics, Indian Institute of Technology-Kanpur, Kanpur-208016, India), S. Ramakrishnan, A. Grover (DCMP&MS, Tata Institute of Fundamental Research, Mumbai– 400005, India), A. Niazi (Department of Physics, Faculty of Natural Sciences, Jamia Millia Islamia University, New Delhi 110025, India), A. Sood (Department of Physics, Indian Institute of Science, Bengaluru 560012, India), G. Shaw, P. Mandal (Department of Physics, Indian Institute of Technology-Kanpur, Kanpur-208016, India), A. Rastogi (School of Physical Sciences, Jawaharlal Nehru University, Delhi 110 067, India)***

Random organization and irreversible transitions in the context of vortices in superconductors driven through a random pinning environment, remains a largely unexplored area. Some recent experiments [1] report of diverging time scales to achieve uniform vortex flow *only above*the plastic depinning threshold of pinned vortices. Our recent time resolved measurements [2] reveals the onset of an unusual jamming phenomenon deep in the driven vortex state in single crystals of 2H-NbS_2 (Tc ~ 6 K). Using a new protocol, we identify two limiting regimes of the de-pinning force, viz., a lower threshold for conventional de-pinning of vortices from pinning centers and a higher threshold for unjamming a disordered vortex configuration. Un-jamming at the larger driving force threshold uncovers a transient regime with giant velocity fluctuations. The transient fluctuating state exhibits critical like slow down to achieve uniform flow upon approaching the higher depinning force threshold from both *above as well as below it*. Analysis of this divergence, characterizes the universality class which our observed nonequilibrium transition belongs to. The critical slowing down in dynamics leads to an unconventional hysteretic current - voltage characteristics which is found at large drives in the superconductor. A further characterization of the jammed phase is obtained via observing the bimodal nature of the vortex velocity distribution in the fluctuating regime. Our results [2] validate the proposed correspondence between the notion of random organization[3] in vortex matter articulated in the context of diffusion of sheared colloids[4].

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P3-30 Spontaneous Spin Accumulation in Singlet-Triplet Josephson Junctions - *V. Yakovenko (University of Maryland)*

We study the Andreev bound states in a Josephson junction between a singlet and a triplet superconductors. Because of the mismatch in the spin symmetries of pairing, the energies of the spin-up and -down quasiparticles are generally different. This results in imbalance of spin populations and net spin accumulation at the junction in equilibrium. This effect can be detected using probes of local magnetic field, such as the scanning SQUID, Hall, and Kerr probes. This effect may help to identify triplet pairing in various superconducting materials.

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P3-31 Driven Vortex Dynamics in Superconducting Narrow Wires - *B. Zhu (National Laboratory for Superconductivity, Institute of Physics, and Beijing National Laboratory for Condensed Matter Physics, Chinese Academy of Sciences, Beijing 100190, China)*

Employing both the time-dependent Ginzburg-Landau equation and the molecular dynamics simulation methods, we have studied numerically the vortex dynamics and the phase transitions in the superconducting wires with the width ranging from hundreds of nanometers to several micrometers with various boundary conditions under the applied magnetic fields and currents. We have found that both the width and the edge pinning of the superconducting wires play important roles on the novel behavior of the driven vortex lattice. Dynamic phase transitions between disorder and periodic collective vortex flow states have been revealed in the simulations under the applied magnetic fields and currents for both cuprate high-Tc and conventional low-Tc materials. We propose that the alternating phase transitions between the regular and irregular moving vortex crystal in the narrow wires can answer for the periodic magnetoresistance oscillations which has been observed in some recent experiments.

This work is in collaboration with X. H. Chao(IOP, Beijing), J. Yuan, H. B. Wang(NIMS, Tsukuba), A. V. Silhanek and V. V. Moshchalkov(INPAC, Leuven).

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P3-32 Phi_0 discretized dynamics of flux entry, exit and annihilation in type-I superconductors - *G. Berdiyorov (Departement Fysica, Universiteit Antwerpen), A. Hernandez-Nieves, D. Dominguez (Centro Atomico Bariloche, San Carlos de Bariloche), M. Milosevic, F. Peeters (Departement Fysica, Universiteit Antwerpen)*

Being a very rich study object, the intermediate state (IS) of type-I superconductors recently attracted renewed interest [1-4]. It consists of coexisting flux-bearing normal and flux-prohibitive superconducting domains, formed in complex patterns due to the presence of two competing interactions [1,2]. Another degree of complexity is added to the problem in the presence of an applied current, which results in e.g., splitting the flux domains into smaller pieces [3]. These domains can undergo different dynamics phases, controlled by the external current [4]. To our knowledge, no theoretical reports addressed such current-induced topological transformations and kinematic phases of IS structures.

In this work, we study flux dynamics in a current-carrying type-I superconductor using the time-dependent Ginzburg-Landau theory. The stray magnetic field of the current induces IS, where nucleation of flux domains is discretized to *a single fluxoid at a time*, while their final shape (tubular or laminar), size and nucleation rate depend on applied current and edge conditions. The current induces opposite flux domains on opposite sides of the sample, and subsequently drives them to annihilation - which is *also discretized*, as a sequence of vortex-antivortex pairs. Dicretization of both nucleation and annihilation leave measurable traces in the voltage across the sample and in locally probed magnetization, similar to recent experimental findings [4]. Reported dynamic phenomena thus provide an unambiguous proof of a flux quantum being the smallest building block of the IS in type-I superconductors.

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P3-33 Effect of Disorder and Restricted Geometry on Transport Properties of Superconducting Nanoperforated Films - *A. Mironov, T. Baturina, D. Nasimov, A. Latyshev (A. V. Rzhanov Institute of Semiconductor Physics SB RAS, 13 Lavrentjev Avenue,630090, Novosibirsk, Russia), V. Vinokur (Materials Science Division, Argonne National Laboratory 60439, Argonne, Illinois, USA)*

That a thin film of the same material can be a superconductor but can very well turn an insulator, is one of the most remarkable aspects of disordered superconductors. The engine driving the transition between the superconducting and insulating states is disorder the action of which can be enhanced by the proper choice of the system geometry. We have performed a comparative study of the transport properties of continuous and nanoperforated TiN films, enabling us to separate the disorder and the geometry effects. The patterning into a square array of nanoscale holes with the periods of 80 nm and 200 nm converts a thin TiN film into an array of superconducting weak links [1] and stimulates both, the disorder- and magnetic field-driven superconductor-to-insulator transitions, pushing them to the lower degree of microscopic disorder [2]. Depending on the original degree of disorder the nanopatterning either suppresses the critical temperature, or drives the initially superconducting film into an insulating state, or else, transforms the originally insulating film into an even more pronounced insulator. We show that all the above effects result from the enhancement of the role of the two-dimensional Coulomb interaction, which changes the characteristic energies of the film on length scales significantly larger than the mean free path or the superconducting coherence length.

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P3-34 Edge superconducting state in Nb thin film with rectangular arrays of antidots - ***W. Zhang, S. He, H. Liu, G. Xue, H. Xiao, B. Li, Z. Wen, X. Han, S. Zhao, C. Gu, X. Qiu (Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences)***

Superconducting Nb thin films with rectangular arrays of antidots have been systemically investigated by transport measurements. In low fields, the magnetoresistance curves demonstrate well-defined dips at integral and rational numbers of flux quanta per unit cell, which corresponds to a superconducting wire network-like regime. When the magnetic field is larger than a saturation field, the interstitial vortices interrupt the collective oscillation in low fields and form vortex sublattice which produces a larger flux interval. In higher fields, a crossover behavior from an interstitial sublattice state to a ‘single object’ state is observed, characterized by oscillations with a period of $Phi_0/(pi*r_{eff} ^2)$, originating from the existence of edge superconducting states around the antidots.

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P3-35 Magnetization measurements in oblique magnetic fields: The influence of geometry and correlated pinning - ***V. Mishev, M. Eisterer, H. Weber (Atominstitut, Vienna University of Technology)***

Magnetization measurements are a well established technique for the characterization of superconducting materials. Such measurements are usually carried out with the magnetic field perpendicular to the sample surface, taking advantage of the symmetry of the sample and thus simplifying the data evaluation. However, in order to obtain a better understanding of geometry effects, the general case of a superconductor in oblique magnetic fields has to be studied. Another problem that has to be taken into consideration when examining a superconductor in oblique fields is the anisotropy of the critical current density in the material. In order to evaluate the influence of each effect, samples with different properties were prepared. The effect of geometrical anisotropy was measured using samples of an isotropic superconductor with different shapes. On the other hand, the material anisotropy and more specifically the effect of correlated pinning were evaluated using a cylindrical sample, rotated along its geometrical symmetry axis and thus changing the orientation of the applied magnetic field with respect to the correlated pinning centres. The measurements were carried out in a 5 T vector VSM, which assesses both the parallel and the orthogonal components of the magnetic moment. We will show that the ability to separately describe the influence of geometry and correlated pinning is important for the fundamental understanding of the critical state in superconductors as well as for applications.

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P3-36 Pinning force scaling of various state-of-the-art multifilamentary Nb3Sn wires and the role of additional small defects - ***T. Baumgartner, M. Eisterer, H. Weber (Atominstitut, Vienna University of Technology), C. Scheuerlein, L. Bottura, B. Bordini, R. Flükiger (CERN)***

The magnetic field and temperature scaling behavior of the volume pinning force in various types of state-of-the-art multifilamentary Nb_3Sn wires was assessed. The data were obtained from magnetization measurements in a SQUID magnetometer as well as from transport measurements of J_c and from resistive measurements of the upper critical field in a 17 T magnet. Established pinning force models were examined with regard to their applicability to the results of these measurements. The effect of small defects introduced by fast neutron irradiation on the scaling parameters was investigated by sequential irradiation of short wire samples in the TRIGA Mark-II reactor in Vienna. The findings presented in this work will be relevant to the LHC (Large Hadron Collider) luminosity upgrade project, which is likely to involve the replacement of the present Nb-Ti inner triplet quadrupole magnets by more powerful Nb_3Sn magnets.

P3-37 Spin Imbalance and Spin-Charge Separation in a Mesoscopic Superconductor - ***C. Quay, D. Chevallier, C. Bena, M. Aprili (Université Paris-Sud 11/CNRS)***

Spin-polarised electrons injected into a superconductor create both spin and charge imbalances. These relax via different mechanisms and over different length and time scales. While charge imbalance in superconductors have been studied in great detail both theoretically and experimentally [1], spin imbalance have received much less experimental attention, despite intriguing predictions of spin-charge separation effects [2,3]. We present evidence for spin imbalance and spin-charge separation in a mesoscopic superconductor.

A superconductor at equilibrium contains paired and unpaired quasiparticles. Imagine injecting two spin up electrons into a small superconducting volume and taking out a Cooper pair. With the condensate chemical potential held constant, the pair is rapidly replaced by one of the `extra' spin up electrons and a spin down electron, leaving a spin down hole. Thus, at the end, the charge in the volume is the same as that at equilibrium, but the spin has increased by two.

We have performed nonlocal transport measurements at low temperature (50mK) in nanofabricated FISIF lateral spin valves [4]. (F = Co, I = Al_2O_3 and S = Al.) A current applied between the first F and the S injects spin-polarized electrons into S and removes Cooper pairs. Using a second ferromagnetic finger placed within the Al spin relaxation length, we measure the chemical potential difference between the condensate and the up or down spins in S. Spin (charge) imbalance is obtained directly by subtracting (adding) the signals for parallel and antiparallel F configurations as suggested in [3]. At low injection current, quasiparticles in the S are almost purely spin ones (with nonlocal spin resistances on the order of 10Ω) with very little accompanying charge.

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P3-38 Magnetic blockade mechanism for superconducting vortex-antivortex pair creation in zero external field - *J. Miller, A. Wijesinghe (Univ. of Houston, Dept. of Physics & Texas Ctr. for Superconductivity)*

We propose a magnetic analog of the Coulomb blockade effect for quantum nucleation of flux vortex pairs in high-Tc superconducting (HTS) films and grain boundaries in zero applied magnetic field. This magnetic blockade instability occurs at theta = pi where theta is the “vacuum” angle. The theta term has also recently been discussed in the context of several other systems, including charge and spin density waves [1], topological insulators [2], the quantum Hall effect [3], and spontaneous CP violation. Our model predicts a sharp pair creation threshold current, formally similar to the Coulomb blockade voltage of a tunnel junction, and explains the observed thickness dependence of critical currents in HTS coated conductors. We use the Schrodinger equation to compute the evolving macrostate amplitudes, coupled by a generalized tunneling matrix element. The simulations yield excellent quantitative agreement with measured voltage-current characteristics of bi-crystal and other HTS grain boundary junctions. The model also predicts non-sinusoidal behavior in the voltage oscillations resulting from time-correlated vortex tunneling and yields behavior consistent with observed harmonic and sub-harmonic Shapiro steps.

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P3-39 Magnetization evidence for surface superconductivity at Tc3(>Tc) and its permeation into bulk at a lower temperature in a spherical Nb crystal. - ***U. Vaidya (Dept. of CMP & MS, Tata Institute of Fundamental Research, Mumbai - 400 005), S. Ramakrishnan, A. Grover (Dept of CMP & MS, Tata Institute of Fundamental Research, Mumbai - 400 005), H. Takeya (National Institute of Materials Science, Ibaraki)***

While enunciating the notion of possibility of nucleation of superconducting order parameter at the surface of a semi-infinite specimen for field applied parallel to the sample surface on the basis of Ginzburg-Landau equations, it was remarked that the surface superconductivity could first nucleate at the equator of a spherical specimen and, thereafter, permeate over the entire surface and eventually into the bulk of the specimen [1]. The surface superconductivity and the concurrent giant vortex states have been discussed in the literature [2,3] and the superconductivity nucleating at a temperature T_{c3}, distinct from its permeation into the bulk at T_c ($<T_{c3}$) has been explored [2,4]. Some of us had recently reported positive magnetization on field cooling concurrent with surface superconductivity between T_{c3}(H) and T_{c2}(H) in a very weakly pinned spherical single crystal of Nb [5]. Motivated by a recent report of an oscillatory magnetization at low fields in the domain of superconductivity in a crystal of a low $T_c$superconductor, we have performed high resolution magnetization measurements with high thermal stability (better than 1 mK) at low fields and close to T_{c3} in a spherical single crystal of Nb specimen. We observe that the H_{c2}(T) and H_{c3}(T) lines meet the t-axis at different temperatures, viz. 9.29 K and 9.35 K respectively. In *iso-field*measurements at very low fields, we have found the presence of oscillatory M-T response. In fact, between $H_{c2}(T)/T_{c2}(H)$ and $H_{c3}(T)/T_{c3}(H)$, the magnetization response has metastable character for all H. Detailed results shall be presented.

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P3-40 Surface Superconductivity and the determination of Hc3 and Hc2 lines in a single crystal of Ca3Ir4Sn13 - ***S. Kumar (Dept. of Physics, Indian Institute of Technology, Bombay), A. Grover (Dept. of Condensed Matter Physics and Material Science, Tata Institute of Fundamental Research, Mumbai- 400005), A. Thamizhavel (Dept. of Condensed Matter Physics and Material Science, Tata Institute of Fundamental Research, Mumbai- 400005), C. Tomy (Dept. of Physics, Indian institute of Technology Bombay, Powai, Mumbai- 400076), R. Singh (Dept. of Physics, University of Warwick, Coventry, United Kingdom)***

The observation of concave curvature in field dependence of superconducting transition temperature ($T_c(H)$) concurrent with paramagnetic magnetization and oscillating character in the thermal variation of field cool magnetization in single crystal of low T_c $Ca_3Rh_4Sn_{13}$ [1] was ascribed to compressed flux in the domain of surface superconductivity at low fields transforming to the Abrikosov state. We have pursued the exploration of this notion in a single crystal of cubic superconductor $Ca_3Ir_4Sn_{13}$ (T_c = 7.10K) via detailed ac and dc magnetization measurements concurrently performed using a SQUID-VSM system for fields applied in two different orientations of the sample. We report here the identification of features pertaining to paramagnetic Meissner effect and the oscillatory characteristics in *M-T* curves at low fields in $Ca_3Ir_4Sn_{13}$ in different orientations. We also note that the fingerprint(s) of surface superconductivity in $Ca_3Ir_4Sn_{13}$ can be observed up to very high fields in both the orientations. A new observation is that $H_{c3}(T)$ and $H_{c2}(T)$ are distinct and they meet the T-axis at different temperatures T_{c3} (in the limit *H* approaching zero field) and $T_c(0)$, respectively. The isothermal *M-H* scans between T_{c3} and $T_c(0)$ elucidate the superposition of responses arising from multi-quanta vortex states and the pinned Abrikosov lattice emerging from the compressed flux. Below $T_c(0)$, the fingerprints of $H_{c1}(T)$, $H_{c2}(T)$, and $H_{c3}(T)$ can be clearly identified in both the orientations.

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P3-41 Sub-THz Emission from Internal I-V Branches of Intrinsic Josephson Junctions in Bi2Sr2CaCu2O8+d - ***M. Tsujimoto (University of Tsukuba), T. Yamamoto (Japan Atomic Energy Agency), R. Klemm (University of Central Florida), K. Delfanazari, T. Kitamura, M. Sawamura, T. Kashiwagi, H. Minami, M. Tachiki, K. Kadowaki (University of Tsukuba)***

The discovery of intense, continuous and monochromatic sub-terahertz (THz) electromagnetic (EM) wave emission from single crystalline high-T_c superconducting $Bi_2Sr_2CaCu_2O_{8+\square}$(Bi-2212) [1] has opened the door to the possibility of filling the "terahertz gap" in the EM spectrum [2]. In 1992, it was established that Bi-2212 behaves as a stack of intrinsic Josephson junctions (IJJ's) showing the multiple branches in the *c*-axis current-voltage (*I-V*) characteristics [3]. In a single Josephson junction, application of dc voltage *V* across IJJ's led to an ac Josephson current and EM radiation with the same frequency f_J, satisfying the Josephson relation, $f_J = 2eV/h$, where *e* is the electric charge and *h* is Planck's constant [4]. The THz wave radiation is induced by applying dc *V* to the stack of IJJ's in the small mesa structure. Besides satisfying the Josephson relation, it was therefore consistently reported that the radiation frequency locked onto an internal cavity mode frequency [1,5,6].

In this study, we found that the THz wave emission can also take place in an inner region of the multiple *I-V* structures, where the number of active IJJ's, *N*, is fixed but different for each branch. We investigated these emissions in detail in order to confirm the ac Josephson effect as a fundamental mechanism for generating THz waves. By examining the inner *I-V* region, we observed the radiation frequency f_J can widely vary depending on the voltage per IJJ (*V/N*), where *N* can accurately be estimated from the *V*-dependence of f_J. These emissions with different *N* may provide us with the valuable information on the synchronization of a stack of IJJ's.

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P3-42 Irreversible or reversible THz wave emission from intrinsic Josephson junctions: Numerical study - ***Y. Nonomura (Computational Materials Science Unit, National Institute for Materials Science)***

Since the discovery of THz wave emission from intrinsic Josephson junctions without external magnetic field, [1] intensive experimental and theoretical studies have been made. Novel current-driven strong emission states characterized by the pi-phase kinks [2] were proposed in the coupled sine-Gordon (CSG) model. In these states hysteresis behavior is observed with respect to the application process of the bias current, and such irreversible behavior was also reported in experiments. [1] On the other hand, reversible emission was also reported. [3] Such hysteresis behavior is generally due to nonlinearity, namely the sine term in the CSG model. First, we concentrate on behavior of the fundamental mode by varying strength of the sine term (i.e. the critical current). As the strength of nonlinearity decreases, the width of hysteresis decreases, and hysteresis vanishes when the strength of nonlinearity becomes smaller than that of the bias current at the emission peak. Although complete reversible behavior only occurs when the bias current exceeds the critical current, which means breakdown of superconductivity in actual systems, the width of hysteresis becomes very small when the bias current approaches the critical current, and emission can be observed in the reverse process. Such "quasi-reversible" behavior is also observed in a higher-harmonic mode in the vicinity of the critical current, which may explain experimental "reversible emission". [3]

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P3-43 Enhancement of Terahertz Radiation from Intrinsic Josephson Junctions - ***K. Kadowaki (Faculty of Pure & Applied Sciences, University of Tsukuba, WPI-MANA, JST-CREST), R. Klemm (Department of Physics, University of Central Florida), M. Tachiki (Faculty of Pure & Applied Sciences, University of Tsukuba, JST-CREST), H. Asai, T. Kashiwagi, H. Minami (Faculty of Pure & Applied Sciences, University of Tsukuba, WPI-MANA, JST-CREST), M. Tsujimoto, K. Delfanazari, M. Sawamura (Graduate School of Pure & Applied Sciences, University of Tsukuba, WPI-MANA, JST-CREST), T. Kitamura (Graduate School of Pure & Applied Sciences, University of Tsukuba, WPI-MANA, JST-CREST)***

In this presentation, we show, firstly, the present status of understanding of the mechanism of THz radiation from intrinsic Josephson junctions including recent theoretical calculations based on the numerical simulation. Secondly, the engineering approach to make radiation stronger is given, because it is essential for the applications. We have investigated several different kind of array structures experimentally and theoretically.

The impedance matching between the mesa and free space is important and can be improved by using antennae, which have to be well designed. A comparison of experimental radiation patterns and theoretical simulation calculations will be argued. Thirdly, we present imaging set-up under development as an example of useful applications.

P3-44 Duality transformation between hole arrays and wire networks in superconducting Nb films - *X. Qiu (Institute of Physics, Chinese Academy of Sciences, Zhongguancun Nansanjie 8, Haidian, Beijing 100190), S. He, W. Zhang, H. Liu, H. Xiao, X. Han, S. Zhao (Institute of Physics, Chinese Academy of Sciences)*

Transport measurements on superconducting Nb films with periodic hole arrays have been carried out at different temperatures and applied magnetic fields. The arrays are honeycomb and kagome lattices with edge-to-edge separation between nearest neighboring holes comparable to the coherence length at temperature close to Tc0. Fine structures in the field dependent resistance R(H) and transition temperature Tc(H) curves are observed in both arrays. Comparison of experimental data with calculation results shows that these structures resemble those observed in wire networks with triangular and T3 symmetries, whose dual are honeycomb and kagome, respectively. A geometrical duality transformation between hole arrays and wire networks has been established. Our results suggest that in these specified periodic hole arrays the physics associated with the fine structures is dominated by that in wire networks.

We thank Q. Niu, X.C. Xie, V.V. Moshchalkov, F. Nori for fruitful discussion. This work is supported by National Basic Research Program of China(No.2009CB929100, 2011CBA00107, 2012CB921302) and National Science Foundation of China (No. 10974241).

P3-46 Dynamical properties of Josephson vortices in large mesas of intrinsic Josephson junctions in Bi2Sr2CaCu2O8+d - *T. Kitamura, T. Kashiwagi, M. Tsujimoto, K. Delfanazari, M. Sawamura, H. Minami, K. Kadowaki (University of Tsukuba, CREST-JST, WPI-MANA)*

Dynamical properties of Josephson vortices such as *lock-in* phenomena [1], periodic oscillation of Josephson vortex flow resistance [2], step-wise change of flow resistance on a function of the tilted angle, etc. have been investigated intensively when the sample size is comparable with or slightly larger than the Josephson length l_J ~mm. It is interesting to ask what is going to happen, when the size of the sample goes beyond l_J towards l_c, where the Josephson plasma resonance as well as the THz emission phenomena are observed. In order to study the dynamical properties and THz emission phenomena simultaneously, we constructed a new cryostat system where both measurements can be done.

We present experimental results of integrated phenomena associated with Josephson vortices in sample sizes between l_J and l_c as functions of the sample size and magnetic fields, etc.

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P3-47 Tunable, Coherent and Continuous Terahertz Waves Emission from Various Shapes of Mesas in Intrinsic Josephson Junctions Bi2Sr2CaCu2O8+d: Designing of Mesa Arrays - *K. Delfanazari (University of Tsukuba, CREST-JST, WPI-MANA), R. Klemm (Department of Physics, University of Central Florida), T. Yamamoto (Semiconductor Analysis and Radiation Effects Group, JAEA), T. Hattori (University of Tsukuba CREST-JST), R. Nakayama, H. Minami, K. Kadowaki (University of Tsukuba, CREST-JST, WPI-MANA), M. Tsujimoto, T. Kashiwagi, H. Asai (University of Tsukuba, CREST-JST, WPI-MANA), M. Sawamura, T. Kitamura (University of Tsukuba, CREST-JST, WPI-MANA)*

Intense, coherent and tunable terahertz (THz) waves from intrinsic Josephson junctions (IJJs) in layered high temperature superconductor $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) are generated by applying a dc-voltage along the *c*-axis of Bi-2212 single crystal which is sculptured by various milling techniques such as photolithography, focused ion beam (FIB), or Ar-ion milling, into a mesa structure [1, 2]. The mechanism of THz radiation for rectangular and disk mesas has been understood by the oscillation of the superconducting current uniformly and the displacement current non-uniformly in the mesa [3]. Furthermore, the mesa geometry acts as a cavity resonator which may enhance the radiation power. Besides, all cases have normally linear polarization.

There have been many efforts for enhancing the emission intensity by synchronizing either the radiating junctions in a stack of IJJs or radiating mesas on the same crystal which is so called mesa array. For designing as well as performing of mesa arrays, circular polarization has to be taken into account as an important parameter.

However, there are some geometries that are found to have circular polarization in the case of triangular, pentagonal, hexagonal and elliptical mesas which can be promised candidates for designing of mesa arrays. Therefore, we study various mesas with different geometries by using the FIB milling technique for understanding the cavity role in THz radiation from IJJs. Triangular mesas; isosceles, equilateral and right angled [4], pentagonal, hexagonal and elliptical mesas with various sizes are fabricated and the temperature dependence of the *c*-axis resistance, *IV*, temperature dependence of the outermost *IV* characteristics and spectra are studied.

[1] L. Ozyuzer, *et al*., Science **318**, 1291 (2007).
[2] K. Kadowaki, *et al*., Physica C **468** 634 (2008).
[3] M. Tsujimoto, *et al*., Phys. Rev. Lett. **105** 037005-1 (2010).
[4] K. Delfanazari, *et al.*, JPCS, to be published 2012.

P3-48 Fluctuating pancake vortices probed by the c-axis resistivity due to dissipation of the Josephson vortex lattice - ***I. Kakeya (Kyoto University), A. Koshelev (Argonne National Laboratory), A. Buzdin (Institut Universite de France and Universite de Bordeaux), T. Yamamoto (Uniervsity of Tsukuba), K. Kadowaki (University of Tsukuba)***

In strongly anisotropic layered superconductors in tilted magnetic fields, the Josephson vortex lattice coexists with the lattice of pancake vortices. Due to the interaction between them, the dissipation of the Josephson vortex lattice is very sensitive to the presence of the pancake vortices. If the c-axis magnetic field is smaller than the corresponding lower critical field, the pancake stacks are not formed but the individual pancakes may exist in the fluctuational regime either near the surface in large-size samples or in the central region for small-size mesas. We calculate the contribution of such fluctuating pancake vortices to the c-axis conductivity of the Josephson vortex lattice and compare the theoretical results with measurements on small mesas fabricated out of $Bi_2Sr_2CaCu_2O_{8+\delta}$ crystals. A fingerprint of fluctuating pancakes is a characteristic exponential dependence of the c-axis conductivity observed experimentally. Our results provide strong evidence of the existence of the fluctuating pancakes and their influence on the Josephson vortex lattice dissipation.[1]

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This work was supported by UChicago Argonne, LLC, operator of Argonne National Laboratory, a US Department of Energy Office of Science laboratory, operated under Contract No. DE-AC02-06CH11357, Sumitomo Foundation, and KAKENHI #23681030.

P3-49 Enhancement of terahertz-wave emission from Bi2212 mesas by electrode thickness - ***I. Kakeya (Department of Electronic Science and Engineering, Kyoto University), Y. Omukai, N. Hirayama, S. Mizuta, M. Suzuki (Kyoto University)***

Radiations of monochromatic and continuous electromagnetic waves with frequencies ranged between 0.3 and 0.9 THz and powers up to 5 mW from rectangular mesa structures of Bi2212 intrinsic Josephson junction (IJJ) have been reported [1]. The radiation is described by the synchronization of standing waves (cavity modes) of thousands of stacked IJJs although the lengths of the IJJs are not uniform because of the trapezoidal cross section of the mesa [2]. So far, it has not been clarified yet the property of a sample which divides into emitting and non-emitting. This is because of lack of systematic experimental results with carefully controlled junction parameters. Therefore, the central issue of this study is how to induce the synchronized Josephson plasma oscillations by changing a junction parameter which affects thermal distribution inside the mesa: thickness of the electrode.

We prepared several mesa structures with the same geometry of 80 x 400 x1.0 mm^3 but different thicknesses of Ag electrodes on Bi2212 single crystals. The electrode thicknesses are 30, 70, 400 nm for types A, B, and C, respectively. THz emission was observed in types A and B, while neither response of the bolometer nor anomalies in IV characteristics were found in type C. Since the THz emission is found at the resistive quasiparticle branch of the *IV* characteristics, temperature of the mesa is raised by the injected bias current. The temperature rise is more significant in a mesa with thinner electrode because the electrode is a major heat leak path. Therefore, the local temperature rise is considered to be the origin of the synchronization of phase kink for the THz emission.

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P3-50 Superconducting Order Parameter of a Ferromagnetic Josephson Junction in the Presence of a Magnetic Domain Wall - ***A. Bill, T. Baker, A. Richie-Halford, A. Moke (Department of Physics & Astronomy, California State University Long Beach, CA 90840-9505)***

Theoretical studies have predicted the existence of an odd-frequency triplet component in the order parameter of a superconductor-ferromagnet proximity system with an inhomogeneous magnetization. Recent experimental studies done on a junction that includes a ferromagnet with helical magnetization profile have indicated that such a component may explain their data. We seek to revisit the study of diffusive ferromagnetic Josephson junctions with inhomogeneous magnetization by considering a model for domain walls that properly accounts for their experimentally observed non-linear structure. The order parameter and Josephson critical current are determined for various domain wall configurations with a particular focus on the triplet components. The results of our experimentally realizable system are compared with those obtained from a variety of theoretical models and previous experimental findings. We also propose an experiment to unequivocally identify the odd-frequency triplet component.

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P3-51 Influence of Heat Treatment on the Properties of Hybrid Systems SC / FM Multilayers. - ***U. Chacón Hernandez, M. Fontes (Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil), E. Baggio-Saitovitch (E. Baggio-saitovitch11 Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil), L. Liu (PUC-Rio de Janeiro, Brazil), J. Gonzalez (Universidade Federal do Espirito Santo, Vitoria, Brazil, Brazil), Y. Xing (Universidade Federal Fluminense Niteroi, Brazil)***

Hybrid systems, such as the superconductor/ferromagnet (SC/FM) nanocomposites, allow a huge opportunity to study the coexistence of superconductivity and magnetism. In this work we studied Nb/(Co,FeNi)/Nb multilayers prepared through magnetron sputtering deposition technique. The niobium superconducting thickness was constant about 50 nm, while different thicknesses (5, 10 and 20 nm) were used for the ferromagnetic layers. The multilayers were characterized by x-rays and transmission electron microscopy. The SC and FM transition temperatures were determined by resistivity and magnetization measurements. As expected the superconducting properties are modified as a consequence of the proximity effect. In the presence of high magnetic fields (> B_{C2}) the phase diagram (B-T) of the multilayers is also modified due to the presence of the FM layers. Finally the as-prepared multilayers were annealed to 500 ^{o}C during one hour. For FM layers with thickness of 10 and 20 nm respectively, the SC transition temperature decreases for Cobalt FM layer, while it increases for NiFe one. On the other hand, in the case of FM thickness equal to 50 nm, always the SC Tc decreases. The B-T phase diagram for high applied magnetic field is also modified by the annealing process. Our studies suggest that the disorder induced by the annealing process is crucial to the physical properties of the films.

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P3-52 Observation of fishtail effects in BaFe2-xNixAs2 single crystals - ***Y. Zhang (National Laboratory for Superconductivity, Institute of Physics and Center for Condensed Matter Physics, Chinese Academy of Sciences, PO Box 603, 100190 Beijing,People's Republic of China), S. Jia (National Laboratory for Superconductivity, Institute of Physics and Beijing National Laboratory for Condensed Matter Physics,Chinese Academy of Sciences, Beijing 100190, China), C. Yang (National Laboratory for Superconductivity, Institute of Physics and Center for Condensed Matter Physics, Chinese Academy of Sciences, PO Box 603, 100190 Beijing, People's Republic of China.), H. Luo, W. Huang (National Laboratory for Superconductivity, Institute of Physics and Center for Condensed Matter Physics, Chinese Academy of Sciences, PO Box 603, 100190 Beijing,People's Republic of China)***

Magnetic loop measurements of a series of $BaFe_{2-x}Ni_xAs_2$ (x= 0.065, 0.085, 0.10, 0.15, 0.18) single crystals were performed with magnetic fields up to 9.0 T. Apparent fishtail effects were found for the samples with x=0.15 and 0.18, while the other samples showed no apparent relation to the fishtail effects in these measurements. By using these data and magnetization relaxation data, the irreversibility lines, second peak lines, and the crossover field for the transition from the first peak to the second peak are presented and discussed.

P3-53 Scanning Hall probe microscopy of vortex dynamics. - ***B. Raes (INPAC Institute for Nanoscale Physics and Chemistry, Nanoscale Superconductivity and Magnetism Group, K.U.Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium), A. Silhanek (Département de Physique Université de Liège Bât. B5, R/51 Allée du 6 août, 17 B-4000 Sart Tilman), V. Moshchalkov (INPAC - Institute for Nanoscale Physics and Chemistry, Director, Katholieke Universiteit Leuven, Celestijnenlaan 200 D,B-3001 Leuven, Belgium), J. Gutierrez, G. Junyi (INPAC Institute for Nanoscale Physics and Chemistry, Nanoscale Superconductivity and Magnetism Group, K.U.Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium), L. Li, J. Van de Vondel (Institute for Nanoscale Physics and Chemistry (INPAC), Nanoscale Superconductivity and Magnetism Group, K.U.Leuven,Celestijnenlaan 200D, B-3001 Leuven, Belgium), J. Tempère (Laboratium TQC, Dept. Fysica, Campus Drie Eiken,D.N.017Universiteitsplein 1, 2610 Wilrijk)***

Among the most powerful experimental methods to gain information about the ac-dynamics of vortices is the ac-susceptibility technique which detects the in-phase an out-phase response upon shaking the flux-line lattice with a small alternating magnetic field. So far, all the experimental and theoretical reports are focused on the global ac-susceptibility response, where the recorded non-local signal represents an average over all trapped flux lines, each in a different pinning potential and subjected to a different environment. Moreover, the relation between this global ac-response and the microscopic vortex dynamics is indirect.

We will use a novel local imaging technique with single vortex resolution, termed scanning ac-susceptibility microscopy (SSM), which allows us to directly visualize the local dynamics of individual vortices submitted to ac excitations. This technique combines the individual vortex resolution of scanning Hall probe microscopy and the phase-sensitive detection of the ac-susceptibility technique. Additionally, we have developed analytical tools which allow us to map the local response to the integrated response described by theory.

Using this technique we are able to track, on a local scale, transitions between different ac-dynamic regimes upon changing the amplitude of the ac modulation, the temperature or the magnetic field. A dynamical induced disorder-order transition in a system with weak random pinning is directly observed and studied with SSM. The vortex mobility during this transition is tracked by the local in-phase response, while the out-of phase response allows us to map the local viscous drag the vortex experiences, which is in one-to one relation to the local dissipation.

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P3-54 Escape regimes for phase in a Josephson junction. - ***G. Rotoli (SUN - Seconda Università di Napoli), A. Kawakami (Advanced ICT Research Institute, National Institute of Information and Communications Technology, Kobe), D. Stornaiuolo (CNR-SPIN UOS-Napoli), L. Longobardi (Darthmouth College), G. Papari (NEST, CNR-NANO e Scuola Normale Superiore, Pisa, Italy), D. Massarotti, L. Galletti (Università di Napoli "Federico II" and CNR-SPIN UOS-Napoli), G. Pepe, A. Barone, F. Tafuri (Università di Napoli "Federico II" and CNR-SPIN, UOS Napoli)***

The behavior of gauge invariant phase in a Josephson junction (JJ) can be subjected to very different regimes. At very lo temperature quantum effects dominate so the phase-particle undergoes to tunnelling throught maxima of a washboard

potential. Above crossover temperature the phase-particle escapes to finite voltage state via thermal noise hopping above the potential barrier.
Finally, at higher temperatures, phase diffusion regime is characterized by a fully developed brownian motion of the phase-particle in the washboard landscape.
Recently we have measured and analyzed via comparison with numerical simulations of classical behavior of the phase, the data both from NbN and YBCO biepitaxial JJ. We found significative comparison which can be used to fit the JJ quality factor Q.
Authors acknowledges support from Prin Miur 2009 and Cineca Supercalcolo 2011.

P3-55 Vortex Flipping by Exchange Field in Superconductor-Ferromagnet Spin Valve Structures - ***E. Patiño (Universidad de los Andes), M. Blamire (Cambridge University), Y. Maeno (Kyoto University), M. Aprili (Laboratoire de Physique des Solides)***

Superconductor(S)/Ferromagnet(F) structures have been subject of intensive research in recent years. This interest has been motivated by the new physical properties that arise in S/F structures. The present work focuses its attention in magnetic properties of these structures where little work has been carried out. In particular we are interested in F/S/F/AF spin valve structures with one of the F layers pinned by an antiferromagnetic (AF) layer. Here report magnetization measurements of Nb/Co and Ni/Nb/Ni/CoO/Nb structures performed with the field parallel to the film surface. Our results show strong evidence of vortex flipping by the exchange field of the ferromagnetic layers. These vortices appear to be equally influenced by each of the ferromagnets. Here three main vortex processes have been identified; vortex pinning, vortex flipping, and vortex creation.
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P3-57 Approaching the depairing current limit in YBCO Nanowires - ***S. Nawaz, R. Arpaia, T. Bauch, F. Lombardi (Chalmers University of Technology)***

Superconductive devices at the nanoscale can have a fundamental role in shedding light into the mechanism leading to High Temperature Superconductivity (HTS). The study of the transport properties of HTS nanowires with dimensions much smaller than the Pearl length (λ- = 2 λ2/t, where 't' is the thickness and 'λ' is the penetration depth of the film) gives access to a regime where the local properties of superconductors have a fundamental role. From the application point of view, realization of reproducible HTS nanowires can open new perspectives for the realization of single photon detectors and nanoSQUIDs which is a constantly growing field.
Transport studies of YBa2Cu3O7-x (YBCO) nanowires with widths ranging from 2um down to 50nm have been carried out. All the wires were fabricated by conventional electron beam lithography in combination with a hard carbon mask and Argon ion etching. The measured critical current density monotonically increases for decreasing wire width, with values approaching the depairing limit (Jc=3x108A/cm2) for the smallest wires. The pronounced variation of the critical current densities for wire widths below the Pearl length λ- ≈ 1000 nm is unexpected. From simulations of the current distribution in our wire geometries we can clearly attribute this behavior to an enhanced local current density at the edges of the junction between wire and wider electrodes.

P3-58 Engineering Magnetic Pinning in Superconducting/Ferromagnetic Hybrids - ***V. Vlasko-Vlasov (Argonne National Laboratory), A. Melnikov (3Institute of Physics of Microstructures, Novgorod), U. Welp, D. Rosenmann, W. Kwok (Argonne National Laboratory), A. Buzdin (University of Bordeaux)***

Arresting thermally excited vortex dynamics is crucial for multiple applications of superconducting (SC) materials and devices. We address this problem by engineering temperature independent magnetic pinning landscapes in combinations of SC and ferromagnetic (FM) films. Using direct magneto-optical imaging and macroscopic magnetic and transport measurements we study effects of various domain structures on the vortex motion and I-V characteristics in different SC/FM bilayers. We confirm a strong magnetic pinning of vortices by FM domain walls (DW) and reveal a considerable transport anisotropy introduced by the aligned FM stripe domains. Using dielectric FM layers to exclude the proximity interactions in the hybrids we find a strong magnetostatic attraction between SC vortices and magnetization in FM domains resulting in the formation of coupled SC/FM domains. This coupled domain structure defines a new electromagnetic response of the hybrid making it similar to that in a type-I superconductor. It attenuates the magnetic flux dynamics and suppresses thermo-magnetic avalanches due to the synergetic action of the pinning of DWs in the FM layer, pinning of vortices in the SC layer, and mutual pinning of vortices and DWs. The DW–vortex coupling defining the directional motion of vortices along the FM domains result also in the orientation of domain walls in FM layers by moving vortices [1].
By varying the width of SC bridges on the FM substrates and the width of FM applications on the SC substrates we study rectification and self-healing pinscapes defined by the local domain/vortex interactions.
This work was supported by DOE-BES under Contract No. DE-AC02-06CH11357.
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P3-59 Superconducting state in a mesoscopic segment ring - ***J. Aguiar (Departamento de Física, Universidade Federal de Pernambuco, 50670-901, Recife-PE), J. Barba-Ortega (Departamento de Física, Universidad Nacional de Colombia, Bogotá), E. Sardela (UNESP-Universidade Estadual Paulista, Departamento de Física, Caixa Postal 473, Bauru-SP)***

The study of mesoscopic superconducting structures has attracted the attention of scientific community, both from experimental and theoretical point of view due to the possibility of obtaining a large enhancement of the critical parameters such as, the critical fields and the critical superconducting current density. Once the mesoscopic regime is attained, i.e., when the sample size becomes comparable to superconducting penetration depth, *l*, and/or coherence length, *x*, the vortex-surface interactions can become comparable to the inter-vortex interaction and the local flux density becomes intrinsically dependent on sample geometry, both on shape and size. In this work we study the formation of vortices in a mesoscopic superconducting segment ring. We evaluate the magnetization, superconducting-normal magnetic field transition, the superconductor density. Our results point out that, as we reduce the superconducting width remaining the same area, the third nucleation field increases while the first critical field decreases. Nevertheless, the angular width of the segment ring exhibits a linear behavior with the third nucleation field and the first nucleation field is independent of the form of the segment ring.

