Advanced Research Workshop

Advanced Materials and Technologies for Micro/Nano-Devices, Sensors and Actuators

Abstracts of Invited Lectures
&
Contributed Papers

June 29 – July 2, 2009
St. Petersburg, Russia

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in association with Agency for Science and Technology "Intellect"

Workshop Program

June 29, Monday morning

8:30- 9:00 am
Registration

9:00- 9:15 am
E. Gusev and A. Dideikin
Welcome notes

Session 1. Micro/Nano-Systems: Past, Present and Future

Session Chairs: E.Gusev and R. Jammy

9:15- 9:45 am
V. Vaganov
Siantis Inc, California, USA
Challenges of complete CMOS / MEMS systems integration:
Part I – History of MEMS/NEMS in Russia (USSR)

9:45- 10:15 am
M. Esashi
The World Premier International Research Center Advanced Institute for Materials Research, Tohoku University, Japan
MEMS for practical applications

10:15 – 10:45 am Coffee Break

10:45- 11:15 am
G.M. Rebeiz, I. Reines, R. Mahameed, H. Sedaghat-Pisheh, and C. Patel
The University of California, San Diego, La Jolla, CA
Advances in RF MEMS: angular-based actuators for high-yield stress-robust designs

11:15- 11:45 am
T.J. Sommer
European Commission, Directorate General Information Society and Media, Brussels, Belgium
European approach towards smart systems and public private partnerships

11:45- 12:15 pm
J.-C. Eloy, L. Robin, E. Mounier
Yole Développement, France
MEMS markets overview

12:15 – 1:45 pm Lunch

June 29, Monday afternoon

Session 2. Device and Reliability Physics

Session Chairs: G.Rebeiz and M. Esashi

1:45- 2:15 pm
S. Krylov, N. Dick
School of Mechanical Engineering, Faculty of Engineering,Tel Aviv Israel
Pull-in dynamics of electrostatically actuated bistable curved microbeams

2:15- 2:45 pm

P.G. Steeneken*, J. Stulemeijer+
**NXP Semiconductors, AE Eindhoven, The Netherlands,*
+Epcos Netherlands, AS Nijmegen, The Netherlands
Numerical continuation methods for non-linear MEMS actuators and oscillators

2:45- 3:15 pm

G. Papaioannou
University of Athens, Greece
The impact of dielectric material and temperature on dielectric charging in MEMS capacitive switches

3:15- 3:45 pm

P. Blondy, R. Stéfanini, S. Courrèges, A. Pothier, J.C. Orlianges, A.Crunteanu, M. Chatras
XLIM Research Institute, Limoges – France
Development of reliable and high power MEMS varactors

3:45 – 4:00 pm Coffee Break

3:45- 5:45 pm
Monday afternoon poster session

June 30, Tuesday morning

Session 3. MEMS/NEMS Technologies and Appplications

Session Chairs: V. Vaganov and T. Sommer

9:00- 9:30 am

D. Adams, D. Ascanio, N. Belov, B. Kim, G. Knight, G. Tchelepi
Nanochip, Inc., Fremont
T-K. Chou, J. Heck, Q. Ma, V. Rao
Intel Corp., Santa Clara
Nanochip: A MEMS-based ultra-high data density memory device

9:30- 10:00 am

M.M. Hussain[1], C.E. Smith[1], D. Elata [2,3], K. Akarvardar[2], R. Parsa[2], K. Yoo[2], J. Provine[2], J. Williams[4], K. Rader[1], J. Barnett[1], C. Park[1], M. Cruz[1], P.D. Kirsch[1], H.-S.P. Wong[2], R.T. Howe[2], R. Jammy[1]
[1]SEMATECH, 2706 Montopolis Dr. Austin TX 78741, USA,
[2]Stanford University, USA
[3]Technion,
[4]Texas State University, USA
Ultra low power Sub-100nm laterally actuated Nano-Electro-Mechanical (NEM) switch in an industry standard process flow for logic and memory applications

10:00- 10:30 am

V.G. Golubev
Ioffe Physical-Technical Institute RAS, St Petersburg, Russia
Three-dimensional photonic crystals based on opal-semiconductor and opal-metal nanocomposites

10:30 – 11:00 am Coffee Break

11:00- 11:30 am
B. Vigna
ST Microelectronics, Italy
Low-cost silicon Coriolis' gyroscopes consumerize inertial measurement units