P3-60 Powerful coherent terahertz emission from $Bi_{2}Sr_{2}CaCu_{2}O_{8+\delta}$ mesa array - ***T. Benseman (Materials Science Division, Argonne National Laboratory), H. Minami, K. Kadowaki (Institute for Materials Science, University of Tsukuba), K. Gray, A. Koshelev, W. Kwok, U. Welp (Materials Science Division, Argonne National Laboratory), T. Yamamoto (Quantum Beam Science Directorate, Japan Atomic Energy Agency)***

There is rapidly growing interest in the generation of electromagnetic (EM) waves at terahertz frequencies (1 THz = 10^{12} c/sec), because of their potential applications in novel nondestructive imaging and spectroscopy in a wide range of settings. These include not only the physical, chemical and biological sciences, but also pharmaceuticals, manufacturing, medical diagnostics, high-bandwidth communication technologies, and security and defense purposes [1]. Compact, stable and high-power sources of THz radiation are highly desirable for these applications. A variety of technologies have been developed [1, 2]; nevertheless, the frequency range from 0.5 to 2 THz, the so-called THz-gap, has been difficult to fill with solid-state sources. However, we have recently shown that stacks of intrinsic Josephson junctions in the highly anisotropic high-T_{c} superconductor $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) can be induced to emit coherent continuous-wave radiation in this frequency range [3]. When a DC voltage V_{J} is applied across a Josephson junction, high-frequency electromagnetic oscillations will be generated at the Josephson frequency $f_{J} = 2eV_{J}/h$, i.e. 1 mV per junction corresponds to 0.482 THz. Our stacks were designed in such a way that an electromagnetic cavity resonance synchronizes a large number of intrinsic Josephson junctions into a macroscopic coherent state.

Here we demonstrate 150 microwatts of radiation power at 0.51 THz, using three synchronized stacks patterned on a single Bi-2212 crystal. The emitted power scales roughly as the square of the number of energized stacks, while the total power spectrum is monochromatic to within observational limits. These results imply that the stacks radiate coherently.

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P3-61 Stability of fractional vortex states in a two-band mesoscopic superconductor - ***C. de Souza Silva, J. Pina (Departamento de Fisica, Universidade Federal de Pernambuco, Cidade Universitária, 50670-901 Recife-PE), M. Milosevic (Departement Fysica, Universiteit Antwerpen, Groenenborgerlaan 171, B-2020 Antwerpen)***

In 2001, superconductivity at considerably high temperature, 39 K, was discovered in MgB_2 [1]. Besides the unusually high critical temperature value for such a simple compound, it was demonstrated that MgB_2 is a two-gap superconductor, with considerably strong interaction between its two bands giving rise to a variety of interesting phenomena not observed in conventional single-band superconductors [2]. These observations refueled the interest on the physics of multigap superconductors. For instance, the possibility of non-monotonic vortex-vortex interactions in these materials, and the resulting formation of complex vortex patterns, has been intensively investigated and a matter of strong debate [3]. Another particularly interesting problem is the possibility of finding different vortex states at different bands of the material, which would result on fractional flux structures. In this work, we use the two-component Ginzburg-Landau approach to investigate the stability of fractional vortex states in a two-band mesoscopic disk under a magnetic field. We found out that this system can stabilize fractional vortex states at a certain range of the microscopic parameters: inter-band coupling parameter, Fermi velocities and partial density of states. We also demonstrate that by placing a small magnet nearby the superconducting disk one can easily control the range of parameters where these metastable fractional states take place. The stability of the fractional vortices can then be enhanced or completely washed out by tuning the intensity and polarity of the dot magnetic moment.

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P3-62 Vortex dynamics in ferromagnetic superconductors - ***S. Lin, L. Bulaevskii, C. Batista (Theoretical Division, Los Alamos National Laboratory)***

Superconductivity and magnetism are at the heart of modern condensed matter physics. While they seem to be antagonist according to the standard BCS theory, large families of magnetic superconductors were discovered in the last decades [1-4]. The interplay between superconductivity and magnetism allows to control the superconducting strength through the magnetic subsystem, or to manipulate magnetic moments by changing the superconducting properties. These phenomena open new possibilities for applications to superconducting electronics and magnetic storage devices.

Abrikosov vortices are a natural link between the superconducting condensate and magnetic excitations. Because the vortex is a magnetic object, it is expected to interact strongly with magnetic moments via Zeeman coupling. Thus the magnetic moments provide a novel handle to control vortex behavior in the static and dynamic regimes.

We study the vortex dynamics in ferromagnetic superconductors [5] and show that vortices attract each other at large distances due to polarization of the magnetic moments. Vortex clusters are then stabilized in the ground state for a low vortex density. The motion of vortex clusters driven by the Lorentz force excites magnons. These magnon excitations become unstable at a threshold velocity above which domain walls are generated for a slow relaxation of the magnetic moments. The domain walls modulate the vortex configuration. This underlying dynamics of vortices and magnetic moments can be probed by transport measurements. Finally, we discuss a novel way to measure the spectrum of magnetic excitation in magnetic materials using motion of vortex lattice based on the present study [6].

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P3-63 Spin Josephson effect with a single superconductor - *P. Brydon (Technische Universität Dresden)*

The physics of heterostructures involving superconductors and ferromagnets continues to attract much attention. A relatively new direction in this field is to replace the singlet superconductor by a triplet superconductor, which considerably enriches the physics due to the interplay of the ferromagnetic moment with the spin of the Cooper pairs [1]. A particularly remarkable feature is the existence of the spin Josephson effect: spin-flip reflection processes at the interface with the ferromagnet generate a spontaneous Josephson-like spin current in the triplet superconductor, where the angle between the **d** vector and the magnetic moment plays the role of the phase difference [1,2]. Remarkably, the sign of the spin current strongly depends upon the orbital pairing state of the triplet superconductor; furthermore, unlike the normal charge Josephson effect, only a single superconductor is required. The interface free energy for a thin ferromagnet layer on a bulk triplet superconductor has been analytically calculated, and reveals that the spin Josephson coupling induces an anisotropy axis in the ferromagnet [3]. As the sign of the anisotropy term depends on the orbital pairing state, this evidences a novel spin-orbital coupling effect, which could be observed using FMR. A recent self-consistent treatment indicates that the spin Josephson effect dominates the physics of the triplet superconductor-ferromagnet bilayer, mostly due to the strong dependence of the triplet gap near the interface on the orientation of the ferromagnetic moment [4].

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P3-64 Existence and detection of flat zero-energy surface bands of noncentrosymmetric superconductors - *P. Brydon (Technische Universität Dresden), A. Schnyder (Max-Planck-Institut für Festkörperforschung), C. Timm (Technische Universität Dresden)*

It has recently been established that nodal noncentrosymmetric superconductors are topologically non-trivial, with the nodal rings possessing a non-zero topological charge [1]. A bulk-boundary correspondence consequently guarantees the existence of aflat band of singly degenerate zero-energy states within the projection of the nodal lines onto the surface Brillouin zone. Using the quasiclassical scattering method [2,3], we construct the surface bound state spectra of such superconductors, and provide a condition for theexistence of the zero-energy flat states in terms of the sign of the gaps on the forward- and backward-facing Fermi surfaces. The zero-energy surface states leave distinct signatures in the tunneling conductance, which can be used as an experimental test of the order parametersymmetry. The interface of a noncentrosymmetric superconductor and a ferromagnet is hence identified as being of particular interest, as the tunneling conductance sensitively depends upon the orientation of the ferromagnetic moment. Furthermore, due to the nontrivial spin structure of the noncentrosymmetric superconductor, a finite surface current density can develop at the interface with the ferromagnet [4], to which the surface states make an important contribution.

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P3-65 Torque formula for multi-band anisotropic superconductors – the upper critical field can be determined without ambiguity - - *T. Ishida, N. Hayashi (Osaka Prefecture University), D. Kubota (Osaka Vacuum, Ltd.)*

The contribution of the vortex core has been taken into account properly in constructing a torque theory for multiband superconductors. We employ the prescription for describing the internal magnetic field in the vortex lattice by Hao *et al.* [1] and by Yaouanc *et al.* [2] to derive a torque formula as a natural extension of a preceding London theory [3]. In marked contrast with the preceding model, our formula [4] does not contain a phenomenological parameter η, which prevents us from obtaining a *true* upper critical field H_{c2} by analyzing an experimental torque curve. The parameter η was originally introduced to take care of the uncertainty in determining the vortex core size ξ_v . Furthermore, we reveal that the η value is universally scaled by anisotropy γ, magnetic field B, and H_{c2} due to field dependence of ξv . This may revitalize the single-band Kogan model in combination with a universal function $\eta(\gamma,B,H_{c2})$ instead of a constant η. This simplified method supplies a convenient root in torque analysis without losing the merits of new formula.

This work was partly supported by a Grant-in-Aid for Scientific Research from MEXT (Grant No. 23226019).

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P3-66 Sequential change in vortex configurations in superconducting Mo80Ge20 square network - ***H. Huy (Osaka Prefecture University), T. Ishida (Department of Physics and Electronics, Osaka Prefecture University), M. Hayashi (Faculty of Education and Human Studies, Akita University), T. Yotsuya (NanoSquare Research Center, Osaka Prefecture University)***

The amorphous superconducting $Mo_{80}Ge_{20}$film is a good model substance in studying properties of nanostructured superconductors because of the nature of weak pinningin this material [1]. The films were deposited on a Si (100) substrate by sputtering using a $Mo_{80}Ge_{20}$ target. The superconducting networks were prepared by a lift-off technique. Theoretically, we predict a sequential change in vortex configurations in 10x10 networks in the frame work of the nonlinear Ginzburg-Landau equation as a function of temperature [2]. The vortex distributionin$Mo_{80}Ge_{20}$network has been investigated by means of a scanning SQUID microscope. We systematically investigate a change in vortex patterns as a function of temperature. At higher temperatures, a diagonal stripe structure can be seen in vortices. Diagonal dimers can be seen at intermediate temperatures. At lower temperatures, the vortex structure essentially becomes similar to that of Abrikosov lattice since vortex-vortex interaction becomes repulsive from each other. This is qualitatively similar to what the theory predicted earlier [2].

Since the coil is scanned in the plane located parallel to the sample surface at the certain height, the actual spatial resolution is deteriorated than vortex at the sample surface. We attempted to improve the spatial resolution of the SQUID microscope on the basis of the inverse Biot-Savart law algorithm.The magnetic flux picked up by the SQUID coil is first converted in the Fourier space form. After algebraic calculation in the Fourier space, we successfully applied the inverse Fourier transform to restore the images at the sample surface. A significant improvement has been achieved for vortex images taken by the scanning SQUID microscope [3].

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P3-67 Threshold Critical Current Density to Trigger Flux Avalanches in Superconducting Thin Films - ***W. Ortiz, M. Motta, F. Colauto (Departamento de Física, Universidade Federal de São Carlos), A. Silhanek (Département de Physique, Université de Liège,), R. Dinner, M. Blamire (Department of Materials Science, University of Cambridge), T. Johansen (Department of Physics, University of Oslo), G. Ataklti, V. Moshchalkov (INPAC - Institute for Nanoscale Physics and Chemistry, Nanoscale Superconductivity and Magnetism Group, Katholieke Universiteit Leuven)***

Under certain conditions of temperature and magnetic field, sudden flux bursts (avalanches) develop into superconducting films, as a consequence of thermomagnetic instabilities, which occur when heat dispersion is slower than magnetic diffusion. Based on a systematic study of the magnetic response (including magneto-optical imaging) of Nb films we have found the existence of a threshold critical current density above which vortex avalanches are triggered. The experimental results reveal that this threshold value is nearly constant within the whole range of temperatures and magnetic fields investigated. The fact that an avalanche is triggered once the critical current reaches the threshold is in close correspondence with the behavior of granular material in sandpiles, which slides down whenever the slope exceeds the angle of repose. Our results are in perfect agreement with the predictions of a model for thermomagnetic instabilities in superconducting films, published previously by Yurchenko and coworkers [Phys. Rev. B 76, 092504 (2007)].

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P3-68 Visualizing the ac magnetic susceptibility of superconducting films via magneto-optical imaging - ***M. Motta, F. Colauto, W. Ortiz (Departamento de Física, Universidade Federal de São Carlos, 13565-905 São Carlos, SP, Brazil), A. Silhanek (Département de Physique, Université de Liège, B-4000 Sart Tilman, Belgium), R. Dinner, M. Blamire (Department of Materials Science, University of Cambridge, Pembroke Street, Cambridge CB2 3QZ, UK), T. Johansen (Department of Physics, University of Oslo, POB 1048, Blindern, NO-0316 Oslo, Norway), R. Zadorosny (Faculdade de Engenharia, UNESP - UniversidadeEstadual Paulista, Departamento de Física e Química, 15385-000, Ilha Solteira, SP, Brazil), G. Ataklti, V. Moshchalkov (INPAC - Institute for Nanoscale Physics and Chemistry, Nanoscale Superconductivity and Magnetism Group,Katholieke Universiteit Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium)***

Flux avalanches occur when sudden flux penetrates into type-II superconducting films [1]. The most common signature associated to avalanches is flux jumps in magnetization loops. However, a reentrant signature of the avalanche regime in ac susceptibility ($\chi = \chi' + i\chi''$) has been recognized [2].

In this work we have established a link between the global ac response and the local flux distribution of superconducting films by combining magnetic ac susceptibility, dc magnetization and magneto-optical (MO) imaging, as published in Ref. 3. The investigated samples are three Nb films: a plain specimen, used as a reference sample, and other two films patterned with square arrays of antidots.

At low temperatures, low applied dc fields and small ac amplitudes of the excitation field, the Meissner screening prevents penetration of flux into the sample. Above a certain threshold ac drive, flux avalanches are triggered during the first cycle of the ac excitation. The subsequent periodic removal, inversion, and rise of flux occurs essentially through the already created dendrites, giving rise to an ac susceptibility signal weakly dependent on the applied field. This intradendrite flux oscillation is followed, at higher values of the excitation field, by a more drastic process consisting of creation of new dendrites and antidendrites. In this more invasive regime, the ac susceptibility shows a clear field dependence. Remarkably, the MO images taken enabled us to establish a reliable link among the three experimental techniques employed. Being able to literally see the flux distribution at different experimental conditions allowed us recognize the actual signature of the avalanches in ac susceptibility measurements.

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P3-69 Observation of dendritic flux avalanche in superconducting MoSi films - ***F. Colauto, M. Motta, W. Ortiz (Departamento de Fisica, Universidade Federal de Sao Carlos, 13565-905 Sao Carlos, SP, Brazil), M. Blamire (Department of Materials Science, Cambridge University, Pembroke Street, Cambridge CB2 3QZ, United Kingdom), T. Johansen (Department of Physics, University of Oslo, POB 1048, Blindern, NO-0316 Oslo, Norway)***

Superconducting films can offer flexibility for innovation in electronic applications, hence for a reliable application, stability is important. However, films of materials classified as Low Temperature Superconductors (LTS) are vulnerable to the occurrence of flux avalanches. This arises at certain temperatures, when the sample is submitted to a magnetic field intensive enough and perpendicular to its plane [1-2]. The phenomenon is well understood as thermomagnetic instability, in which vortex movement release heat generating a positive feedback [3]. Magneto-optical imaging (MOI) technique has been crucial to understand how the profile of magnetic field sets in. Instead of homogeneous penetration, the path created has a dendritic arrangement. In this work we have observed flux avalanches on an amorphous film of MoSi (for 16 at% Si). The morphology of the avalanches has been studied by means of magneto-optical images and threshold limits of magnetic field and temperature have been determined through magnetometry. The avalanches can be prevented by placing a metallic layer in close contact with the superconducting film [4]. This brings the material to recover its capabilities of screening fields and transport superconducting currents.

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Research supported by Brazilian agency FAPESP

P3-71 Nonlinear Vortex Dynamics in Thin Niobium Films with Anisotropic Washboard Pinning Nanostructures - ***O. Dobrovolskiy (Physikalisches Institut, Goethe-University), V. Shklovskij (Institute for Theoretical Physics, NSC-KIPT), E. Begun, M. Huth (Physikalisches Institut, Goethe-University)***

The influence of nanofabricated anisotropic pinning sites on the magneto-resistivity tensor of epitaxial thin films of niobium in the mixed state was studied by electronic dc transport measurements and accompanying theoretical modeling. The thin films were prepared by dc magnetron sputtering of niobium onto sapphire substrates. A system of uniaxial and equividistantly arranged grooves has been fabricated by focused ion beam (FIB) milling [1]. The magneto-resistivity tensor of the films was determined in the limit of small current densities at various temperatures close to the critical temperature and in different small magnetic fields corresponding to the matching fields for the vortex ensemble with the underlying pinning potential landscape. The angle between the current and the grooves was set at seven fixed angles between 0° and 90°. One non-structured film was used for reference purposes. Perfect guiding of the vortices along the milled grooves was observed over a wide parameter range. The measured data are interpreted within the stochastic modeling approach of competing isotropic and anisotropic pinning [2].

O.V.D. gratefully acknowledges financial support by the DFG through Grant No. DO 1511/2-1.

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P3-72 Interplay between disorder and superconductivity: Kernel polynomial method investigation - ***L. He, S. Yun, S. Feng (Department of Physics, Beijing Normal University)***

We employ the Kernel polynomial method to study the competitive relationship between disorder and superconductivity in the two-dimensional inhomogeneous superconductors. After solving the Bogoliubov-de Gennes equations self-consistently, we compare the suppression of d-wave superconductivity by the increasing of disorder strength with that of s-wave superconductivity, and we find that at the strong disorder strength the phase separation of Anderson localized and superconducting phases can survive in the s-wave superconductor. In addition, the localization of electronic state is investigated by the time evolution of its Green's function, and the relative standard deviation of the on-site probability amplitude shows clearly that the delocalization effect is sufficiently large in the d-wave superconductor.

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P3-73 Resonant generation of coherent phonons in a superconductor by ultrafast optical pump pulses - *A. Avella (Dipartimento di Fisica "E.R. Caianiello" - Università degli Studi di Salerno), D. Manske, A. Schnyder (Max-Planck-Institut für Festkörperforschung)*

We study the generation of coherent phonons in a superconductor by ultrafast optical pump pulses. The nonequilibrium dynamics of the coupled Bogoliubov quasiparticle-phonon system after excitation with the pump pulse is analyzed by means of the density-matrix formalism with the phonons treated at a full quantum kinetic level. For ultrashort excitation pulses, the superconductor exhibits a nonadiabatic behavior in which the superconducting order parameter oscillates. We find that in this nonadiabatic regime the generation of coherent phonons is resonantly enhanced when the frequency of the order-parameter oscillation is tuned to the phonon energy, a condition that can be achieved in experiments by varying the integrated pump pulse intensity.

Phis. Rev. B **84,** 214513 (2011)

P3-75 Momentum-resolved spectral function of ultra-cold bosons in two-dimensional optical lattices - *T. Zaleski (Institute of Low Temperature and Structure Research, PAS)*

We study the excitations of strongly interacting bosons con?ned in two-dimensional square lattice. Using combined Bogoliubov method and the quantum rotor approach, we map the Hamiltonian of strongly interacting bosons onto U(1) phase action. Furthermore, we calculate the momentum and energy one-particle spectral function and its dependence on the presence of the superfluid phase. We show that the destruction of the ordered phase leads to opening of the gap in the excitation spectrum in **k**=0. On the other hand, superfluidity manifests itself as a sharp coherence peak resulting from long-range order. Correlation effects lead to appearance of a smearing of the band structure of incoherent particles, although the remnants of the Bogoliubov excitations are still present in the coherent part of the spectrum.

P3-76 Scaling of the density profiles of cold atoms near the quantum critical point in two- and three-dimensional optical lattices - *T. Kopec, T. Zaleski (Institute of Low Temperature and Structure Research, PAS)*

Abstract We study the critical behavior near the quantum critical point of strongly interacting bosons placed in an optical lattice. Using combined Bogoliubov method and the quantum rotor approach, we map the Hamiltonian of strongly interacting bosons onto U(1) phase action in order to calculate analytically the density profiles as a function of hopping and reduced chemical potential. Our approach allows us to explicitly compute the scaling form of the density n_s for systems confined in two-dimensional square and three-dimensional cubic lattice. We find a good convergence of n_s with the universal scaling function in a wide temperature range that is accessible in the current experiments on the density profiles in cold bosonic systems.

P3-77 Scanning Tunneling Spectroscopy Studies on Strongly Disordered NbN Close to Anderson Metal Insulator Transition. - *A. Kamlapure (Tata Institute of Fundamental Research, Homi Bhabha Road, Colaba, Mumbai 400005, India.), L. Benfatto (ISC-CNR and Department of Physics, Sapienza University, Piazzale Aldo Moro 5, 00185 Rome, Italy.), G. Saraswat, M. Chand, M. Mondal, S. Kumar, J. Jesudasan, V. Bagwe, V. Tripathi, P. Raychaudhuri (Tata Institute of Fundamental Research, Homi Bhabha Road, Colaba, Mumbai 400005, India.)*

We report the scanning tunneling spectroscopy measurements on series of disordered conventional s-wave superconductor, NbN, close to Anderson metal insulator transition. We observe that strongly disordered NbN reveals the formation of Pseudogapped state, which is characterized by a dip in the tunneling conductance close to Fermi level above Tc. A pseudogapped state is also seen all the way up to 6K in a sample where the superconducting ground state is completely suppressed by disorder. We propose that this dip is a signature of superconducting correlations persisting locally even after the global superconductivity is destroyed. This conclusion is further supported by the emergence of BCS-like coherence peak once that an overall Altshuler-Aronov background is subtracted. Based on the temperature at which the pseudogap vanishes, called as T*, we establish the phase diagram highlighting the pseudogap state and the superconducting state near Anderson metal insulator transition.

Our work enlightens also the local properties of disordered superconductors. At the lowest temperature accesible in our setup we observe a gap inhomogeneity leading to the formation of domain structures in which we see regions of varying superconducting gap values separated by regions with low gap value. In the pseudogapped state these domains evolves continuously with temperature and different domains evolve to give different T* locally in the same sample.

We propose a scenario based on phase fluctuations to understand the pseudogap state in strongly disordered NbN films. In presence of strong disorder the superconductor segregates into phase incoherent islands where superconductivity exists locally, but the global superconducting state is destroyed.

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P3-78 Length scales, collective modes and topological excitations in multiband systems. - *E. Babaev (UMass Amherst), J. Carlstrom, M. Silaev (KTH Stockholm), J. Garaud (UMass Amherst)*

We disscuss a general framework for calculations of length scales and collective modes in multiband systems, using both Ginzburg-Landau and microscopic theories. For two-band theories we discuss the effects of hybridization due to interband intractions on the characteristic length scales of the theory. Next we show that in three band systems with broken time-reversal symmetry the normal modes are mixed phase/density collective excitations. As a result the gradients of densities and phase differences can be inextricably intertwined in vortex excitations in three band system. This leads to several unusual properties of vortices and domain walls.Finally we discuss the superconducting regimes in multicomponent or layered systems where one of the coherence lengths is smaller than the magneticfield pentration length while the other one is larger, which was termed recently type-1.5 superconductivity.

ulien Garaud, Johan Carlstrom, Egor Babaev
Phys. Rev. Lett. 107, 197001 (2011)
Mihail Silaev, Egor Babaev
Phys. Rev. B 84, 094515 (2011)
Johan Carlstrom, Julien Garaud, Egor Babaev
Physical Review B, vol. 84, Issue 13, id. 134518 (2011)

P3-79 Odd-Frequency Triplet Pairing in Mixed-Parity Superconductors - *P. Gentile (Dipartimento di Fisica "E. R. Caianiello", Università di Salerno and CNR-SPIN, Fisciano (SA)), J. Linder (Department of Physics, Norwegian University of Science and Technology, Trondheim), C. Noce, A. Romano, G. Annunziata, M. Cuoco (Dipartimento di Fisica "E. R. Caianiello", Università di Salerno and CNR-SPIN, Fisciano (SA))*

The topic of unconventional proximity effect (PE) and quantum states in ferromagnet/superconductor (F/S) hybrids [1] is at the center of a wide investigation especially for the possibility of generating spin triplet odd-in-time superconducting pair correlations (STOT) which propagate within a strong diffusive F over very long distances, comparable with the penetration length scale of spin singlet pairs in a normal metal. This long-range PE may offer the possibility to exploit completely polarized supercurrents in the rapidly developing field of spintronics, and also provides the opportunity to unify mesoscopic superconductivity and spintronics through the exploitation of triplet supercurrents in devices like spin-transistors, spin-filters, etc. The recent experimental efforts addressing the generation and detection of STOT have been based on the theoretical prediction that magnetic inhomogeneity is a key aspect to generate STOT, at least for singlet superconductors. However, in all devices so far realized the fine tuning of the magnetic profile is a complicate task, and this in turn probably hampers the controlled manipulation of spin triplet supercurrents. To avoid this problem, we propose an alternative perspective for the generation of STOT, looking at the almost unexplored context of unconventional superconductors (US), and also considering F/S hybrids. We show that the generation of STOT is intimately connected to the symmetry breaking in US, and that the main source of STOT is provided by the presence of mixed-parity states [2]. Such feature turns out to be relevant both for the symmetry determination of US and also for hybrids, since it can lead to STOT without invoking magnetic inhomogeneities or non-collinearity.

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P3-80 Magnetic field profile and microscopic parameters of nonlocal superconductors. - *V. Kozhevnikov (Tulsa Community College), H. Fritzsche (Canadian Neutron Beam Centre NRCC, Chalk River Laboratories), M. Trekels, A. Volodin, K. Temst, M. Van Bael, C. Van Haesendonck, J. Indekeu (KULeuven), A. Suter, T. Prokscha, E. Morenzoni (Paul Scherrer Institute), V. Gladilin (Universiteit Antwerpen)*

One of the longest standing problems of experimental superconductivity is quantitative measurement of the in-depth distribution of the magnetic field penetrating into superconductors in the Meissner state. Such measurements, being important on their own, provide the most direct way to determine the London penetration depth, the key parameter whose absolute value is still not known for any superconductor. The theory predicts that in nonlocal superconductors the field profile is non-monotonic with sign reversal at a certain depth. Knowledge of the field profile in such superconductors also yields dimension of the Cooper pairs: the Pippard coherence length. The measurements of such kind, for the first time performed with two extreme nonlocal superconductors (indium and tin), will be reported. The field profile was thoroughly measured using Low-Energy muon Spin Rotation spectroscopy and Polarized Neutron Reflectometry. Results of the measurements unambiguously confirm the nonlocal effect, first predicted by Pippard six decades ago. Obtained intrinsic parameters include the London penetration depth, the Pippard coherence length and the mass of the Cooper pairs. All quantities are determined with justified uncertainties. Application of the developed methodology to unconventional superconductors will be discussed.
Supported by NSF via DMR 0904157 grant.

P3-81 The critical magnetic field and the magnetic flux density in the intermediate state of a Pippard superconductor. - *V. Kozhevnikov (Tulsa Community College), C. Van Haesendonck (KULeuven), R. Wijngaarden, J. de Wit (VU University Amsterdam)*

One of the fundamental problems of unconventional superconductivity is the magnetic structure of vortices. In order to contribute to solution of this problem and to address number of unsolved fundamental questions of the intermediate state (IS) we undertook an experimental and theoretical study of IS in an extreme type-I superconductor (indium) focusing on the domain structure and on the critical field of the IS-N (normal) transition. Results shed new light on the structure and evolution of the magnetic flux density in normal domains and may lead to new insights in the structure of vortices in type-II materials. A 2.5 micron thick indium film with mean free path 11 microns was placed in the superconducting vector (3D) magnet. Magneto-optical images were taken simultaneously with measurements of the sample resistance using a small low frequency AC current. The equilibrium domain structure of the IS state was investigated as a function of independently regulated in- and out-of-plane magnetic fields and/or DC transport current applied to the sample. The critical field of the IS-N transition was controllably varied in a range from 100% down to 40% of the thermodynamic critical field. A theoretical model based on the Tinkham interpretation of the Landau laminar structure quantitatively accounts for the experimental results for both ordered and disordered domain patterns.
Supported by NSF via grant DMR 0904157.

P3-82 GENERALIZED BEC FORMALISM AND BCS THEORY: SUPERCONDUCTORS AND COLD ATOMS - ***M. de Llano (Instituto de Investigaciones en Materiales, UNAM, Mexico, DF, MEXICO), M. Grether (Facultad de Ciencias, Universidad Nacional Autónoma de México, 04510 México, DF), V. Tolmachev (N.E. Baumann State Technical University, 107005, 2-ja Baumanscaja St., 5, Moscow, RUSSIA)***

A recent reexamination of BCS theory leads one to devise a generalized Bose-Einstein condensation (BEC) formalism (GBEC); for a condensed review see Ref. 1. The new formalism essentially boils down to a boson-fermion (BF) model containing three new ingredients: i) Cooper pairs (CPs) as real bosons, in contrast to BCS pairs which at best are only hard-core bosons; ii) BF vertex interactions (analogous to electron-phonon vertices) and iii) two-hole CPs (2hCPs) along with two-electron CPs (2eCPs) are accounted for on an equal footing. This makes it a *ternary* gas mixture that improves upon usual binary ones. In addition to the usual normal phase, *three* condensed stable thermodynamic phases ensue at substantially higher T_cs than appear in BCS theory. These phases are: two pure BECs of 2eCPs and of 2hCPs as well as a mixed phase with both kinds of CPs. BCS theory is precisely recovered as a special case from the mixed phase for *equal* numbers of both kinds of CPs. In contrast to the well-known BCS *exponential* rise from zero of T_c the GBEC scheme exhibits a *linear* rise as function of doping as eminently observed in high-T_c superconductors. In fermionic cold atoms Ref. 2, the divergence of the scattering length at unitarity, and that signals a two-body bound state, is recalled. A possible solution of this conundrum is discussed via a so-called "thermodynamic (or van der Waals) perturbation theory" not in terms of a low-density expansion involving the divergent scattering length but rather as a divergence-free power series in the attractive portion of the two-fermion interaction Ref. 3.

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P3-83 The Nagaoka polaron in the Ising t-J model - ***M. Maska (Department of Theoretical Physics, University of Silesia), E. Kochetov (Bogolyubov Theoretical Laboratory, Joint Institute for Nuclear Research), M. Mierzejewski (Department of Theoretical Physics, University of Silesia), L. Vidmar (J. Stefan Institute), J. Bonca (J. Stefan Institute and Department of Physics, FMF, University of Ljubljana)***

It is believed that the *t-J* model close to half filling has a ferromagnetic ground state in the small-*J* limit. With increasing *J* this state evolves into an antiferromagnetic background with ferromagnetic polarons. Using recently developed approach to the *t-J*model [1] the formation of ferromagnetic polarons is analyzed. The advantage of the proposed method is that large systems up to a few hundred lattice sites can be easily studied by means of a modified classical Monte Carlo technique [2]. It is particulary important in the small-*J* regime, where the size of the polaron is large. This is the regime which is not accessible by the Quantum Monte Carlo and Lanczos methods.

For one and a few holes we calculate how the size and shape of the ferromagnetic polaron depends on *J*. We show that the results obtained for the so-called "Ising *t-J* model" are consistent with the exact digonalization studies for the *t-J* model [3], but allows to analyze this model also for much smaller *J*. We demonstrate that in this regime a phase separation occurs for a finite concentration of holes. Some dynamic properties of the polaron in a nonequilibrium system are discussed as well.

M. M. Maska acknowledges support from the Foundation for Polish Science under the "TEAM" program.

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P3-84 Superconductivity and zero-point oscillations - ***B. Vasiliev (Institute for Physical and Technical Problems)***

Currently it is accepted to think that in order to explain the phenomenon of superconductivity is necessary to understand the mechanism of formation of electron pairs.However, the paired electrons can not form a superconducting condensate. They are not identical, since the uncorrelated zero-point fluctuations differ they from each other. To create a unified ensemble of identical particles, the pairs must order their zero-point fluctuations. For this reason, the ordering of zero-point oscillations in the electron gas is the cause of superconductivity creation and the parameters characterizing this ordering determine the properties of superconductors. The assumption of condensation of zero-point oscillations gives possibility to construct the model of superconductivity, which is characterized by the ability to obtain estimates for the critical parameters of elementary superconductors, which are in the satisfactory agreement with measured data. The ordering of zero-point fluctuations of atoms in liquid helium can explain the formation of superfluid states in He-4 and He-3.

Vasiliev B.V. : Superconductivity as a consequence of an ordering of the electron gas zero-point oscillations, Physica C, v.471,277-284 (2011)
http://bv-vasiliev.narod.ru/superconductivity/

P3-85 Strong coupling perturbation theory approach to find the critical current of a cold atom Josephson junction analog - ***J. Freericks (Department of Physics, Georgetown University), M. Gupta, H. Krishnamurthy (Indian Institute of Science, Bangalore)***

The NIST experimental group led by Gretchen Campbell is working on creating analogs of Josephson junctions with superfluid Na condensates. The atoms are trapped in a ring trap with a barrier put across the trap in a radial direction. They can measure the critical current through the junction as a function of the barrier properties as well as determine effects that enter at higher velocities when vortices are created. We use a strong-coupling perturbation theory approach, which has been proven to be highly accurate for describing the Bose Hubbard model when one is in the Mott phase or in the strongly coupled

superconductor, to describe the Josephson junction and to calculate the critical current as a function of the barrier parameters. We will compare our preliminary data to experiment as best we can.
This work is supported under ARO Award W911NF0710576 with funds from the DARPA OLE Program.

P3-86 Transition Temperatures of Superconductors estimated from Periodic Table Properties - *O. Isikaku-Ironkwe (RTS Technologies, San Diego 92122 & The Center for Superconductivity Technologies(TCST), Department of Physics, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria)*

Predicting the transition temperature, Tc, of a superconductor from Periodic Table normal state properties is regarded as one of the yet–to-be-solved grand challenges of superconductivity. By studying the correlations of Periodic Table properties with known superconductors, it is possible to estimate their transition temperatures. Starting from the isotope effect and correlations of superconductivity with electronegativity (??), valence electron count (Ne), atomic number(Z) and formula weight (Fw), we derive an empirical formula for estimating Tc that includes an unknown parameter,(Ko). With average values of ??, Ne and Z, we develop a material specific characterization dataset (MSCD) model of a superconductor that is quantitatively useful for analyzing and comparing superconductors. We show that for most superconductors, Ko correlates with Fw, Ne, Z, the number of atoms (An) in the formula, the number of elements (En) and with Tc. We study nine superconductor families and use the discovered correlations to predict similar and novel superconductors and also estimate their Tcs. Thus the material specific equations derived in this paper, the material specific characterization dataset (MSCD) system developed here and the discovered Tc-En-An correlation, provide the building blocks for the analysis, design and search of potential novel high temperature superconductors with specific estimated Tcs.
This research was supported by Dr. Michael J. Schaffer, formerly at General Atomics, San Diego, California, USA. I acknowledge useful discussions with Dr. Jim O'Brien at Quantum Design, San Diego and Professor M. Brian Maple at U.C. San Diego.

P3-87 Isotope and interband effects in a multi-band model of superconductivity - *A. Bussmann-Holder (Max-Planck-Institute for Solid State Research), H. Keller (Physik-Institut der Universität Zürich)*

Isotope effects (IE) are essential in determining the pairing mechanism in superconductors. While for BCS type superconductors clear consensus about the IE exists, this is unknown in multiband superconductors (MBS). We demonstrate here that for MBS the IE on the superconducting transition temperature can vary between the BCS value and zero as long as the intraband couplings are affected. It can, however, exceed the BCS value when interband effects are dominant. In both cases a sign reversal is excluded. In addition, we show that the interband coupling substantially contributes in enhancing T_c. The results are independent of the pairing symmetry and the system specific band structure.
The results will be compared to experimental data obtained for copper oxides, MgB_2 and the Fe based superconductors. Interpretations of the experimental results in terms of the theoretical modeling are presented. The exotic isotope effects on the penetration depth and the pseudogap temperature T* observed in copper oxide superconductors are addressed as well and shown to be a consequence of polaron formation.

P3-88 The superconductive transition temperature in low-conductivity metals - *M. Osofsky, C. Krowne (Naval Research Laboratory), R. Soulen, Jr. (Naval Research Laboratory (retired)), G. Woods (University of South Florida)*

It is well known that the transport properties of very dirty metals, i.e. those near the metal-insulator transition, are quite different from those near the clean limit. We review these properties for several systems that we have studied and that have been published by others. We then demonstrate empirically that several disparate classes of superconductors whose only common feature is proximity to a metal/insulator transition (MIT), share a common phase diagram Tc(r). Here r is a coordinate characterizing the disorder and is completely defined in terms of measurable quantities. We then describe this phase diagram by expanding the range of applicability of the Allen-Dynes equation for T_c to include the effects of strong electron-electron interactions in disordered three dimensional and quasi-two dimensional metals. Using this model, we successfully fit data taken for several conventional low T_c and A15 superconductors as well as for the cuprates. The modified Allen-Dynes expression is also used to propose the physical conditions needed to obtain T_c even higher than that observed for the cuprates.

P3-89 Bosonic Josephson junction as an open system - *Q. Gu, H. Zheng, Y. Hao (Department of Physics, University of Science and Technology Beijing, Beijing 100083, China)*

Two atomic Bose-Einstein condensates separated by a barrier that allows atoms to tunnel make up a bosonic Josephson junction (BJJ), analogous to the superconducting Josephson junction (SJJ). Experimentally the BJJ can be realized by trapping the condensate in the double-well potential. The BJJ can not only exhibit Josephson-like current-phase effects as in the SJJ, but also demonstrate a number of new phenomena that are not accessible with SJJ's, including the π-phase oscillations and macroscopic quantum self-trapping (MQST).
We investigate dynamics of a quasi-1D double-well Bose-Einstein condensate subjecting to dissipation and external manipulation by solving the time-dependent Gross-Pitaevskii equation numerically. Both the particle imbalance and the relative phase between the two wells are calculated. It is shown that the system evolves from the self-locked population imbalance in the MQST regime to the population-balanced state in the presence of the dissipation. The evolution trajectories at different dissipation rates are obtained. The dissipation effect has been studied in the two-mode approximation previously. The present approach extracts the spatial information of condensates and allows for calculating the spatial phase fluctuation. We also study dynamical behaviors of the double-well condensate immersed in an incommensurate optical lattice. It is observed that the MQST region enlarges remarkably and the π-phase MQST tends to convert into the running phase MQST. Moreover, the BJJ oscillation region around the zero-phase point can be destroyed and in consequence a running phase MQST region develops instead, provided that the incommensurate potential is large enough.

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P3-91 Fermionic fingerprints of broken Matsubara time translations in correlated electron system: hidden order, pseudo-gap, DOS-peaks and high-Tc pre-requisites - *S. Mukhin (Theoretical physics and quantum technologies department, Moscow Institute for Steel and Alloys)*

The Euclidian action for the quantum order parameter (QOP) that breaks spontaneously Matsubara translations in the fermionic system (Mukhin 2011) is found analytically. The Green's function of the fermionic excitations in the state with QOP is also derived in analytic form (Mukhin, Galimzyanov 2012). QOP is obtained using results of the inverse scattering theory (Brazovskii *et al.*, 1980) and manifests an exact quasi-classical self-consistent Matsubara time-periodic order parameter of a correlated fermi-system close to the spin-density wave domain of its phase diagram. The repulsive Hubbard model with frustrated "nesting" is used for calculations. It is found that the Green's function of the QOP has only second order poles in the complex plane of frequences. Hence, QOP does not scatter anything in Minkowski world and might be a candidate for a "hidden order" in high-Tc cuprates. Simultaneously, the single-particle fermionic Green's function in the QOP state demonstrates the pseudo-gap in the DOS at the Fermi-level and a peak away from it at the energies of order of the QOP amplitude. The density of states in the gap is depleted exponentially with QOP amplitude, while the height of the peaks at the edges of the pseudo-gap (i.e. above and below the Fermi-level) are exponentially enhanced. Hence, the QOP state is a good candidate for the "hidden order" state of the hight-Tc cuprates. The fermionic DOS peaks induced by the QOP may become pre-requisites for high-Tc superconducting transition when e.g. phonon attraction between electrons exists. Experimental observables: depleted low temperature specific heat, side-bands in fermionic spectrum (e.g. for ARPES experiments), and non-monotonic calorimetric temperature dependences are discussed.

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P3-92 New fermionic superfluid state - *G. Kastrinakis (Institute of Electronic Structure & Laser - Foundation for Research and Technology-Hellas, Iraklio, Crete 71110)*

We introduce a new fermionic variational wavefunction, suitable for interacting multi-species systems of spinful fermions. The spin singlet version can be found in [1], and two spin triplet versions can be found in [2],[3]. This wavefunction sustains superfluidity. In this frame, we also introduce a new quantum index, which is related to the internal structure of the quantum state. Applications include quark matter, neutron stars, cold atoms and the high temperature superconductors, such as copper oxides and iron pnictides. Spin up and down fermions are, in principle, inequivalent. Due to the inclusion of adequate 2-fermion correlations, a wider class of Hamiltonians than sheer Bardeen-Cooper-Schrieffer (BCS) type, comprising interaction and hybridization between different fermion species, can be treated "exactly", as in the well known manner of BCS theory. We present the finite temperature version of the theory. We discuss the appearance of charge and spin density wave order (which is irrespective of the presence of superconductivity).

We present numerical solutions for a system composed of 2 different kinds of electrons in 2-d [2]. Using realistic tight-binding dispersion relations and realistic effective intra-species and inter-species potentials, we demonstrate a novel feature of the respective ground states at zero temperature. Namely, for a range of inter-species potentials, the Fermi occupation factor equals 0.5 for a symmetric locus of momenta around zero momentum . For higher momenta, and up to the Fermi momentum, the occupation factor is equal to 1.

We obtain both d-wave and s-wave superconducting gaps, which may or may not brake spontaneously the original C4 symmetry (square) of the Hamiltonian to C2 symmetry (rectangle).

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P3-93 Superfluid Correlation on Multi-leg Repulsive Hubbard ladders: DMRG Studies - *M. Machida, M. Okumura, S. Yamada (Japan Atomic Energy Agency)*

We study how superfluid correlation develops in multi-leg Hubbard ladders close to half-filling in a wide range of U/t by using the directly-extended density matrix renormalization group (dex-DMRG) method [1]. The number of the leg of Hubbard ladders is varied from 2 to 5, in which the accuracy of the employed DMRG method is fully sustained[2]. At first, we measure pair correlation of a singlet-pair on two-leg ladder model and creat a map to reveal how the pair correlation develops depending on U/t and hole-doping ratio into the half filling. Comparing the results in two-leg ladder with those of 3 to 5 leg-ladder models, we give an answer on a question whether the multi-leg Hubbard ladders support superfluid correlation with increasing the number of legs or not. Furthermore, we examine multi-leg Hubbard ladders with harmonic trap potential (V) to clarify a condition to realize strong superfluidity in ultra cold Fermi gases loaded on optical lattices. We make a map on the superfluidity correlation in a wide range of U/t and V/t and suggest the best setup to find out unconventional superfluidity driven by the repulsive interaction.

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P3-94 Strong link between lattice distortion driven by anti-polar phase and superconductivity in high temperature superconductors materials - ***g. tarek (Department of Physics, Faculty of Sciences M'hamed bougara University, Boumerdes, Algeria)***

As it has been demonstrated [1], high-temperature superconductors (HTS) exhibit an anti-polar phase with long range order in normal and superconducting states. The strong repulsive interaction between these electric dipole moments drives local lattice distortion as a microscopic scale of minimization of polarization. In particular, CuO6 octahedron clusters or CuO_5 pyramid clusters in cuprates are distorted so as to minimize the total electrostatic energy of a whole system.

The in plane correlation, between these electric dipoles moments and lattice distortion, is established in normal state while the out of plane correlation characterized by a discontinuity in the polarization takes place only at the superconducting state.

In this work we report Cu(2)-O(1)distance in Y-Ba-Cu-O as function of polarization at room temperature which is found to mirror exactly the Tc (7-□) behavior, thus corroborating the strong and direct link of this electric phase with lattice distortion and superconductivity phenomenon in all HTS.

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P3-95 Superconductivity in Conical Magnets: Pairbreaking vs pairweakening - ***G. Zwicknagl (Institut fuer Mathemat. Physik, TU Braunschweig, Mendelssohnstr. 3, 38106 Braunschweig)***

The influence of spatially modulated exchange fields on superconducting properties is discussed. Of particular interest are conically magnets where the non-collinear magnetic structure can help to control the symmetry of the pair wave function. The limiting cases - homogeneous ferromagnetic and antiferromagnetic exchange fields - have been extensively studied. They exhibit pair-breaking and pair-weakening, respectively. The central focus of the present work is the variation with magnetic modulation length of superconducting properties. In particular, I discuss the evolution of the induced triplet components and analyze their orbital structures. Spin-resolved tunnelling spectra highlight the cross-over from the typical pair-breaking due Zeeman splitting to pair-weakening.

P3-96 Spontaneous four-fold symmetry breaking driven by electron-lattice coupling and strong correlations - ***N. Furukawa (Department of Physics, Aoyama Gakuin University), S. Okamoto (Materials Science and Technology Division, Oak Ridge National Laboratory)***

We study spontaneous four-fold symmetry breaking transitions of the extended Hubbard model on a two-dimensional lattice in which electrons couple with the orthorhombic lattice distortion through the modulation in the transfer energies. We identify a second order instability towards the spontaneous symmetry breaking from a tetragonal symmetric phase to an orthorhombic distorted phase as a function of doping with varying the interaction strength. Moderate instability is observed near the van Hove filling for all the interaction strengths studied. Additionally, a very strong instability is found in the underdoped pseudogap regime when the interaction strength is large enough to yield the Mott insulating phase at half filling. We discuss the implication of our results to the four-fold symmetry breaking reported in high-Tc cuprates where the underlying crystal does not have a structural anisotropy.

P3-97 The magnetic field induced phase separation in a model of a superconductor with local electron pairing - ***K. Kapcia, S. Robaszkiewicz (Electron States of Solids Division, Faculty of Physics, Adam Mickiewicz University, Umultowska 85, PL-61-614 Poznan, Poland, EU)***

In our work we have studied a model which is a simple generalization of the standard model of a local pair superconductor with on-site pairing (i. e. the model of hard core bosons on a lattice) to the case of finite pair binding energy. We have analyzed the extended Hubbard model with pair hopping in the atomic limit for arbitrary electron density and chemical potential and focus on paramagnetic effects of the external magnetic field. The Hamiltonian considered consists of (i) the effective on-site interaction U and (ii) the intersite charge exchange interactions I, determining the hopping of electron pairs between nearest-neighbor sites.

The phase diagrams and thermodynamic properties of this model have been determined within the variational approach (VA), which treats the on-site interaction term exactly and the intersite interactions within the mean-field approximation. Moreover, at ground state some results derived within random phase approximation (and spin-wave approximation) for d=2 and d=3 lattices and within the low density expansions for d=3 lattices are presented.

Our investigation of the general case (as a function of the electron concentration and as a function of the chemical potential) shows that the system can exhibit not only the homogeneous phases: superconducting (SS) and nonordered (NO), but also the phase separated states (PS: SS-NO). The systems considered exhibit interesting multicritical behavior including tricritical points. Depending on the values of interaction parameters, the PS state can occur in higher fields than the SS phase (field-induced PS).

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P3-98 Superconducting Features of Fermi Systems near l=0 Pomeranchuk Instabilities: A Crossing Symmetric Approach - ***K. Reidy (Dept of Physics, Kent State University), K. Bedell (Dept of Physics, Boston College), K. Quader (Dept of Physics, Kent State University)***

In Fermi systems, interactions can cause symmetry-breaking deformations of the Fermi surface, called Pomeranchuk instabilities. In Fermi liquid (FL) theory language, this occurs when one of the Landau harmonics $F_l^{(a,s)} \rightarrow -(2l + 1)$; e.g. $F_0^{(s,a)} \rightarrow -1$ are related to ferromagnetic transition (a), and density instabilities (s). The corresponding points in parameter space may be viewed as quantum critical points (QCP).

Using graphical and numerical methods to solve coupled non-linear integral equations that arise in a crossing symmetric equation (TSCE) scheme, we study the behavior of spin/density excitations, effective mass, ferromagnetic, spin density wave, phase separation, and superconducting transitions near l=0 Pomeranchuk instabilities in a 3D Fermi system. Considering momentum dependence of the renormalized FL interactions, we find interesting results for repulsive and attractive couplings of arbitrary strengths; viz. attraction in both singlet and triplet pairing amplitudes (though singlet pairing is primarily favored); possibility of a second ferromagnetic transition due to finite-q spin waves, and possibility of phase separation with and without ferromagnetic transition. Some of our results may apply to ferromagnetic superconductors, such as UGe2 and UIr.

P3-99 Fluctuation effects in disordered superconducting films above Tc - ***N. Breznay, A. Kapitulnik (Stanford University)***

We study the appearance of superconducting fluctuation effects in the transport properties of disordred thin films. First, we have measured a large contribution to the Hall resistance, which we can track to temperatures well above Tc and magnetic fields well above the upper critical field, Hc2(0). This contribution arises from Aslamazov-Larkin superconducting fluctuations, and we find quantitative agreement between our data and recent theoretical analysis based on time dependent Ginzburg-Landau theory. Second, the measured magnetoresistance in the fluctuation regime above Tc is well described by theories that describe localization and superconducting fluctuations effects. This analysis allows for careful study of the so-called ghost critical field and quasiparticle dephasing rates at temperatures near Tc.

We acknowledge the support of National Science Foundation award NSF-DMR-9508419.

P3-100 Fluctuoscopy of Disordered Two-Dimensional Superconductors - ***A. Glatz, V. Vinokur (Argonne National Laboratory), A. Varlamov (University of Rome, Tor Vergata)***

I will present our results for the fluctuation conductivity (FC) in disordered two-dimensional superconductors placed in a perpendicular magnetic field. In our works [1,2] we finally derived the complete solution in the temperature-magnetic field phase diagram. The obtained expressions allow both to perform straightforward (numerical) calculation of the FC surface $\delta\sigma(T,H)$ and to get all 27 asymptotic expressions in the seven qualitatively different domains of the phase diagram. This surface becomes in particular non-trivial at low temperatures, where it is trough-shaped and close to the quantum phase transition non-monotonic, in agreement with experimental findings. I will show our main results and demonstrate how these can be used as a high precision tool (fluctuoscope) to determine the critical temperature, critical magnetic field, and dephasing time from experimental data in superconducting films [3].

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P3-101 Two-band superconductors: Hidden criticality deep in the superconducting state - ***L. Komendova, Y. Chen, A. Shanenko, M. Miloševic, F. Peeters (Departement Fysica, Universiteit Antwerpen, Groenenborgerlaan 171, B-2020, Antwerpen, Belgium)***

We found that two-band superconductors harbor hidden criticality deep in the superconducting state, stemming from the critical temperature of the weaker band taken as an independent system [1]. For sufficiently small interband coupling the coherence length of the weaker band exhibits a remarkable deviation from the conventional monotonous increase with temperature, having a pronounced peak close to the hidden critical point. This can strongly affect most of the superconducting properties, and can be experimentally observed (in e.g. multigap borides and pnictides) by imaging of the variations of the vortex core in a broader temperature range. In particular the effects crucially depending on the disparity of the characteristic length scales (e.g. nonmonotonic intervortex interaction [2], appearance of fractional vortices in mesoscopic samples [3]) shall be most pronounced in the vicinity of this hidden criticality.

We will present an analytic proof that the interband coupling is the governing field of this criticality with the same critical exponents as e.g. the magnetic field in the ferromagnetic materials. Furthermore, we will show the numerical results for the evolution of a vortex core with temperature obtained in the microscopic Bogoliubov-de Gennes formalism, which not only proves the existence of hidden criticality, but also motivates further experiments on multiband materials.

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P3-102 On the possible common nature of the ground state in Cu- and Fe-based HTSCs - *K. Mitsen, O. Ivanenko (Lebedev Physical Institute RAS)*

A qualitative model describing the ground state and the mechanism of superconducting pairing in Cu- and Fe-based high-temperature superconductors (HTSCs) is suggested. In this model, doping by localized charges (as well as physical or chemical pressure) is supposed to be responsible for the suppression of the gap between the occupied anionic band and unoccupied states of the cation band and the formation of an electron-excitonic band of unusual nature. The resulting HTSC ground state is strongly correlated insulator with not fully occupied band, where the transition of an electron to a cation is possible only in the presence of a hole on one of the nearest anions. Therefore, an electron and hole can only move around each other or together (as charge-transfer exciton) i.e. incoherent electron transport is impossible in this system. However, despite the fact that incoherent electronic transport cannot take place, the existence of unoccupied states in the band provides the possibility of coherent transport, when the entire electron system moves as a whole (a condensate). Besides, incoherent hole transport is possible in this system if there were a mechanism of free hole generation. We discuss here both of these possibilities. We show that each pair of nearest cations in this system acts as a two-atom negative-U center (NUC). It is the interaction of band electrons with NUCs that is proposed to be responsible both for superconducting pairing (at $T<T_c$) and free hole generation (at $T>T_c$) in the system.

P3-103 Mechanism of Fermi arcs and pseudogap formation in cuprates - *O. Ivanenko, K. Mitsen (Lebedev Physical Institute)*

In the framework of the model for the electron structure of Cu- and Fe-based HTSC [1], we will show that both Fermi arcs and the pseudogap in cuprates results from the d-wave symmetry of the order parameter. In accordance with model interaction of band electrons with negative-U centers (NUC) is responsible for superconducting pairing in the system. The Fermi arcs appear over the parts of *d*-gaped Fermi surface (FS) where pair breaking due to hybridization of band states with pair level of NUCs takes place. The value of pair hybridization $G\mu T$. The pair hybridization results in transitions of electron pairs (k_1,k_2) to NUCs. Each transition is accompanied by the appearance of two quasiparticles -k_1, -k_2 satisfying the condition $E(\boldsymbol{k}_1)+E(\boldsymbol{k}_2) < G$. As the temperature increases, the region for which transitions of electron pairs to NUCs are possible stretches from point (p/2; p/2) along the contour of the FS so that a "belt" of length *L* is formed. Deparing processes should lead to vanishing of the superconducting order parameter around nodes in an arc of length $L(T)$ along the Fermi contour. However, owing to the preservation of coherence, a nonzero order parameter persists on the entire FS excluding the nodes. At the same time, filling of NUCs with real electrons leads to a reduction in the number of NUCs available for virtual transitions of electron pairs. At $T=T_c$ the NUC occupancy approaches a critical value h_c at which point the superconducting coherence is destroyed and a transition to the normal state takes place. The gap closes along an arc of length L, meanwhile, along the remaining part of the FS, there still exists a gap (the pseudogap), which corresponds to incoherent pairing.

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P3-104 Meissner Response of Superconductors: Quantum Non-Locality vs. Quasi-Local Measurements in the Conditions of the Aharonov-Bohm Effect - *A. Gulian (Chapman University)*

Theoretical explanation of the Meissner effect involves proportionality between current density and vector potential [1] which has many deep consequences. Among them, one can speculate that superconductors in a magnetic field “find an equilibrium state where the sum of kinetic and magnetic energies is minimum” and this state “corresponds to the expulsion of the magnetic field” [2]. This statement still leaves an open question: from which source is superconducting current acquiring its kinetic energy?

A naïve answer, perhaps, is from the energy of the magnetic field. However, one can consider situations (Aharonov-Bohm effect), where classical magnetic field is absent in the space area where the current is being set up. Experiment demonstrates [3] that despite the local absence of magnetic field, the current nevertheless is building up. From which source is it acquiring energy then? Locally, only a vector potential is present. How does the vector potential facilitate the formation of the current? Is the current formation a result of truly non-local quantum action or, instead, the local action of the vector potential has experimental consequences which are measurable quasi-locally?

We discuss possible experiments with a hybrid normal-metal superconductor circuitry which can spread a light on this puzzling situation. Knowing experimental answers would be important for further theoretical developments.

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P3-105 Application of Superconducting Materials to a Novel Antenna Design for Gravitational Waves - *A. Gulian, V. Nikoghosyan, L. Sica, J. Tollaksen (Chapman University), S. Nussinov (Chapman University & School of Physics and Astronomy, Tel-Aviv University, Ramat-Aviv, Tel-Aviv, Israel), J. Foreman (Independent Researcher)*

Contemporary efforts to register gravitational waves (GW) are focused on measuring distance between pairs of mirrors using light interferometry. In this paper we attack the detection of gravitational waves using superconducting electrons (Cooper pairs) moving in an ionic lattice.

The major challenge is that the tidal action of the gravitational wave is extremely weak (compared with electromagnetic forces). Any motion caused by GW which violates charge neutrality will be impeded by Coulomb forces acting on the charge carriers (Coulomb blockade) in superconductors, as well as in normal metals.

We elaborate a design which avoids the effects of Coulomb blockade. It exploits two different superconducting materials used in a form of thin wires – "spaghettis." The spaghettis will have a diameter comparable to the London penetration depth, and length of about 10 meters.

To achieve strain sensitivity 10^{-26}, the antenna would require approximately ten billion spaghettis, which calls for a challenging manufacturing technology. The readout of the sub-femtoampere range current would be performed by superconducting electronics (SQUIDs). The antenna will require deep (sub-K) cryogenic cooling and magnetic shielding.

This design may be a viable successor to LISA and LIGO missions, having the prospect of higher sensitivity, and some other useful features.

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P3-106 Mechanisms of Photonic Cooling in Superconductors - *A. Gulian (Chapman University), G. Melkonyan (GMLab, 873 Rue Jean-Noel, Quebec, G1X 2N3, Canada & Gitelik University Foundation, Momiki 5, Yeghegnadzor, Vayots Dzor, 3601, Armenia)*

Recent advantages in laser cooling [1] inspire hope that new types of all-solid-state cryocoolers could come to replace those based on mechanical coolers with liquid cryogens. In these photonic coolers, electrons interact with low energy photons, so that atomic transitions occur with the assistance of phonons. As a result, phonons disappear, and photons with higher energy are being emitted, taking away the energy of the absorbed phonon together with the energy of the excited atom, thus lowering the temperature of the system.

This was demonstrated to work in the range of temperatures from room halfway down to absolute zero, already breaking the longstanding limit for thermoelectric coolers (~160K). At the same time, the energy of photons is much higher than the energy of assisting phonons, and thus the efficiency of coolers is small, and rapidly degrades with any parasitic absorption of photons. To reach the 4K-range of temperatures it is advantageous to consider lower energy photons (THz or lower), and replace atomic systems by superconducting materials.

For the influence of this radiation the phonon emission spectra in superconductors are well known in theory [2]. A remarkable feature of these spectra is the occurrence of negative fluxes in a specific range of phonon energies ("phonon deficit" effect). This effect in combination with phonon filtering has been suggested for cooling purposes [3]. However, some new opportunities enter based on acoustic rectification (thermal "diodes"). Combining thermal diodes with the phonon deficit effect may yield effective coolers at intermediate cryogenic temperatures from 70K down to 4K and lower.

We present detailed design consideration and efficiency calculations.

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P3-107 Ab-Initio Studies of Negative Dielectric Response of Some Crystalline Materials with Account of the Local-Field Effects - *G. Melkonyan (GMLab, 873 Rue Jean-Noel, Quebec, G1X 2N3, Canada & Gitelik University Foundation, Momiki 5, Yeghegnadzor. Vayots Dzor, 3601, Armenia), M. Gulian (UMBC & Chapman University)*

It was noticed a while ago that the dielectric function in metals (actually, its reciprocal value) may become negative in a static limit for finite values of the wave vector [1]. This opportunity is very important for deciphering the mechanism of high-temperature superconductivity.

Analytic calculations performed by Dolgov and Maksimov [2] revealed that the real part of inverse dielectric function is really negative in case of some superconducting materials, such as Al, as well as for metallic hydrogen. However, for non-superconducting metals, such as K, this is not the case. An opinion was expressed [1] that negative values of epsilon for mentioned range of parameters may be characteristic even for Si and Ge. Walter and Cohen [3] and other authors have studied the wave-vector dependent dielectric function for Si and Ge. They did not obtain negative values for these dielectric responses. However, their dielectric functions are noticeably decreasing with the increasing wave vectors.

We perform calculations of the dielectric function for Si and Ge using ABINIT program with the DP code and following the approach first suggested by Reining et al. [4]. This approach involved two phenomenological parameters. We confirm the negative values for the dielectric function of Si obtained in Ref. [4], and get similar results for Ge. At the same time, the validity of parameters which deliver such results, needs substantiation.

We discuss also the dielectric properties of superconducting materials, such as Pb, Sn and Al on the same basis.

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P3-108 Magnetic Field Modulated Microwave Spectroscopy in search of new superconductors - *I. Schuller, G. Ramírez, J. De la Venta, A. Basaran (University of California, San Diego)*

Magnetic Field Modulated Microwave Spectroscopy (MFMMS) is a high-sensitivity technique capable of detecting small volumes of superconducting phases as small as 10^{-11} cm^3, even in discontinuous samples. This method relies on the measurement of the temperature dependence of reflected microwave power from a sample that is subjected to an oscillating magnetic field. The signature of superconductivity appears as a peak at the transition temperature. Debates about the exact absorption mechanism are still underway. Here we report on an exhaustive number of measurements, in many known superconductors, in order to clarify the microwave absorption mechanism. In addition we have performed measurements of nano-patterned structures as well as purposefully mixed-phase samples in order to establish the detection limits of

superconducting volume. These, together with extensive studies of MFMMS from materials undergoing other phase transitions, allows a unique determination of minute superconducting phases embedded in an otherwise non-superconducting matrix. The correlation between MFMMS and magnetic measurements is very useful for the identification of unknown phases. These together with the (bulk and thin film) synthesis of phase-spread alloys are playing a crucial role in the search for new superconductors and in the enlightened design of new materials using combinatorial techniques.
Work supported by AFOSR MURI #F49550-09-1-0577.

P3-109 REBCO superconducting thin films with oxide nanoparticle additions deposited on NiW metal tapes by PLD - ***Y. Li, L. Liu, Y. Wang, S. Zhu, P. Zhu (Department of Physics, Shanghai Jiao Tong University), D. Xu (Department of Physics, Shanghai Jiao Tong University,)***

REBCO superconducting thin films with different oxide nanoparticle additions have been fabricated on NiW tapes by pulsed laser deposition process. For stoichiometric (123) REBCO films, it was found that when REBCO thickness was smaller than 0.8 micrometer, REBCO superconducting films had a high critical current density J_c of 4.0x10^6 A/cm^2 (at 77 K, self magnetic field) . As REBCO film thickness increased over 1.0 micrometer, the J_c values of REBCO films decreased with increasing of REBCO film thickness. X-ray diffraction (XRD) and high resolution scanning electron microscope (SEM) observation showed that a-axis orientation was easily formed in thick REBCO films. XRD analysis showed that REBCO films usually had pure c-axis orientation at higher substrate temperatures, however BaCuO3 particles were found in REBCO films. Consequently, the REBCO thick films had relatively rough surface and low J_c of 2.0x10^6 A/cm^2 (at 77 K, in zero magnetic field). SEM and AFM observations showed that thick REBCO films had micrometer-scale grains and relatively broad grain boundaries which blocked superconducting current paths. In order to control the grain size and grain boundary width of REBCO films, $Y_2O_3$and ZrO_2 doping effects were investigated. AFM and SEM images showed the presence of nano-scale Y_2O_3, YSZ, $BaZrO_3$ oxide particles on REBCO superconducting film surface. These nanoparticles on REBCO film surface changed REBCO epitaxial growth process and acted as new crystal nucleus. REBCO superconducting thin films with oxide nanoparticle additions showed smooth surface and higher superconducting critical current density.

P3-110 Cooling experiments of 200 m-class superconducting direct current transmission system with high performance terminals - ***T. Kawahara, H. Watanabe, M. Hamabe, Y. Ivanov, J. Sun, S. Yamaguchi (Center of Applied Superconductivity and Sustainable Energy Research, Chubu University), M. Emoto (National Institute for Fusion Science)***

Resent energy saving and environmental protection highly demand the developing of new technologies such as applied superconductivity. Among superconducting applications, superconducting transmission and distribution (T&D) system seems to be one of the most important applications because of low energy loss transmission. Long distance superconducting transmission systems can save total energy by energy sharing, and such large systems can be scaled up from smaller networks. Reducing heat leak to the low temperature part is the most important technology for the superconducting applications and especially for small ones. Therefore the heat leak reduction at the terminal is the key technology for actual uses. In Chubu University, we are developing 200 m-class superconducting direct current transmission system of CASER-2 following 20 m-class system of CASER-1 [1]. In CASER-2, we also used Peltier current lead (PCL) as heat insulation at the terminal. PCL is composed of a thermoelectric material and a copper lead. Small thermal conductivity and large thermopower of thermoelectric ones can effectively insulate the heat leak to the low temperature end. We already have 4th cooling experiments on the CAESR-2 and obtained the performance of the terminals including PCL. For every cooling experiment, we observed large temperature difference between both sides of thermoelectric elements of PCL and then the good thermal insulation was obtained.
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P3-111 Contactless measurements of the transverse resistivity in Nb3Sn wires - ***U. Gambardella, A. Saggese (CNR-SPIN UOS Salerno), V. Corato, G. De Marzi, T. Spina (ENEA-CRE Frascati), P. Fabbricatore, S. Farinon (INFN-Genova)***

The transverse resistivity in superconducting wires plays a relevant role in the overall dissipations of coils where *ac* or pulsed magnetic fields are required. The value of the transverse resistivity may be measured by using several techniques ranging from hysteresis magnetization measurements at increasingly ramp rates [1], to the direct four probe measurements [2]. Here, the transverse resistivity in Nb3Sn wires is evaluated measuring the wire characteristic frequency by using *ac* susceptibility technique. This method, successfully applied to NbTi wires [3], is limited to the actual penetration of the *ac* field within the sample, which may be hindered by compact layout of the superconducting bundles of filaments. When the penetration is effective we observe the frequency dependence of the dissipations, whose peak represents the characteristic frequency of the wire or its time constant. The value of the time constant is straightforward connected to the transverse resistivity of the wire. The measurements on Nb3Sn wires, using this method, show a peak at measurable frequencies that moves at higher values by increasing the *dc* magnetic field.
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P3-112 Superconducting microwave cavity for making cold polar molecules - ***M. Michan (University of British Columbia), K. Enomoto (Toyama University), P. Djuricanin, O. Nourbakhsh, T. Momose (University of British Columbia)***

Control of the translational motion of molecular beams has been a challenge in molecular physics and spectroscopy for a long time. Here, we propose the use of superconducting microwave cavities for the control of translational motion of cold polar molecular beams. We especially focus on the deceleration and focusing of molecular beams by the dipole force of near-resonant microwave radiation in order to make cold and ultracold molecules. The degree of deceleration and focusing is much improved by adopting a superconducting cavity because of its high quality factor. A superconducting cavity with a high quality factor produces a large ac Stark shift in polar molecules, which allows us to efficiently control molecular motion. Our discussion is based on the experimental characterization of a prototype cavity: a lead-tin coated cylindrical copper cavity, which has a quality factor of 10^6 and tolerates several watts of input power. Such a microwave device provides a powerful way to control molecules not only in low-field-seeking states, but also in high-field-seeking states such as the ground rotational state. We discuss the performance of the prototype microwave cavity we have constructed, and results of simulation of focusing and deceleration of polar molecules based of the obtained cavity performance.

P3-114 Experiments on Resonant Activation and Macroscopic Quantum Tunneling in Large Magnesium DiBoride Thin Film Josephson Junctions - ***R. Ramos (Indiana Wesleyan University), S. Carabello, J. Lambert, J. Mlack (Drexel University), D. Cunnane, C. Zhuang, Y. Shen, K. Chen, X. Xi (Temple University), W. Dai, Q. Li (The Pennsylvania State University)***

There has been a significant number of experiments on resonant activation and macroscopic quantum tunneling (MQT) on Josephson junctions based on superconductors such as Nb, Al and even YBCO. These studies have exploited the Josephson junction as an experimental testbed to study the escape of a particle from a potential barrier in the classical and quantum regime. We report results of superconducting-to-normal state switching experiments using large (as big as 0.3mm x 0.3mm) Magnesium DiBoride (MgB_2)-based thin-film Josephson heterojunctions with Pb or Nb counter-electrodes at and above dilution refrigerator temperatures. Magnesium diboride is a BCS superconductor with a T_c = 39K. Measurements were made with and without RF excitation in the thermal regime, showing both a primary peak (indicating escape from the zero-voltage state) and a second, “resonant peak” consistent with resonant activation. We report features in our data that suggest evidence of quantum behavior including sharp peaks in the escape rate enhancements and a bending in the graph of calculated escape temperatures T_{esc} versus sample temperature.

P3-115 Superconducting Fault Current Limiter with Instantaneous Response and Recovery - ***L. Fleishman, E. Volkov (Krzhizhanovsky Power Engineering Institute), V. Malginov (Lebedev Physical Institute RAS)***

A superconducting fault current limiter (FCL) requires high resistance of superconducting wire after its transition to the normal state. This is typical of the second generation (2G) stabilizer free high-temperature superconducting (HTS) wire. However heat generation in such a wire determines long recovery time of the limiter and its low fault tolerance. In this report a method to obtain current limiting action with instantaneous response and recovery is proposed and verified by experiments. In order to avoid the HTS wire overheating first generation (1G) wire was used which is of high thermal stability due to its low resistivity matrix. It makes possible to use the flux flow resistance of the HTS wire without quenching thus overcoming the problem of delayed response, overheating, and long recovery. An experimental study was made on a prototype transformer-type FCL using a nonlinear resistor made from 1G Bi-2223/Ag tape. The resistor is connected across the transformer secondary winding terminals and cooled by liquid nitrogen. With 1G HTS wire the current limiting action of the device is instantaneous and the current peaks are repeatedly limited in every half-cycle. After the fault clearing the current assumes its normal magnitude and the voltage drops instantaneously to almost zero normal value with no voltage transients. The instantaneous response and recovery of the 1G current limiter represent considerable advantage over the FCL based on 2G wires.

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P3-116 Classification of Superconducting Cables for Electric Power Applications - ***E. Dzhafarov, E. Volkov (Krzhizhanovsky Power Engineering Institute)***

Classification of low temperature (LTSC) and high temperature superconducting cables (HTSC) for direct and alternating current for electric power industry based on the conventional and prospective design is presented. The developed classification of superconducting cables for power applications taking into consideration industrially produced LTSC and HTSC cables allows one to determine the ways of development of highly effective superconducting cables to use them in superconducting electrical machines and magnetic systems for direct and alternating current. Flat superconducting cables produced in a form of a tape are characterized by high degree of stabilization due to better cooling conditions provided by more favorable ratio of surface area to volume. Superconducting cables produced in a form of bars with rectangular or square cross sections are composed of stabilized flat superconducting tapes, soldered to each other, and used to increase capacity of electrical equipment at direct and alternating currents. Design of multifilament superconducting cables with a localized magnetic field implementing the principle of superconductor operation in self magnetic field may be a prospective direction of production of highly effective superconducting cables with high current carrying capacity.

This work was supported by the Russian Superconductor Industry Program.

P3-117 Magnetic flux penetration behavior and its composition dependence of melt-processed HTS bulk magnets - ***T. Oka (Niigata University), K. Yokoyama (Ashikaga Institute of Technology), H. Nabana, Y. Yamada, J. Ogawa, S. Fukui, T. Sato (Niigata University)***

The penetration behavior of the magnetic flux into the YBCO-based HTS bulk magnets were precisely evaluated during the pulsed field magnetization processes. The flux motion and resultant trapped field densities were was measured at the surface center of the bulk sample at the temperature of 30 K. It is known that as the Y211 concentration changes at various portions in a bulk magnet, the Jc values have substantial position dependence even in a sample. In this paper, the bulk magnets with various Y211 contents were fabricated so as to examine how the concentration of Y211 particles affects to the flux-penetration behaviors when intense magnetic pulsed fields were applied to the samples. As a result, the applied field at which the magnetic flux began to invade the sample increased with increasing Y211 content. On the other, the temperature of the samples equally elevated with increasing applied magnetic flux densities. This means that the heat generation happened under the thermally insulated condition. The flux invasion to the center part of the sample tended to be suppressed with increasing Y211 contents, which means that the pinning centers which originated from the presence of Y211 particles in the YBCO matrix are promoted with increasing Y211 addition. The highest trapped field of 2.1 T was obtained for the sample which contains 28.5 % Y211. Since the distribution of Y211 particles in the YBCO matrix is known to be different between the grain growth conditions, the trapped field performances are well affected by the grain growth behavior.

P3-118 AC Loss Analysis of Striated HTS Compact Cables - ***K. Choi (Korea Polytechnic University), W. Kim (Korea Electric Power Research Institute), Y. Kim, S. Lee, S. Park (Korea Polytechnic University), C. Park (Seoul National University), J. Lee (Woosuk University)***

One of the most important impacts of the superconductor is it can carry a very large current through a very small cross-section without severe Joule losses. Low temperature superconducting conductors or cables have been developed to be able to carry hundreds of thousand amperes. But high temperature superconductors (HTS) just start to be developed for large currents. Though the shape of HTS tape is not good for cables, many researches are being progressed like Roebel conductors, compact cables, and HTS cable in conduit conductors.

These cables can show good performances for DC application. However the AC loss problem due to the shape of HTS tape is not solved yet. The only way to reduce the AC loss of a given superconductor is to make it as filaments and twist them. We have investigated the effect of striated HTS tape in Roebel conductors, but it is uncertain [1]. The HTS compact cable concept has been proposed by a research group of NIST and University of Colorado [2].

In this paper, the AC loss characteristics of the striated HTS compact cable were analyzed. We made striations on the HTS tapes which composed the compact cable. The surface of the tape was scribed by laser. The AC loss was measured by a magnetization method using pick-up and cancel coils. The samples were installed in a racetrack magnet with 60 Hz AC magnetic field. The AC losses of unstriated and striated ones were measured and compared.

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P3-119 Signature of proximity induced superconductivity by Bi in topological Bi_2Te_2Se and Bi_2Se_3 films and single crystals: Evidence for a robust zero energy bound state possibly due to Majorana fermions - ***G. Koren (Physics Department, Technion - Israel Institute of Technology)***

Point contact conductance measurements on topological Bi_2Te_2Se and Bi_2Se_3 films [G. Koren *et al*., PHYSICAL REVIEW B **84**, 224521 (2011)] and single crystals reveal a signature of superconductivity below 2-3 K. In particular, critical current dips and a robust zero bias conductance peak are observed. The latter suggests the presence of zero energy bound states which could be assigned to Majorana fermions in an unconventional topological superconductor. We attribute these novel observations to proximity induced local superconductivity in the films and crystals by small amounts of superconducting Bi inclusions or segregation to the surface. EDS, AFM and TEM results on the films and crystals provide supportive evidence for these effects.

P3-121 Nd2-xCexCuO4 and Nd2CuO4: Differences and commons in square planar coordinated cuprate superconductors - ***Y. Krockenberger, H. Yamamoto, M. Mitsuhashi (NTT Basic Research Laboratories), M. Naito (Tokyo University of Agriculture and Technology)***

The appearance of superconductivity (SC) in cuprates is assumed to be associated to the doping level of the CuO_2 plane thus similar electronic- and magnetic correlations are expected for both, electron- and hole doping. Since the discovery of electron doped cuprate superconductors [1] it is known that SC is induced after an annealing (AN) treatment. Despite numerous investigations of the AN process, the underlying oxygen diffusion processes remained enigmatic. The AN process itself has been considered as a vexatious path to be followed in order to induce SC in electron doped cuprates, thus limiting the efforts for improvements of that very AN process. Consequently, the electronic phase diagram adopted the widely known appearance with an antiferromagnetic-insulating (AFI) and a SC phase. Systematic variation, tuning and analysis of the AN process have shown that while a 1-step AN process is sufficient to induce SC for optimally doped T'-cuprates, a 2-step AN process is necessary for dopand-free T'-cuprates [2]. High quality films of T'-$Nd_{2-x}Ce_xCuO_4$ (x =0.00 and 0.15) have been grown by MBE on (001) $SrTiO_3$ substrates. The films have been treated by either a 1-step- or 2-step AN process in order to induce SC [3]. Magneto-resistance measurements were used for the determination of the SC coherence length ξ_{GL}. The SC transition temperature T_c is higher for x =0.00 samples. For x =0.00 and 0.15 T'-cuprates, bulk-like shielding was detected. As the SC

properties observed are common in doped and dopant-free T'-cuprates we suggest that the underlying electronic correlations in T'-cuprates are significantly altered compared to octahedrally coordinated hole doped cuprates.
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P3-122 Interface-superconductivity in the presence of Rashba spin-orbit coupling and magnetic fields - ***F. Loder (Experimental Physics VI & Theoretical Physics III, University of Augsburg), T. Kopp (Experimental Physics VI, University of Augsburg), A. Kampf (Theoretical Physics III, University of Augsburg)***

Two-dimensional electron systems at oxide interfaces are influenced by a Rashba type spin-orbit coupling (SOC), which is tunable by a transverse electric field. Ferromagnetism at the interface can simultaneously induce strong local magnetic fields. This combination of SOC and magnetic fields leads to anisotropic two-sheeted Fermi surfaces, which enforces superconductivity with finite-momentum pairing. We derive a generalized pairing model realizing both, the Fulde-Ferrell-Larkin-Ovchinnikov superconductor in the limit of vanishing SOC and a mixed-parity pairing state with zero pair momentum in the absence of a magnetic field. In both limits, and also in the intermediate regime, we determine the superconducting order parameter self-consistently. We characterize the nature of this unusual pairing state and discuss it in the context of superconductivity in coexistence with ferromagnetism at LaAlO3-SrTiO3 interfaces [1,2].
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P3-123 Transport property of compensated topological insulator, Bi2Se3 - *A. MAEDA (Department of Pure and Applied Sciences, University of Tokyo), R. Kondo (Department of Physics, Okayama University), T. YOSHINAKA, Y. IMAI (Department of Pure and Applied Sciences, University of Tokyo)*

Bi_2Se_3 is one of the most popular candidates of topological insulator predicted by theories. However, it usually shows a bulk metallic behavior with *n*-type carrier because Se vacancies act as donors of electron. In order to observe the transport properties dominated by the topological surface states, almost completely compensated samples are needed. This is also an essential basis for the study of topological superconductivity. Here we investigate various techniques to fabricate almost completely compensated Bi2Se3 single crystals, including Mg and Ca substitution as a foreign dopants (n_e, n_p ~ 10^{17}-10^{19} cm^{-3}) [1,2], and also with a nominal molar composition ratio of 1:2 (=Bi:Se)[3], which is free from foreign dopants (n_e ~ 10^{17} cm^{-3}), and investigated transport properties in these samples. Mg-doped *p*-type and dopant-free *n*-type single crystals show the semiconducting behavior in the temperature dependence of electrical resistivity below about 50 K. In these two crystals, clear SdH oscillations are observed, which indicates the high quality of the crystals. On the other hand, one *p*-type Ca-doped sample shows an insulating behavior below 150 K, while there is no SdH oscillations. These results indicate that the kinds of dopant affect the transport properties in a complex manner. We also investigate Hall coefficient, and Seebeck coefficient, of compensated samples and discuss the best method suitable for the almost complete ~~best~~ compensation of Bi_2Se_3.
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P3-124 Aspects of Crystal Growth of the Superconducting Topological Insulator CuxBi2Se3 - ***J. Schneeloch, R. Zhong, Z. Xu, J. Tranquada, G. Gu (Brookhaven National Laboratory), A. Yang (Princeton University)***

Numerous crystals of the superconducting topological insulator $Cu_xBi_2Se_3$, discovered recently by Hor, et. al [1], were synthesized for 0.1≤x≤0.5. We report Meissner fractions of roughly 10%. The crystals were either grown from a melt or via the Traveling-Solvent Floating Zone method; most were later annealed. Aspects of these processes were varied to determine the effect on Meissner fraction, including growth method (floating zone vs. from a melt), Cu composition, melt cool-down rate, annealing pressure under Ar gas, annealing temperature and duration, thickness of pieces annealed, and method of quenching (i.e., liquid nitrogen vs. water, and whether or not the ampoule was broken open upon submersion). Our data suggest the following: The Meissner fraction is optimal for 0.25≤x≤0.35. Floating zone growth yields poor superconductivity. As for the melt-grown method, a melt cool-down rate of 18 °C/h yields better results than a slower rate of 1.8 °C/h. Annealing pressure within 0.2-0.9 bar Ar has little effect on Meissner fraction. Annealing temperature is optimal for 560-600 °C, though high Meissner fractions have been found in samples annealed up to 660 °C. Very flat pieces (<0.1mm thick) yield little superconductivity compared to thicker pieces. The effects of annealing duration and method of quenching are not yet clear.
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P3-125 Unusual doping dependence of electronic structure on CuxBi2Se3 revealed by ARPES - ***Y. Tanaka (Department of Physics, Tohoku University), N. Xu, P. Zhang, P. Richard, H. Ding (Beijing National Laboratory for Condensed Matter Physics, and Institute of Physics, Chinese Academy of Sciences), T. Takahashi (Department of Physics, and WPI-AIMR, Tohoku University), K. Nakayama, T. Sato (Department of Physics, Tohoku University), Y. Suzuki, P. Das, K. Kadowaki (Institute of Materials Science, University of Tsukuba), S. Souma (WPI-AIMR, Tohoku University)***

The recent discovery of superconductivity at ~ 3.8 K in Cu-doped Bi_2Se_3 [1] has stirred fierce debates on the nature of its ground state and whether it provides a platform of topological superconductivity or not. To investigate the doping-induced evolution of the electronic structure, we have performed angle-resolved photoemission spectroscopy of $Cu_xBi_2Se_3$ in a wide range of Cu doping. We found that the topological surface state is preserved even in the heavy-doped region, indicative of the robustness of topological property in $Cu_xBi_2Se_3$ against doping. Such a peculiar nature of the surface state is useful for realizing topological superconductivity. We also revealed that both the topological surface state and the bulk bands exhibit unusual evolution with Cu doping, suggesting unconventional nature of the superconductivity in $Cu_xBi_2Se_3$.

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P3-126 Insulator-superconductor transition in nano-composites built from bi-layers of Co clusters and Bi - ***E. Baggio-Saitovitch, W. Herrera, I. Dinola, C. Rojas-Ayala, H. Micklitz (Brazilian Center for Research in Physics), Y. Xing (Instituto de Física, Universidade Federal Fluminense)***

Superconductivity (SC), ferromagnetism (FM) and topological Insulator (TI) are the ingredients in the actual field of research in novel compounds in nanometer scale. SC-FM nano-composites can be fabricated by depositing onto a cold substrate well-defined FM clusters of nanometer size trapped in SC matrix. We have successfully employed this technique to obtain SC Pb films with embedded FM Co particles[1]. In this work we show some evidence for the competition between Mott insulators (IS) like behavior and SC in as-prepared samples and competition between SC and TI in annealed Co-clusters/Bi bi-layers. We deposited an amorphous Bi film at 4.2 K with thickness between 3 and 7 *nm* on top of former deposited Co clusters with a mean size of ~ 4.5 *nm*. Total amount of deposited clusters corresponds to a mean layer thickness between 0.7 and 5.5 *nm*. In-situ transport measurements were performed between 2 and 100 K, show hopping (tunneling) conductivity as $\sigma = \sigma_0 \exp[-(T_0/T)^{1/2}]$ above the superconductor transition (T_c) and re-entrance into the normal state with hopping (tunneling) conductivity again below T_c. After heating up to≈ 60 K the amorphous Bi crystallizes showing typical behavior of a two -dimensional metal with weak localization due to some disorder and no indication of superconductivity. The crystallized Bi films on top of the Co-clusters, on the other hand, show a strong increase in resistivity ρ with decreasing temperature and the sharp drop in ρ at Tc. This can be explained by an opening of a gap in the density of states (DOS) at the Co/Bi interface layer of the Bi film due to the presence of Co magnetic moments. Such an opening of gap in the DOS has been predicted at the surface of traditional TI like Bi_3Se_2, decorated with magnetic impurities [2,3].