11:30 - 12:00 pm
A. Müller, D. Neculoiu
IMT-Bucharest, Bucharest, Romania
G. Konstantinidis
FORTH-IESL-MRG Heraklion, Crete, Greece
T. Vähä-Heikilä
VTT Technical Research Centre of Finland, Espoo, Finland
Microwave and millimetre wave devices based on micromachining of III-V semiconductors

12:00 - 12:20 pm
E. Gusev
Qualcomm MEMS Technologies, San Jose, USA
MEMS based displays

12:20 - 12:40 pm
P. Maltsev
SMC "Technological Centre" MIET, Moscow, Russia
Description of the Nano/Microelectromechanical systems RTD targets of the Russian Federation programmes

12:40 – 2:00 pm Lunch

June 30, Tuesday afternoon

Sessions 4: Advanced Processes and Materials – I (5)

Session Chairs: E.Garfunkel and A. Müller

2:00 - 2:30 pm
H. Ashraf, J. Hopkins, L. M. Lea
Surface Technology Systems, Imperial Park, Newport, UK
Development of DRIE for the next generation of MEMS Devices

2:30 - 3:00 pm
J. Kiihamäki, H. Kattelus, M. Blomberg, R. Puurunen, M. Ylönen, P. Pekko, J. Saarilahti, H. Ritala
VTT Technical Research Centre of Finland, Espoo, Finland
Low-temperature processes for MEMS device fabrication

3:00 - 3:30 pm
N. Hoivik, H. Liu, K. Wang, K. Aasmundtveit
Institute for Microsystem Technology, Vestfold University College, Tønsberg, Norway
High temperature stable Au/Sn and Cu/Sn interconnects for 3D stacked applications

3:30 –4:00 pm Coffee Break

4:00 - 4:30 pm
M.M.V. Taklo*, K. Schjølberg-Henriksen*, N. Lietaer*, J. Prainsack#, J. Weber¤, M. Klein¤, P. Schneider+
**SINTEF, Department for Microsystems and Nanotechnology, Oslo, Norway*
#Infineon Technologies, Graz, Austria
¤Fraunhofer IZM, Berlin/Munich, Germany
+Fraunhofer ISS EAS, Dresden, Germany
D integration of MEMS and IC: Design, technology and simulations

4:30 - 4:50 pm
A.N. Krivosheeva, A.V. Korlyakov, V.V. Luchinin, V.M. Pasyuta
Saint Petersburg Electrotechnical University "LETI", St. Petersburg, Russia
Passive and active membranes for MEMS

June 30, Tuesday evening: River boat trip & reception
5:30-8 pm

July 1, Wedn morning: Guided Excurcion around the city and to the Hermitage (half-day)
9:00 am -1 pm

1:00 – 2:00 pm Lunch

July 1, Wednesday afternoon
Session 5. Sensors
Session Chairs: R. Ghodssi and A. Dideykin

2:00 - 2:30 pm
V. Vaganov
Siantis Inc, California, USA
Challenges of complete CMOS / MEMS systems integration:
Part II – Recent Progress and Challenges

2:30 – 3:00 pm
Y. Eichen, A. Shemesh, S. Stolyarova, Y. Nemirovsky
Technion-Israel Institute of Technology, Israel
MEMS composite porous silicon crystalline silicon cantilever-array biosensors: continuous sensing of explosive and chemical warfare agents

3:00 – 3:30 pm
R. Triantafyllopoulou, S. Chatzandroulis, C. Tsamis
DEMOKRITOS, Institute of Microelectronics, Athens, Greece
Low power chemical sensors for safety and security applications

3:30 –3:45 pm Coffee Break

3:45 – 4:15 pm
M.Jatlaoui[1], F.Chebila[1], P.Pons[1], H.Aubert[1], F.Coccetti[1], G.Papaioannou[1,2], M.Dragoman[3], D. Neculoiu[3], D.Dragoman[4], A.Muller[3], G.Konstantinidis[5], R.Plana[1]
[1]LAAS, University of Toulouse, France
[2]Solid State Physics Section, University of Athens, Greece
[3]National Research and Development Institute in Microtechnology, Bucharest, Romania

[4]*University of Bucharest, Romania.*
[5]*FORTH-IESL-MRG, Heraklion, Greece*
RF MEMS/NEMS Technologies for advanced sensors and scavengers

4:15 – 4:45 pm
P.J. French
TU Delft, EI-EWI-DIMES, The Netherlands
Smart sensors: advantages and pitfalls

4:45 – 5:45 pm
Panel Discussion – Future of Micro/Nano-Systems Integration
Moderator: V. Vaganov