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P3-127 Aniostropic properties of a new noncentrosymmetric superconductor BiPd - ***B. Joshi, A. Thamizhavel, A. grover, S. Ramakrishnan (Tata Institute of Fundamental Research)***

Noncentrosymmetric superconductors are a topic of great current interest. Conventional superconductors can only have one spin state - either singlet or triplet - due to the Pauli principle and the law of conservation of parity. However, *noncentrosymmetric superconductors* can have a mixed spin states[1]. Recently, we have shown[2] that a-BiPd which has a monoclinic (P_21) structure with the absence of the centre of inversion exhibits bulk superconductivity at 3.8 K. We have successfully grown a high quality single crystal of a-BiPd with residual resistivity ratio (RRR) of 170 with a sharp superconducting transition at 3.8 K. In this work, we report the anisotropic bulk properties such as, resistivity and susceptibility of this compound from 1.5 K to 300 K. We observe significant anisotropy (~50%) in the bulk properties which probably arises from the spin-orbit coupling in this compound. Contrary to our earlier assumption[2], we find that the Rasbha type spin-orbit coupling in this compound is significant. We also present our recent uppercritical field measurements and magnetization measurements which suggests a weak pinning of flux lines in the mixed state of this superconductor.

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P3-128 Novel Josephson effect in triplet Josephson junctions: the story begins - ***D. Manske (Max Planck Institute for Solid State Research)***

In the theoretical study of Josephson junctions, it is usually assumed that the properties of the tunneling barrier are fixed. This assumption breaks down when considering tunneling between two triplet superconductors with misaligned d-vectors in a TFT-junction (triplet–ferromagnet–triplet) [1,2]. Such a situation breaks time-reversal symmetry, which radically alters the behaviour of the junction, stabilizing it in a fractional state, i.e. the free energy minimum lies at a phase difference intermediate between 0 and ??. Fractional flux quanta are then permitted at the junction [3]. A further consequence of the d-vector misalignment is the appearance of a Josephson spin current, which flows even in the absence of an equilibrium charge current. Not only do our calculations enhance the physical understanding of transport through triplet superconductor junctions, but they also open the possibility of novel spintronic Josephson devices [4].

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P3-129 Electric field induction of superconductivity at complex oxide interfaces - ***A. Balatsky, J. Haraldsen, S. Trugman (LANL), P. Wolfle (TU Karlsruhe)***

We examine the e?ects of electric ?eld coupling to a superconductivity at the interface. Due to the breaking of inversion symmetry at the interface, the superconducting order parameter square ψ^2 can couple linearly to an electric ?eld E or a polarization P order parameter in a Ginzburg-Landau formalism. Therefore, we examine two main e?ects; 1) the coupling of a paraelectric fluctuations to a superconductor and 2) the coupling of an external electric ?eld on the superconducting state produced at an interface[1,2]. For the paraelectric, we show that linear coupling of an electric polarization allows the superconducting state to induce a net polarization for a paraelectric at the interface, which then decays o? into the bulk. In the second case, we examine the modi?ed electronic states and change in carrier density at the interfaces of complex oxide ?lms produced by an external electric ?eld. Further, we examine the correlation between carrier density and the superconducting critical temperature Tc by investigating capacitance and density of states. We find strong correlations between nonlinear conductance observed in these interfaces and Tc. We will discuss implications of this work in the context of interfaces formed by LaAlO3 and SrTiO3 thin ?lms.

[1] J. T. Haraldsen, S. A. Trugman, and A. V. Balatsky, Phys. Rev. B 84, 020103 (2011)[2] Electric field effect on superconductivity at complex oxide interface, Jason T. Haraldsen, Peter Wölfle, Alexander V. Balatsky, arXiv:1112.5466

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P3-130 Andreev Bound-states in topological superconductors - ***Y. Nagai, M. Machida (CCSE, Japan Atomic Energy Agency)***

The discovery of a superconductor CuxBi2Se3 has sparked intensive discussion in terms of a new avenue of theoretical concept of condensed matters, called “topological superconductivity”. Andreev bound-state is a key localized quantum state to inquire not only unconventional pairing symmetry and Majorana fermions brought about by topological superconductivity in details. The presence leads to distinct observables, e.g., zero bias conductance peak (ZBCP). Recently, Sasaki et al. measured ZBCP’s in CuxBi2Se3 and compared them with calculation results considering all possible superconducting pairing symmetries to confirm if Majorana fermions really contribute to create the ZBCP’s[1]. However, the study proved that ZBCP’s data is insufficient to exclude other non Majorana possibilities. Therefore, more clear and significant evidence of topological superconductivity is now in great demand.

In this paper, we concentrate on the Andreev bound-states in topological superconductors with aid of large-scale parallel solver for Bogoliubov de-Gennes equations [2]. A highlight of the paper is that novel Andreev bound states emerge in vortex as well as surface depending on the symmetry particularity in a case of topological superconductivity. Moreover, comparing with the past result of chiral p-wave superconductivity [3], we clarify what is a clue to elucidate the topological superconductor CuxBi2Se3.

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[3] M. Takigawa, M. Ichioka, and K. Machida, Phys. Rev. B 65, 014508 (2001).

P3-131 Atomic scale scanning tunneling spectroscopy through the superconducting and insulating phases of TiN thin films - ***P. Kulkarni (Laboratorio de Bajas Temperaturas, Departamento de Fisica de la Materia Condensada, Instituto de Ciencia de Materiales Nicolas Cabrera, Facultad de Ciencias Universidad Autonoma de Madrid, E-28049 Madrid, Spain), T. Baturina (A.V. Rzhanov Institute of Semiconductor Physics SB RAS, 13 Lavrentjev Avenue, Novosibirsk 630090, Russia), M. Baklanov (IMEC, Kapeldreef 75, B-3001 Leuven, Belgium), J. Rodrigo, H. Suderow, S. Vieira (Laboratorio de Bajas Temperaturas, Departamento de Fisica de la Materia Condensada, Instituto de Ciencia de Materiales Nicolas Cabrera, Facultad de Ciencias Universidad Autonoma de Madrid, E-28049 Madrid, Spain), V. Vinokur (Materials Science Division, Argonne National Laboratory, Argonne, Illinois 60439, USA)***

Superconductor to insulator transition in ultra-thin superconducting films can be tuned by the magnetic field or thickness. Scanning tunneling microscopy and spectroscopy characterization in superconducting and nearly insulating ultra-thin polycrystalline films of TiN reveal novel atomic level features of the superconductor to insulator transition (SIT). We show that the zero field transition is not related to either the crystallite size or morphology, but to the increase in electronic scattering, as viewed in the topographic images across SIT. The tunneling conductance curves in the insulating film exhibit the V-shape structure, the temperature evolution of which indicates the important role of Coulomb interaction. The shape of the curves does not depend on the spatial position. The spectra at both superconducting and insulating sides develop the decrease in the low bias conductance within comparable energy scales. Magnetic field noticeably influences spectra at the superconducting side, leading to a destruction of coherence peaks. Insulating gaps are however much less influenced by the applied magnetic field. Both films are found to have similar pseudo-gap like density of states at high temperatures. The very low temperature zero bias conductance at high magnetic field approches to zero in the insulating film, whereas it remains at about half the high bias conductance in the superconducting film.

P3-132 Proximity Effect in the Topological Insulator Bi2Te3 - ***S. Charpentier, R. Arpaia, S. Nawaz, S. Wang, Y. Song, T. Bauch, F. Lombardi (Chalmers University of Technology)***

Bismuth based compounds Bi2Se3 and Bi2Te3 have been recentely identified as topological insulators materials [1-3]. This new state of matter, in combination with the possibility to form Majorana fermions, when a topological insulator is contacted with a superconductor [4-6], can open new prospective for both fundamental studies and applications. Here we present our study on the proximity effect through a thin film of Bi2Te3 in Josephson junctions made with Al/Ti electrodes. We have used Bi2Te3 films grown by molecular beam epitaxy that we exfoliate to obtain flakes that are then transferred on a SiOx substrate. The flakes are contacted with Al/Ti using e-beam lithography. The presence of proximity effect through Bi2Te3 has been confirmed by the observation of a Josephson current showing a clear Franhofer like dependence as a function of the external magnetic field and several high order Shapiro steps under microwave irradiation. The dependence of the Josephson current as a function of the distance between the electrodes is in progress.

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P3-133 Effects of Epitaxial Strain and Rare-Earth Magnetism on the Transport Properties of the Conducting Interface Between Insulating Oxides - ***J. Markert, M. Monti [1], C. Stolle, S. Mozaffari (Department of Physics, University of Texas at Austin, Austin, TX 78712 USA)***

The nearly two-dimensional conducting interface between two insulating oxides, $SrTiO_3$ (STO) and $LaAlO_3$ (LAO), has recently been shown to exhibit superconductivity near 0.2 K [2]. We have performed pulsed laser deposition (PLD) growth of various epitaxial oxide thin films on single crystal STO(001) substrates. We studied the effects of epitaxial strain and rare-earth composition on the conducting interface properties. We have prepared clean, uniformly-terraced TiO_2-terminated STO substrates, and have grown epitaxial thin films of $LaAlO_3$, $LaGaO_3$ (LGO), and $RAlO_3$ on STO using a KrF pulsed excimer laser. Our work emphasizes the importance of understanding the effects of both epitaxial strain and R^{3+} magnetism on the transport properties of the conducting interface between $RAlO_3$ and STO. We demonstrate that the interfaces between LAO/STO and LGO/STO are metallic with carrier concentrations of 1.1 x 10^{14} cm^{-2} and 4.5 x 10^{14} cm^{-2}, respectively. Rare-earth aluminate films, $RAlO_3$, with R = Ce, Pr, Nd, Sm, Eu, Gd, and Tb, were also grown on STO. Conducting interfaces were found for R = Pr, Nd and Gd, and the transport results indicate that for R≠ La, the magnetic nature of the R^{3+} ions causes increased scattering with decreasing temperature that we model with the Kondo effect. Epitaxial strain between the polar $RAlO_3$ films and the non-polar STO substrate appears to play a crucial role in the transport properties of the metallic interface, where a decrease in the R^{3+} ion size causes an increase in sheet resistance and an increase in the apparent Kondo temperature.

1) Current address: U.S. Army Research Laboratory, Adelphi, MD 20783-1197

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P3-134 Thermodynamic signatures of topological transitions in non-centrosymmetric superconductors - ***B. Mazidian (University of Bristol), A. Hillier (ISIS facility, STFC Rutherford Appleton Laboratory), J. Quintanilla (ISIS facility, STFC Rutherford Appleton Laboratory SEPnet and Hubbard Theory Consortium, University of Kent), J. Annett (University of Bristol)***

Superconductors which lack inversion often exhibit unconventional behaviour. This is thought to arise in such systems as a result of the admixture of singlet and triplet pairing on the superconducting gap via spin-orbit coupling (SOC). The available pairing symmetries for any superconductor can be classified by a group theoretical analysis of the crystal point group. Here we present the symmetry allowed order parameters for each irrep of the non-centrosymmetric (NCS) cubic group O. This point group describes the crystal structure of the superconductors LiPdxPt3−xB, where the strength of SOC, and therefore the degree of triplet admixture can be continuously tuned by doping, and the more recently discovered Mo3Al2C, whose pairing symmetry is at present unclear.

Furthermore, we present a detailed analysis of the possible gap-node topologies allowed by a triplet admixture with the full symmetry of the lattice. We find that 2 distinct point node topologies are possible, as well as related line nodes and fully-gapped states. There are topological transitions between these states. We compute the low temperature specific heat and find that some of these topological transitions are signalled by anomalous power-law dependencies.

P3-135 Proximity-Induced Superconductivity in Topological Insulator Bi2Te3 Nanotubes - ***R. Du, W. Zhao, M. Chan, Q. Li (Department of Physics, The Pennsylvania State University, University Park, PA, USA), Y. Yin, X. Li (Hefei National Laboratory for Physical Sciences at Microscale, Department of Physics, University of Science and Technology of China, Hefei, China), J. Wang (International Center for Quantum Materials and State Key Laboratory for Mesocopic Physics, School of Physics, Peking University, Beijing 100871, China)***

We have studied proximity-induced superconductivity in candidate topological insulator Bismuth Telluride (Bi_2Te_3) nanotubes. Bi_2Te_3 nanotube samples were synthesized by solution phase method, with diameters of 70nm (ex) and 50nm (in) and the length of 3~10 µm. Superconducting tungsten (W) contacts were fabricated on the nanotube samples by focusing ion beam (FIB) assisted deposition. Electrical transport measurements were conducted at low temperatures (down to 0.5K) and high magnetic fields (up to 9T). Proximity effect induced superconducting transition was observed in the nanotubes. In superconducting state, strong periodic magnetoresistance oscillations were observed when the magnetic field was applied perpendicular to the nanotubes. The period of the oscillations is around 6000Oe for the nanotube with the length of 2µm between the inner edges of two voltage electrodes. Magnetoresistance fluctuations instead of periodic oscillations were observed when the magnetic field was applied parallel to the tubes, which disappeared when the sample became normal. Further measurements are being conducted and the possible origin of the effects will be discussed.

P3-138 Cryogenic Magic Angle Spinning (cryo-MAS) Nuclear Magnetic Resonance (NMR) experiments on powder superconductors above and below th critical temperature (Tc). - ***R. Stern, I. Heinmaa, E. Joon (NICPB), M. Denning, M. Carravetta (School of Chemistry, University of Southampton, Southampton)***

Cryogenic magic-angle spinning NMR has been suggested as a novel powerful technique to study various powder superconducting materials. Data at 4.7T and 8.5T have been obtained on a diluted sample of magnesium diboride powder in the normal and superconducting states [1]. We demonstrate that magic-angle spinning NMR is possible on type-II superconductors both in normal state [2] as well as below Tc despite the sample rotation which may interfere with the field penetration through vortices. The data provide accurate information on the magnetic shift variation and longitudinal relaxation data down to a temperature of 8 K. The onset of superconductivity is unaffected by the sample rotation, as revealed by a steep variation of the magnetic shift just below the critical temperature. A big improvement in resolution is achieved through sample rotation over the entire temperature range. In other examples (YBCO, k-(ET2)Br) cryo-MAS offers an alternative access to various changes in lineshape and -width with temperature.

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[2] Stern, R.; Heinmaa, I.; Pavlov, D. A.; Bryntse, I. *NATO Science series II: M, P AND C* **2005**, *183*, 4.

Research was supported by EPSRC (UK), the University Research Fellowship (RS, UK) and the Estonian Science Foundation.

P3-139 Coexistence of Superconductivity and Magnetism of LaAlO3/SrTiO3 Heterostructure Interface - ***L. Li (University of MIchigan), R. Ashoori (Massachusetts Institute of Technology), J. Mannhart (Max Planck Institute for Solid State Research, Stuttgart), C. Richter (University of Augsburg)***

The $LaAlO_3/SrTiO_3$ heterostructure is a potential candidate for a high mobility two-dimensional electron system with novel electronic and magnetic properties. Magnetic ordering has been proposed to arise from the d-electrons transferred by polarization discontinuity. However the magnetization of this system has not previously been studied, due to the small volume of the interface. Using torque magnetometry, we detect the magnetic moment of the interface system directly [1]. Our results indicate the existence of a magnetic ordering at the two-dimensional conductive interface. The ferromagnetic-like ordering state persists up to 200 K. Such a state is hardly explained by ion-exchange at the interface, since LaTiO3 is antiferromagnetic. Moreover, the same magnetic behavior persists even when the sample is superconducting, which suggests an unconventional two-dimensional superconducting phase.

[1] Lu Li, C. Richter, J. Mannhart, and R. C. Ashoori. *Nature Physics* **7***. 762* (2011)

P3-140 Search for Superconductivity at Van Hove Singularities in Carbon Nanotubes - ***Y. Yang (Physics department, Georgetown University), B. Cooper, R. Lewis, C. Lobb (Department of Physics, University of Maryland), S. Shafranjuk (Physics and Astronomy Department, Northwestern University), P. Barbara (Physics department, Georgetown University), G. Fedorov (RRC Kurchatov Institute)***

Single-walled carbon nanotubes are one-dimensional conductors consisting of a layer of carbon atoms wrapped in the shape of a cylinder, with diameter of a few nanometers and length of several micrometers. Although it is well known that a carbon nanotube can be semiconducting or metallic depending on its chirality, the occurrence of superconductivity in this system with a very small number of conducting channels is still not understood.

Measurements of intrinsic superconductivity in ropes [1] and arrays [2] of carbon nanotubes, as well as multi-walled carbon nanotubes (carbon nanotubes nested into each other) [3] and films of boron-doped carbon nanotubes [4], show a wide range of critical temperatures, from 500 mK to 12 K. One possible cause for the large spread in critical temprature is the fact that these samples contain multiple nanotubes with different electronic properties due to their own diameters and chiralities.

Here we discuss anomalous transport features with critical temperature of about 25 K measured in isolated single-walled carbon nanotubes at the Van Hove singularities (VHSs) [5], which indicates that nanotubes may become superconducting when the gate voltage shifts the Fermi energy into the VHSs. In this scenario, the transport features are caused by proximity effect at the interface between the superconducting nanotube and the normal electrode [6] and the superconducting properties can be tuned by chemical doping or by applying an electric field.

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Invited Sessions

I11 - The Pseudogap
Regency, 3:30 PM to 5:50 PM
Session Chair: Maurice Rice

I11-01 Evidence for Intertwining of Stripes and Superconductivity in La(2-x)Ba(x)CuO(4) - ***J. Tranquada (Brookhaven National Laboratory)***

The occurrence of charge and spin stripe order in $La_{2-x}Ba_xCuO_4$ is now well established, with the strongest order occurring at x = 1/8, where the onset of bulk superconductivity is strongly suppressed [1]. Transport and susceptibility measurements on the x=1/8 material indicate that 2D-like superconducting correlations coexist with stripe order for T < 40 K. Frustration of the interlayer Josephson coupling has motivated the concept of a pair-density-wave superconductor, with intertwined spin, charge, and superconducting orders [1]. Recent studies have begun to address the situation at x = 0.095. Here bulk superconductivity sets in at 32 K, coexisting with gapless spin fluctuations and no apparent spin resonance [2]. Spin and charge stripe orders are weak in zero field, but are significantly enhanced by a magnetic field applied along the c-axis [3]. Such a field is also found to decouple the superconducting planes, in a fashion reminiscent of the x=1/8 phase. The decoupling has now been followed up to fields of 35 T [4].

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1. See: Physica C Special Issue on Stripes and Electronic Liquid Crystals in Strongly Correlated Systems.
2. Z.J. Xu, C. Stock, A. Kolesnikov, G.D. Gu, and J.M. Tranquada (unpublished).
3. J.S. Wen et al., arXiv:1009.0031; arXiv:1111.5383.
4. Z. Stegen, S.J. Han, J. Wu, G.S. Boebinger, G.D. Gu, Q. Li, and J.M. Tranquada (unpublished).

I11-02 Assessing density wave order in underdoped cuprates using neutron scattering - ***V. Hinkov (Max-Planck-UBC Centre for Quantum Materials), T. Keller (Forschungsneutronenquelle Heinz Maier-Leibnitz FRM2, Technische Universität München, Garching), A. Ivanov (Institut Laue Langevin, Grenoble), Y. Sidis (Laboratoire Leon Brillouin), P. Bourges (Laboratoire Leon Brillouin, CEA-CRNS), D. Haug, B. Keimer, C. Lin (Max-Planck Institute for Solid State Research)***

In this presentation I will discuss the doping evolution of spontaneously symmetry-broken states in YBa(2)Cu(3)O(6+x) with an emphasis on their manifestation in the magnetic properties of the system. Coming from the parent compound, I will show how first long-range AFM order is lost, albeit 3D AFM correlations persist up to a doping level of x ~ 0.4. Slightly below that x, concurrent quasi-1D incommensurate correlations set in which dominate magnetic neutron scattering results in a wide doing range around x ~ 0.5.

I will discuss the results within different density wave theories and assess suggested spin stripe and spiral scenarios. Finally, I will briefly address the relation of the presented results to the recent observations of charge modulations at the somewhat higher doping levels around and above x ~ 0.6.

I11-03 Suppression of the antinodal coherence in underdoped cuprates as revealed by muon-spin rotation and angle-resolved photoemission - ***R. Khasanov (Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland), A. Kaminski (Ames Laboratory and Department of Physics and Astronomy, Iowa State University, Ames, IA~50011, USA), T. Takeuchi (Department of Crystalline Materials Science, Nagoya University, Nagoya 464-8603, Japan), T. Kondo (Institute for Solid State Physics, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba Japan 277-8581), M. Bendele (Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland), S. Ray (School of Physcs and Astronomy, University of St. Andrews, Fife, KY16 9SS, UK), S. Lee (School of Physics and Astronomy, University of St. Andrews, Fife, KY16 9SS, UK)***

In a classical BCS superconductor, pairing and coherence of electrons are established simultaneously below the critical transition temperature ($T_{\rm c}$), giving rise to a gap in the electronic energy spectrum. In the high-temperature cuprate superconductors, however, a pseudogap extends above $T_{\rm c}$ thus making the relationship between the pseudogap and superconductivity to be one of the central issues in this field. By combining the results of the superfluid density measurements by means of muon-spin rotation with the angle-resolved photoemission spectroscopy studies performed for the similar single crystalline (BiPb)$_2$(SrLa)$_2$CuO%_{6+\delta}$ samples [1], we demonstrate that the opening of the pseudogap correlates with the corresponding decrease of the coherent electron states associated with superconductivity [2,3]. We therefore conclude that some parts of the Fermi surface do not develop superconducting coherence, which leads to the unusual superconducting response of the underdoped copper oxides.

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3. Khasanov et al., Phys Rev. B, 82, 020511(R), (2010)

I11-04 One gap, two gaps, and universality in the copper oxide superconductors - ***J. Campuzano (Argonne National Laboratory and University of Illinois at Chicago), U. Chatterjee, D. Hinks, H. Zheng, S. Rosenkranz, H. Claus, M. Norman (Argonne National Laboratory), G. Gu (Brookhaven National Laboratory), M. Randeria (Ohio State University), D. AI (University of Illinois at Chicago), J. Zhao (University of Illinois at Chicago and Argonne National Laboratory)***

A dramatic change in energy gap anisotropy upon reducing carrier concentration has often been observed in the copper-oxide superconductors (HTSC). A simple d-wave gap in materials with the highest superconducting Tc evolves with underdoping into a "two-gap" behavior, with different k-dependences in different regions of momentum space. It is tempting to associate the large antinodal gap, that persists even above Tc in underdoped materials, with a second order parameter distinct from d-wave superconductivity. We use angle-resolved photoemission spectroscopy (ARPES) to show that the two-gap behavior, and the concomitant destruction of well defined electronic excitations, are not universal features of HTSC, and depend sensitively on how the underdoped materials are prepared. Depending on cation substitution, underdoped crystals either show two-gap behavior or not. In contrast, many characteristics of HTSC like the superconducting dome (Tc versus doping), nodal quasiparticles, antinodal gap that decreases monotonically with doping, and the pseudogap, are present in all samples, irrespective of whether they exhibit two-gap behavior or not. Our results imply that universal aspects of high Tc superconductivity are insensitive to differences in the electronic states in the antinodal region of the Brillouin zone.

The work at Argonne National Laboratory was supported by UChicago Argonne, LLC, Operator of Argonne National Laboratory. Argonne, a U.S. Department of Energy, Office of Science laboratory is operated under Contract No. DE-AC02-06CH11357 (S.R., A.K., M.R.N, and J.C.C.). M.R. was supported by the National Science Foundation grant DMR 0706203.

I11-05 Study of density-wave order in underdoped cuprates by ARPES, LEED, and REXS - ***A. Damascelli (University of British Columbia), Y. Yoshida, H. Eisaki (AIST), B. Keimer (MPI Stuttgart), L. Petaccia (Sincrotrone Trieste), J. Rosen, R. Comin, G. Levy, G. Sawatzky (University of British Columbia), G. Blake, T. Palstra (University of Groningen)***

While there is mounting evidence for a broken symmetry in the pseudogap state of the high-T_c cuprates, the identification of a specific origin remains elusive. Through the combination of electronic (ARPES) and structural (LEED) probes, we uncover a temperature dependent evolution of the CuO_2 plane band dispersion in highly-ordered Bi2201, which stems from a hitherto-undetected evolution of the incommensurate superstructure associated with the two modulation vectors Q1 and Q2. The quasilinear, continuous variation of the modulation wavelength 2pi/Q2 from 66 to 43A, below a characteristic T_{Q2}=130K, provides evidence for a charge-density-wave-like ordering at the surface of the material. For a fuller understanding, these results are complemented by a detailed study of structural/electronic modulations by bulk-sensitive x-ray diffraction and resonant-elastic x-ray scattering. Altogether these findings point to a remarkable electron-lattice coupling, with a complex interplay between competing nesting instabilities and surface-vs-bulk ordering.

I11-06 Direct observation of charge ordering in underdoped YBCO in high magnetic fields - ***E. Blackburn (School of Physics and Astronomy, University of Birmingham), N. Christensen (DTU Physics, Technical University of Denmark), J. Chang (EPFL, Lausanne & Paul Scherrer Institute), S. Hayden (H H Wills Physics Laboratory, University of Bristol), M. Zimmermann (HASYLAB at DESY, Hamburg), A. Holmes, E. Forgan (School of Physics and Astronomy, University of Birmingham), R. Liang, W. Hardy, D. Bonn (University of British Columbia)***

We have used synchrotron X-ray diffraction in fields up to 17 T to observe the field- and temperature-dependence of charge ordering in a high-quality single crystal of underdoped YBCO. We obtain the q-vector and coherence lengths of this order and observe the interplay between the magnetic field, charge ordering and superconductivity in this crystal. These observations indicate that competing orders, often breaking translational invariance in the basal plane, are a common feature of cuprate superconductors.

I11-07 Phase Diagram of High-Tc Superconductivity and Antiferromagnetism in Cuprates - ***H. Mukuda (Osaka university), A. Iyo (AIST), S. Shimizu, Y. Kitaoka (Osaka university)***

We present extensive nuclear magnetic resonance (NMR) investigations of n-layered cuprates with n = 3, 4, and 5, which have revealed the intimate relationship between antiferromagnetism (AFM) and high-temperature superconductivity (HTSC) for a disorder-free CuO2 plane with hole carriers homogeneously doped[1-4]. The intrinsic phase diagram possesses the following features: The AFM metallic state is robust and coexists uniformly with the HTSC at a single CuO2 plane in a region extending up to the optimally doped one. The critical carrier density p_c at which the AFM order collapses decreases from p_c=0.10 to 0.08 to 0.075 as the interlayer magnetic coupling becomes weaker when decreasing from n = 5 to 4 to 3, respectively. This provides a reasonable explanation why the AFM order in n = 1:La-Sr-Cu-O and n = 2:Y-Ba-Cu-O compounds collapses at carrier densities with p_c = 0.02 and 0.055, respectively. We reveal that the SC gap and Tc exhibit a maximum irrespective of n at p = 0.16 just outside p_c (M_AFM = 0) = 0.14, where the AFM moment (M_AFM) inherent in the CuO2 plane totally disappears in the ground state. We highlight that the ground-state phase diagram of AFM and HTSC is in good agreement with the ground-state phase diagrams in terms of the t–J model. The results suggest that the in-plane superexchange interaction J plays a vital role as a glue for Cooper pairs or mobile spin-singlet pairs, which will lead us to a coherent understanding why Tc is so high for hole-doped cuprates.

[1] S. Shimizu et al. J. Phys. Soc. Jpn. 80, 043706 (2011)
[2] S. Shimizu et al. Phys. Rev. B 83, 214514 (2011)
[3] S. Shimizu et al. Phys. Rev. B 85, 024528 (2012)
[4] H. Mukuda et al. J. Phys. Soc. Jpn. 81, 011008 (2012) [review]

I12 - Fermiology of Pnictides
Palladian, 3:30 PM to 5:50 PM
Session Chair: Hong Ding

I12-01 ARPES studies of iron-based superconductors - ***D. Feng (State Key Laboratory of Surface Physic and Department of Physics, Fudan University)***

We address two issues in iron based superconductors with angle resolved photoemission spectroscopy (ARPES).

1. The nodal gap. $BaFe_2(As_{1-x}P_x)_2$ is a prototypical iron-based superconductor with nodal gap behaviors. We directly observed a ring node on the largest hole Fermi surface near the Z point at the Brillouin zone boundary. We found that the nodes are likely due to the strong three dimensional character of this Fermi surface (large kz dispersion, strong mixing of d_{3z2-r2} orbitals). Moreover, we found that such a strong presence of the d_{3z2-r2} orbitals near Z is a general character of iron pnictides with nodes, including $Ba(Fe_{1-x}Ru_x)_2As_2$, KFe_2As_2, etc. Our results suggest that the nodal superconductivity in iron pnictides is an accidental one under the s-wave pairing symmetry, and explains that when the Fe-Pnictogen height is reduced sufficiently, nodal superconductivity could be induced by the enhanced presence ofd$_{3z2-r2}$ states at E_F around Z.

2. The role of Fermi surface nesting. In $K_xFe_{2-y}Se_2$ (T_c=31K), large electron Fermi surfaces are observed around the zone corners with an almost isotropic superconducting gap of 10.3 meV, while there is a very small hole pocket around Z, which

demonstrate the inter-band scattering or Fermi surface nesting is not a necessary ingredient for the unconventional superconductivity in iron-based superconductors. Moreover, the electronic structure and superconductivity evolution in $LiFe_{1-x}Co_xAs$, $LiFe_{1-x}Cr_xAs$, and $NaFe_{1-x}Co_xAs$ indicate that while nesting is not important for superconductivity, correlation is likely a necessary ingredient. The role of nesting for the spin density wave formation in the parent compound will be discussed as well.

This work is conducted in collaboration with Yan Zhang, Z. R. Ye, F. Chen, C. He, Q. Q. Ge, M. Xu, Juan Jiang, X. H. Chen, D. H. Lu. S. Kimura.

1. Y. Zhang et al. arXiv:1109.0229v1 (2011), Nature Physics (in press).
2. Y. Zhang et al. Nature. Materials 10, 273 (2011).
3. Y. Zhang et al. arXiv:1111.6430v1 (2011)

I12-02 ARPES on iron-based superconductors - *S. Borisenko (IFW-Dresden)*

I will overview our recent ARPES results on different types of iron pnictides and chalcogenides. We perform our measurements at lowest possible temperature of the order of 1K. We systematically collect the data to understand the fermiology, self-energy and symmetry of the order parameter in all studied materials. Our results strongly suggest that particular electronic structure near high symmetry points is a necessary requisite for the superconductivity. We also speculate of what could be the driving force to bind electrons in pairs in these superconductors.

S. V. Borisenko et al. Symmetry 4, 251-264 (2012).

I12-03 Quantum oscillations in iron-based superconductors - *A. Coldea (University of Oxford)*

I will present quantum oscillations studies of 111, 122 and 1111 iron-based superconductors and metals that allow mapping out the Fermi surface and provide information about the role of electronic correlations. We find that the measured *k*-dependent orbits and their angular dependence can be identified and matched to the calculated ones from the first principle calculations using experimental lattice parameters. The results often point out towards quasi-nesting between the inner electron and hole bands for different classes of compounds. The strength of the electronic correlations is determined by comparing the orbitally averaged effective masses with the calculated band mass and we find that the stronger the correlations the higher T_c that a characteristic to particular families of compounds tuned by isoelectronic substitution. This reflects the importance of the exact details of the Fermi surface and their orbital character, in particular the *c*-axis warping, in determining the superconducting gap symmetries. I will also discuss the effect of the electron doping and the sensitivity of the hole bands to isoelectronic substitutions that leads to major topological change of their Fermi surface and its implications on superconductivity.

This work reflects collaboration between groups at Bristol University, Stanford University and Kyoto University by using high magnetic field facilities in Nijmegen, Tallahassee and Toulouse. We acknowledge financial support from EPSRC, Euromagnet ||, NSF.

PRL 101, 216402 (2008); PRL 103, 026404 (2009); PRL 104, 057008 (2010); PRL 108 047002(2012)

I12-04 Quantum oscillations in iron-based superconductors - *T. Terashima (National Institute for Materials Science), K. Kihou, C. Lee, H. Kito, Y. Tomioka, T. Ito, A. Iyo, H. Eisaki (AIST), T. Saito, H. Fukazawa, Y. Kohori (Chiba University), H. Harima (Kobe University), N. Kurita, M. Tomita, H. Satsukawa, A. Harada, K. Hazama, M. Imai, A. Sato, S. Uji (National Institute for Materials Science), M. Kimata, T. Liang, M. Nakajima, S. Ishida, S. Uchida (University of Tokyo)*

Precise determination of electronic structures near the Fermi level is indispensable in elucidating the mechanism of iron-based high-T_c superconductivity. To this end, measurements of quantum oscillations such as de Haas-van Alphen (dHvA) oscillations in magnetization and Shubnikov-de Haas (SdH) oscillations in resistivity are best suited. Those measurements are a true bulk probe into the Fermi surface and, with the aid of band-structure calculations, can determine three-dimensional shape of the Fermi surface. They can also determine effective masses and relaxation times of electrons, the former of which provide direct information about strength of many-body interactions.

In this talk, we will present our SdH measurements on detwinned $BaFe_2As_2$ [1] and dHvA measurements on KFe_2As_2 [2, 3]. The Fermi surface of $BaFe_2As_2$ in the antiferromagnetic phase is found to consist of one hole and two electron pockets, all of which are three-dimensional and closed, and can reasonably be accounted for by LSDA band calculations. We find only moderate mass enhancements m^*/m_{band} of 2–3. In the case of KFe_2As_2, four quasi-two-dimensional Fermi surface cylinders ε, α, ζ, and β are observed in qualitative agreement with ARPES [4]. In sharp contrast to $BaFe_2As_2$, agreement between the observed and LDA-calculated Fermi surface is poor: LDA calculations seem to predict wrong crystal-field splitting of Fe 3*d* states. Large effective masses up to 19 m_e, m_e being the free electron mass, are found and indicate strong electronic correlations. The Sommerfeld coefficient estimated from the observed Fermi surface and effective masses is consistent with the measured value of 93 mJ/K^{2}mol [5].

[1] T. Terashima *et al.*, Phys. Rev. Lett. **107**, 176402 (2011).
[2] T. Terashima et al., J. Phys. Soc. Jpn. **79**, 053702 (2010).
[3] T. Terashima et al., in preparation.
[4] T. Yoshida et al., J. Phys. Chem. Solids **72**, 465 (2011).
[5] H. Fukazawa et al., J. Phys. Soc. Jpn. **80**, SA118 (2011).

This work was supported by JST, TRIP.

I12-05 ARPES studies of iron-based superconductors - ***V. Brouet (Universite Paris Sud - CNRS), A. Taleb-Ibrahimi, P. Le Fèvre, F. Bertran (Soleil Synchrotron), D. Colson (SPEC CEA-Saclay)***

There is a consensus that the multiband nature of iron pnictides is essential for defining their electronic properties. Many models for the superconducting and antiferromagnetic orders heavily rely on the interaction between different electron and hole Fermi Surface (FS) sheets. ARPES experiments are then very appealing in these materials, as they can in principle resolve the properties of each hole and electron bands independently. Despite many ARPES investigations of iron pnictides, the structure of the electron pockets is still poorly understood. By combining ARPES measurements in different experimental configurations, we clearly resolve the 2 bands forming one electron pocket, including the sides oriented towards Z, which are often missing in ARPES experiments. We give special attention to the distinction between the main bands, defined in a unit cell containing only 1Fe, and the folded bands, defined in a unit cell containing 2 Fe. We show that this distinction is meaningful, as ARPES intensities are modulated by these effects, and this allows to greatly simplify the spectra.

We identify a deep electron band along one ellipse axis with the dxy orbital and a shallow electron band along the perpendicular axis with the dxz/dyz orbitals, in good agreement with band structure calculations. We find that the mean free paths and Fermi velocities associated with dxy are longer than those for dxz/dyz. This suggests that the two types of orbitals play different roles in the electronic properties.

Having mapped the entire ellipse, we study precisely its nesting with the hole pockets, its evolution in the magnetic state[1] and under Fe/Co[2] and Fe/Ru[3] substitutions.

1. M. Fuglsang Jensen *et al.*, *Physical Review B* **84**, 014509 (2011)
2. V. Brouet *et al.*, *Physical Review B* **80**, 155115 (2009)
3. V. Brouet *et al.*, *Physical Review Letters* **105**, 087001 (2010)

I12-06 Direct observation of superconducting gaps in iron-based superconductors by laser ARPES - ***K. Okazaki (Institute for Solid State Physics (ISSP), University of Tokyo), C. Chen (Beijing Center for Crystal R&D, Chinese Academy of Science (CAS)), T. Shimojima, H. Miyahara, R. Arita (Department of Applied Physics, University of Tokyo), T. Saito, H. Fukazawa, Y. Kohori (Department of Physics, Chiba University), K. Hashimoto, T. Shibauchi, Y. Matsuda, H. Ikeda (Department of Physics, Kyoto University), T. Kiss (Graduate School of Engineering Science, Osaka University), Y. Ota, Y. Kotani, W. Malaeb, Y. Ishida, S. Shin (Institute for Solid State Physics (ISSP), University of Tokyo), K. Kihou, C. Lee, A. Iyo, H. Eisaki (National Institute of Advanced Industrial Science and Technology (AIST)), S. Watanabe (Research Institute for Science and Technology, Tokyo University of Science), A. Chainani (RIKEN SPring-8 Center)***

We have developed a new apparatus for laser-excited angle-resolved photoemission spectroscopy (laser ARPES) achieving the ultrahigh energy resolution ~ 70 μeV and the sample temperature ~ 1.5 K. We would like to show our recent results of superconducting-gap measurements on the several iron-based superconductors (FeSCs) by this laser ARPES apparatus, mainly for KFe_2As_2 and $FeTe_{0.6}Se_{0.4}$.

KFe_2As_2 is an extremely hole doped compound in $(Ba,K)Fe_2As_2$ system and no longer has electron Fermi surfaces. Regardless of this, KFe_2As_2 still exhibits superconductivity with T_c of 3.4 K and has been suggested to havesuperconducting (SC) gap nodes by the several transport measurements. We directly observe the SC gaps of the three hole Fermi surfaces (FSs) around the Brillouin-zone center. Unusual anisotropies and FS-sheet dependence are found and the SC-gap nodes are also identified.

$FeTe_{0.6}Se_{0.4}$ has the simplest crystal structure among the FeSCs and shows superconductivity at 14.5 K. The band structure in the normal state is fairly renormalized and the Fermi surfaces are reconstructed, probably due to the electron correlation effect. We find that the band dispersion in the superconducting state can be reproduced by that of the Bogoliubov quasiparticle in the BCS regime by taking account of the unusual normal state dispersion. A clear fourfold anisotropy is also found in the SC-gap of this compound.

This research is supported by JSPS through its FIRST Program.

I12-07 Direct observation of anisotropic superconducting gaps in LiFeAs by high-resolution ARPES - ***K. Nakayama (Department of Physics, Tohoku University), H. Miao, P. Richard, H. Ding (Beijing National Laboratory for Condensed Matter Physics, and Institute of Physics, Chinese Academy of Sciences), T. Takahashi (Department of Physics, and WPI-AIMR, Tohoku University), Y. Li, Z. Liu, G. Chen, S. Wang (Department of Physics, Renmin University of China), K. Umezawa, T. Sato (Department of Physics, Tohoku University)***

The superconducting gap, which characterizes the energy cost for breaking a Cooper pair, is an important quantity to clarify the superconducting mechanism, since the momentum dependence of the gap size is directly associated with the pairing interactions. However, no consensus has been reached on the gap character in the newly discovered iron-based superconductors. To address this issue, we have performed high-resolution angle-resolved photoemission spectroscopy on LiFeAs [1]. We revealed the opening of multiple nodeless superconducting gaps with the magnitude varying from 2.5 meV to 5.0 meV, depending on the Fermi surface. We also succeeded in directly observing the moderate gap anisotropy along some of the Fermi surfaces. The anisotropy is fourfold symmetric with an antiphase between hole and electron Fermi surfaces. These observations strongly suggest complex anisotropic interactions for the superconducting pairing in LiFeAs.

[1] K. Umezawa *et al.*, Phys. Rev. Lett. **108**, 037002 (2012).

I13 - Bulk Properties of Superconducting State of Pnictides
Diplomat, 3:30 PM to 6:00 PM
Session Chair: Hai-Hu Wen

I13-01 Quantum critical point hidden beneath the superconducting dome of BaFe2(As,P)2 - *T. Shibauchi (Department of Physics, Kyoto University)*

An enduring question in condensed matter physics is whether high transition temperature (T_c) superconductivity is driven by an underlying quantum critical point (QCP) separating different electronic phases at absolute zero-temperature. In particular, whether a QCP lies beneath the superconducting dome or the criticality is avoided by the transition to the superconducting state has been a central issue. We report a sharp depression of the superfluid density in very clean samples [1,2] of the iron-based superconductor, $BaFe_2(As_{1-x}P_x)_2$ that gives the first convincing signature of a second-order quantum phase transition deep inside the dome. We find that the *x*-dependence of London penetration depth exhibits a sharp peak at the optimum composition $x = 0.30$ ($T_c = 30$ K). This likely results from pronounced quantum fluctuations associated with the QCP which separates two distinct superconducting phases [3]. Moreover, from the magnetic torque measurements we find evidence for the electronic nematic transition well above the structural transition temperature extending to the overdoped side of the superconducting dome [4]. These results indicate that the nematic instability precedes the superconductivity in pnictides whilst the QCP inside the dome has an antiferromagnetic nature.