July 2, Thursday morning
Sessions 6: Advanced Processes and Materials – II
Session Chairs: N. Hovik and P. Mal'tsev

9:00 – 9:30 am
R. Ghodssi, S.T. Koev, P.H. Dykstra, M.T. Meyer, K. Gerasopoulos, G.W. Rubloff, W.E. Bentley, G.F. Payne, J.N. Culver
University of Maryland, College Park, MD, USA
Integration of diverse biological materials in Micro/Nano devices

9:30 – 10:00 am
A.A. Balandin
Nano-Device Laboratory, University of California- Riverside, USA
Graphene properties and possible micro/nano-device applications

10:00 – 10:20 am
J. Oberhammer, N. Somjit, M. Sterner, G. Stemme
KTH-Royal Institute of Technology, 10044 Stockholm, Sweden
Monocrystalline-silicon microwave MEMS devices: multi-stable switches, W-band phase shifters, and MEMS tuneable frequency-selective surfaces

10:20 –10:45 am Coffee Break

10:45 – 11:15 am
E. Garfunkel
Rutgers University, Piscataway, NJ, USA
Surface characterization for MEMS/NEMS materials and processes

11:15 – 12:15 pm
A. Rusakov[§], P. Bystrov[§], A. Knizhnik[§], B.V. Potapkin[+,§]
[§]*Kintech Lab Ltd, Moscow, Russia*
[+]*RRC "Kurchatov Institute", Moscow, Russia*
Modeling of dry etching and deposition in production of MEMS

12:15 – 12:45 pm
H. Randriamahazaka*, P. Martin, J. Ghilane, J-C. Lacroix
Université Denis Diderot – Paris, France
Electrochemical models for the redox switching of conjugated polymers

12:45 – 2:00 pm Lunch

July 2, Thursday afternoon
Session 7. Nanodevices and Technologies
Session Chairs: A. Vul' and B. Potapkin

2:00 – 2:30 pm
I.V. Lebedeva, O.V. Ershova
Moscow Institute of Physics and Technology, 141701 Dolgoprudny, Russia
A.A. Knizhnik, B.V. Potapkin
RRC "Kurchatov Institute", Moscow, Russia
Kintech Lab Ltd, Moscow, Russia
A.M. Popov, Yu.E. Lozovik
Institute of Spectroscopy,Troitsk, Russia
Modelling of NEMS based on carbon nanostructures

2:30 – 3:00 pm
Yu.E. Lozovik
Institute of Spectroscopy, Moscow Troitsk, Russia
Graphene: properties and modeling of nanodevices

3:00 – 3:30 pm
A.T. Dideykin
Ioffe Institute, St.Petersburg, Russia
Detonation nanodiamond - the promising material for MEMS/NEMS applications

3:30 – 3:50 pm
S.L. Rumyantsev[*+] **M.S. Shur***, **A. Motayed**[♣], **A.V. Davydov**[♣], **M.E. Levinshtein**[+]
**Rensselaer Polytechnic Institute, Troy NY*
[+]*Ioffe Institute of Russian Academy of Sciences, St. Petersburg, Russia*
[♣]*National Institute of Standards and technology, Gaithersburg, Maryland*
Low frequency noise in nano-objects

3:50 – 4:10 pm
P.S. Dorozhkin, A. Schekin, A. Shelaev, V. Bykov
NT-MDT Co., Zelenograd Moscow, Russia
Combined scanning probe microscopy and micro/nano Raman studies of modern nanostructures

June 29, Monday afternoon, **3:45-5:45 pm**
Poster Session

P.1 **O. Adiguzel**
Firat University, Department of Physics, Turkey
Internal stresses in martensite formation in copper based shape memory alloys

P.2 **Pashaev**[*], **V. Aliyev**[*], **O. Davarashvili**[**], **M. Enukashvili**[**], **V. Zlomanov**[***]
[*]*Institute of Physics NAS, 33, Cavid ave., AZ-1143, Baku, Azerbaijan*
[**]*Tbilisi State University, 1, Chavchavadze ave.,380028, Tbilisi, Georgia*
[***]*Moscow State University, GSP-2, 119991, Moscow, Russia*
Mismatch problems in heterostructures on the base of IV-VI semiconductors

P.3 **G. Ayvazyan, R. Barsegyan**
Engineering Academy of Armenia, Armenia
Mechanical stress in PECVD silicon oxide films for MEMS application

P.4 **D. Chicherin[1], M. Sterner[2], Z. Baghchehsaraei[2], J. Oberhammer[2], S. Dudorov[1], Z. Du[1], T. Zvolensky[1], A. Vorobyov[3], M. de Miguel Gago[3], E. Fourn[3], R. Sauleau[3], T. Labia[4], G. El Haj Shhade[4], F. Bodereau[4], P. Mallejac[4], J. Åberg[5], C. Simovski[1], A.V. Räisänen[1]**
[1]Dept. Radio Science and Engineering, TKK – Helsinki University of Tech., Finland
[2]Microsystem Technology Lab, KTH - Royal Institute of Technology, Sweden
[3]Autocruise S.A., France
[4]IETR, Université de Rennes 1, France
[5]MicroComp Nordic AB, Sweden
MEMS tunable metamaterials for beam steering millimeter wave applications

P.5 **A.L. Despotuli, A.V. Andreeva**
Institut of Microelectronics Technology and High Purity Materials, Russian Academy of Sciences, Chernogolovka, Russia
Nanoionic supercapacitors for new technologies

P.6 **O.V. Ershova, V. Lebedeva**
Moscow Institute for Physics and Technology, Dolgoprudny, Russia
A.A. Knizhnik, B.V. Potapkin
RRC Kurchatov Institute, Moscow, Russia
Yu.E. Lozovik, A.M. Popov
Institute for Spectroscopy RAS, Troitsk, Moscow Region, Russia
Graphene bilayer: Nanotribology and NEMS applications

P.7 **V. Ivanov, K. Kandaswamy**
School of Civil and Environmental Engineering, Nanyang Technological University, Singapore
C. Yang
School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore
R. Stocker
Department of Civil and Environmental Engineering , Massachusetts Institute of Technology, USA
V. Stabnikov
Institute of Municipal Activity, National Aviation University, Kiev, Ukraine
Microfluidic cell separator for microsensor of live bacterial cells

P.8 **G.V. Kamarchuk, A.P. Pospelov, A.V. Yeremenko, A.V.Savitsky, E.C.Faulques, and I.K. Yanson**
B.Verkin Institute for Low Temperature Physics & Engineering of NAS of Ukraine, Ukraine
National Technical University "Kharkov Polytechnical Institute", Kharkov, Ukraine
Institute des Materiaux Jean Rouxel, Nantes, France
Point-contact gas-sensitive nanosensors

P.9 **V.A. Karachevtsev, A.Yu. Glamazda, M.V. Karachevtsev, O.S. Lytvyn**
B.I.Verkin Institute for Low Temperature Physics and Engineering, Kharkov, Ukraine,
V. Lashkaryov Institute of Semiconductor Physics, Kyiv, Ukraine
Bionanohybrids formed by carbon nanotubes:DNA for biosensing

P.10 **A. Kharlamov, V. Fomenko, A. Skripnichenko, N. Gubareni**
I.N.Frantsevich Institute for Problems of Materials Science, Kiev,Ukraine
Thread-like anisotropic transparent crystals of carbon

P.11 **R.R. Khaydarov*, R. A. Khaydarov[#], Y. Estrin[#], S. Evgrafova[+], S. Wagner[&]**
**Institute of Nuclear Physics, Tashkent, Uzbekistan*
[#]ARC Centre of Excellence for Design in Light Metals, Monash University and CSIRO Division of Materials Science and Engineering, Clayton, Victoria, Australia
[+]V.N. Sukachev Institute of Forest SB RAS, Krasnoyarsk, Russia
[&]Institute of Technical Chemistry, Leibniz University Hannover, Germany
Nanosilver-based materials for industrial applications

P.12 **A.B. Kozyrev**
St. Petersburg Electrotechnical University (LETI), St. Petersburg, Russia
Characterization of ferroelectrics for microwave applications

P.13 **R.V. Gelamo, F.P. Rouxinol, C. Verissimo, A. Abbaspour, A.R. Vaz, M.B. de Moraes, S.A. Moshkalev**
Center for Semiconductor Components, Campinas, SP, Brazil
Carbon nanotube based pressure and gas sensors

P.14 **W. Nawrocki**
Faculty of Electronics and Telecommunications, Poznan University of Technology, Poznan, Poland
Physical limits for scaling of electronic devices

P.15 **S.V. Ordin[1],A.J. Zjuzin[1], Yu. Ivanov[2] and S. Yamaguchi[2]**
[1]Ioffe Physical-Technical Institute RAS, St. Petersburg, Russia
[2]Center of Applied Superconductivity and Sustainable Energy Research (CASER), Chubu University, Japan
Nano-structured materials for thermoelectric devices