This work has been done in collaboration with K. Hashimoto, S. Kasahara, Y. Mizumaki, R. Katsumata, H. J. Shi, S. Tonegawa, T. Terashima, H. Ikeda, Y. Matsuda (Kyoto), K. Cho, M. A. Tanatar, R. Prozorov (Ames), H. Kitano (Aoyama-Gakuin), N. Salovich, R. W. Giannetta (Urbana-Champaign), A. Carrington (Bristol), K. Sugimoto, T. Fukuda (SPring-8), and A. H. Nevidomskyy (Rice).

[1] S. Kasahara *et al.*, Phys. Rev. B **81**, 184519 (2010).
[2] H. Shishido *et al.*, Phys. Rev. Lett. **104**, 057008 (2010).
[3] K. Hashimoto *et al.*, preprint.
[4] S. Kasahara *et al.*, preprint.

I13-02 Gap structure of iron-based superconductors from thermal conductivity - *J. Reid (University of Sherbrooke), A. Iyo, H. Eisaki (AIST and JST-TRIP), K. Kihou (AIST and JST-TRIP), Y. Kohori (Chiba University and JST-TRIP), T. Saito, H. Fukazawa, C. Lee (Chiba University and JST-TRIP), B. Shen, H. Wen (National Laboratory for Superconductivity, Institute of Physics and Beijing National Laboratory for Condensed Matter Physics), M. Tanatar, H. Kim, R. Prozorov (The Ames Laboratory), A. Juneau-Fecteau, R. Gordon (University of Shebrooke), S. René de Cotret, J. Chang, N. Doiron-Leyraud, X. Luo, H. Shakeripour, L. Taillefer (University of Sherbrooke)*

We have used low-temperature thermal conductivity as a bulk directional probe of the superconducting gap to investigate the pairing symmetry of iron-based superconductors (e.g. [1, 2, 3]). Here I focus on the hole-doped material $(Ba,K)Fe_2As_2$. At full K concentration, all aspects of the thermal conductivity of KFe_2As_2 are in detailed and quantitative agreement with theoretical calculations for a d-wave superconductor, including its dependence on impurity scattering, current direction, magnetic field and temperature [4]. This is in sharp contrast with the situation at optimal concentration, where the gap is nodeless. A decrease in K concentration therefore produces a transition from d-wave symmetry to s-wave symmetry, with an associated 10-fold enhancement of T_c. At low K concentration, the onset of antiferromagnetic order causes a reconstruction of the Fermi surface, which in turn causes nodes to appear in a certain range of K concentrations [5]. These studies show that the superconducting gap and symmetry of iron pnictides depend sensitively on the details of the Fermi surface as it evolves with doping.

Work done in collaboration with A. Juneau-Fecteau, R. T. Gordon, S. René de Cotret, J. Chang, N. Doiron-Leyraud, X. G. Luo, H. Shakeripour, H. Kim, M. A. Tanatar, R. Prozorov, T. Saito, H. Fukazawa, Y. Kohori, K. Kihou, C. H. Lee, A. Iyo, H. Eisaki, B. Shen, H.-H. Wen and L. Taillefer.

[1] X. G. Luo et al., Phys. Rev. B **80**, 140503 (2009).
[2] J.-Ph. Reid et al., Phys. Rev. B **82** 064501 (2010).
[3] M. A. Tanatar et al., Phys. Rev. B **84**, 054507 (2011).
[4] J.-Ph. Reid et al., arXiv:1105:2232.
[5] J.-Ph. Reid et al., arXiv:1201.3376.

I13-03 Universal Non - Universality of the Energy Gap in Fe-based Superconductors - *R. Prozorov (The Ames Laboratory and Department of Physics & Astronomy, Iowa State University)*

Experimental determination of the anisotropy of the electromagnetic and thermodynamic responses is crucially important for any superconductor. Precision measurements of the London penetration depth at low temperatures provide direct information on the superfluid density and the analysis of its temperature dependence allows drawing conclusions regarding the structure of the superconducting energy gap, thus providing direct insight into the pairing mechanism. A more objective picture is, indeed, reached by considering results of other gap structure - sensitive measurements, such as thermal conductivity, specific heat, optical and electronic spectroscopies. I will summarize the experimental results on the doping - dependent superconducting energy gap studies based on the London penetration depth measurements in single crystals of “11”, “111”, “1111”, “122” and “10-3-8” families of iron – based superconductors and compare them to the results from other techniques. Non-Fermi liquid behavior, Fermi sheet – dependent energy gaps with doping-dependent three-dimensional anisotropy as well as significance of pair-breaking scattering follow from the experimental observations. In many systems, the results support s+/- pairing that evolves from nodeless to nodal upon departure from the optimal doping. This trend appears to be intrinsic, unrelated to the

coexistence of long – range magnetic order and superconductivity or the electronic anisotropy of the normal state. In some materials, however, there is a compelling evidence for symmetry – imposed line nodes in the superconducting gap.
This work was supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under contract No. DE-AC02-07CH11358. R. Prozorov and R. W. Giannetta, Superc. Sci. Technol. 19, R41 (2006). R. Prozorov and V. G. Kogan, Rep. Prog. Phys. 74, 124505 (2011).

I13-04 Thermal transport in iron-based superconductors - ***I. Vekhter (Louisiana State University), A. Vorontsov (Montana State University)***

Thermal transport at low temperatures and under applied magnetic field has been a powerful probe of the shape of the superconducting gap in complex materials. I will review the theoretical approaches to electronic heat transport in multiband superconductors, and discuss to what extent the temperature and field dependence of the thermal conductivity can be used to infer the gap shape on multiple Fermi surface sheets. I will present the theory for the variation of the thermal and transport coefficients under rotated magnetic field in anisotropic superconductors, and compare the results with experiments on several iron-based superconductors. I will specifically focus on the complexities brought about by the presence of several bands with potentially different gap shapes, and consider in detail the competing effects of the Fermi surface and gap anisotropies.
This work has been supported in part by DOE under Grant No. DE-FG02-08ER46492, and by NSF under Grant No. DMR-1105339 and cooperative agreement EPS-1003897.

I13-05 specific heat studies of iron-based superconductors - ***G. Stewart (Physics/University of Florida), K. Gofryk, F. Ronning (Los Alamos National Laboratory), A. Sefat (Oak Ridge National Laboratory), K. Kim, K. Choi (Physics/Seoul National University), J. Kim, B. Faeth, G. Tam (Physics/University of Florida)***

Specific heat measurements of materials deep in their superconducting state have been used to infer information about nodal structure since the 'Volovik - effect' work of Moler et al. [1] experimentally showed that gamma varies at H**0.5 in YBCO. Our recent work (e. g. Wang et al., [2]) has shown that, with the multiple bands present in the iron superconductors, gamma as a function of field can present results that are quite rich in their variety. We present gamma vs H results over a broader range of the superconducting dome than heretofore reported in Co-doped BaFe2As2, using single crystals that have been annealed according to an optimization protocol developed in our laboratory. Interesting behavior that provides useful insight into the nodal structure of the bands, as well as the interaction strength between the bands, is found in the overdoped regime that contrasts with behavior in the underdoped regime. Field results on other systems will be presented as time permits.
Work at Florida (contract no. DE-FG02-86ER45268), Los Alamos, and Oak Ridge supported by the U. S. Dept. of Energy, Office of Basic Energy Sciences. Work in Seoul supported by The National Creative Research Initiative (Grant No. 2010-0018300).
[1] K. Moler et al., Phys. Rev. Lett. **73**, 2744 (1994).
[2] Y. Wang et al., Phys. Rev. B **84**, 184524 (2011).

I13-06 NMR studies of iron-based superconductors - ***T. Imai (McMaster University and Canadian Institute for Advanced Research)***

We will revisit the key features of the anomalous normal state properties of iron-based high Tc superconductors as revealed by NMR measurements. We will emphasize the similarities and dissimilarities between various iron-arsenide and iron-selenide systems, and attempt to elucidate the fundamentally important ingredient(s) of the mechanism behind their high Tc superconductivity.

I14 - Superconductor-Insulator Transition
Empire, 3:30 PM to 6:00 PM
Session Chair: Ivan Božovic

I14-01 Localization of preformed Cooper pairs in disordered superconductors - ***B. Sacépé (Néel Institute, CNRS), M. Feigel'man (L.D. Landau Institute for Theoretical Physics), L. Ioffe (Serin Physics Laboratory, Rutgers University), T. Dubouchet, C. Chapelier, M. Sanquer (SPSMS-INAC, CEA Grenoble), M. Ovadia, D. Shahar (Weizmann Institute of Science)***

The concept of localized Cooper pairs in disordered superconducting films close to the Superconductor-Insulator Transition (SIT) has intrigued scientists for several decades. Although interplay between localization and superconductivity has been extensively studied on the macroscopic scale by transport measurements, very little is known about the microscopic details of the superconducting state in the high disorder limit. In this talk I will present a study of the local superconducting gap performed on highly disordered, amorphous, indium oxide films by means of scanning tunneling spectroscopy [1]. Our measurements reveal that the superconducting transition follows a two-step process in which Cooper pairs first perform above Tc, leading to the opening of a pseudogap in the density-of-states (DOS), and then condense at Tc into a non-uniform superconducting state. The spatial mapping of the local DOS shows that this superconducting state is a mixture of superconducting and insulating gapped regions in which Cooper pairs are either delocalized into the condensate or localized by the disorder. The presence of localized Cooper pairs is evidenced in our DOS measurements by the lack of BCS coherence peaks at the gap edges. The statistical analysis of the coherence peak height shows furthermore that the SIT is driven by the proliferation of localized Cooper pairs.
[1] B. Sacépé, *et al.* Nature Physics 7, 239 (2011)

I14-02 Proximity Effects and Metallic States in Mesoscopic Superconductor-Normal Metal Arrays - *N. Mason (University of Illinois at Urbana-Champaign)*

In this talk, I will discuss our experiments on arrays of superconducting islands patterned on normal metal films [1]. The underlying normal metal can become superconducting due to the proximity effect; thus, by changing the size and spacing of the superconducting islands, we can controllably change the superconducting properties of the metal film. Such systems are also predicted to exhibit 2D zero-temperature metallic states, which cannot be explained by conventional transport theory. I will discuss electrical transport measurements of these systems, including characterization of the superconducting transitions, vortex dynamics in a finite magnetic-field, and evidence that the system approaches unusual metallic ground states as the island spacing is increased.

[1] Eley *et al*, *Nature Physics* **8**, 59 (2012). This work was supported by the DOE-DMS under grant DE-FG02-07ER46453 through the Frederick Seitz Materials Research Laboratory at the University of Illinois at Urbana-Champaign

I14-03 Superconducting phase transitions in ultrathin TiN films: recent SI transition results - *T. Baturina (A. V. Rzhanov Institute of Semiconductor Physics SB RAS, 13 Lavrentjev Avenue, 630090, Novosibirsk, Russia)*

One of the most remarkable features of thin disordered superconducting films is that a film of the same material can be a superconductor but can very well turn an insulator. The engine driving the transition between the superconducting and insulating states is disorder, which is quantified by the unique parameter, the resistance per square. I will present our recent results on the detailed study of transport properties of ultrathin TiN films in the critical vicinity of the superconductor-insulator transition (SIT), including the non-monotonic temperature dependences of the resistance, broadening of superconducting transition, pseudogap-like behavior, and the change of the resistive properties on passing the SIT itself, and show that they are all controlled by the resistance per square [1,2].

I will discuss the effect of enhancement of superconducting fluctuations caused by the proximity to the SIT, vortex- and charge Berezinskii-Kosterlitz-Thouless transitions, and the role of electronic inhomogeneity on the mesoscale in forming the critical state [3].

1. T. I. Baturina et al., EPL 97, 17012 (2012).
2. B. Sacépé, C. Chapelier, T. I. Baturina, V. M. Vinokur, M. R. Baklanov, M. Sanquer, Phys. Rev. Lett. 101, 157006 (2008); Nat. Commun. 1, 140 (2010).
3. V. M. Vinokur and T. I. Baturina, to be published in 40 Years of the Berezinskii-Kosterlitz-Thouless Theory, World Scientific (2012).

I14-04 A superconducting gap in an insulator - *D. Shahar (The Weizmann Institute)*

When a the disorder of a superconducting material is high enough it can undergo a transition into an insulating state. I will discuss the mounting evidence that this insulator is, paradoxically, a result of superconductivity itself. I will present evidence for the role played by superconductivity in forming the insulating state obtained from various experimental probes such as temperature and magnetic filed dependent transport, absorption and the more recent tunneling experiments, which show clear evidence for a superconducting gap in the insulating state. Finally, I will demonstrate the existence of Little-Parks-like oscillations in nano-patterned insulating samples.

I14-05 New Developments in the Theory of the Disorder-Driven Superconductor-Insulator Transition - *N. Trivedi (The Ohio State University)*

We show that increasing disorder in an s-wave superconductor suppresses the transition temperature and drives it to zero at a quantum phase transition. Beyond the critical disorder the system enters a novel insulating phase of pairs. We show that the single-particle energy gap in the density of states survives across the transition, but coherence peaks exist only in the superconductor. With increasing disorder, the system forms superconducting blobs on the scale of the coherence length embedded in an insulating matrix. In the superconducting state, the phases on the di fferent blobs are coherent across the system whereas in the insulator long range phase coherence is disrupted by quantum fluctuations. For a finite disorder, the emergent granularity leads to a pseudogap, a characteristic suppression in the density of states, persisting even above the transition temperature. In the insulator, we find a characteristic energy gap scale in the pair susceptibility that vanishes as the transition is approached from the insulating side, despite a robust single-particle gap. These results are obtained using quantum Monte Carlo simulations that treat, on an equal footing, inhomogeneous amplitude variations and phase fluctuations, a major advance over previous theories. We make several testable predictions for local spectroscopic probes and for dynamical conductivity experiments.

K. Bouadim, Y-L. Loh, M. Randeria and N. Trivedi, Nature Physics 7, 884-889 (2011); A. Ghosal, M. Randeria, and N. Trivedi, Phys. Rev. B 65, 014501 (2001); Phys. Rev. Lett. 81, 3940 (1998).

Acknowledgement: DOE DE-FG02-07ER46423 (N.T., Y.L.L.), NSF DMR-0907275 (K.B.), NSF DMR-1006532 (M.R.), and Ohio Supercomputing Center.

I14-06 Superconductor-Insulator transition and energy localization - *M. Feigel'man (L.D.Landau Institute for Theoretical Physics), L. Ioffe (Rutgers University), E. Cuevas (University of Murcia), M. Mezard (University Paris-Sud)*

The origin of continuous energy spectrum in large disordered interacting quantum systems is one of the key unsolved problems in quantum physics. While small quantum systems with discrete energy levels are noiseless and stay coherent forever in the absense of any coupling to external world, most large-scale quantum systems are able to produce thermal bath, thermal transport and excitation decay. This intrinsic decoherence is manifested by a broadening of energy levels which aquire a finite width. The important question is what is the driving force and mechanism of transition(s) between two different types of many-body systems - with and without decoherence and thermal transport ? Here we address this question via two complementary approaches applied to the same model of quantum spin - 1/2 system with XY-type exchange interaction and random transverse field. Namely, we develop analitical theory for this spin model on a Bethe lattice [1] and implement numerical study of exact level statistics [2] for the same spin model on random graph. The relevance of this spin model to the study of pseudogaped superconductivity and S-I transition in some amorphous materials (InOx, TiN) was proposed theoretically in [3] and supported by scanning tunnelling spectroscopy and transport experiments [4]. Both theoretical and numerical studies [1,2] predict the presense of two quantum phase transitions which separate three different phases: A) ordered phase (superconductor with a pseudogap), B) disordered noisy phase (hopping insulator), and C) disordered coherent phase (absolute insulator without charge or energy transport). For the phase B a hard-gap activation behaviour is predicted, with a gap value vanishing at the transition to the ordered phase A.

1. M. V. Feigel'man, L. B. Ioffe, and M. Mezard, Phys. Rev. B **82**, 184534 (2010).
2. E. Cuevas, M.V. Feigel'man, L. B. Ioffe, and M. Mezard, submitted to Nature Comm.
3. M.V. Feigel'man, L. B. Ioffe, V.E. Kravtsov and E. Cuevas, Ann. Phys., **325**, 1390 (2010).
4. B. Sacepe, T. Doubochet, C. Chapelier et al, Nature Phys. **7**, 239 (2011).

I15 - Light Element, High Pressure and Other Superconductors
Congressional, 3:30 PM to 6:00 PM
Session Chair: Stuart Brown

I15-01 Superconductivity proximate with antiferromagnetism in Cs3C60 - ***K. Prassides (Department of Chemistry, Durham University)***

A_3C_{60} (A = alkali metal) superconductors were known to adopt face-centred cubic (fcc) structures with their superconducting T_c increasing monotonically with increasing interfullerene spacing, reaching a 33 K maximum for $RbCs_2C_{60}$ – this physical picture had remained unaltered since 1992. Trace superconductivity (s/c fraction<0.1%) at 40 K under pressure was also reported in 1995 in multiphase samples with nominal composition Cs_3C_{60}. Despite numerous attempts by many groups worldwide, this remained unconfirmed and the structure and composition of the material responsible for superconductivity unidentified. Thus the possibility of enhancing fulleride superconductivity and understanding the structures and properties of these archetypal molecular solids had remained elusive. Here I will present our recent progress in this field in accessing high-symmetry hyperexpanded alkali fullerides in the vicinity of the Mott-Hubbard metal-insulator boundary and at previously inaccessible intermolecular separations. The physical picture that emerges for the alkali fullerides is that, contrary to long-held beliefs, they are the simplest members of the high-T_c superconductivity family. We demonstrated this by showing that in the two hyperexpanded Cs_3C_{60} polymorphs (fcc- and A15-structured) [1,2], superconductivity emerges upon applied pressure out of an antiferromagnetic insulating state and displays an unconventional behaviour – a superconductivity dome – explicable by the prominent role of strong electron correlations.

[1] Y. Takabayashi *et al*., Science **323**, 1585 (2009).
[2] A. Y. Ganin *et al*., Nature **466**, 221 (2010).

I15-02 NMR investigation of the Pressure induced Mott transition to Superconductivity in the Cs3C60 isomeric compounds - ***H. ALLOUL (LPS, UMR 8502 CNRS, Université Paris-Sud 91405, Orsay), Y. IHARA (Hokkaido University), P. WZIETEK (LPS UMR 8502 CNRS, Université Paris-Sud 91405, Orsay), D. PONTIROLI, M. ARAMINI, M. RICCO (Parma University), T. MITO (Univerity of Hyogo)***

The superconductivity (SC) of A_3C_{60} compounds, where A is an alkali ion, has been initially ascribed to a BCS mechanism, with a pairing mediated by on ball optical phonon modes. While this has led to consider that electronic correlations were not important, further detailed studies of A_nC_{60} compounds with n =1, 2, 4 [1,2] gave evidences that their electronic properties cannot be explained by a simple progressive band filling of the C_{60} six-fold degenerate t_{1u} molecular level. This could only be ascribed to the influence of electron correlations and of Jahn-Teller Distortions (JTD) of the C_{60} ball, which energetically favour evenly charged C_{60} molecules [1].

This is underlined by the recent discovery of two expanded fulleride Cs_3C_{60} isomeric phases which are Mott insulators at ambient pressure [3-4]. Both phases undergo a pressure induced first order Mott transition to SC with a *(p, T)* phase diagram displaying a dome shaped SC range, a common situation encountered in correlated electron systems [4].

NMR experiments allowed us to study the magnetic properties of the Mott phases which exhibit a low spin S=1/2 state. We do evidence clear deviations from BCS expectations near the Mott transition, and could follow the phase diagram up to a critical point near room T, analogous to that observed at the liquid-gas transition.

So, although superconductivity involves an electron-phonon coupling, the incidence of electron correlations has an importance on the electronic properties, as had been anticipated from DMFT calculations [5]. These results establish then the existence of a clear 3D Mott transition to a superconducting state in a family of compounds in which the multi-orbital molecular state degeneracy has been lifted by JTD.

[1] M. Capone *et al* Phys. Rev. **B 62** ,7619 (2000).
[2] V. Brouet *et al*, Phys. Rev. **B 66**, 155122(2002) ; ibidem 155123(2002)
[3] Y. Takabayashi *et al*, Science **323**, 1585 (2009).
[4] Y. Ihara *et al* PRL. **104**, 256402 (2010); EPL **94**, 37007 (2011).
[5] M. Capone *et al* RMP **81**, 943 (2009).

I15-03 Questions on the role of graphene in the emergence of superconductivity in CaC6 - ***M. Ellerby (London Centre for Nanotechnology, University College London), C. Renner (Department of Condensed Matter Physics, University of Geneva), K. Rahnejat, C. Howard, N. Shuttleworth, S. Schofield, C. Hirjibehedin, G. Aeppli (London Centre for Nanotechnology, University College London), K. Iwaya (World Premier International (WPI) Research Center, Advanced Institute for Materials Research)***

Electronic properties of graphitic materials may be modified through changes of charge carrier concentration. In graphene, doping is often achieved via the electric-field effect; however, the amount of charge added to the system may be enhanced through chemical doping, i.e. decoration of the graphene surface with atoms [1]. In bulk graphite, significant doping can lead to superconductivity; the highest doping of graphite is achieved via intercalation of calcium between the graphene sheets to form CaC6, with a superconducting transition temperature Tc of 11.5K [2]. Questions remain as to the role of the intercalant, calcium, and the matrix graphene sheets.

Having approached these questions in several ways, we present our scanning tunnelling microscopy (STM) and spectroscopy (STS) results, which we use to explore the graphene-terminated surface of CaC6 at the atomic scale at temperatures of 78K [3], which is significantly above Tc. Analysis of the STM studies excitingly provides strong evidence of the first direct measurement of a CDW in a graphitic system. The CDW state and superconductivity are often found in close proximity in low dimensional systems, e.g. in the NbSe2 and TaS2, and the interplay between these two states is thought by some to be of crucial importance to understanding superconductivity itself. In this work we will outline our study of the CDW state and indicate how this study is developed.

[1] C.A. Howard, M.P.M. Dean, and F. Withers, Phys. Rev. B 84, 241404 (2011)
[2] T.E. Weller, M. Ellerby, S.S. Saxena, R.P. Smith, and N.T. Skipper, Nat. Physics 1, 39 (2005).
[3] K.C. Rahnejat, C.A. Howard, N.E. Shuttleworth, S.R. Schofeld, K. Iwaya, C.F. Hirjibehedin, Ch. Renner, G. Aeppli, and M. Ellerby, Nat. Commun. 2, 558 (2011)

I15-04 What Have We Learned from High-Pressure Experiments on Cu-oxide and Fe-based Superconductors? - ***J. Schilling (Department of Physics, Washington University)***

Hundreds of high-pressure experiments have been carried out on Cu-oxide and Fe-based high-temperature superconductors (HTSC). Compared to studies where the doping level is changed, the application of high pressure varies the normal- and superconducting-state properties in a relatively well-defined manner. In optimally doped cuprates, Tc normally increases slowly with pressure, climbing for $HgBa_2Ca_2Cu_3O_8$ from 134 K to approximately 160 K at 30 GPa, the highest known value of Tc for any superconductor [1]. Hydrostatic pressure experiments are most suitable for quantitative interpretation and testing theoretical models. However, in these quasi 2-D HTSC, even hydrostatic experiments are unable to identify whether the observed changes under pressure arise mainly from a decrease in the separation between the superconducting planes or in the area of the planes. Such basic questions can only be unequivocally answered by studying the normal- and superconducting-state properties as a function of directional (uniaxial) pressure. Unfortunately, to-date very few such experiments have been carried out. In this talk I will outline the insights gained from hydrostatic and uniaxial pressure experiments in both Cu-oxide and Fe-based HTSC. In optimally doped HTSC, Tc is enhanced by *increasing* the separation of the planes or*decreasing* their area [2-3].

[1] L. Gao *et al.*, Phys. Rev. B 50, 4260 (1994).
[2] F. Hardy *et al.*, Phys. Rev. Lett. 105, 167002 (2010); Phys. Rev. Lett. 102, 187004 (2009).
[3] S.L. Bud'ko *et al.*, Phys Rev. B 79, 054525 (2009).

I15-05 Elemental superconductivity under high pressure - ***K. Shimizu, T. Matsuoka, M. Sakata, Y. Nakamoto, T. Ishikawa, T. Kagayama (KYOKUGEN, Center for Quantum Science and Technology under Extreme Conditions, Osaka University)***

To understand the fundamental mechanism and capability of "superconductivity" systematically, we have focused on pressure–induced superconductivity in elements. Not a few elements are superconductive at high-pressure condition even if the elements are not metallic at ambient pressure. Almost ambient-pressure superconductors show the negative pressure dependence in the T_c, however some pressure-induced superconducting elements were found to exhibit positive and reach relatively high-T_c at high pressure; for example, calcium reaches almost 30 K at pressure above 200 GPa [1] which is the highest T_c among elements. How can we push the T_c up by applying pressure? In my presentation, pressure-induced superconductive elements that show the relatively high T_c and positive pressure effect are reviewed.

*This work supported by the NEXT program (GR068) and Global COE Program of MEXT, Japan.

[1] M. Sakata *et al*., Phys. Rev. B 83, 220512(R) (2011).

I15-06 2D Low-Z Compounds: New Prospects for HTS? - ***W. Pickett, E. Ylvisaker (University of California Davis)***

Electron-phonon coupling is the only pairing mechanism for which there is a quantitative theory, and this aspect allows serious searching for new high temperature superconducting materials. MgB2 provides the reigning paradigm: some very strongly coupled modes in a stiff material.Nakanishi and Katayama-Yoshida (SSC, 2012) have argued that the delafossite CuAlO2, when hole-doped, may display Tc ~ 50 K due to strong el-ph coupling to the O-Cu-O dumbbell stretch mode. We have studied this system with first principles linear response calculations, which allows quantitative predictions to be made, and have found that treating the metallic screening explicitly is necessary for quantitative conclusions. We have also studied hole-doped BeB2C2 with the same methods. Moudden (Eur. Phys. J., 2008) has studied this system, but before the structure had been fully characterized experimentally. Though all structures considered for this compound have had layered B-C honeycomb sheets reminescent of MgB2, we find that specific aspects of the structure affect electron-phonon coupling strongly.Results for both of these systems, alternately discouraging and encouraging, will be analyzed and presented.

Nakanisha and Katayama-Yoshida, SSC 152, 24(2012).
Moudden, Eur. Phys. J. B 64, 173 (2008).
B. Albert, private communication.

Thursday, August 2, 2012

Plenary 8 - Superconductivity Near Quantum Critical Points
G. Lonzarich (University of Cambridge, Shoenberg Lab. for Quantum Matter, Cavendish Lab.)
Regency, 8:30 AM to 9:15 AM
Session Chair: Frank Steglich

The study of itinerant-electron systems on the border of charge and spin density wave transitions at low temperatures is leading to an increasing number of discoveries of unusual forms of superconductivity and other types of quantum order. Examples will be reviewed of electron-electron pair instabilities in particular on the border of ferromagnetic, antiferromagnetic, ferroelectric and structural quantum phase transitions. The extent to which current thinking can account for the wide range of transition temperatures observed near to such quantum critical points will be discussed.

Plenary 9 - Overview of Superconductivity and Mott Physics in Organic Materials
K. Kanoda (University of Tokyo)
Regency, 9:15 AM to 10:00 AM
Session Chair: Frank Steglich

Organic conductors have complicated structure in real space, but the electronic structure in k-space is well understood by a simple tight-binding picture of "molecular orbital" on molecular lattice; no need to look into the interior of the molecular orbital. The layered organic systems k-$(ET)_2X$ provide playgrounds for Mott physics in two dimensions. As the conducting layer is modeled to a quasi-triangular lattice of ET dimers, whose anisotropy is varied by anion X, spin frustration as well as Coulomb repulsion is expected to influence the nature of ground states. Actually, depending on the anisotropy of the triangular lattice, an antiferromagnic state (for X=$Cu[N(CN)_2]Cl$) or a spin liquid state (for X=$Cu_2(CN)_3$) appears in the Mott insulators, and both give way to superconducting state when pressurized or doped. In this conference, I first give a brief introduction on organic materials and then review Mott physics and its relevance to superconductivity, which include the following issues; i) anomalous criticality of Mott transition in two dimensions; ii) competition between spin-ordered and spin-liquid phases in Mott insulators and the nature of the spin liquid; iii) similarity and dissimilarity of the metallic/superconducting phases nearby the antiferromagnetic phase and spin liquid phase in the light of emergence of pseudogap; iv) destruction of the pseudogap by magnetic field; v) possible inhomogeneous-to-homogeneous quantum phase transition in doped triangular lattice.
This presentation is based on the collaboration with F. Kagawa, Y. Shimizu, Y. Kurosaki, H. Oike, T. Furukawa, H. Hashiba, H. Kasahara, K. Miyagawa, H. Taniguchi, S. Yamashita, Y. Nakazawa, M. Maesato and G. Saito.

Keynote Sessions

K7 - Cuprates Theory
Regency, 10:30 AM to 12:00 PM
Session Chair: Fu-chun Zhang

K7-01 Superconductivity in the Pseudogap Phase - *T. Rice (ETH Zurich)*
The phenomenological theory put forward by Yang, Rice and Zhang some years ago for the underdoped cuprates has had considerable success in explaining many anomalous properties of the pseudogap phase [1]. In this theory the pseudogap is an insulating gap, which has its origin in umklapp scattering processes in the p-p channel. Consequently, a finite energy d-wave cooperon excitation appears and generates an attraction for quasiparticles on the near nodal pockets through virtual processes, similar to the case of the weakly doped 4-leg Hubbard model discussed by Konik, Rice and Tsvelik [2]. A finite energy d-wave cooperon excitation also appears at weak doping in finite cluster diagonalizations of the strong coupling t-J model [3,4]. The similar behavior in both limits of weak and strong coupling leads to the conclusion that the pseudogap cannot be classified purely as a friend or a foe of superconductivity.

1. For a recent review see T. M. Rice, K.-Y. Yang and F. C. Zhang, Rep. Prog. Phys. **75,** 016502, (2012)
2. R. Konik,T. M. Rice and A. M. Tsvelik, Phys. Rev. B 82, 054501 (2010)
3. A. L. Chernyshev, P. W. Leung and R. J. Gooding, Phys. Rev. B 58, 13594, (1998)
4. T. A. Maier, D. Poilblanc and D. J. Scalapino, Phys. Rev. Lett. 100, 237001 (2008).

K7-02 The onset of antiferromagnetism in metals - ***S. Sachdev, M. Punk (Harvard University), M. Metlitski (Kavli Institute for Theoretical Physics, Santa Barbara)***

The critical theory of the onset of antiferromagnetism in metals, with concomitant Fermi surface reconstruction, has recently been shown to be strongly coupled in two spatial dimensions. The onset of unconventional superconductivity near this critical point is reviewed: it involves a subtle interplay between the breakdown of fermionic quasiparticle excitations on the Fermi surface, and the strong pairing glue provided by the antiferromagnetic fluctuations.

We also discuss the possibility that the antiferromagnetic critical point can be replaced by an intermediate `fractionalized Fermi liquid' (FL*) phase, in which there is Fermi surface reconstruction but no long-range antiferromagnetic order. We describe an explicit computation of the Fermi surface in the FL* phase starting from the t-J model. We discuss the relevance of the FL* phase to the underdoped cuprates and the heavy-fermion materials.

This research was supported by the National Science Foundation DMR-1103860 and by a MURI grant from AFOSR

K7-03 Theory of the pseudogap phase in the cuprates and implications for the pairing mechanism - ***C. Varma (University of California, Riverside)***

I will review the model for the cuprates which led to the prediction of loop current order in the cuprates. Given this order, the quantum-critical region leading to the Marginal fermi-liquid and the coupling to fermions leading to d-wave superconductivity have been shown to follow.

I will discuss some further consequences of the loop current order, in particular the magneto-oscilaltions in the superconducting state, and the anisotropic gap in the one-particle spectra.

K8 - Heavy Fermion
Palladian, 10:30 AM to 12:00 PM
Session Chair: Brian Maple

K8-01 superconductivity in single atomic layer of heavy fermion CeCoIn5 - ***Y. Matsuda (Department of Physics, Kyoto University), H. Shishido (Department of Physics and Electronics, Osaka Prefecture University), Y. Mizumaki, T. Shibauchi, M. Shimozawa (Department of Physics, Kyoto University), H. Kontani (Department of Physics, Nagoya University), T. Terashima (Research Center for Low Temperature and Materials Sciences, Kyoto University), H. Ikeda (shimo@scphys.kyoto-u.ac.jp)***

The coexistence of low dimensionality and strong Coulomb correlation effects often sets the stage for the emergence of novel electronic states. An itinerant electron system with the strongest correlations is achieved in heavy-fermion (HF) metals, which contain a dense lattice of localized magnetic moments interacting with a sea of conduction electrons to form a Kondo lattice. In the Ce-based compounds with 4f-electrons, in particular, the effective mass of the itinerant electrons is enhanced by a few hundred times the bare electron mass; these HF often exhibit superconductivity with nontrivial pairing states. However, to date the electronic structures of all known HF compounds are essentially 3D. Then an outstanding question is whether a single 2D Ce-layer with ultimately strong electron correlations can exhibit superconductivity, and if this is the case, how its properties compare to those in bulk systems. Here we report on the first realization of 'heavy superconducting electrons' in a 2D Kondo lattice, which were obtained by fabricating heterostructures unavailable in nature. Superlattices with HF $CeCoIn_5$ and nonmagnetic $YbCoIn_5$ layers are grown alternately by the molecular-beam-epitaxy technique[1][2]. Superconductivity is observed even in superlattice with one-unit-cell thick $CeCoIn_5$ layers, demonstrating a heavy-electron superconductivity with purely 2D electron correlations. Most remarkably, the superconductivity in superlattices persists under significantly higher reduced magnetic fields than in the bulk [2]. We discuss this result in the light of an extremely strong coupled nature arising from two-dimensionalization [2] and local inversion symmetry breaking at the interface of the HF [3].

[1]H.Shishido *et al*. Science **327**, 980 (2010)
[2]Y. Mizukami *et al*. Nature Physics **7**, 849 (2011).
[3] D. Maruyama, M. Sigrist, and Y. Yanase, J. Phys. Soc. Jpn **81**, 034702 (2012)

K8-02 Spin fluctuation pairing in CeCu2Si2 - ***O. Stockert (Max-Planck-Institut für Chemische Physik fester Soffe)***

In contrast to phonon-mediated conventional BCS-type superconductivity, spin fluctuations are thought to play an important role in the pairing mechanism of unconventional superconductors, such as high-Tc cuprate superconductors or heavy-fermion superconductors. Here, we focus on the prototypical heavy-fermion superconductor $CeCu_2Si_2$ and show that almost critical antiferromagnetic spin fluctuations drive the superconducting pairing. Thermodynamic and transport properties show that $CeCu_2Si_2$ is located at an antiferromagnetic quantum critical point (QCP) already at ambient conditions. The spin fluctuations as obtained by high-resolution inelastic neutron scattering indicate an almost critical slowing down. Their temperature dependence together with the behavior in heat capacity and electrical resistivity identify the QCP as of spin-density-wave type.

Entering the superconducting state, the spin fluctuations are gapped and spectral weight is transferred to higher energies. Analysis of the relevant energies, i.e., the superconducting condensation and the magnetic exchange energies, indicate that almost quantum critical magnetic excitations are at the origin of Cooper pair formation in $CeCu_2Si_2$.

Work performed in collaboration with J. Arndt, E. Faulhaber, C. Geibel, H. S. Jeevan, M. Loewenhaupt, K. Schmalzl, W. Schmidt, S. Kirchner, Q. Si and F. Steglich.

K8-03 Discovery of Pu-based superconductors and relation to other classes of unconventional superconductors - *E. Bauer (Los Alamos National Laboratory)*

Since the discovery of unconventional superconductivity at 18.5 K in $PuCoGa_5$ [1] and at 8.7 K in $PuRhGa_5$ [2], attention has been focused on understanding the origin of the high transition temperatures, which are an order of magnitude higher than all other Ce- or U-based heavy fermion superconductors. The recent discovery of superconductivity in two new Pu-based materials $PuCoIn_5$ [3] and $PuRhIn_5$, the first In analogs of the "Pu115" family of superconductors, allows for a detailed comparison with other heavy fermion superconductors. Indeed, although their transition temperatures are lower (T_c=1-2 K), these $PuMIn_5$ superconductors with their expanded unit cell volumes by up to 30% relative to $PuCoGa_5$ appear to be close to (or at) a quantum critical point. One plausible scenario based upon the available data is that superconductivity arises from proximity to an antiferromagnetic quantum critical point in $PuMIn_5$, while superconductivity in $PuCoGa_5$ may instead be mediated by valence fluctuations (with its own distinct superconducting dome) as is found in $CeCu_2Si_2$ under pressure [4,5]. In this talk, I will present the physical properties of these $PuMIn_5$ and $PuMGa_5$ (M=Co, Rh) materials and discuss their relation to other families of superconductors.

[1] J.L. Sarrao et al. Nature **420** 297 (2002)
[2] F. Wastin et al. J. Phys.: Condens. Matter **15** S2279 (2003)
[3] E.D. Bauer et al. J. Phys.: Condens. Matter **24** 052206 (2012)
[4] H.Q. Yuan et al. Science **302** 2104 (2003)
[5] K. Miyake and H. Maebashi, J. Phys. Soc. Japan **71** 1007 (2002)

K9 - Material Trends in Cuprates, Pnictides, Intermetallics
Diplomat, 10:30 AM to 12:00 PM
Session Chair: Hide Takagi

K9-01 material trends in cuprates and pnictides, focus on structure - *H. Eisaki (National Institute of Advanced Industrial Science and Technology (AIST))*

High-transition temperature (high-T_c) superconductors, copper-oxides and iron-pnictides (chalcogenides), possess structural commonality that they consist of the alternating stacks of superconducting layers, namely, CuO_2 and FeAs planes, and so-called block layers. While the fundamental structural units are mostly unchanged, the maximum T_c ($T_{c,max}$) for different compounds varies by nearly a decade, implying that $T_{c,max}$ strongly depends on the detail of each material. For example, in the latter case, it is empirically known that T_c is intimately correlated with the configuration of the $FeAs_4$ local structure and that the highest T_c is attained when the $FeAs_4$tetrahedron forms regular shape.

In this talk, we discuss the factors which determine $T_{c,max}$ of the high-T_c superconductors, by showing several examples. In particular, we pay attention to the relationship between the crystal structures and $T_{c,max}$ of these materials.

K9-02 Phase diagrams of Fe based superconductors - *B. Büchner (IFW Dresden)*

Using a broad spectrum of experimental techniques, such as NMR, µSR, ARPES, magnetometry, thermodynamics, x-ray diffraction, and transport measurements, we have studied the interplay between magnetism and superconductivity in several classes of iron pnictide superconductors. In $LaO_{1-x}F_xAsFe$ and other 1111 type materials an intimate interplay between magnetism and electronic properties is evident. Moreover, measurements of the electrical field gradient by NQR yield clear-cut evidence for nanoscale order of charges and/or orbitals which are reminiscent to the famous stripe order found in cuprates. The phase diagram of Co doped NaFeAs is qualitatively very similar to that of the 1111 and 122 type pnictides. In contrast, LiFeAs, a second member of the 111 type pnictide shows quite different behaviour. From our measurements on pristine material as well as hole and electron doped compounds we do not find evidence forstrong antiferromagnetic correlations. Instead, measurements of NQR, µSR, magnetisation and magnetic resonance reveal a weak ferromagnetic order in hole doped LiFeAs. Based on our determination of the phase diagram and the results from spectroscopic studies the possible relationship between this unusual ferromagnetic state and superconductivity in stoichiometric LiFeAs is discussed.

K9-03 Chemistry of new oxide and iron-pnictide superconductors - *R. Cava (Department of Chemistry, Princeton University)*

In this talk I will review our recent results on the chemistry and structural characteristics of superconductors in the oxide, chalcogenide, and pnictide families. Examples will include detailed structural studies of the BaPbO3 - BaBiO3 system, and chemical and structural characterization of superconducting early transition metal bronzes.

The speakers research in superconductivity is supported by the DOE, grant DE-FG02-98ER45706, and the AFOSR, grant FA9550-09-1-0593.

I16 - Time Reversal Symmetry Breaking and the Pseudogap
Regency, 1:30 PM to 3:30 PM
Session Chair: Chandra Varma

I16-01 pseudogap magnetic excitations in hole-doped cuprates - ***Y. Sidis, P. Bourges (Laboratoire Leon Brillouin, CEA-CNRS, CEA-Saclay), Y. Li (Max Planck Institut, Stuttgart), M. Greven (University of Minnesota)***

There has been a long-standing debate among condensed-matter physicists about the origin of the pseudo-gap state in high-temperature superconducting cuprates. Two theoretical approaches have been opposed: in the former, the pseudo-gap state is a precursor of the superconducting state, in the later, it corresponds to another state of matter, competing with superconductivity. Supporting the second scenario, polarized neutron diffraction has revealed the existence of a 3D long range magnetic phase, hidden inside the pseudo-gap state of underdoped $YBa_2Cu_3O_{6+x}$ and $HgBa_2CuO_{4+\delta}$ [1-3]. In both systems, its ordering temperature T_{mag} decreases linearly as a function of the hole doping (p) and vanishes near p_{pg} ~0.19, the end point of the pseudo-gap phase according to thermodynamic measurements. Furthermore T_{mag} matches the pseudo-gap temperature T* deduced from resistivity measurements. This magnetic phase can be described as an Intra-Unit-Cell antiferromagnetic state: time reversal symmetry is broken, but lattice translation invariance is preserved. The occurrence of such a magnetic state has been predicted in the circulating current theory of the pseudo-gap proposed by C.M. Varma. In this theory, staggered current loops give rise to orbital-like magnetic moments within CuO_2 unit cell. In addition, the theory predicts specific quasi non-dispersive collective magnetic excitations [5] and two Ising-like magnetic excitations have been recently observed in the pseudo-gap state of $HgBa_2CuO_{4+\delta}$ in inelastic neutron scattering measurements [6].

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[2] Y. Li et al, Nature 455, 372 (2008)
[3] P. Bourges, and Y. Sidis, C. R. Physique, 12, 461, (2011).
[4] C. M. Varma, Phys. Rev. B 73, 155113 (2006).
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[6] Y. Li et al., Nature 468, 283 (2010); to appear in Nat. Phys. (2012).

I16-02 Hidden magnetic excitations and Fermi-liquid behavior in the cuprates - ***M. Greven (University of Minnesota)***

Magnetic correlations might cause the superconductivity in the cuprates and are generally believed to be antiferromagnetic. Following our success in growing sizable crystals of the structurally simple compound $HgBa_2CuO_{4+\square}$ we used polarized neutron diffraction to demonstrate that the unusual translational-symmetry preserving magnetic order previously observed in $YBa_2Cu_3O_{6+\square}$ is a universal property of the pseudogap phase. Our subsequent inelastic neutron scattering experiments revealed several accompanying, weakly dispersive magnetic excitation branches in $HgBa_2CuO_{4+\square}$ We find that the excitations mix with conventional antiferromagnetic fluctuations. Our results point toward the need for a multi-band description of the cuprates, and they are consistent with the notion that the phase diagram is controlled by an underlying quantum critical point. We will also discuss new *ab*-plane dc resistivity data for $HgBa_2CuO_{4+\square}$ that reveal Fermi-liquid-like (T^2) behavior in the pseudogap regime.

X. Zhao *et al*., Adv. Mat. **18**, 3243 (2006). N.Barisc *et al*., Phys. Rev. B **78**, 054518 (2008); preprint (2012). Y. Li *et al*., Nature **455**, 372 (2008); Nature **468**, 283 (2010); Phys. Rev. B **84**, 224508 (2011); Nat. Phys., doi:10.1038/nphys2271 (2012). G. Yu *et al*., Nat. Phys. **5**, 873 (2009); Phys. Rev. B **81**, 064518 (2010).

Work supported by DOE-BES.

I16-03 Discovery of a new magnetic mode in YBa2Cu3O6.6 - ***H. Mook (Oak Ridge National Lab), M. Stone, M. Lumsden, A. Christianson (Neutron Science Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831), J. Lynn (NIST Center for Neutron Research, NIST, Gaithersburg, MD 20899)***

Although it has been over 25 years since the discovery of the high temperature cuprate superconductors they remain one of the most interesting and challenging problems in condensed matter physics. YBa2Cu3O6+x (YBCO) is arguably the most studied cuprate system where extensive studies of the magnetic excitations have been completed, yet we have used inelastic neutron scattering to discover a new excitation quite distinct from the magnetic excitations observed in the material so far. In particular, the excitation is essentially dispersionless rather than strongly dispersive, with intensity completely independent of the Cu-O bilayers of the YBCO structure that the conventional spin excitations obey. Polarized neutron measurements unambiguously confirm the origin of the excitation as magnetic, but it breaks translational symmetry and so is different than the scattering recently found in HgBa2CuO4+d. The temperature scale is intermediate between superconductivity (TC = 60 K for this oxygen doping) and the very high temperature scale of the conventional spin excitations. Overall the new scattering is consistent with expectations for the pseudogap phase stemming from theoretical models of circulating currents in the unit cell, offering an answer to the nature of the long-sought hidden order of the pseudogap phase, a new state of matter that controls the phase diagram via a quantum critical point.

I16-04 Search for magnetic order in the pseudogap regime of La2-xSrxCuO4 by muSR - ***J. Sonier (Department of Physics, Simon Faser University), S. Komiya (Central Research Institute of Electric Power Industry), W. Huang (Department of Physics and Astronomy, McMaster University), M. Kennett (Department of Physics, Simon Fraser University), V. Pacradouni (Powertech Labs Inc.)***

We report results of a high precision search for orbital-like magnetic order in the pseudogap region of La2-xSrxCuO4 single crystals using zero-field muon spin relaxation (ZF-muSR). In contrast to previous studies of this kind, the effects of the dipolar and quadrupolar interactions of the muon with nearby nuclei on the time dependence of the muon spin polarization are calculated. In addition, ZF-muSR spectra with a high number of counts were recorded to determine whether a magnetically ordered phase is present in dilute regions of the sample. Despite these efforts, we find no evidence for static magnetic order of any kind in the pseudogap region above the hole-doping concentration p = 0.13. Related results on YBa2Cu3Oy will also be presented.

This work was supported by the Natural Sciences and Engineering Research Council of Canada, and the Canadian Institute for Advanced Research.

I16-05 Optical Studies of Time Reversal Symmetry Breaking and Charge Ordering in the Pseudogap phase of High-Temperature Superconductors - ***A. Kapitulnik (Departments of Physics and Applied Physics, Stanford University, Stanford CA 94305, USA), H. Karapetyan (Department of Applied Physics, Stanford University, Stanford CA 94305, USA), J. Xia (Department of Physics and astronomy, University of California Irvine, Irvine, CA 92697), E. Schemm (Department of Physics, Stanford University, Stanford, CA 94305)***

We present high-resolution linear-birefringence and magneto-optical (MO) data on several HTSC systems as a function of temperature and training with magnetic field. Measurements are taken using a zero-area-loop Sagnac interferometer [1], modified to measure both, time reversal symmetry breaking (TRSB) and birefringence effects [2]. The birefringence measurements accurately locate structural phase transitions and/or transitions into a charge-ordered phase, while an onset of a MO-Kerr effect indicates the onset of TRSB. While we previously reported onset of Kerr signal at the pseudogap temperature T* for the YBCO system [3], our recent studies show similar effects in single layer-BSCO [4], and in LBCO [2]. A markedly stronger effect is found in the case of La2-xBaxCuO4 (LBCO) with x=1/8 [2]. For this system a first-order structural transition from an orthorhombic to tetragonal phase is accompanied by an onset of a Kerr signal. The signal then exhibits a weak inflection at the charge order transition, rises to a maximum around the spin-order transition, and decreases to a finite value when superconducting correlations are substantial. However, despite the sharp onset of the Kerr signal, hysteretic training effects are observed, indicating that TRS has been broken at much higher temperatures. Such an effect was previously observed by us in YBCO, being strongest also close to x=1/8 doping [3], while it has recently been reported on similar LBCO crystals through Nernst measurements [5]. These results, together with detailed magnetic studies on similar crystals [6] may point to a unique magnetic structure in the material that is strongly altered when charge-ordering takes place so as to allow the Kerr effect to be visible.

Work supported by DOE Grant DE-AC02-76SF00515.

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[2] H. Karapetyan, et al., arXiv:1203.2977 .
[3] J. Xia, et al., Phys. Rev. Lett. 100, 127002 (2008).
[4] R.-H. He, et al., Science 331, 1579 (2011).
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[6] M. Hucker, et al., Phys. Rev. B 78, 214507 (2008).

I16-06 Ultrasound measurements around Tc and T* in cuprate superconducting single crystals - ***A. Migliori, A. Shehter, J. Betts (Los Alamos National Laboratory), S. Riggs (Stanford University), B. Ramshaw (UBC), R. Liang, W. Hardy, D. Bonn (University of British Columbia)***

The elastic moduli and ultrasonic attenuation were measured in ultra-high quality, mostly de-twinned, optimally and under-doped cuprate superconducting single crystals. By measuring detwinned single crystals, many artifacts associated with polycrystalline or twinned materials are eliminated, leaving the fundamental thermodynamic response to ultrasonic measurements. Measurments were made from well below the superconducting transition Tc to well above the purported pseudogap transition. Reproducible bulk modulus discontinuities of order 50 parts per million at Tc were observed that are consistent with the expected thermodynamics of a second order phase transition, the Tc observed, and the approximate Fermi energies for the materials, thus placing most of the thermodynamic and entropy effects at Tc, and not at higher temperatures, leaving little room for preformed pairs. Departures were observed at higher temperatures from the expected smooth "Varshni" function at temperatures where the pseudogap is expected to appear. These departures are accompanied by distinct peaks in ultrasonic attenuation.

This work was performed under the auspices of the U.S. Department of Energy at Los Alamos National Laboratory in the National High Magnetic Field Laboratory, supported by the National Science Foundation under Grant No. DMR-0654118, and the State of Florida.

I17 - Theory: Numerical Studies
Palladian, 1:30 PM to 3:30 PM
Session Chair: Douglas Scalapino

I17-01 DCA calculations on the Hubbard model - ***M. Jarrell (LSU)***

A quantum critical point is found in the phase diagram of the two-dimensional Hubbard model with next neighbor hopping t'=0 [1]. It is due to the vanishing of the critical temperature associated with a phase separation transition as t' -> 0, and it separates the non-Fermi liquid region from the Fermi liquid. Near the quantum critical point, the pairing is enhanced since the real part of the bare d-wave pairing susceptibility exhibits an algebraic divergence with decreasing temperature, replacing the logarithmic divergence found in a Fermi liquid [2]. Marginal Fermi liquid behavior is seen in the thermodynamics, transport and single-particle properties for a wide range of doping and temperatures above the QCP. A van Hove singularity, coming from the relatively flat dispersion near (0,pi), crosses the Fermi level near the quantum critical filling. At this filling, the Fermi surface topology changes, indicating a Lifshitz transition which persists for t' < 0. Thus, for t'>0 the model displays a first-order phase separation transition with a second order terminus. As t' -> 0 this terminus goes to zero temperature generating a quantum critical point. A zero temperature critical line persists for t'<0 associated with a Lifshitz transition.

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This work is supported by DOE SciDAC project DE-FC02-06ER25792 and the NSF EPSCoR LA-SiGMA project EPS-1003897.

I17-02 interplay of superconductivity and pseudogap in dynamical mean field calculations on the Hubbard model - ***E. Gull (MPI PKS Dresden), O. Parcollet (CEA Saclay), A. Millis (Columbia University)***

In correlated electron systems, superconductivity typically occurs in proximity to other regimes of nontrivial electronic behavior; for example,in high temperature copper-oxide superconductors the superconducting phase and the pseudogap regime overlap. The interplay between superconductivity and other phases is a strong coupling phenomenon which has resisted theoretical analysis.

In this talk we present results from new and unbiased numerical methods to unravel the interplay between superconductivity and the pseudogap in the two dimensional Hubbard model which is believed to capture essential aspects of the physics of high temperature copper-oxide superconductivity. We find that superconductivity generically occurs near half filling and in the proximity of the normal state pseudogap, but that the pseudogap itself acts to suppress superconductivity. The onset of nductivity is shown to lead to states within the pseudogap.

I17-03 theory of pseudogap in underdoped cuprates - ***M. Imada, Y. Yamaji, Y. Motome (Department of Applied Physics, University of Tokyo), S. Sakai (Ecole Polytechnique)***

Pseudogap ubiquitously found in the underdoped cuprates is a puzzling phenomenon not well understood after more than 20 years of the discovery. Recent theoretical and computational progress has renewed its understanding as a unique unconventional metal. In the mean-field picture, gap formations including magnetic and superconducting origins are understood always as consequences of hybridizations of quasiparticles (QP), where the Green's-function pole of the hybridization partner causes the self-energy divergence of the QP Green's function meaning the zero of the QP Green's function itself. Recent progress in a cluster extension of the dynamical mean-field theory has revealed a coexisting evolution of the poles (Fermi surface) and zeros of the Green's function with non-Fermi liquids separated by several topological transitions from the overdoped region [1]. The energy-momentum dependent spectra well reproduce the arc/pocket and pseudogap formation. We propose that the pseudogap retains an s-wave-like full-gap structure even in the nodal point, though it looks as if it were d-wave like below the Fermi level. In addition, the spectral asymmetry, back-bending and waterfall dispersions as well as the low-energy kink emerge in agreement with the underdoped cuprates, supporting the proximity of the Mott insulator. We also propose that the exciton concept known in semiconductors can be extended to doped Mott insulators by using the composite fermion (CF) picture, where the QP hybridizes with the CF [2]. The pairing channel opened between a QP and a CF solves the puzzle of the dichotomy between the d-wave superconductivity and the precursory insulating gap in the antinodal region. We propose them as the mechanism of superconductivity [2].

[1] S. Sakai, Y. Motome and M. Imada, Phys. Rev. Lett. 102, 056404 (2009); Phys. Rev. B 82, 134505 (2010)
[2] Y. Yamaji and M. Imada, Phys. Rev. Lett. 106, 016404 (2011); Phys. Rev. B 83, 214522 (2011)

I17-04 Optimizing Tc in cuprates and iron-based superconductors - ***K. Kuroki (Department of Engineering Science, The University of Electro-Communications)***

In recent years, accelerating amount of study on correlated electron systems has been performed by taking into account accurately the band structure obtained from first principles calculation. As for unconventional superconductivity in correlated electron systems, although there remains some ambiguity concerning the pairing mechanism itself, theoretical studies on, e.g, lattice structure and/or element dependence with certain reliability is now becoming possible.

In the present talk, we first show for the iron pnictide superconductors that by adopting a five orbital model that takes into account all the Fe 3d bands accurately[1], the strong lattice structure sensitivity of the Tc and the superconducting gap observed experimentally can be understood within the spin fluctuation mediated s+- pairing scenario[2,3]. Moreover, we find that there is a certain configuration of the disconnected Fermi surfaces and their orbital characters for which the s+- superconductivity is optimized[3].

In this context, It is also interesting to give a fresh look at the material dependence of Tc in the cuprates from the viewpoint of constructing an accurate model Hamiltonian from first principles. By constructing a two-orbital model that considers not only the dx2-y2 but also the dz2 Wannier orbitals, we find that a change in the lattice structure affects the level offset between the two orbitals (i.e., the dz2 component mixture in the Fermi surface), which in turn affects the Tc of the d-wave superconductivity[4,5]. Our approach gives an understanding for the material dependence of Tc within the single layered cuprates[5] as well as its variation against uniaxial or hydrostatic pressure[6].

[1] K. Kuroki et al., Phys. Rev. Lett. 101 (2008) 087004.
[2] K. Kuroki et al., Phys. Rev. B 79 (2009) 224511.
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[4] H. Sakakibara et al., Phys. Rev. Lett. 105 (2010) 057003.
[5] H. Sakakibara et al., Phys. Rev. B 85 (2012) 064501.
[6] H. Sakakibara et al., arXiv : 1203.4353.

I17-05 Superconductivity, pseudogap and Mott transition - ***A. Tremblay (Universite de Sherbrooke), G. Sordi (Institut Laue-Langevin, Grenoble), K. Haule (Rutgers University), P. Semon (Universite de Sherbrooke)***

In the cuprates, especially in the pseudogap regime, superconductivity is highly non-BCS. For example, there is local pair formation and a tendency to form inhomogeneous structures. In cuprates and in layered organic conductors, this can be a consequence of the intricate interplay between superconductivity, pseudogap and Mott transition. We provide a unified perspective on this interplay with the-two dimensional Hubbard model. In the strongly correlated regime that is relevant here, cluster generalizations of dynamical mean-field theory provide the best available tools. We use a continuous-time quantum Monte Carlo method as solver for the self-consistent 2 x 2 dynamical mean-field cluster. In the normal state, there is a first-order transition, with an associated large compressibility, that separates the pseudogap phase from the overdoped metal [1-3]. The metallic normal state close to the Mott insulator is unstable to d-wave superconductivity. While superconductivity [4] can prevent the normal state phase transition, that transition leaves its mark on the dynamic properties of the superconducting phase. For example, as a function of doping one finds a rapid change in the particle-hole asymmetry of the superconducting density of states. In the pseudogap regime, the dynamical mean-field superconducting transition temperature *Tcd* does not scale with the order parameter. *Tcd* corresponds to the local pair formation temperature and is distinct from the pseudogap temperature.

Supported by NSERC, Tier I Canada Research Chair (A.-M.S.T.), and by NSF DMR-0746395 (K.H.). Computing time provided by CFI, MELS, Calcul Québec and Compute Canada.

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[2] G. Sordi et al., PRB **84**, 075161 (2011);
[3] G. Sordi et al., arXiv:1110.1392 (2011);
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I17-06 Superconductivity in strongly correlated materials – what can we learn from ultracold atomic gases? - ***M. Randeria (The Ohio State University)***

I will review some recent developments in ultracold atoms experiments and theory that give insight into various aspects of superconductivity and strongly correlations in quantum materials. Progress in transport, thermodynamics and spectroscopy of strongly interacting Fermi systems sheds light on questions of conceptual importance: Is there an upper bound on Tc/Ef for a Fermi superfluid? Is there a pairing pseudogap above Tc in short coherence length superconductors? I will conclude by discussing cold atom emulation of simple Hamiltonians, like Bose and Fermi Hubbard models, which capture the essential physics of real materials.

Supported by NSF DMR-1006532 and DOE-BES DE-SC0005035.

I18 - More Pnictides
Diplomat, 1:30 PM to 3:30 PM
Session Chair: Bernd Büchner

I18-01 Doping Evolution of Resistivity and Optical Conductivity of Iron Pnictides and Cuprates: What is the Roles of “Doping” ? - ***S. Uchida (Department of Physics, University of Tokyo)***

We investigate doping evolution of the transport and optical properties of $BaFe_2As_2$ with dopants on the three different atomic sites; (a) $Ba(Fe_{1-x}Co_x)_2As_2$, (b) $BaFe_2(As_{1-x}P_x)_2$, and (c) $Ba_{1-x}K_xFe_2As_2$. In every case, doping suppresses the orthorhombic-antiferromagnetic (AFO) phase, allowing for the emergence of the superconducting state, similar to the doping in the case of cuprates. The Co substitution corresponds to electron doping, and in fact the resistivity steadily decreases with this doping. By contrast, the isovalent P substitution for As leads to similar reduction of resistivity, while the resistivity does not show a remarkable change for K substitution, corresponding to hole doping. Hence, doping in Fe pnictides is not simply changing the carrier density or the shape of Fermi surface which differentiates this class of iron compounds from the cuprates.

We find that the dopant atoms, as a source of disorder, control the suppression rate of the AFO phase and induce resistivity anisotropy in the AFO phase. In the paramagnetic-tetragonal (PT) phase of the undoped compound, the motion of carriers is highly incoherent. The effect of doping in the PT phase is to increase a fraction of coherent carriers even in the case of isovalent P substitution.

This work has been done in collaboration with M. Nakajima, S. Ishida, and T. Liang (Univ. of Tokyo), and with Y. Tomioka, T. Ito, C.H. Lee, K. Kihou, A. Iyo, and H. Eisaki (AIST), and supported by JST, Transformative Research-Project on Iron Pnictides, Tokyo102-0075, Japan

I18-02 Magnetic interactions in iron pnictides - *E. Bascones, M. Calderón, G. León, B. Valenzuela (Instituto de Ciencia de Materiales de Madrid)*

In iron pnictides superconductivity emerges when an antiferromagnetic (AF) parent compound is doped or pressure is applied. Contrary to cuprates the parent compound is metallic and shows columnar ordering. The itinerant or strong coupling origin of magnetism and the role of Hund's coupling are still unsettled. The localized description generally assumes AF exchange constants satisfying 2J_2>J_1, with J_1 and J_2 referring to first and second nearest neighbors respectively. The itinerant picture relies on Fermi surface nesting. In order to make connection between the itinerant and localized picture we have analyzed the magnetic interactions of iron superconductors[1] on the basis of a ?ve orbital model [2,3] treated both within Hartree-Fock [1,3]and Heisenberg approximations [1]. We have calculated the exchange constants and found that they strongly depend on the charge and orbital filling and can become ferromagnetic at large Hund's coupling. (pi,0) ordering is found for a range of parameters. However an unusual orbital reorganization can stabilize (pi,pi) checkerboard ordering and results in an unexpected sensitivity of the AF ordering to crystal field parameters. A similar orbital reorganization is found within Hartree-Fock but the stability of the (π, 0) state increases. Ferromagnetism is absent in Hartree-Fock but a Double Stripe Phase shows up. I will discuss the implications of these results on the nature of magnetism in iron pnictides.

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[3]E. Bascones, M.J. Calderon, B. Valenzuela, Phys. Rev. Lett. 104, 227201 (2010)

I18-03 Structural collapse and 47 K superconductivity in CaFe2As2 by rare-earth substitutions - *S. Saha, T. Drye, N. Butch, R. Hu, S. Ziemak, K. Kirshenbaum (Center for Nanophysics and Advanced Materials, Department of Physics, University of Maryland, College Park, Maryland 20742), J. Paglione (Center for Nanophysics and Advanced Materials, Department of Physics, University of Maryland, College Park, Maryland 20742, USA), J. Lynn (Center for Neutron Research, National Institute of Standards and Technology, Gaithersburg, Maryland 20899), P. Zavalij (Department of Chemistry and Biochemistry, University of Maryland, College Park, Maryland 20742)*

The interplay between structural, magnetic and superconducting properties in iron-based superconductors has been a central theme in attempts to elucidate the nature of Cooper pairing [1, 2]. $CaFe_2As_2$ shows an antiferromagnetic (AFM) order associated with a structural transition below T_0 ~170 K [3]. Interestingly, upon suppression of AFM order $CaFe_2As_2$ shows a superconducting phase below T_c of ~ 10 K straddling the critical pressure where the isostructural collapse (CT) occurs [3] only under nonhydrostatic experimental conditions [3], suggesting that the change in electronic structure that occurs through CT is not supportive of pairing. We have substituted aliovalent light rare-earths into the Ca site of $CaFe_2As_2$ single crystals to fine tune structural, magnetic, and electronic properties. Neutron and single-crystal x-ray scattering experiments indicate that a CT of the tetragonal unit cell can be controllably induced at ambient pressures by the choice of substituent ion size [3]. This instability is driven by the interlayer As-As anion separation, resulting in an unprecedented thermal expansion coefficient of 180 $\times 10^{-6}K^{-1}$. Superconductivity with onset T_c ~47 K, the highest in intermetallics, is stabilized by the suppression of AFM order via chemical pressure, electron doping or a combination of both. Extensive investigations on the observed partial volume-fraction diamagnetic screening rules out extrinsic sources such as strain mechanisms, surface states, or foreign phases as the cause of this superconducting phase that appears to be stable in both collapsed and uncollapsed structures, raising important questions regarding which elements of chemical, electronic and magnetic structure are important to Cooper pairing.

This work was supported by AFOSR-MURI Grant No. FA9550-09-1-0603 and NSF-CAREER Grant No. DMR-0952716.

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I18-04 Recent ARPES in Cuprates and Pnictides - *X. ZHOU (Institute of Physics, Chinese Academy of Sciences, Beijing 100190)*

In this talk, I will report on three aspects: (1).The latest development of vacuum ultra-violet laser-based photoemission techniques, including high resolution spin-resolved angle-resolved photoemission (ARPES); (2).Recent results of laser ARPES on cuprates, focusing on the extraction of Eliashberg Functions in the superconducting state of Bi2212; (3).Latest ARPES results on the Fe-based superconductors, focusing in particular on $A_xFe_{2-y}Se_2$(A=K, Tl, Rb, Cs) superconductor and single-layer FeSe superconductor.

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I18-05 Shallow pockets and very strong coupling superconductivity in FeSexTe1-x - ***A. Kanigel (Physics Department - Technion)***

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I18-06 Probe the superconducting-gap structure of iron-based superconductors by thermal conductivity measurement - ***S. Li (Department of Physics, Fudan University)***

We present heat transport studies of iron-based superconductors $FeSe_x$ (T_c = 8.8 K), $BaFe_{1.9}Ni_{0.1}As_2$ (T_c = 20.3 K), $BaFe_{1.73}Co_{0.27}As_2$ (T_c = 9.2 K), KFe_2As_2 (T_c = 3 K) and $Ba(Fe_{0.64}Ru_{0.36})_2As_2$ (T_c = 20 K) down to 50 mK. In zero field, the absence of a residual linear term k_0/T in $FeSe_x$, $BaFe_{1.9}Ni_{0.1}As_2$, and $BaFe_{1.73}Co_{0.27}As_2$ samples is strong evidence for nodeless superconducting gap. For $FeSe_x$, the field dependence of k_0/T is very similar to that in $NbSe_2$, a typical multi-gap s-wave superconductor. From optimally doped $BaFe_{1.9}Ni_{0.1}As_2$ to overdoped $BaFe_{1.73}Co_{0.27}As_2$, the behavior of $k_0/T(H)$ changes dramatically upon increasing electron doping. For the extremely hole-doped KFe_2As_2, we found nodal superconducting gap, which is attributed to the intraband pairing via antiferromagnetic spin fluctuations. For the isovalently Ru-doped $Ba(Fe_{0.64}Ru_{0.36})_2As_2$, we also found nodal superconducting gap, which may have the same origin as in $BaFe_2(As_{0.67}P_{0.33})_2$. I will discuss the current situation of the superconducting-gap structure in iron-based superconductors.

I19 - Heavy Fermion Superconductors 1
Empire, 1:30 PM to 3:30 PM
Session Chair: Greg Stewart

I19-01 High-quality single crystal growth and superconducting properties in actinide heavy fermion materials - ***Y. Haga (Advanced Science Research Center, Japan Atomic Energy Agency)***

Heavy fermion superconductors in actinide compounds are extensively studied because of their unusual properties. A large spatial extent of 5f electron wave function and magnetic / multipole degree of freedom are considered to the origin of exotic characteristics in the normal state. We will review recent progresses in high-quality single crystal growth and characterization in these compounds. Among them, URu_2Si_2 is known to show superconductivity coexisting with another phase transition with an unidentified order parameter. Successful preparation of high-quality single crystal enabled us to investigate low temperature transport properties in detail[1,2]. It was found that anomalous temperature (T) dependent resistivity was observed only when superconductivity took place at low temperature. On the other hand, a transuranium superconductor $NpPd_5Al_2$ [3] shows a T-linear resistivity above the superconducting transition temperature 5 K with a large electronic specific heat as well as a large magnetic susceptibility, suggesting a non-Fermi-liquid characteristics in the normal state. These features will be discussed in comparison with other heavy fermion superconductors.

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[3] D. Aoki *et al*., J. Phys. Soc. Jpn. **76** (2007) 063701.

I19-02 Textured Superconducting State in the Heavy Fermion CeRhIn5 - ***T. Park (Sungkyunkwan University), V. Sidorov (Institute for High Pressure Physics of Russian Academy of Sciences), X. Lu, I. Martin, E. Bauer, J. Thompson (Los Alamos National Laboratory), H. Lee (Stanford University), S. Seo (Sungkyunkwna University)***

Anisotropic, spatially textured electronic states often emerge when the symmetry of the underlying crystalline structure is lowered. However, the possibility recently has been raised that novel electronic quantum phases with real-space texture could arise in strongly correlated systems even without changing the underlying crystalline structure [1]. In this presentation we discuss evidence for such texture in the heavy-fermion superconductor $CeRhIn_5$ [2]. When long-range antiferromagnetic order coexists with unconventional superconductivity, there is a significant temperature difference between resistively- and thermodynamically-determined transitions into the superconducting state, but this difference disappears in the absence of magnetism. Anisotropic transport behaviour near the superconducting transition in the coexisting phase signals the emergence of textured superconducting planes that are nucleated preferentially along the superconducting nodal directions and that appear without a change in crystal symmetry. We argue that $CeRhIn_5$ is not unique in exhibiting a difference between resistive and bulk superconducting transition temperatures, indicating that textured superconductivity may be a general consequence of coexisting orders in strongly correlated electronic systems.

[1] E. Fradkin et al., Annu. Rev. Condens. Matter Phys. **1**, 153 (2010).
[2] T. Park et al., Phys. Rev. Lett. **108**, 077003 (2012).

I19-03 Ising Quasiparticles and Hidden Hastatic Order in URu2Si2 - ***P. Chandra (Center for Materials Theory, Dept. of Physics and Astronomy, Rutgers University), P. Coleman (Center for Materials Theory, Department of Physics and Astronomy, Rutgers University), R. Flint (Department of Physics, Massachusetts Institute of Technology)***

The hidden order that develops below 17.5 K in the heavy fermion compount URu2Si2 has eluded identification for more than twenty-five years. In this talk I show that the recent observation of Ising quasiparticles in URu2Si2 suggests a novel two-component order describing hybridization between electrons and the Ising 5f2 states of the uranium atoms. This "hastatic

order" is distinct from conventional magnetism, breaking both single and double time-reversal symmetry operations, mixing states of different Kramers parity. It accounts for the magnetic anomalies in torque magnetometry and the pseudo-Goldstone mode in neutron scattering. Hastatic order is predicted to induce a basal-plane magnetic moment of order 0.01 \mu_B, a gap to longitudinal spin fluctuations that vanishes continuously at the first-order antiferromagnetic transition and a narrow resonant nematic feature in the scanning tunnel spectra.
Work done in collaboration with P. Coleman (Rutgers) and R. Flint (MIIT).

I19-04 Magnetic field splitting of the spin-resonance in CeCoIn5 - *C. Stock (NIST and Indiana University), C. Petrovic (Brookhaven National Labs), C. Broholm (Johns Hopkins University)*

The presence of an underdamped resonance peak in the neutron scattering response has proven to be a strong indication of unconventional superconductivity. Spin resonances have been observed in a number of cuprate and iron based superconductors and have been associated with the gap function undergoing a change in sign. In particular, $CeCoIn_5$ shows a sharp spin resonance below the superconducting transition temperature indicative of strong coupling between f-electron magnetism and superconductivity with d-wave symmetry. The results show that neutron scattering can be used to probe the electronic properties of a superconducting phase. [1]
It is expected that applied magnetic fields, which suppress the superconducting order parameter, should have a strong effect on the spin resonance. Such effects have been difficult to pursue in the cuprates and iron based superconductors where chemical doping is required and resonance energies are high. $CeCoIn_5$ is, however, particularly well suited owing to the stoichiometric nature of the compound and the accessible field and energy scales.
We will present a series of results on the spin resonance in the unconventional superconductor $CeCoIn_5$. In particular, using high magnetic fields we will show that the spin resonance is a doublet, Zeeman splitting into two modes under an applied field. An extrapolation of the lower peak reaches zero energy near to the high field “Q-phase” [2] where incommensurate magnetic order has been reported. Based on these results, we suggest that the Q-phase is a bose condensate of spin excitons.
[1] C. Stock et al. Phys. Rev. Lett. **100**,087001 (2008).
[2] M. Kenzelmann et al. Science **321**, 1652 (2008).

I19-05 Composite order and tandem pairing in the 115 family of heavy fermion superconductors - *R. Flint (Massachusetts Institute of Technology), P. Coleman (Rutgers University)*

In the BCS paradigm, Cooper pairs form from well-defined quasiparticles, but the highest temperature heavy fermion superconductors pose a different problem. Here the heavy electrons are forming as they pair, and the internal pair structure is as important as the forces holding it together. This issue is paramount in the “115” family of superconductors: $Ce(Co,Rh,Ir)In_5$, $Pu(Co,Rh)Ga_5$ [1], $NpPd_5Al_2$ [2] and $PuCoIn_5$[3]. The direct transition from incoherent local moments to heavy fermion superconductivity cannot be explained within the conventional spin fluctuation pairing mechanism, but can easily be accounted for by the formation of composite pairs favored by the two channel Kondo effect[4]. These composite pairs are local d-wave pairs formed by two conduction electrons in orthogonal channels screening the same local moment. As composite and magnetic pairing both favor d-wave pairing, the two can work in tandem to raise the overall transition temperature, and naturally reproduce the two dome structure seen in the Ce 115s[5]. Moreover, the local nature of composite pairing can explain the remarkable insensitivity of CeCoIn5 to rare-earth substitution. There is a clear difference between the two mechanisms, in that only composite pairing necessarily involves a redistribution of charge within the unit cell. A smoking gun test for composite pairing then is to look for a sharp charge redistribution at the superconducting transition temperature: either a monopole effect, as a cusp in the Mossbauer isomer shift in $NpPd_5Al_2$, or a quadrupole effect like the NQR shift in $(Ce,Pu)CoIn_5$.
[1] J. L.Sarrao and J.D. Thompson, JPSJ 76, 051013(2007)
[2] D. Aoki et al, JPSJ 76, 063701 (2008)
[3] E. D. Bauer et al. J. Phys Cond. Mat. 24, 052206 (2012)
[4] R. Flint, M. Dzero and P. Coleman, Nat. Phys. 4, 643 (2008)
[5] R. Flint and P. Coleman, PRL 105, 246404 (2010)

I19-06 Evolution of the superconducting critical temperature in Yb-substituted CeCoIn_5 - *M. Maple (University of California, San Diego)*

The extraordinary correlated electron phenomena found in intermetallic compounds containing lanthanide ions with an unstable valence (Ce, Pr, Sm, Eu, Tm, Yb) can be traced to the hybridization of localized 4*f* and conduction electron states. The physics underlying the correlated electron phenomena is associated with the Kondo effect for moderate hybridization in which the valence (4*f* shell occupation) is nearly integral and “valence fluctuations” for strong hybridization where the valence is nonintegral. In this talk, we describe recent x-ray diffraction, electrical resistivity, magnetic susceptibility, and specific heat measurements on the superconducting heavy fermion system $Ce_{1-x}Yb_xCoIn_5$ which reveal that the correlated electron state is stabilized throughout the range $0 \leq x \leq 0.8$, apparently due to cooperative behavior of Ce and Yb ions involving their unstable valences [1]. Phase separation occurs for $x > 0.8$. Interestingly, the superconducting critical temperature decreases linearly with x from 2.3 K at x = 0 towards 0 K at x = 1. Non-Fermi liquid behavior that varies with x is observed at low temperature, although there is no readily identifiable quantum critical point. The strongly intermediate valence state of Yb in $Ce_{1-x}Yb_xCoIn_5$ has recently been verified by angle resolved photoemission spectroscopy (ARPES), extended x-ray absorption fine structure (EXAFS), and x-ray absorption near-edge structure (XANES) measurements [2,3]. Measurements of the pressure dependence of the normal state electrical resistivity and superconducting critical temperature as a function of x will be presented. The behavior of $CeCoIn_5$ substituted with Yb is compared to the behavior of $CeCoIn_5$ substituted with other lanthanides.

Supported by US DOE and NSF.
[1] L. Shu, R. E. Baumbach, M. Janoschek, E. Gonzales, K. Huang, T. A. Sayles, J. Paglione, J. O'Brien, D. A. Zocco, P.-C. Ho, C. A. McElroy, M. B. Maple, *Phys. Rev. Lett.* **106**, 156403 (2011).
[2] C. H. Booth *et al*., *Phys. Rev. B* **83**, 235117 (2011).
[3] L. Dudy, J. D. Denlinger, L. Shu, M. Janoschek, J. W. Allen, M. B. Maple, in preparation.

I20 - Sr2RuO4
Congressional, 1:30 PM to 3:30 PM
Session Chair: Jim Sauls

I20-01 Topological superconductivity and chiral edge states of Sr2RuO4 - *Y. Maeno (Kyoto University), Y. Tanaka (Nagoya University), H. Kashiwaya, K. Saito, M. Koyanagi (National Institute of Advanced Industrial Science and Technology (AIST))*

The pairing symmetry of Sr2RuO4 has been accepted as chiral p-wave based on various experimental data. An important aspect of the chiral p-wave symmetry is that the phase of the pair potential evolves continuously with rotation in the ab-plane. Therefore, the chiral p-wave superconductor can be regarded as a typical example of topological superconductors. The detection of topologically protected edge state at the in-plane surfaces is the best test to confirm the topological nature of a superconductor. Here we report in-plane tunneling spectroscopy of Sr2RuO4 searching for the topological edge states. We fabricate Sr2RuO4[100]/Au tunneling junction on in-situ cleaved surfaces of 1.5K-phase. The spectrum shows the appearance of a broad hump inside the energy gap. By comparing with the theoretical conductance spectrum, the presence of the broad hump is shown to be consistent with the formation of chiral edge states[1]. We believe this is the first evidence for the topological superconductivity of Sr2RuO4. We further apply a magnetic field to confirm the time reversal symmetry due to the chiral p-wave symmetry. The obtained field responses suggest the presence of spontaneous field at the edge of field cooled Sr2RuO4.

This work was supported by the "Topological Quantum Phenomena" (No. 22103002) KAKENHI on Innovative Areas from MEXT of Japan.

[1] S. Kashiwaya *et al.*, Phys. Rev. Lett. **107**, 077003 (2011).

I20-02 Probing the Physics of the Fractional Vortex State in Mesoscopic Rings of Sr2RuO4 - *R. Budakian (University of Illinois at Urbana Champaign)*

In the past decade, there has emerged strong evidence to support spin-triplet superconductivity in the layered-perovskite Sr2RuO4 (SRO), whose ground state is thought to be analogous to the A-phase of superfluid 3He. It is believed that the spin and orbital degrees of freedom of the superconducting order parameter can give rise to states with remarkable properties, such as chiral domains, and half-quantum vortices (HQV) that may obey non-Abelian statistics. With regards to the latter, recent theoretical work suggests that the HQV state could be made energetically favorable in mesoscopic SRO samples. In this talk, I will present a new method for ultrasensitive cantilever magnetometry that allows us to probe the magnetic response of mesoscopic samples of SRO. Our most intriguing observation is the appearance of fractional fluxoid states having half the magnetic moment of the full, or integer, fluxoid. In this talk, I will discuss the conditions required to stabilize the half-integer fluxoid states, and also present some ideas as to their origin.

This wok was supported by the U.S. Department of Energy Office of Basic Sciences, grant DEFG02-07ER46453 through the Frederick Seitz Materials Research Laboratory and the grants-in-aid for the Global Centers of Excellence "Next Generation of Physics" programs from the Ministry of Education, Culture, Sports and Technology of Japan.

I20-03 Superconducting junctions between Sr2RuO4 and conventional superconductors - *M. Sigrist (ETH, Zurich), T. Nakamura, S. Anwar, S. Yonezawa, T. Terashima (Kyoto University), M. Yakabe, H. Takayanagi (Tokyo University of Science), R. Ishiguro (Tokyo University of Science)*

Sr2RuO4 is a leading candidate of a chiral p-wave, spin-triplet superconductor [1]. A number of experiments on its superconducting junctions have demonstrated unusual behavior attributable to chiral domains or chiral edge states. In this presentation we focus on superconducting junctions utilizing eutectic crystal of Sr2RuO4 and Ru metal.

We first describe unusual behavior of superconductor/normal-metal/superconductor (SNS) junctions fabricated by depositing a thick film of Pb on the surface of a Sr2RuO4 crystal with eutectic Ru inclusions of micron-size [2]. The critical current of such junctions exhibits interference between the two superconductors, ascribable to a mismatch of their phase winding numbers surrounding a Ru island; thus such junctions can be called “topological superconducting junctions”.

We have also fabricated superconducting quantum interference devices (SQUIDs) using Nb/Ru/Sr2RuO4 junctions. The superconducting loop of a Nb-Sr2RuO4 hybrid dc SQUID is composed of Nb, Sr2RuO4 and two Nb/Ru/Sr2RuO4 junctions, and made by building a Nb bridge between two individual Ru micro inclusions on the ab-plane surface of the Ru-Sr2RuO4 eutectic system. The critical current between Nb and Sr2RuO4 parts of such dc-SQUIDs oscillates with every flux quantum through the SQUID loop. We will describe how the phase shift in the SQUID loop varies with temperature and discuss possible mechanism of such behavior.

We acknowledge support of E. Watanabe, D. Tsuya, H. Oosato, T. Sakurai, and Y. Yamaoka. This work was supported by the "Topological Quantum Phenomena" (No. 22103002) KAKENHI on Innovative Areas from MEXT of Japan.

[1] For an extensive recent review: Y. Maeno *et al*., J. Phys. Soc. Jpn. **81** (2012) 011009.
[2] T. Nakamura *et al*., Phys. Rev. B **84** (2011) 06512(R).

I20-04 New magnetic phase diagram of (Sr,Ca)2RuO4 - ***Y. Uemura (Columbia University, Physics Department)***

Superconducting state of Sr2RuO4 has been long considered to be surrounded by Fermi liquid normal metals, isolated from magnetically ordered state in the Ca rich side of (Sr,Ca)2RuO4. We have performed muon spin relaxation and ac- and dc-magnetic susceptibility studies in (Sr,Ca)2RuO4 and Sr2(Ru,Ti)O4 since 1999, and found that (Sr,Ca)2RuO4 has ground state with static magnetic order in nearly the entire region of (Sr,Ca) substitutions. Observed MuSR line shapes, history dependence of dc-susceptibility and peak in the imaginary part of ac-susceptibility suggest spin-glass behaviors and highly random spin configurations. There are some similarities with the incommensurate spin density wave state found in Sr2(Ru,Ti)O4 by neutron studies of Braden et al. [1] The crossover from T-square resistivity to lower power above the "Fermi liquid temperature T_{FL}", known in a wide range of (Ca,Sr) concentrations, occurs together with the loss of static magnetic order, similarly to the case of MnSi, suggesting strong coupling of spin fluctuations in charge conduction processes. Including these new results in the ruthenates, we will discuss similarities and differences of unconventional cuprate, ruthenate and FeAs superconductors, and highlight important roles played by spin fluctuations. A main part of this presentation was published by J.P. Carlo et al. [2].

1] M. Braden, O. Friedt, Y. Sidis, P. Bourges, M. Minakata, Y. Maeno, Phys. Rev. Lett. 88 (2002) 197002.
[2] J.P. Carlo, T. Goko, I.M. Gat-Malureanu, P.L. Russo, A.T. Savici, A.A. Aczel, G.J. MacDougall, J.A. Rodriguez, T.J. Williams, G.M. Luke, C.R. Wiebe, Y. Yoshida, S. Nakatsuji, Y. Maeno, T. Taniguchi, Y.J. Uemura, Nature Materials 11 (2012) 323.

I20-05 intrinsic Hall effect in a multiband chiral superconductor - ***C. Kallin, E. Taylor (McMaster University)***

Although substantial experimental evidence points toward chiral p-wave superconducting order in Sr2RuO4, a number of puzzles remain and the unambiguous identification of the order is still an open question. Evidence for broken time-reversal symmetry is a key signature since it distinguishes chiral p-wave order from many other possible odd-parity or triplet orders. The polar Kerr effect, which is closely related to the frequency dependent Hall conductivity, is a sensitive and direct probe of broken time-reversal symmetry. A non-zero Kerr effect has been observed in the superconducting state of Sr2RuO4.[1] This effect is thought to arise from impurities, from so-called "skew scattering" in a disordered chiral p-wave superconductor, since one can show quite generally that a clean one-band chiral p-wave superconductor does not give rise to an anomalous Hall effect or Kerr effect, despite exhibiting broken time-reversal symmetry. However, since the Kerr effect is observed in the cleanest available samples, this explanation is somewhat questionable. Recently, we have shown that a clean, multiband chiral superconductor can support an intrinsic, anomalous Hall effect and, hence, a Kerr effect.[2] Provided there is substantial superconductivity on the two quasi-one dimensional (alpha and beta) bands of Sr2RuO4, this effect can give rise to a Kerr angle that is in agreement with experiments. Consequently, further experiments on purposely disordered samples of Sr2RuO4 could distinguish between different models proposed for the superconducting state of Sr2RuO4.

[1] J. Xia, Y. Maeno, P. T. Beyersdorf, M. M. Fejer, and A. Kapitulnik, Phys. Rev. Lett. 97, 167002 (2006).
[2] E. Taylor and C. Kallin, Phys. Rev. Lett. in press (2012).

This work was supported by NSERC and the Canadian Institute for Advanced Research.

I20-06 hidden quasi-1D superconductivity in Sr2RuO4 - ***S. Raghu (Stanford University)***

We show that the interplay between spin and charge fluctuations in Sr_2RuO_4 leads unequivocally to triplet pairing which has a hidden quasi-one-dimensional character. The resulting superconducting state spontaneously breaks time-reversal symmetry and is of the form $\Delta\sim(p_x+ip_y)z$^ with sharp gap minima and a *d* vector that is only *weakly* pinned. The superconductor lacks robust chiral Majorana fermion modes along the boundary. The absence of topologically protected edge modes could explain the surprising absence of experimentally detectable edge currents in this system.

1) Phys. Rev. Lett. 105, 136401 (2010).
2) Phys. Rev. B 81, 224505 (2010)

I21 - Nematicity and Orbital Order in Pnictides
Palladian, 4:00 PM to 6:05 PM
Session Chair: Collin Broholm

I21-01 Nature of magnetic excitations in superconducting iron superconductors - ***P. Dai (UT/IOP)***

Since the discovery of the metallic antiferromagnetic (AF) ground state near superconductivity in iron-pnictide superconductors, a central question has been whether magnetism in these materials arises from weakly correlated electrons, as in the case of spin-density-wave in pure chromium, requires strong electron corrleations, or can even be described in terms of localized electrons such as the AF insulating state of copper oxides. We use inelastic neutron scattering to determine the absolute intensity of the magnetic excitations throughout the Brillouin zone in iron-based superconductors BaFe2-xNixAs2, which allows us to obtain the size of fluctuating magnetic moment, and its energy distribution. We find that superconducting and nonsuperconducting BaFe2-xNixAs2 have fluctuating moments with magnitude similar to those for the AF insulating copper oxides. The commom theme in both classes of high temperature superconductors is that magnetic excitations have partly localized character, thus showing the importance of strong correlations for high temperature superconductivity.

I21-02 Understanding the role of disorder in Fe-arsenide superconductors. - ***J. Analytis (Stanford Institute for Material and Energy Science)***

Disorder has a profound affect on iron-pnictide superconductors, changing the transport anisotropy, the magneto-elastic coupling, and the properties of the superconductivity itself. In the 122 structural motifs, the parent compounds have a folded band structure with compensated hole and electron pockets. Some of these pockets are thought to be protected from disorder by the topological properties of the band structure. However, the influence of disorder on each pocket is in general very difficult to reveal because transport properties will in general measure an average of all Fermi surfaces, and other Fermi surface probes (such as ARPES) will not be sensitive to subtle changes in the dynamical properties of each Fermi surface. We present results of detailed quantum oscillation studies which aim to understand how the dynamics of each Fermi surface pocket is affected by disorder.

This work is supported by the Department of Energy, Office of Basic Energy Sciences, Division of Materials Science.

I21-03 Anomalous elastic behavior in the iron-based superconductors Ba(Fe,Co)2As2 and Fe(Se,Te) - ***M. Yoshizawa, S. Simayi, K. Sakano, R. Takezawa, Y. Nakanishi (Graduate School of Engineering, Iwate University)***

In many iron-based superconductors, superconducting phases are located near structural and/or magnetic phases. It would be interesting and important to clarify the correlation between the order parameter fluctuation of the neighbor phase and the emergence of superconductivity. We have investigated the elastic properties of $Ba(Fe_{1-x}Co_x)_2As_2$ [1], and related compounds. In the case of $Ba(Fe_{1-x}Co_x)_2As_2$, the elastic constant C_{66} shows large softening associated with the structural phase transition from tetragonal to orthorhombic. We found that the temperature dependence of C_{66} is characterized by a large Jahn-Teller energy, which indicates the strong electron-lattice coupling. If we look at the data by using the elastic compliance S_{66} (=1/C_{66}) instead of C_{66}, it is found to behave just like a magnetic susceptibility in the vicinity of a magnetic quantum critical point (QCP). The amount of anomalous S_{66} correlates with the superconducting transition temperature. This suggests that this system is dominated by structural fluctuations. On the basis of our findings, we infer that the superconductivity of the iron-based superconductor is mediated by the structural fluctuations as the same as the superconductivity by magnetic fluctuations near the magnetic QCP. Recently, we have investigated $Fe(Se_{1-x}Te_x)$. For this 11 system, there exist two neighboring orders corresponding to FeSe and FeTe. FeSe shows a structural transition without magnetic order. FeTe shows magneto-structural transition. The structural transitions for FeSe and FeTe associate C_{66} and C_{44} anomalies, respectively. The importance of C_{66} fluctuation is also suggested for this system.

This work was performed under the collaboration of K. Kihou, C. H. Lee, A. Iyo, H. Eisaki, M. Nakajima, S. Uchida, Y. Koshika, K. Kawata and T. Watanabe. This work was supported by a Grant-in-Aid for Scientific Research on Innovative Areas, ‘‘Heavy Electrons’’, from MEXT, and JST-TRIP, Japan.

[1] M. Yoshizawa *et al*., J. Phys. Soc. Jpn. 81 (2012) 024604.

I21-04 spin-orbital models of iron-based superconductors - ***R. Singh, R. Applegate (Physics Department, University of California at Davis, CA 95616), C. Chen, T. Devereaux (Stanford Institute for Materials and Energy Science, SLAC National Accelerator Laboratory, Menlo Park, CA 94025)***

We discuss the interplay of magnetism and structural transitions in the iron pnictide family of superconducting materials using a spin-orbital model with coupled Heisenberg-spin and Ising orbital degrees of freedom. Mean-field theory, Monte Carlo simulations, exact diagonalization and general arguments allow us to show that these models exhibit nearby antiferromagnetic and orbital-based tetragonal to orthorombic structural transitions. These transitions can happen simultaneously or the structural transition can happen at a somewhat higher temperature. The transitions can be first or second order. We also show that relativistic spin-orbit coupling can combine with orbital order to produce a magnetic phase, where the moments are aligned along the direction of antiferromagnetic order. We use our model study to develop a phenomenology of the experimental phase diagram of the different family of the iron pnictide materials. We will discuss similarities and differences of our approch to explain the nematic behavior observed in neutron-scattering, photoemission and other transport measurements, from those where either spin-physics or orbital-physics is dominant, while the other merely participates in an epiphenomena.

This work is supported in part by NSF grant number DMR-1004231 and by the US DOE under contract number DE-AC02-76SF00515.

R. Applegate et. al. Physical Review B 85, 054411 (2012); C. C. Chen et al, Phys. Rev. B 80, 180418 (2009); Phys. Rev. B 82, 100504 (2010); Phys. Rev. Lett. 106, 067002 (2011); NJP 13, 043025 (2011).

I21-05 Nematic degrees of freedom and itinerant magnetism in the iron-based superconductors - ***R. Fernandes (Columbia University and Los Alamos National Lab)***

The discovery of the iron pnictides opened a new direction in the research of quantum materials. Besides high-Tc superconductivity (SC), these compounds also display magnetic and structural phase transitions that follow each other across the phase diagram. Experiments reveal that the anisotropies of the orthorhombic-paramagnetic phase cannot be attributed solely to the lattice distortion, indicating that the structural transition is a secondary effect of an electronic tetragonal symmetry-breaking. In this talk, I will show that magnetic fluctuations naturally give rise to such an anisotropic electronic state, called Ising-nematic, whose properties agree with experimental observations. This emergent phase is a consequence of the degeneracy of the itinerant magnetic ground state, affecting the properties of the normal and SC states. By enhancing magnetic fluctuations, nematic order assists the magnetic transition and can also affect the electronic spectrum via the opening of a pseudogap due to magnetic precursors. Because magnetic fluctuations become anisotropic in the nematic phase, the scattering of electrons by spin-fluctuations gives rise to a resistivity anisotropy whose sign changes from electron-doped to hole-doped compounds. Due to the magneto-elastic coupling, nematic fluctuations soften the shear modulus in the normal state and

harden it in the SC state. The latter effect is an indirect consequence of the competition between SC and magnetism for the same electronic states, which also causes the orthorhombic distortion to be suppressed below Tc. I will also discuss the interplay between nematic fluctuations and the SC transition temperature, as well as the relationship between nematic order and orbital order.
This work is supported by the NSF Partnerships for International Research and Education (PIRE) program OISE-0968226.

I22 - Heavy Fermion Superconductors 2
Diplomat, 4:00 PM to 6:05 PM
Session Chair: Meigan Aronson

I22-01 Routes to heavy-fermion superconductivity - ***F. Steglich (MPI for Chemical Physics of Solids, Dresden), Q. Si (Department of Physics and Astronomy, Rice University, Houston), H. Yuan (Department of Physics, Zhejiang University, Hangzhou), O. Stockert, S. Wirth, C. Geibel (MPI for Chemical Physics of Solids, Dresden), S. Kirchner (MPI for Physics of Complex Systems, Dresden)***

Superconductivity in lanthanide- and actinide-based heavy-fermion metals can have different microscopic origins. Among others, pairings invoking fluctuations of the valence [1], quadrupole moment [2] and spin [3] of the localized 4f/5f shell have been proposed. Spin-fluctuation mediated superconductivity was recently demonstrated [4] in the neighborhood of a spin-density-wave (SDW) quantum critical point (QCP), thus verifying earlier predictions of extended SDW fluctuations acting as the driving force for superconductivity [5]. In addition to the latter, local spin fluctuations appear to also contribute to the Cooper pairing in this case, as is inferred from inelastic-neutron-scattering results and calculations of the gain in exchange energy upon entering the superconducting state [4, 6].

[1] H.Q. Yuan et al., Science 302, 2104 (2003).
[2] M.B. Maple et al., J. Phys. Soc. Jpn. 71 (Supplement), 23 (2002).
[3] N.D. Mathur et al., Nature 394, 39 (1998).
[4] O. Stockert et al., Nature Phys. 7, 119 (2011).
[5] D. J. Scalapino et al., Phys. Rev. B 34, 8190 (1986).
[6] O. Stockert et al., J. Phys. Soc. Jpn. 81, 011001 (2012).

I22-02 Hidden order and hybridization gap in the Kondo lattice URu2Si2 - ***W. Park (University of Illinois at Urbana-Champaign), P. Tobash, F. Ronning, E. Bauer, J. Sarrao, J. Thompson (Los Alamos National Laboratory), L. Greene (University of Illinois at Urbana-Champaign)***

The Kondo lattice heavy fermion system URu_2Si_2 undergoes a second order phase transition at 17.5 K. Despite ubiquitous gap-like behaviors observed in various experiments over the last two and half decades, the exact order parameter for this ordered state (hidden order) remains to be identified. The challenges may lie in the intriguing interplay between the itinerant and localized sectors originating from the multiple *f*-electrons in this compound. We employ quasiparticle scattering spectroscopy (QPS), better known as point-contact spectroscopy, to study how the localized *f*-electron states get hybridized with the conduction bands resulting into renormalized heavy-fermion bands at low temperature. QPS is a powerful spectroscopic technique to measure the bulk electronic properties using a ballistic metallic junction. We have taken conductance data on URu_2Si_2 over a wide temperature range [1]. The differential conductance spectra exhibit a distinct double-peak structure with pronounced asymmetry. Our analysis with the help of a recent theory [2] shows this is a signature for a novel-type of Fano resonance that occurs in a Kondo lattice. According to this theory, the double peaks arise from the hybridization gap in the heavy fermion density of states as derived in the periodic Anderson model. We find this hybridization gap opens well above the hidden order transition temperature, indicating it is not the hidden order parameter. Consequences of our findings on the microscopic mechanism of the hidden order transition in URu_2Si_2 will be discussed.
The work at UIUC is supported by the U.S. DOE under Award No. DE-FG02-07ER46453. The work at LANL is carried out under the auspices of the U.S. DOE, Office of Science. [1] W. K. Park et al., arXiv:1110.5541. [2] M. Maltseva, M. Dzero, P. Coleman, PRL 103, 206402 (2009).

I22-03 Mapping the transition between real and complex order parameter phases in the heavy fermion superconductor UPt3 - ***D. Van Harlingen (University of Illinois at Urbana-Champaign)***

The heavy fermion material UPt_3 was the first superconductor suspected to have unconventional pairing symmetry as a result of the two peaks observed in the specific heat. We have determined the order parameter symmetry by measuring the magnitude and phase anisotropy via directional Josephson critical current measurements and Josephson interferometry. In accordance with theoretical predictions, we find that there are two distinct superconducting phases: a high temperature phase characterized by a real order parameter of the form $(k_x^2-k_y^2)k_z$ that forms at an upper transition temperature of ~550mK, and a low temperature phase with a complex order parameter of the form $(k_x+ik_y)^2k_z$ that onsets below ~500mK. We have mapped the transition between the two phases, observing the onset of an imaginary component at the lower transition temperature

1. J. D. Strand, D. J. Van Harlingen, J. B. Kycia, and W. P. Halperin, Phys. Rev. Lett. 103, 197002 (2009).
2. J. D. Strand, D. J. Bahr, D. J. Van Harlingen, J. P. Davis, W. J. Gannon, and W. P. Halperin, Science 328, 1368 (2010).

I22-04 Visualizing heavy fermions emerging in a quantum critical Kondo lattice - *A. Yazdani (Princeton University)*

In solids containing elements with f-orbitals, the interaction between f-electron spins and those of itinerant electrons leads to the development of low-energy fermionic excitations with a heavy effective mass. These excitations are fundamental to the appearance of unconventional superconductivity and non-Fermi liquid behavior observed in actinide- and lanthanide-based compounds. In this talk, I will describe how we use spectroscopic mapping with the scanning tunneling microscope to detect the emergence of heavy excitations with lowering of temperature in a prototypical family of Ce-based heavy fermion compounds. These experiments demonstrate the sensitivity of the tunneling process to the composite nature of these heavy quasiparticles, which arises from quantum entanglement of itinerant conduction and f-electrons. Scattering and interference of the heavy quasiparticles is used to resolve their energy momentum structure and to extract their mass enhancement, which develops with decreasing temperature. Remarkably, the lifetime of the emergent heavy quasiparticles reveals signatures of enhanced scattering and their spectral lineshape shows evidence of energy-temperature scaling. These findings demonstrate that proximity to a quantum critical point results in critical damping of the emergent heavy excitation of our Kondo lattice system.[1]

Work done in dollaboration with P. Aynajian, E. H. da Silva Neto, A. Gyenis, R. E. Baumbach, J. D.Thompson, Z. Fisk, E. D. Bauer and supported by DOE and NSF.

[1] Refereence: P. Aynajian et al. to appear in Nature (2012).

I22-05 Superconductivity Driven Unequal Magnetic Domain Population in CeCoIn5 - *M. Kenzelmann (Paul Scherrer Institut)*

$CeCoIn_5$ is a heavy-fermion d-wave superconductor that features a novel high-field superconducting phase with spin-density wave (SDW) magnetic order, and serves as an ideal model material to study unconventional superconductivity. The SDW exists only in the superconducting phase and collapses with increasing field together with superconductivity in a first-order phase transition [1]. The origin of the SDW order has lead to a number of theories, some involving FFLO-type superconductivity [2] or nesting effects in the spin-split electronic structure due to strong Pauli paramagnetism [3,4], but is not clear at the moment.

To understand the intricate interplay of SDW and superconductivity, we have performed additional experiments to determine the properties of the SDW order and its dependence on the magnetic field direction. We find that the SDW order does not depend on the magnetic field direction in the basal tetragonal plane, but appears absent or very weak for magnetic field along the tetragonal axis. The SDW order is thus modulated along the lines of nodes of the $d_{x^2-y^2}$ superconducting order parameter.

For fields along the line nodes direction, we find an uneven magnetic domain population with a complete absence with the SDW domain modulated along the magnetic field direction, although both domains are equivalent. This suggests that domain walls in this magneto-superconducting phase are energetically unfavorable, and that superconductivity plays an important role in the selection of the SDW domains. We will discuss our most recent results in the context of the available theories and compare our results to those recently obtained with other results such as NMR measurements.

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[2] Y. Yanase et al, J. Phys. Soc. Jap. **78**, 114715 (2009).
[3] K.M. Suzuki et al, Phys. Rev. B **83**, 140503 (2011).
[4] Y. Kato et al, Phys. Rev. Lett. **107**, 096401 (2011).

In Collaboration with S. Gerber, N. Egetenmeyer, J. Gavilano, E. Ressouche, A. Bianchi, R. Movshovich, E. Bauer, J. Sarrao, and J. Thompson.

I23 - Topological and Other Superconductivity
Empire, 4:00 PM to 6:00 PM
Session Chair: Johnpierre Paglione

I23-01 Fermi-liquid origin of resistivity and superconductivity in n-type SrTiO3 - *D. van der Marel (University of Geneva), I. Mazin (Naval Research Laboratories), D. van Mechelen (University of Geneva)*

SrTiO3 is a semiconductor which, when doped with a low density of electrons, becomes a good conductor with relatively high mobility and strong temperature dependence of the electrical resistivity and the infrared optical conductivity. At low temperatures the material becomes superconducting with Tc below 1 K having a dome-shaped doping dependence, both in the 3D bulk material and at the 2D LaAlO3/SrTiO3 interface. The DC resistivity below 100 K has a T-square temperature dependence. The quasiparticles are in the anti-adiabatic limit with respect to electron-phonon interaction, which renders the interaction mediated through phonons effectively non-retarded. We apply Fermi-liquid theory for the T-square term in the resistivity, and combine this with expressions for Tc and with the Brinkman-Platzman-Rice (BPR) sum-rule to obtain Landau parameters of n-type SrTiO3. These parameters are comparable to those of liquid 3He, indicating interesting parallels between these Fermi-liquids despite the differences between the composite fermions from which they are formed. The physics of the doped semiconductor SrTiO3 stands in stark contrast with the doped cuprates where Tc's are two orders of magnitude higher and correlate with the T-linear term of the resistivity.

This work is supported by the SNSF through Grant No. 200020-130052 and the National Center of Compe- tence in Research (NCCR) "Materials with Novel Electronic Properties-MaNEP."

D. van der Marel, J. L. M. van Mechelen, I. I. Mazin
Physical Review B 84, 205111 (2011)

I23-02 oxygen ordering, its fractal nature, and relation to superconductivity in superoxygenated La2CuO4 -
A. Bianconi (Sapienza University of Rome), N. Poccia (ESRF), A. Ricci (HASYLAB), G. Aeppli (London Centre for Nanotechnology University College London)

Disorder has been considered have negligible or detrimental effects in conventional superconductors. On the contrary lattice heterogeneity of cuprates has been proposed to be an essential feature by Alex Muller and recently Geballe and Marezio have proposed an undefined optimal heterogeneity of oxygen defects and interstitials promoting high temperature superconductivity and we proposed the "superstripes" scenario. We have used Scanning Nano X-ray Diffraction probing both k-space and real-space to shed light on bulk nanoscale phase separation. Here we report that the ordering of oxygen interstitials in the La_2O_{2+y} spacer layers of La_2CuO_{4+y} high-T_c superconductors is characterized by a scale free distribution up to the micron scale. Intriguingly, the scale invariant distribution of dopants ordered domains enhances superconductivity from 17K to 40K [1] The time resolved evolution of the defects nucleation, growth and organization have been investigated by x-ray diffraction under continuous x-ray illumination support this complex lattice scenario [2]. The new insight in the complexity of the well-known superconducting material La_2CuO_{4+y} has allowed us to understand and demonstrate some necessary steps to 'write' superconducting wires on the micrometre scale. Recently clear imaging of bulk nanoscale phase separation in K0.8Fe1.6Se2 [3] support the non trivial granular state of the matter where high temperature superconductivity emerges.

1 M Fratini et al. Nature 466, 841, 2010
2 N Poccia et al. Nat. Mat. 10, 726, 2011
3 A. Ricci et al. Phys. Rev. B 84, 060511, 2011

I23-03 Topological Pairing in Correlated Systems -
Q. Wang (National Lab of Solid State Microstructures, Nanjing University, Nanjing 210093), F. Yang (Department of Physics, Beijing Institute ofTechnology, Beijing 100081), F. Wang (Department of Physics, Massachusetts Institute ofTechnology, Cambridge, MA 02139), D. Lee (Department of Physics, University of California atBerkeley, Berkeley, CA 94720), W. Wang (National Lab of Solid State Microstructures, Nanjing University, Nanjing, 210093), Y. Xiang (National Lab of Solid State Microstructures, NanjingUniversity, Nanjing, 210093)

Topological insulators and superconductors have become a focus of interest in condensed matter physics. These states are characterized by symmetry protected gapless boundary modes. The existence of these modes reflects the fact that it is impossible to deform a topological insulator/superconductor into its non-topological counterpart without crossing a quantum phase transition. Using functional renormalization group and variational Quantum Monte Carlo methods, we study time-reversal-breaking (TRB) and time-reversal-invariant (TRI) superconducting phases in correlated systems. Both type of phases support gapless edge modes and are therefore topological. 1) We find that in doped graphene, the system is a chiral spin density wave state exhibiting the anomalous quantized Hall effect near 1/4 doping (a Chern insulator). When the doping deviates from 1/4, the d+i d TRB pairing becomes the leading instability. 2) We present three different mechanisms for TRI topological pairing. We warm up by studying a one band model mimicking strongly correlated fermions in continuum. This model is relevant to the topological superfluidity in the B phase of He-III. Next we discuss two other different mechanisms for TRI topological pairing. In each case there is a finite parameter range where triplet pairing occurs in the presence of ferromagnetic (or small wavevector magnetic) fluctuation. We explain why, under such condition, a small Rashba coupling can induce topological superconductivity. We also explain why topological pairing does not happen in singlet-dominated materials. We provide a guideline for the search of TRI topological superconductivity in non-centrosymmetric systems.

QHW acknowledges the support by NSFC (under grant No.10974086, No.10734120 and No.11023002) and the Ministry of Science and Technology of China (under grant No.2011CBA00108 and 2011CB922101). FY acknowledges the support by NSFC (under grant No.10704008). DHL acknowledges the support by the DOE grant number DE-AC02-05CH11231.

I23-04 Superconductivity in the topological semimetal YPtBi -
P. Syers (University of Maryland), N. Butch (LANL), K. Kirshenbaum, J. Paglione (University of Maryland)

Superconductivity was discovered in the noncentrosymmetric Half Heusler compound YPtBi. Its Tc, Hc2(0), and normal state carrier concentration were measured using typical resistance and Hall Effect measurements. Unconventional linear magnetoresistance and beating in Shubnikov-de Haas oscillations point to spin-orbit split Fermi surfaces. The sensitivity of magnetoresistance to surface roughness suggests a possible contribution from surface states. The combination of noncentrosymmetry and strong spin-orbit coupling in YPtBi presents a promising platform for the investigation of topological superconductivity.

N. P. Butch, P. Syers, K. Kirshenbaum, A. P. Hope, and J. Paglione, Phys. Rev. B 84, 220504(R) (2011)

This work was supported by AFOSR-MURI (FA9550-09-1-0603) and LDRD (11-LW-003).

I23-05 Lateral Josephson junctions that transmit triplet pair currents -
J. Aarts (Kamerlingh Onnes Laboratorium, Leiden Institute of Physics), M. Anwar (Department of Physics, Kyoto University)

In the last few years, the scenery in the physics of superconductor/ ferromagnet hybrids has changed considerably with the realization that spin triplets may be induced in a ferromagnet through the mechanism of odd–frequency pairing, yielding an s-type triplet Cooper pair rather than the p-type pair expected from the Pauli principle. Since the equal-spin component of the triplet is not susceptible to pair breaking by the exchange field, such correlations can sustain supercurrents over long lengths. This has now been observed in devices using a variety of ferromagnets. The largest distances can be expected in fully spin polarized materials where only one spin band is available, such as halfmetallic ferromagnetic CrO_2. By depositing superconducting contacts on films grown on sapphire substrates and measuring in a lateral geometry, we observed supercurrents to flow over 700 nm at 4.2 K [1], although reproducibillity issues indicated that the mechanism of triplet generation was not yet well in hand. Using a suggestion made recently [2] that a spin-active interface can be fabricated by inserting an N/F*/N sandwich between the S and F layers (N a normal metal and F* a different ferromagnet), we now find that micron-ranged supercurrents can be induced in CrO_2 grown on TiO_2, by using a thin Cu/Ni/Cu intermediate layer [3]. The strength of these currents is considerably larger than those found in devices grown on sapphire. The currents appear to be only weakly sensitive to magnetic fields, in line with the original observations [4]. This appears reasonable given the large area of the lateral Josephson junctions, but is puzzling in view of the fact that the magnetic inhomogeneity created by the N/F*/N contact might well be reduced in strong magnetic fields.

[1] M. S. Anwar *et al.*, Phys. Rev. B **82**, 100501(R) (2010).
[2] T. S. Khaire *et al.*, Phys. Rev. Lett. **104**, 137002 (2010).
[3] M. S. Anwar *et al.*, Appl. Phys. Lett. **100**, 052602 (2012).
[4] R. S. Keizer *et al.*, Nature **439**, 825 (2006).

I23-06 The happy marriage between electron correlations and electron-phonon interaction in Cs3C60 - ***M. Capone (CNR/IOM and International School for Advanced Studies (SISSA)), M. Fabrizio, E. Tosatti (SISSA), C. Castellani (Universita' Sapienza Roma)***

High-temperature superconductivity in Cs-doped fullerides challenges the distinction between conventional electron-phonon superconductors and strongly correlated materials. The phase diagram of these compounds as a function of pressure indeed reflects that of the cuprates as a function of doping, with a superconducting "bell" flanked by an antiferromagnetic state [1].

The similarity is not accidental and descends from a key-role of electron-electron correlations in fullerene-based materials. We have shown that the properties of this compound, and of the whole family of trivalent fullerides, can be understood in a unifying framework by solving a model including strong Hubbard interactions and Jahn-Teller electron-phonon coupling [2]. This shows that phononic pairing can actually be favored by correlations leading to a phase diagram which has been experimentally confirmed [3].

We propose several methods to further verify the role of electronic correlations, from a peculiar behavior of the optical spectra and of the kinetic energy to a pseudogap in the normal state. Since phonon pairing in this compound involves spin degrees of freedom, a central role of spin entropy is expected, in analogy with unconventional magnetic driven superconductors [2]. The behavior of the superconductor-insulator line as a function of temperature represents a test of this observation.

The analogies and difference with aromatic molecular superconductors such as doped picene are briefly discussed [4].

The work is sponsored by EU through ERC Starting Grant SUPERBAD and FP7 LEMSUPER

[1] Y. Takabayashi, et al., Science 2009, 323, 1585
[2] M. Capone et al., Rev. Mod. Phys. 81, 943 (2009)
[3] M. Capone et al. Science 296, 2364 (2002)
[4] G. Giovannetti and M. Capone, Phys. Rev. B 83, 134508 (2011)

I24 - Applications Related
Congressional, 4:00 PM to 5:40 PM
Session Chair: Leonardo Civale

I24-01 Single spin sensitivity with a nano-sized SQUID-on-tip device working at 4 K - ***D. Vasyukov (Weizmann Institute of Science), M. Huber (University of Colorado, Denver), Y. Anahory, L. Ne'eman, A. Finkler, Y. Myasoedov, M. Rappaport, E. Zeldov (Weizmann Institute of Science), Y. Segev (Weizmann Institute of Sciene)***

NanoSQUIDs residing on the apex of a quartz tip, suitable for scanning probe microscopy with record size, spin sensitivity, and operating magnetic fields, are presented. The SQUID-on-tip (SOT) is fabricated by pulling a quartz tube into a sharp pipette, followed by three thermal evaporation steps of a thin superconducting film onto the sides and the apex of the pipette. This self-aligned fabrication method requires no additional lithographic processing or etching. An aluminum SOT of 200 nm diameter, operating at 300 mK, showed flux sensitivity of $F_n = 1.8\ mF_0/Hz^{1/2}$ and spin sensitivity of $S_n = 65\ m_B/Hz^{1/2}$ [1]. We have developed SOTs made of Nb and Pb that have the advantage of operating at 4.2 K. Nb SOTs showed pronounced quantum oscillations up to an unprecedented field of 1.2 T. Their flux and spin noise, however, is higher with $F_n = 3.6\ mF_0/Hz^{1/2}$ and $S_n = 150\ m_B/Hz^{1/2}$. The best performance was achieved with a Pb SOT with an effective diameter of 160 nm with $F_n = 0.05\ mF_0/Hz^{1/2}$ at 4.2 K that was operational at fields up to 0.6 T. This corresponds to a spin sensitivity of $S_n = 1.4\ m_B/Hz^{1/2}$, which is more than an order of magnitude more sensitive than that of any other SQUID to date. This extraordinary sensitivity, combined with the ability of the SQUID-on-tip to scan the sample within a few nm from the sample surface, opens the pathway to direct imaging and investigation of magnetic moments as small as those of a single electron spin.

[1] A. Finkler, Y. Segev, Y. Myasoedov, M. L. Rappaport, L. Neeman, D. Vasyukov, E. Zeldov, M. E. Huber, J. Martin and A. Yacoby, *Nano Lett.* **10**, 1046 (2010)

I24-02 Pinning by Composite Defects in Cuprates and Pnictides - ***W. Kwok, L. Fang, C. Chaparro, Y. Jia, U. Welp, A. Koshelev (Materials Science Division, Argonne National Laboratory), G. Crabtree (Materials Science Division, Argonne National Laboratory & Dept. of Physics, Electrical and Mechanical Engineering, University of Illinois at Chicago), A. Kayani (Physics Department, Western Michigan University), S. Zhu (Physics Division, Argonne National Laboratory)***

Two key factors, the critical current and its anisotropy, limit the widespread application of high temperature superconductors for energy delivery. Presently, the critical current in the best commercial YBCO coated conductors wires is only about 20% of the theoretical depairing current. Breaking this 'glass ceiling' and doubling the critical current could reduce the cost of these wires by one-half. Furthermore, the critical current anisotropy in the presence of magnetic fields remains a roadblock for their application in superconducting rotating machinery. Here, we demonstrate that composite defects - a combination of correlated and point disorder induced by heavy-ion and proton irradiation, respectively - enhances the critical current, while also reducing the superconducting anisotropy. We report on transport, magnetization and specific heat measurements in irradiated YBCO [1], on hole-doped $Ba_{0.6}K_{0.4}Fe_2As_2$ and on isovalent $BaFe_2(As_{1-x},P_x)_2$ crystals [2]. Particularly, in $Ba_{0.6}K_{0.4}Fe_2As_2$, we find a pronounced increase of the critical current, a near doubling of the upper critical field and a sharp reduction of the superconducting anisotropy. The enhanced pinning arises from the pinning of double-kink vortex loops by point/cluster defects induced by proton irradiation, which results in the localization of the vortex on the heavy–ion induced correlated defects. Our results demonstrate that introducing composite defects in high temperature superconductors can be a viable route to creating an isotropic, high-pinning superconductor.

[1] J. Hua et al., Phy. Rev. B 82, 024505 (2010)
[2] L. Fang et al., Phys. Rev. B 84, 140504 (2011)

Work supported by the CES-EFRC funded by the DoE-BES (WKK, LF, CC, YJ, WKK), and by DoE-BES (UW,AEK, SX GWC) under #DE-AC02-06CH11357. Irradiation was conducted at Argonne's ATLAS facility (SZ) and at Western Michigan University (AK).

I24-03 Heavy Fermion Superconductor Ce2PdIn8 studied by 115In Nuclear Quadrupole Resonance - ***H. Fukazawa, R. Nagashima, S. Shimatani, Y. Kohori (Department of Physics, Chiba University, Chiba 263-8522, Japan), D. Kaczorowski, D. Gnida (nstitute of Low Temperature and Structure Research, Polish Academy of Sciences, P.O. Box 1410, PL-50-950 Wroclaw, Poland)***

Ce2PdIn8 is a recently discovered heavy-fermion-superconductor with superconducting critical temperature Tc = 0.7 K [1]. Resistivity, magnetic susceptibility, specific heat, and thermal conductivity measurements clearly show non-fermi-liquid behavior and unconventional superconductivity below Tc [1-3]. This compound is outstanding because of its similarity to well-studied heavy fermion superconductor CeCoIn5. In order to investigate microscopically the compound, we have performed nuclear quadrupole resonance (NQR) measurements on heavy fermion superconductor Ce2PdIn8 with superconducting critical temperature Tc = 0.64 K. Below Kondo coherence temperature T_coh ~ 30 K, the spin-lattice relaxation rate 1/T1 decreases with decreasing temperature T and is proportional to T^1/2 between Tc and T_K. This indicates that Ce2PdIn8 is located very close to an antiferromagnetic quantum critical point from the viewpoint of NQR. Below Tc, 1/T1 shows no coherence peak and is proportional to T3. This is clear evidence for the realization of unconventional superconductivity with line nodes in this compound.

This work is supported by Grants-in-Aid for Scientific Research (Nos. 22684016 & 21102505) from MEXT and JSPS, Global COE and AGGST financial support program from Chiba University.

[1] D. Kaczorowski et al., Phys. Rev. Lett. 103, 027003 (2009).
[2] Y. Tokiwa et al., Phys. Rev. B, 84, 140507(R) (2011).
[3] J. K. Dong et al., Phys. Rev. X 1, 011010 (2011).

I24-04 On-chip superconductivity above 7 K in microstructured 10 nm thin Ga films embedded in Si wafers - ***R. Skrotzki (1Dresden High Magnetic Field Laboratory (HLD) and Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf (HZDR), P.O. Box 51 01 19, D-01314 Dresden, Germany 2Department of Chemistry and Food Chemistry, TU D, T. Herrmannsdörfer, V. Heera, J. Fiedler, R. Schönemann, P. Philipp, L. Bischoff, M. Voelskow, A. Mücklich, B. Schmidt, W. Skorupa, M. Helm, J. Wosnitza (1Dresden High Magnetic Field Laboratory (HLD) and Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf (HZDR), P.O. Box 51 01 19, D-01314 Dresden, Germany)***

Initiated by the finding of doping-induced ambient-pressure superconductivity in classic group-IV semiconductors, in particular our investigation on Ga-doped Germanium [1], we have succeeded in preparing an even more promising candidate for superconducting on-chip application [2].

Ion implantation has been utilized to introduce a high dose of Ga into silicon wafers capped by 30 nm SiO2. Ga segregation underneath the cover was stimulated by subsequent rapid thermal annealing in a narrow time and temperature window. Extended structural investigations by means of XTEM, EDX, RBS/C, and SIMS confirm a reproducible formation of 10 nm thin amorphous Ga-rich layers.

In the normal state these layers reveal a sheet resistance with a negative temperature derivative and an absolute value close to the quantum resistance which is about 6 kOhm. The superconducting onset temperature accounts for up to 10 K while a zero-resistance state coincides with diamagnetic screening below 5 K verified by means of resistivity and dc magnetization measurements. Further, superconductivity remains stable up to remarkable high magnetic fields of more than 8 Tesla and exhibits a distinct critical-field anisotropy manifesting its thin-film character. Homogeneity and scale-independent behavior down to 3 micron have been proven by lateral microstructuring via photolithography rendering critical-current densities higher than 50 kA/cm2.

Recently, focussed-ion beam technique has been implemented in order to create Josephson junctions - key elements of the prospective first ever built gallium SQUID.

[1] T. Herrmannsdoerfer et. al., Phys. Rev. Lett. 102, 1027003 (2009).
[2] R. Skrotzki et al., Appl. Phys. Lett. 97, 192505 (2010).

Friday, August 3, 2012

S3 - ICAM / I2CAM Sponsored Symposium on Superconductivity for Sustainable Energy
Regency, 8:30 AM to 11:00 AM
Session Chair: George Crabtree

S3-01 Superconductivity for the Electricity Grid - *A. Malozemoff (Consultant to AMSC)*

High temperature superconductors (HTS) bring unique advantages to the electric power grid, spawning an increasing number of demonstrations and in-grid installations. Each year brings new progress. For example, in 2011 LS Cable & System announced the energization of a 500 m 22.9 kV/1.25 kA HTS power cable in KEPCO's Icheon substation in South Korea as well as plans for a series of additional installations in the Korean grid, using wire from its earlier 3 million meter order to AMSC. Siemens, Nexans and AMSC announced the successful test of a one-phase 66 kV/0.9 kA HTS fault current limiter at the Powertech high power laboratory in Vancouver, Canada. And already in 2012, Nexans announced the energization of a 12 kV/560 A HTS fault current limiter at a coal plant in the Vattenfall grid in Boxberg, Germany. Many other projects are underway in the US, Europe, Japan, Korea, China and New Zealand. Although first generation HTS wire based on a deformation processed powder-in-tube technology with BSCCO continues to be used for some of these projects, second generation HTS wire based on a coated conductor technology with YBCO is increasingly the vehicle of choice. This and other trends in the growth of this important new superconductor power grid technology will be assessed.

S3-02 Application of superconducting technology in 20th and 21st centuries - *K. Kitazawa (Japan Science and Technology Agency)*

Superconductivity in the 20th century was restricted in its application to rather special purposes such as accelerators and MRIs.
Now it is noteworthy that in the near future scheduled in 2027, the superconducting maglev line will be completed between Tokyo and Nagoya for the opening according to the announcement by JR Tokai company. The new maglev system has been under development for more than half a century for the purpose to realize safer transport system; i.e., change from a point-contact support system to a space-volume supported system. The reason superconducting magnets are needed in the car to replace the wheels is that the cars get repulsion force from the coils set on the ground. The use of repulsion force has an essential advantage to make adjustment of the height of the car unnecessary.
Another remarkable change I notice in the application of superconductivity is the way being paved for the practical usage of superconducting power transmission cables. This owes to the discovery of the high temperature superconductor and the subsequent efforts to improve the critical current of its wire and to fabricate long wires. It is now said that a superconducting underground would cost less than a conventional metallic cable if the cost of construction is considered because of the much smaller cross section needed for the superconductor transmission. Besides a perfect shielding can be made for the possible leakage of electromagnetic wave from the cable.
Then it should become easier for the electric power to be shared over a wide area so that to stabilize the fluctuating power from the future renewable energy. In the long run we can even expect a global superconducting grid to solve the problem of day and night for solar power.

S3-03 High current superconductors: from materials challenges to sustainable energy applications - *X. Obradors (ICMAB - CSIC)*

During 25 years, after the discovery of High Temperature Superconductivity, a huge progress has been made in basic science, materials preparation and technological developments. Achieving high current superconducting wires for large scale applications has been one of the most challenging objectives during all the HTS era. Extraordinary new ideas and materials developments have been demonstrated and second generation $YBa_2Cu_3O_7$ conductors (coated conductors) have emerged as the most attractive opportunity to reduce the cost/performance ratio down to the levels required for energy applications. These quasi-epitaxial multilayered films are deposited on flexible metallic substrates in long lengths without the detrimental influence of grain boundaries. Additionally, they can be accurately nanostructured to achieve very high vortex pinning strengths. Their current-carrying capability is at least a factor 5 above copper for the same cross section, ac losses are decreased by a factor 10 and they can stand large currents under very high magnetic fields. All these features make coated conductors very appealing to achieve the challenge of building up a sustainable electrical grid system based on reliable and efficient power grids and using high power off-shore superconducting wind generators.
In this talk I will present the major past developments and the present existing bottlenecks towards successful manufacturing of these advanced nanostructured materials. A particular emphasis will be made in describing the nanostructuration opportunities to enhance vortex pinning based on cost-effective chemical deposition approaches.

- J. Gutiérrez, T. Puig, X. Obradors et al; Nature Materials 6, 367 (2007)
- J. Figueras, T. Puig, X. Obradors, W.K. Kwok, L. Paulius, G.W. Crabtree, G. Deutscher; Nature Physics 2, 6, 402 (2006)
- A. Llordés, T. Puig, X. Obradors et al.; Nature Materials 11, 329 (2012)

S3-04 Fe-based superconductors: novel properties and potential applications - *A. Gurevich (Old Dominion University)*

Low carrier densities and short coherence lengths in the semi-metallic Fe-based superconductors (FBS) can result in interesting effects at strong magnetic fields due to the interplay of multiband superconductivity, unconventional pairing symmetry and the Zeeman and orbital pairbreaking. Moreover, the low Fermi energies comparable to those of doped semiconductors, and short coherence lengths in multiband FBS offer new opportunities of tuning the upper critical field H_{c2} by doping and strains, which appear to be more effective than the conventional way of increasing H_{c2} by introducing nonmagnetic disorder. These materials features of FBS and the multiband s□pairing symmetry not only significantly increase $H_{c2}(T)$ but also facilitate thermal fluctuations of vortices and result in weak link behavior of grain boundaries which can cause serious obstacles for applications. This talk presents an overview of these effects, particularly the anomalous temperature dependencies of the upper critical fields which often extrapolate to H_{c2} > 100 Tesla at low temperatures, and challenges and opportunities of high-field applications of FBS.

S3-05 Improving critical currents of coated conductors in high magnetic fields - *V. Selvamanickam (University of Houston), Y. Chen, C. Lei (SuperPower), J. Liu, Y. Liu, N. Khatri, Y. Yao, G. Majkic, E. Galtsyan (University of Houston)*

Coated conductors are now being developed for several electric power and magnetic field applications. Prototypes of superconducting devices have been made by several institutions world-wide using coils of coated conductors. In order to achieve cost-performance metric for employment of coated conductors in applications such as wind generators and superconducting magnetic energy storage (SMES), we are working on achieving dramatic improvement of critical current at the operating conditions of these applications i.e. in magnetic fields of 2 to 30 T at temperatures of 4.2 K to 65 K. It is found that the flux pinning characteristics of coated conductors in these operating conditions can be manipulated by tailoring of pinning centers in the superconducting film. Recent progress in processing and characterization of coated conductors to achieve significant improvements in their critical current performance at operating conditions of interest to applications will be discussed in this presentation.

This program is partially funded by the Advanced Research Projects Agency-Energy (ARPA-E) and the National Science Foundation.

I25 - Transport and Other Properties of Cuprates
Palladian, 8:30 AM to 11:00 AM
Session Chair: Peter Armitage

I25-01 Generic transport properties of overdoped cuprates - *N. Hussey (University of Bristol)*

In this talk, we will present a survey of the in-plane transport properties of various families of single-layer cuprates, including $La_{2-x}Sr_xCuO_4$, $Bi_{2-x}La_xSr_2CuO_{6+\square}$ and $Tl_2Ba_2CuO_{6+\square}$ in which superconductivity can be suppressed through over-doping. Starting with a detailed characterization of the correlated metallic state, its Fermi surface and charge dynamics, we will explore the evolution of the electronic state and the gradual destruction of quasiparticles as the carrier density is reduced and superconductivity emerges from the right-hand-side of the phase diagram. In particular, we will focus on properties that appear generic and not affected by the band structure of individual families, such as the growth of the linear-in-temperature resistivity term and the emergence of anisotropic scattering. Significantly, this anisotropic scattering, whose momentum dependence mimics that of the *d*-wave superconducting order parameter, appears to 'switch on' at the edge of the superconducting dome, implying a close and direct correlation between it and the superconducting pairing interaction.

I25-02 Pairing, spin fluctuations and quantum critical scaling at the edge of Fermi liquid stability in a cuprate superconductor - *J. Paglione, K. Jin, N. Butch, K. Kirshenbaum, R. Greene (University of Maryland)*

In the high temperature cuprate superconductors, the pervasiveness of anomalous electronic transport properties suggests that violation of conventional Fermi liquid behavior is closely tied to superconductivity. In other classes of unconventional superconductors, atypical transport is well correlated with proximity to a quantum critical point, but the relative importance of quantum criticality in the cuprates remains uncertain. We present an in-depth study of magnetotransport in thin films of the electron-doped cuprate La2 xCexCuO4 (LCCO) to demonstrate that 1) a tempearture-linear scattering rate is correlated with the Cooper pairing, establishing a fundamental connection between AFM spin fluctuations and the pairing mechanism; and 2) quantum criticality plays a significant role in shaping the anomalous properties of the cuprate phase diagram. We identify a divergence in inelastic scattering and quantum-critical scaling with a line of quantum critical points that surrounds the superconducting phase as a function of both magnetic field and charge doping, and will explain how this zero-temperature phase boundary gives rise to an expanse of finite-temperature non-Fermi liquid behavior, presenting signatures of two distinct flavors of quantum fluctuations.

K. Jin et al., "*Link between spin fluctuations and electron pairing in copper oxide superconductors*", Nature 476, 73 (2011).
N.P. Butch et al., "*Quantum critical scaling at the edge of Fermi liquid stability in a cuprate superconductor*", (arXiv:1112.3950).
This research was supported by NSF DMR-0952716 and DMR-0653535.

I25-03 Nodeless superconductivity arising from antiferromagnetic order in the epitaxially stabilized cuprate archetype Sr$_{1-x}$La$_{x}$CuO$_{2}$ - ***J. Harter, L. Maritato, D. Shai, E. Monkman, Y. Nie, D. Schlom, K. Shen (Cornell University)***

The archetypal high-T_c cuprate is "infinite-layer" $ACuO_2$, where flat CuO_2 planes are separated only by alkaline earth atoms. Its simple structure is free of magnetic rare-earth ions, chains, orthorhombic distortions, incommensurate superstructures, ordered vacancies, and other complications that abound among the cuprates. Furthermore, its ambipolar nature makes $ACuO_2$ an excellent platform for answering one of the fundamental and long-standing questions in the study of cuprates: the possible intrinsic asymmetry between hole and electron doping and its implications for high-T_c superconductivity. Unfortunately, $ACuO_2$ has eluded investigation by sophisticated probes of electronic structure because of the inability to synthesize bulk single crystals. To circumvent this problem, we have synthesized epitaxial films of electron-doped $Sr_{1-x}La_xCuO_2$ by molecular-beam epitaxy and investigated their electronic structure by *in situ* angle-resolved photoemission spectroscopy. Our measurements verify the intrinsic asymmetry between electron and hole doping of cuprates and reveal that strong antiferromagnetism opens a gap along the nodal direction in $Sr_{1-x}La_xCuO_2$, resulting in a coexisting nodeless superconducting state.

This work was supported by the AFOSR (Grant No. FA9550-11-1-0033), the National Science Foundation through the MRSEC program (Grant No. DMR-1120296), and a Research Corporation Cottrell Scholar Award (Award No. 20025). L.M. was supported by the ARO (Grant No. W911NF-09-1-0415).

I25-04 Pseudogap in Copper Oxides: A Raman Scattering Study - ***G. Gu (Matter Physics and Materials Science, Brookhaven National Laboratory (BNL),), Y. Gallais (Univeristé of Paris Diderot Paris 7), M. Méasson, M. CAZAYOUS, D. Colson (Université Paris Diderot Paris 7), S. Blanc (University Paris Diderot Paris 7)***

We investigate the pseudogap in copper oxide superconductors by electronic Raman scattering. We report the signature of the pseudogap of Bi-2212 and Hg 1201 single crystals for several doping levels, from the underdoped to the overdoped side. We identify the energy and temperature of the pseudogap as a function of the doping level and show it is in good agreement with previous scanning tunneling microscopy (STM), (superconductor–insulator–superconductor) tunnel junction (SIS), angle resolved photoemission spectroscopy (ARPES) and resistivity measurements [1,2]. We track the temperature dependence of the coherent quasiparticles dynamic for several doping levels and reveal the impact of the pseudogap on the nodal and antinodal coherent quasiparticles. We finally extract from our analysis the temperature dependence of the scattering rate ratio between nodes and antinodes as a function of doping and compare its evolution with transport and magneto- transport measurements [3].

[1] A. Damascelli et al. RMP 75, 473, (2003).
[2] O. Fisher et al. RMP 79, (2007).
[3] N. E. Hussey, J. Phys Condens. Matter 20, 123201, (2008).

I25-05 Electron-Spin Excitation Coupling in an Electron-doped Copper Oxide Superconductor - ***S. Kunwar (Department of Physics, King Fahd University of Petroleum and Minerals, Dhahran, 31261, Saudi Arabia and Department of Physics, Boston College, Chestnut Hill, MA, 02467, USA), S. Li (Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100080, China and The University of Tennessee, Knoxville, Tennessee 37996-1200, USA), P. Dai (Department of Physics and Astronomy, The University of Tennessee, Knoxville, Tennessee, 37996, USA; Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100080, China and Neutron Scattering Science Division, Oak Ridge NationalLaboratory, Oak Ridge, Tennessee 37831, USA), S. Wilson, Z. Wang, V. Madhavan (Department of Physics, Boston College, Chestnut Hill, MA, 02467, USA), F. Niestemski (Department of Physics, Stanford University, Stanford, California, 94305, USA and Department of Physics, Boston College, Chestnut Hill, MA, 02467, USA), J. Zhao (Department of Physics, University of California, Berkeley, California 94720, USA and Department of Physics and Astronomy, The University of Tennessee, Knoxville, Tennessee, 37996, USA), P. Steffens, A. Hiess (Institut Laue Langevin, 6 Rue Jules Horowitz BP 156, F-38042 Grenoble Cedex 9, France), H. Kang (NIST Center for Neutron Research,National Institute of Standards and Technology, Gaithersburg, Maryland, 20899, USA)***

High transition temperature (High-Tc) superconductivity arises in the cooper oxides after holes or electrons are doped to their Mott-insulating anti-ferromagnetic (AF) parent compounds. Although high-Tc cuprates have been extensively studied, the relationship between antiferromagnetism and superconductivity is not yet clear. In particular, the bosonic excitation, that binds two electrons together to form a cooper pair, whether of magnetic or of non-magnetic (phonon) origin, is still debatable. We use scanning tunneling spectroscopy (STS) and Neutron Scattering to study the evolution of the bosonic excitations in electron-doped superconductor Pr0.88LaCe0.12CuO4-d (PLCCO) with different transition temperatures (Tc) obtained through the oxygen annealing process. We find that the spin excitations detected by neutron scattering have two distinct modes that evolve with Tc in a remarkably similar fashion to the low-energy electron tunneling modes detected by STS. These results demonstrate that anti-ferromagnetism and superconductivity compete locally and coexist spatially on nanometer length scales and the dominant electron–boson coupling at low energies originates from the electron-spin excitations instead of phonons.

- Jun Zhao, F. C. Niestemski, Shankar Kunwar, Shiliang Li, P. Steffens, A. Hiess, H. J. Kang, Stephen D. Wilson, Ziqiang Wang, Pengcheng Dai, & V. Madhavan "Electron-Spin Excitation Coupling in an Electron Doped Copper OxideSuperconductor" Nature Physics 7, 719 (2011).

I25-06 Tc is insensitive to magnetic interactions in cuprate superconductors! - *J. Tallon (MacDiarmid Institute, Industrial Research Ltd), E. Gilioli, F. Licci (IMEM-CNR, Institute of Materials for Electronics and Magnetism), T. Wolf (Karlsruhe Institute of Technology), B. Mallett (MacDiarmid Institute, Victoria University of Wellington)*

A quarter of a century after their discovery the mechanism that pairs carriers in the cuprate high-T_c superconductors (HTS) still remains uncertain. Despite this the general consensus is that it is probably magnetic in origin so that the energy scale for the pairing boson is governed by J, the antiferromagnetic exchange interaction. Recent studies using resonant inelastic X-ray scattering strongly support these ideas. Here, as a simple test, we vary J (as measured by two-magnon Raman scattering) by more than 160% by changing ion sizes in the model HTS system $LnA_2Cu_3O_{7-\delta}$ where A=(Ba,Sr) and Ln=(La, Nd, Sm, Eu, Gd, Dy, Yb, Lu). Such changes are often referred to as "internal" pressure. Surprisingly, we find T_c^{max} *anticorrelates* with J where internal pressure is the implicit variable. This is the opposite to the effect of external pressure and suggests that J is not the dominant energy scale governing T_c^{max}.

I26 - Impurities, Disorder and Thin Film Pnictides
Diplomat, 8:30 AM to 11:00 AM
Session Chair: Peter Hirschfeld

I26-01 Interface induced high temperature superconductivity in single unit-cell FeSe films on SrTiO3 - *Q. Xue (Tsinghua University)*

We report high transition temperature superconductivity in one unit-cell (UC) thick FeSe films grown on the Se-etched $SrTiO_3$(001) substrate by molecular beam epitaxy. A superconductive gap as large as 20 meV and the magnetic field induced vortex state revealed by *in situ* scanning tunneling microscopy suggest that the superconductivity of the 1 UC FeSe films could occur around 77 K. The control transport measurement shows that the onset superconductivity temperature is well above 50 K. We will discuss the mechanism for this extremely high transition temperature and that for unconventional superconductivity. Our work not only demonstrates a powerful way for finding new superconductors and for raising T_C, but also provides a well-defined platform for systematic study of the mechanism of unconventional superconductivity by using different superconducting materials and substrates.

This work was done in collaborated with Xucun Ma, Lili Wang, Xi Chen, Yayu Wang, Shuaihua Ji and Ke He.

I26-02 Unconventional temperature-induced magnetism in iron telluride - *Z. Xu, J. Tranquada, G. Gu, A. Tsvelik (CMPMSD, Brookhaven National Laboratory), M. Stone (NSD, Oak Ridge National Laboratory)*

We have used inelastic neutron scattering to characterize the temperature dependence of both static and dynamic magnetism in a crystal of Fe1.1Te, parent to Fe{1+y}Te{1-x}Se{x} family of superconductors [1]. Our goal was to investigate the relevance of two common scenarios used to describe the magnetism in the families of Fe-based superconductors. In one, the magnetism originates from local atomic spins, while in the other it corresponds to a cooperative spin-density-wave instability (SDW) behavior of conduction electrons. Both assume clear partition into localized electrons, giving rise to local spins, and itinerant ones, occupying well-defined, rigid conduction bands. In contrast to the simple pictures, we find that localized spins and itinerant electrons are coupled together and both contribute to the low-energy dynamical magnetism. In particular, we have evaluated the effective magnetic moment by integrating both the elastic and inelastic magnetic scattering. The effective spin per Fe at T = 10 K, in the antiferromagnetic phase, corresponds to approximately S = 1, consistent with the recent analyses that emphasize importance of Hund's intra-atomic exchange. However, it grows to roughly S = 3/2 in the disordered phase, a result that presents a challenge to current theoretical models. We also find that the pattern of magnetic scattering is typical of a spin liquid. The short-range magnetic correlations are controlled by four-spin plaquettes of coaligned spins, which are favored by the interstitial iron atoms present in our sample, while the neighbor plaquettes are aligned antiferromagnetically.

[1] I. A. Zaliznyak, Z. J. Xu, J. M. Tranquada, G. D. Gu, A. M. Tsvelik, M. B. Stone, Phys. Rev. Lett. 107, 216403 (2011).

This work was supported by the US DOE under Contract DE-AC02-98CH10886.

I26-03 What is x in the phase diagram of substituted Fe pnictides and chalcogenides? - *G. Sawatzky (University of British Columbia), M. Haverkort (Max Planck Institute for Solid State Physics), I. Elfimov (University of British Columbia)*

We demonstate(1) that Co,Ni,Cu and Zn substituted for Fe of BaFe2As2 and FeSe all behaved like equi-valent cations. This raises a number of interesting questions regarding the origin of the substitution dependence in the phase diagram, changes in the Fermi surface similar to doping, the influence of impurity scattering, and questions regarding localization. Our results describe the accumulation of charge (not wave function localization) within the impurity muffin tin to neutralize the effect of the extra nuclear charge of the substituent's. Such a charge accumulation does not mean that there is no change in the Fermi surface. In fact the density of states clearly shows strong changes close to the Fermi energy. We describe how this happens and present band structure evidence for the size and influence of the "impurity " potentials, changes of the Fermi surface as well as possible broadening of the nesting peak in the Lindhard function. We relate this broadening to the concentration dependence of the antiferromagnetic transition temperature. We then go on to describe a method for applying density functional methods to *random* substitutions using a configuration averaging method(2) following closely recent similar applications to impurities in semiconductors and alloys (3,4). This method is directly applicable to the interpretation of ARPES data including the broadening and shifts in the energy and momentum distribution curves in terms of the real and imaginary parts of the self energy. Results for the Co,Ni,Cu,Zn substituted FeSe system will be discussed. A somewhat different method has recently also been applied to the substituted Fe pnictides with qualitatively similar results to those reported here (5).

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(2) W. Haverkort, I. S. Elfimov, G. A. Sawatzky; arXiv:1109.4036, 2011
(3) V. Popescu and A. Zunger Phys. Rev. Lett. 104, 236403 (2010)
(4) V. Popescu and A. Zunger Phys. Rev. B 85, 085201 (2012)
(5) T. Berlijn, Chia-Hui Lin, W. Garber, Wei Ku arXiv:1112.4858, 2012

I26-04 Effect of electron irradiation on iron-based superconductors - ***C. Van Der Beek (Laboratoire des Solides Irradiés, CNRS UMR 7642, CEA - DSM - IRAMIS, Ecole Polytechnique, 91128 Palaiseau Cedex), T. Shibauchi, Y. Matsuda (Department of Physics, Kyoto University, Sakyo-ku, Kyoto 606-8501, Japan), P. Gierlowski (Institute of Physics of the Polish Academy of Sciences, Aleja Lotnikow 32/46, 02-668 Warszawa), S. Demirdis, M. Konczykowski (Laboratoire des Solides Irradiés, CNRS UMR 7642, CEA-DSM-IRAMIS, Ecole Polytechnique, 91128 PALAISEAU cedex), S. Kasahara, T. Terashima (Research Center for Low Temperature and Materials Sciences, Kyoto University,Sakyo-ku, Kyoto 606-8501, Japan), D. Colson (Service de Physique de l'Etat Condensé, CEA Saclay, CEA-DSM-IRAMIS, CNRS URA 2464, F-91191 Gif-sur-Yvette, France), R. Prozorov (The Ames Laboratory, Ames, Iowa 50011, USA Department of Physics & Astronomy, Iowa State University, Ames, Iowa 50011, USA)***

The premise of s± superconductivity in the multiband iron-based superconductors, with a sign-changing order parameter between the electron-like and hole-like Fermi-surface sheets [1], has raised the question of the effect of atomic-scale point-like disorder on superconductivity in these materials. In particular, interband scattering of quasiparticles by point-like disorder was predicted to lead to a strong suppression of the critical temperature, the appearance of sub-gap states [3,4], and a peculiar T2 dependence of the London penetration depth at low temperature [5]. Other scenarios for superconductivity predict accidental gap nodes in an s++ symmetry, with the nodes being lifted in the presence of interband scattering [6].

In this contribution, we compare the effect of the controlled introduction of point-like defects in different iron-based superconductors by 2.5 MeV electron irradiation at 20 K. Preliminary data reveal that the effect point-like defects on the critical temperature of isovalently doped materials vastly outweighs that on the charge-doped compounds. The comparison, notably with the effect on the iron-chalcogenide Fe(Te1-xSex), reveals the importance of pre-existing point-like disorder in these compounds.

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[2] H. Kontani, S. Onari, PRL 104, 157001 (2010).
[3] A. Glatz, A. E. Koshelev, PRB 82, 012507 (2010).
[4] V.G. Kogan, PRB 80, 214532 (2009).
[5] R. Prozorov, V.G. Kogan, Rep. Prog. Phys. 74, 124505 (2011).
[6] V. Mishra et al., PRB 79, 094512 (2009).

I26-05 Impurity bound-state as a prove of order parameter symmetry in iron-based superconductors - ***M. Ogata (Department of Physics, University of Tokyo and JST TRIP), T. Kariyado (Department of Physics, University of Tokyo)***

It has been clarified experimentally and theoretically that the superconducting gap functions in iron-based superconductors have a wide variety depending on their structure of multiple Fermi surfaces. In such situations, it is desirable to develop a systematic way to understand the material dependence and so on. We proposed a simple way to parameterize the gap function in iron pnictides [1]. The key idea is to use orbital representation, not band representation, and to assume real-space short-range pairing. Although this parameterization is very simple, it reproduces fairly well the structure of gap functions obtained in microscopic calculations. Since the present method is simple enough, it is useful for obtaining an intuitive picture and for developing phenomenological theories. Using this method, we studied the temperature dependences of NMR $1/T_1$ [2], such as the coherence peak and T^n behavior below *T*c. In this talk, we discuss a single impurity problem by solving Bogoliubov-de Gennes equation in the five-orbital model constructed from the above analysis. We study the local density of states around a non-magnetic impurity and discuss the bound-state peak structures. It is found that a bound state with nearly zero-energy appears for the impurity potential *I*~1.0 eV in the s+- state, while the bound-state peaks stick to the gap edge in the unitary limit [3]. These results can be used for distinguishing s+- and s++ superconducting states. Novel multiple-peak structure originated from the multi-orbital nature of the iron pnictides is also found, which is characteristic to the iron pnictides. We also discuss the relation to the recent experiment on the Co impurity [4].

Part of this work is a collaboration with Hai-Hu Wen and A. V. Balatsky.

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[2] T. Kariyado and M. Ogata, Physica C **470**, S334 (2010), arXiv: 0911.2963.
[3] T. Kariyado and M. Ogata, J. Phys. Soc. Japan **79**, 083704 (2010), arXiv: 1004.5093.
[4] Huan Yang et al. arXiv:1203.3123.

I26-06 Impurity scattering on the S± - save state for the iron-based superconductors - ***Y. Bang (Dept of Physics, Chonnam National University)***

In this talk, I will discuss the various features of the impurity effects on the S± - wave state in close comparison with the experiments of the iron-based superconductors. After a brief description of the T-matrix method to study the impurity scattering and the generic mechanism of forming an unique and peculiar in-gap state in the S± - wave state by impurities, I will show its consequences on NMR spin lattice relaxation rate, penetration depth, specific heat coefficient, and T_c-suppression.

Then with these results, we can convincingly sort out which experimental data really indicate the presence of a nodal gap beyond the S± - wave state which is believed the most prevailing gap symmetry of the iron-based superconductors.

This work is supported by the Grant No. NRF-2010-0009523 and NRF-2011-0017079 funded by the National Research Foundation of Korea.

Yunkyu Bang, Phys. Rev. Lett. 106, 259701 (2011)
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I27 - Ferromagnetic and Non-Centrosymmetric Superconductors
Ambassador, 8:30 AM to 11:00 AM
Session Chair: Gilbert Lonzarich

I27-01 Ferromagnetism and Superconductivity under Extreme Conditions in Uranium Compounds - *D. Aoki, M. Taupin, V. Taufour, G. Knebel, J. Brison, J. Flouquet (CEA-Grenoble), F. Hardy (KIT), H. Kotegawa (Kobe University), W. Knafo (LNCMI-G), I. Sheikin (LNCMI-T), A. Miyake (Osaka University)*

We review our recent advances on ferromagnetic superconductors, UGe_2 [1], URhGe [2] and UCoGe [3], where the superconductivity (SC) peacefully coexists with ferromagnetism (FM), forming the spin-triplet state of Cooper pairs. Thanks to a variety of ferromagnetic ordered moments M_0 between three ferromagnetic superconductors, (UGe_2: 1.5 μ_B, URhGe: 0.4 μ_B, UCoGe: 0.05 μ_B), striking new phenomena as well as fundamental long-standing issues of itinerant ferromagnetism start to be clarified [4].

We focus on the field-reinforced superconductivity, magnetic fluctuations and Fermi surface instabilities. When the field is applied along the hard-magnetization axis (b-axis) in UCoGe and URhGe, the temperature dependence of the upper critical field H_{c2} shows the unusual S-shaped or field-reentrant behavior[5,6]. Strong Ising-type magnetic fluctuations are clearly demonstrated by the anisotropic field-dependent effective mass detected by the resistivity, specific heat, magnetization measurements. A paradox is that URhGe shows a spin-reorientation with a step-like magnetization curve at 12T with the first-order transition where the field-reentrant superconductivity appears, while no anomaly is detected in magnetization on UCoGe, but resistivity, thermopower, Hall effect indicate the anomaly around 14T. In UCoGe, not only the magnetic fluctuation but also the associated Fermi surface instabilities play a important role for the field-reinforced superconductivity, forming the spin-triplet state [7]. The similarity with a low-carrier superconductor URu_2Si_2 is discussed. The ferromagnetic quantum critical endpoint in UGe2 is also presented, comparing with that in UCoAl.

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[2] D. Aoki, et al.: Nature 413 (2001) 613.
[3] N.T. Huy, et al.: Phys. Rev. Lett. 99 (2007) 067006.
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[6] D. Aoki, et al.: J. Phys. Soc. Jpn. 78 (2009) 113709.
[7] D. Aoki, et al.: J. Phys. Soc. Jpn. 80 (2011) 013705

I27-02 Heavy fermions and superconductivity in ferromagnets - *A. Huxley (University of Edinburgh), C. Stock (NIST), C. Pfleiderer, R. Ritz (TUM), D. Sokolov (University of Edinburgh)*

Superconductivity in ferromagnets with Curie temperatures higher than Tc (namely UGe2 and URhGe) is correlated with a proximity to magnetic transitions between strongly polarized heavy fermion states. Inelastic neutron scattering and thermal expansion measurements will be presented that elucidate both how heavy fermions may survive in the presence of a strong polarization and the nature of the transitions between these states. We also examine whether there are nearby topological transitions of the Fermi-surface. The implications for the paring mechanism for superconductivity will be discussed.

I27-03 NMR study of spin-triplet superconductivity in non-centrosymmetric superconductors - *G. Zheng (Okayama University)*

The spatial inversion-symmetry breaking has great impact on physics of various classes of materials. Here, we present our NMR results that indicate exotic electron pairing in non-centrosymmetric superconductors of $Li_2(Pt_{1-x}Pd_x)_3B$ and LaPtBi. The perovskite-like cubic compounds Li_2Pt_3B and Li_2Pd_3B superconducts at T_c=2.7 K and 7 K, respectively. Through ^{11}B and ^{195}Pt NMR measurements, we find that Cooper pairs are dominantly in the spin-triplet state and there exist line nodes in the superconducting gap function in Li_2Pt_3B [1], while the isostructural Li_2Pd_3B is a spin-singlet, *s*-wave superconductor [2]. By varying *x* in $Li_2(Pt_{1-x}Pd_x)_3B$, we find that the distortion of the $Pt(Pd)B_6$ changes abruptly at *x*=0.8 which enhances drastically the spin-orbit coupling and is responsible for the dominant spin-triplet pairing state [3].

LaPtBi superconducts at T_c=1.5 K and is isostructural to the topological insulators RPtBi (R = rare earth) family. We will discuss the possible spin-triplet state on the basis of ^{197}Pt-NMR and ^{139}La-NQR results.

[1] M. Nishiyama, Y. Inada, and G.-q. Zheng, Phys. Rev. Lett. **98,** 047002 (2007).
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[3] S. Harada, Y. Inada, and G.-q. Zheng, to be published.

I27-04 Superconductivity Induced by Longitudinal Ferromagnetic Fluctuations in UCoGe - *K. Ishida (Dept. of Physics., Grad. Sch. of Science, Kyoto Univ.)*

After the discovery of superconductivity in the ferromagnetic UGe_2 under pressure, the relationship between ferromagnetism and superconductivity has attracted much interest, since most unconventional superconductivity has been discovered near an antiferromagnetic phase. Among the FM superconductors discovered so far, UCoGe [1] is one of the most readily explored experimentally, because of its high superconducting (SC) transition temperature (T_{SC} ~ 0.7 K) and low Curie temperature (T_{Curie} ~ 2.5 K) at ambient pressure. The magnetization has Ising-like anisotropy with the easy axis parallel to the *c* axis, and direction-dependent nuclear-spin lattice relaxation rate ($1/T_1$) measurements have revealed the magnetic fluctuations in UCoGe to be also Ising-type FM ones along the *c* axis (longitudinal FM spin fluctuations). Enigmatic anisotropic behaviors of superconductivity are also reported by studies of the SC upper critical field (H_{c2}) and its angle dependence along each crystalline axis. The observed characteristic H_{c2} behavior and the FM properties are one of mysterious features of UCoGe.

From precise angle-resolved $1/T_1$ and H_{c2} measurements[2], we observed strong suppression of the longitudinal FM fluctuations by the magnetic field along the *c* axis (H^c), and found that H^c is a tuning parameter of the fluctuations. We also found that the superconductivity is observed in the limited H^c region where the longitudinal FM spin fluctuations are active. These results combined with model calculations in which H^c dependence of the fluctuations obtained experimentally is incorporated, strongly suggest that the longitudinal FM spin fluctuations tuned by H^c induce the unique spin-triplet superconductivity in UCoGe[2].

This study on UCoGe has been carried out in collaboration with T. Hattori, Y. Ihara, Y. Nakai, Y. Tada, S. Fujimoto, N. Kawakami (Kyoto Univ.), E. Osaki, K. Deguchi, N. K. Sato (Nagoya Univ.), and I. Satoh (Tohoku Univ.).

[1] N. T. Huy *et al.* Phys. Rev. Lett. **99**, 067006 (2007).
[2] T. Hattori *et al.* Phys. Rev. Lett. **108**, 066403 (2012).

I27-05 Ferromagnetism in the superconducting state of UCoGe: Possible evidence of spontaneous vortex state - *K. Deguchi, A. Takeda, N. Tamura, E. Osaki, S. Ban, N. Sato (Department of Physics, Graduate School of Science, Nagoya University), I. Satoh (Institute for Materials Research, Tohoku University), Y. Shimura, T. Sakakibara (Institute for Solid State Physics, University of Tokyo)*

Superconductivity and magnetism would be antagonistic because of the competitive nature between the screening by Meissner effect and the internal fields generated by magnetic orderings. Recent observation of superconductivity in the ferromagnet has renewed our interest on the interplay of magnetism and superconductivity. Among them, in particular, some uranium-based intermetallic compounds have attracted much attention due to their unusual coexistence of superconductivity and magnetism. One of central topics in the U-based magnetic superconductors is the interplay between superconductivity and ferromagnetism such as in UGe_2 [1], URhGe [2] and UCoGe [3].

UCoGe is a ferromagnet at ambient pressure with a Curie temperature T_{Curie} ~ 2.5 K and with small ordered moments. Interestingly, superconductivity appears within the ferromagnetic phase with a superconducting transition temperature T_{SC} ~ 0.5 K. Measurements of the nuclear spin-lattice relaxation rate $1/T_1$ in Co-NQR [4] and the upper critical field H_{c2} provide evidence for unconventional superconductivity with spin-triplet pairs. Weak and itinerant ferromagnetic order microscopically coexists with superconductivity detected by *m*SR and NQR [4] experiments. By contrast to a regular type-II superconductor, in the ferromagnetic superconductor UCoGe, a spontaneous vortex state or a self-induced vortex state in which a spontaneous magnetization induces a vortex even at zero external magnetic field (without Meissner state), emerges as a compromise of the two competitive orders [5,6]. The nature of superconducting ferromagnet UCoGe is closely related to spin fluctuation and magnetism as a weak itinerant f-electron ferromagnet.

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[2] D. Aoki et al., Nature (London) **413**, 613 (2000).
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[5] K. Deguchi et al., J. Phys. Soc. Jpn. **79**, 083708 (2010).
[6] M. Tachiki et al., Solid State Comm. **34**, 19 (1980).

I27-06 Transport properties in the superconducting ferromagnet UCoGe - *M. Taupin (SPSMS-UMR-E UJF Grenoble 1, INAC-CEA, 17 Rue des Martyrs, 38054 Grenoble Cedex 9), L. Howald (Physik-Institut, Universität Zürich, Winterthurerstrasse 190, 8057 Zürich), D. Aoki, J. Brison (SPSMS-UMR-E UJF Grenoble 1, INAC-CEA, 17 Rue des Martyrs, 38054 Grenoble Cedex 9)*

In 2000, the first ferromagnetic superconductor, UGe2, was discovered. It presents very striking behaviors, notably under high magnetic field: superconductivity can be enhanced by the field, with the presence of a re-entrant superconducting phase at high field. This argues for the close relationship between magnetism and superconductivity in some unconventional superconductors. Two other compounds have been found to have the same properties at ambient pressure: URhGe in 2001 and UCoGe in 2007. This allows more quantitative experiments, such as thermal conductivity measurements. See e.g. [1] for a review.

The compound studied is the superconducting ferromagnet UCoGe, which is ferromagnetic at 2.5K and superconducting at 0.7K. Transport measurements have been performed at low temperature (down to 10mK), under magnetic field (up to 8.5T) and with different samples quality. A piezo-rotator and two goniometers are mounted to allow aligning precisely and in-situ the magnetic field with one crystallographic axis. We show that unusual properties, such as re-entrant superconductivity or upward curvature of the critical field, are confirmed by bulk measurements [2]. We also demonstrate that magnetic fluctuations have a large contribution to the thermal conductivity and are suppressed when the magnetic field is applied along the easy magnetization axis, while they are almost field independent when the field is along another crystallographic axis. This is in good agreement with previous NMR studies [3,4]. We show the first thermal conductivity measurements in the superconducting state and we can compare the normalized superconducting part of different samples and discuss the intrinsic/extrinsic residual term at low temperature.

[1] D. Aoki *et al.*, J. Phys. Soc. Jpn. **81** 011003 (2012)
[2] L. Howald *et al.*, to be published.
[3] Y. Ihara *et al.*, Phys. Rev. Lett. **105**, 206403 (2010)
[4] T. Hattori *et al.*, Phys. Rev. Lett. **108**, 066403 (2012)

Keynote Sessions

K10 - Theory for Tc in Unconventional Superconductors
Regency, 11:30 AM to 1:00 PM
Session Chair: Michael Norman

K10-01 Pairing Symmetry Of Iron-Based Superconductors - *I. Mazin (Naval Research Laboratory)*

In this talk I will review the discussions that have been going on forthe last couple of years about the symmetry (symmetries) of the superconducting order parameter (OP) in Fe superconductors. The issues to be addressed are: (1) parity, (2) angular symmetry of the OP, (3) sign change of the OP, (4) nodal structure, (5) universality, (6) possibility of more than one condensate (SDW and superconductivity, symmetric and asymmetric Cooper pairs, etc). I will also address some widely debated questions, such as (1) pair breaking as a probe of the pairing symmetry, (2) cases of extreme hole or electron doping, (3) effect of the "zone- folding" on pairing symmetry and (4) allowed pairing symmetries in the novel AFe2Se2-based systems.

K10-02 magnetism and charge dynamics in iron pnictides - *G. Kotliar (Rutgers)*

The recently discovered iron pnictides and chalchogenides are Hunds metals, a new class of strongly correlated materials where the correlations are controlled by the strength of the Hunds rule coupling J rather than by the Hubbard U[1]. While correlations in these materials are strong, their physical properties are strikingly different from that of transition metal oxides. We will compare some of the LDA+DMFT results for various spectroscopies: optical conductivity, photoemission and inelastic neutron scattering with experiment and with other theoretical frameworks ranging from weak to strong coupling.[2][3]

Work in collaboration with Kristjan Haule, Haeyong Park and Zhiping Yin

[1] K Haule and G Kotliar New Journal of Physics 11 025021 (2009)
[2] Z. Yin K Haule and G Kotliar Nature Physics 7, 294 (2011)
[3] Hyowan Park, K haule and G. Kotliar Phys. Rev. Lett. 107, 137007 (2011)

K10-03 A common pairing interaction for the unconventional superconductors - *D. Scalapino (UCSB)*

This talk will review theoretical and experimental evidence supporting the idea that there is a common pairing mechanism which is responsible for superconductivity in a class of unconventional, sign changing gap, superconductors. The structure of the pairing interaction which is responsible conventional metallic superconductivity is understood within the Eliashberg framework and first-principle electronic structure and linear response phonon calculations. Here we compare and contrast this with our current understanding of the structure of the pairing interaction of the unconventional superconductors.

Supported by the Center for Nanophase Material Sciences at ORNL, Division of Scientific User Facilities, U.S. DOE.

K11 - Quantum Computation wit Superconductors
Palladian, 11:30 AM to 1:00 PM
Session Chair: Mac Beasley

K11-01 Design of a Superconducting Quantum Computer – *Y. Yin, J. Martinis (UC Santa Barbara)*

The computational power of a quantum computer arises from the superposition of quantum states, which gives a net parallel-processing size that exceeds the number of atoms in the universe for even a modest 300 qubit processor. To build such a computer, many groups around the world are exploring whether experimental systems can be controlled sufficiently well and with enough quantum coherence. A leading candidate in this search is based on “quantum integrated circuits” using superconducting devices. I will review current research that shows that the basic hardware requirements for a quantum computer can likely be met in the next few years, at which time a program to actually build a quantum computer can be started. An architecture based on surface codes allows one to estimate what a quantum computer might look like: even though the physical requirements are challenging, 10 million qubits in a building-sized facility, it is much more realizable than an equivalently powerful classical computer, a continent-sized data farm.

K11-02 Wiring Up Quantum Systems: Microwave Photons and Superconducting Qubits - *S. Girvin (Yale University)*

A revolution is underway in the construction of 'artificial atoms' out of superconducting electrical circuits [1]. These macroscopic (millimeter scale) 'atoms' have quantized energy levels and can emit and absorb quanta of light (in this case microwave photons), just like ordinary atoms. Unlike ordinary atoms, the properties of these artificial atoms can be engineered to suit various particular applications, and they can be connected together by wires to form quantum 'computer chips.' This so-called 'circuit QED' architecture has given us the ability to test quantum mechanics in a new regime using electrical circuits and to construct rudimentary quantum computers which can perform certain tasks that are impossible on ordinary classical computers.

Through clever qubit design and extremely careful microwave engineering, phase coherence times for superconducting qubits have risen by some five orders of magnitude in the last decade. It is now routinely possible to entangle mutliple qubits, control the quantum state of microwave fields at the single photon level, and even carry out rudimentary quantum error correction protocols [2]. In addition, progress in qubit design and fabrication has led to dramatic advances in practical realization of microwave amplifiers which approach the noise performance limits set by the Heisenberg uncertainty principle. This in turn has opened up the field of quantum feedback and control. This talk will review the remarkable experimental progress of the last decade.

This work is in collaboration with Leonid Glazman, Robert Schoelkopf and Michel Devoret, and supported by the NSF, ARO, and IARPA.

[1] 'Wiring up quantum systems,' R.J. Schoelkopf and S.M. Girvin, *Nature* **451**, 664 (2008).

[2] 'Realization of three-qubit quantum error correction with superconducting circuits,' M.D. Reed et al., *Nature* **482**, 382 (2012).

K11-03 prospects of superconducting qubits for quantum computation -- the view from Japan - *J. Tsai (Riken/NEC)*

Coupling qubits in a scalable way is one of the most important functions in the future quantum computer. In coupled flux qubit system, making use of selection rules is a useful strategy for coupling and decoupling qubits in superconducting quantum circuits. Following this approach, we implement a tunable coupling scheme between two flux qubits previously [1]. The qubits are coupled parametrically under microwave driving via the nonlinear inductance of a third qubit. The measured on-state coupling as well as the off-state residual coupling depends on the coupler bias and agrees quantitatively with a calculation of transition matrix elements of a three-qubit Hamiltonian [2]. We improved this coupling scheme using coupling qubit into a scalable one recently. In this scheme, control-phase gate operation can be achieved via a manipulation of geometrical phase. In this scheme, the following characteristics are considered advantageous:

Intrinsically scalable: residual zz couplings between nearest-neighbor logical qubits can be exactly compensated Error does not propagate along the chain Can be scaled in 1D or 2D Tolerate different gap energies of the logical qubits Tolerate asymmetry of the zx coupling between coupler and logical qubits No need to control the phase offset of the microwave signal driving the coupler. Long decoherence time was achieved in similar flux qubit used in this design [3].

Other coupling schemes using electro-magnetic resonators were studied [4].

Supported by Funding Program for World-Leading Innovative R&D on Science and Technology, MEXT KAKENHI "Quantum Cybernetics"

[1] A. O. Niskanen et al, Science, 316, 723, 2007

[2] K. Harrabi et al, Phys. Rev. B 79, 020507(R), 2009

[3] J. Bylander, et al, Nature Physics, doi:10.1038/nphys1994, 2011

[4] Z. H. Peng,et al, Phys. Rev. B 85, 0204537, 2012

Invited and Keynote Presentation Updates

Thursday Invited Speaker presentation, **I20-03**, ***Superconducting junctions between Sr2RuO4 and conventional superconductors*** **by Y. Maeno** has been moved to the Wednesday morning, session **K5 - Organic, Topological and Spin Liquid Superconductivity**.

Thursday Invited Speaker presentation, **I20-03**, has been replaced with **J. Sauls, *Vortices and Vortex Phases of Chiral, Spin-triplet Superconductors*[3].**

Superconductors with a multi-component order parameter can possess topologically stable vortices and inhomogeneous phases that are not possible in single-component superconductors. In this talk I describe the structure of vortices, vortex lattices and related domain walls that are possible ground states and metastable states of chiral spin-triplet superconductors.[1] Among the novel vortex states are stable doubly quantized vortices and meta-stable composite mass/charge and spin vortices with half a flux quantum. Observation of these structures would pro- vide fingerprints of broken time-reversal symmetry and/or space-inversion symmetry in multi-component, spin- triplet superconductors, such as thin films of 3He, and widely discussed theoretical models of the ground states for Sr2RuO4, as well as heavy fermion superconductors. Theoretical results for the order parameter structures, fermionic spectrum, charge/mass/spin currents and magnetic field distributions of these vortex states are reported. Phase stability and the H-T phase diagram for vortex lattices (VL) of singly- and doubly quantized vortices in chiral spin-triplet superconductors are reported. Comparisons with small angle neutron scattering studies of the flux lattices in Sr2RuO4 are presented. In particular, I discuss the role of Fermi surface anisotropy, and the point group symmetry of pairing basis states, on the energetics and stability of singly vs. doubly quantized lattices of vortices, and the implications one can draw from comparison with existing SANS measurements for the order parameter symmetry of Sr2RuO4.[2,3]

- 1. J. A. Sauls and M. Eschrig, New J. Phys. 11 , 075008 (2009).
- 2. M. Ichioka, K. Machida, and J. A. Sauls, J. Phys. (IOP), accepted (2012).
- 3. The research reported here is part of a collaboration involving M. Eschrig (Royal Holloway, University of London, UK), M. Ichioka and K. Machida (Okayama University, Japan).

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