P.16 **Y. Voronov, A. Kovalenko, M. Nickiforova, B. Podlepetsky, N. Samotaev**
Department of Micro- and Nanoelectronics, Moscow Engineering Physics Institute, Moscow, Russia
A.Vasiliev, S. Gogish-Klushin, O.Gogish-Klushina, D.Kharitonov, R.Pavelko
Russian Research Center Kurchatov Institute, Moscow, Russia
Gas sensors based on microtechnology and MEMS platforms

P.17 **E. Bichoutskaia[1], A.M. Popov[2], Y.E. Lozovik[2], O.V. Ershova[3], I.V. Lebedeva[3,4,5], A.A. Knizhnik [4,5]**
[1]Department of Chemistry, University of Nottingham, University Park, Nottingham, UK
[2]Institute of Spectroscopy, Russian Academy of Sciences, Troitsk, Moscow region, Russia
[3]Moscow Institute of Physics and Technology, Dolgoprudny, Moscow region, Russia
[4]RRC "Kurchatov Institute", 1, Moscow, Russia
[5]Kinech Lab Ltd, Moscow, Russia
NEMS based on interaction of the walls of carbon nanotubes

P.18 **P.V. Seredin*, A.V. Glotov*, E.P. Domashevskaya*, I.N. Arsentyev[+], D.A. Vinokurov[+], I.S. Tarasov[+]**
**Voronezh State University, Voronezh, Russia*
[+] Ioffe Physical Technical Institute RAS, St. Petersburg, Russia
Structure property of AlxGa1-xAs/GaAs(100) autoepitaxial heterostructures

P.19 **N. Starodub*, N. Mel'nichenko[+], A. Shmireva[x]**
**National University of Life and Environmental Science, Kiev , Ukraine*
[+]Kiev National Technical University of "KPI", Kiev, Ukraine
[x]Taras Shevchenko Kiev National University, Kiev, Ukraine
Biosensors based on the nanostructured silicon: development and practical application

P.20 **S. Sukhoveyev**
Electronics Department, Sub-Faculty of Micro System Techniques, Moscow State Institute of Radioengineering, Electronic and Automatic (Technical University), Moscow, Russia
MEMS and NEMS on basis of fibrous composites

P.21 **V.V. Tomaev**
Department of Chemistry, St. Petersburg State University , St. Petersburg, Russia
The new ferroelectric sensors material on the base of nanocomposites PbSe+$PbSeO_3$

P.22 **V.V. Tomaev, Yu.S. Tver'yanovich, M.D. Bal'makov**
Department of Chemistry, St. Petersburg State University, St. Petersburg, Russia
SnO_2 –based film with a filamentary nanomorphology for gas sensors materials

P.23 **O.O. Udovyk**
I.Frantsevich Institute for Problems of Materials Science, National Academy of Sciences of Ukraine
Solar fullerenes and carbon nanotubes

Invited Lectures

&

Oral Contributions

Graphene Properties and Possible Micro/nano-device Applications

Balandin A.A.

Nano-Device Laboratory, Department of Electrical Engineering and Materials Science and Engineering Program, University of California – Riverside, Riverside, California 92521 USA

Graphene, a recently exfoliated allotrope of carbon, which consists of a single atomic plane of hexagonally arranged sp^2 bound carbon atoms [1], has attracted tremendous attention owing to its unique properties. From the practical point of view, the most interesting properties of graphene are its extraordinary electron mobility of up to ~200,000 $cm^2V^{-1}s^{-1}$, outstanding mechanical rigidity and its extremely high thermal conductivity exceeding ~3000 W/mK near room temperature [2]. These and other properties of graphene make it a promising material for applications in low-power electronic devices, biological and chemical sensors, low-noise high-frequency transistors, heat spreaders, interconnects and MEMS/NEMS.

In this talk I will review our results pertinent to the mechanical, vibrational, thermal and electronic properties of the single-layer and few-layer graphene. Specifically, I will describe characterization of material properties of graphene using the micro-Raman spectroscopy, focusing on determining the number of graphene layers and their quality through deconvolution of the 2D band in its Raman spectrum [3]. The lattice vibrations and phonon properties of graphene will be discussed in details [4]. The unique measurement procedure for investigation of the phonon transport and heat conduction in graphene flakes suspended across trenches in Si/SiO_2 wafers will be described. In the last part of the talk, I will review our results for the electronic flicker noise in graphene devices [5]. It was discovered that the level of the low-frequency noise in graphene devices is substantially lower than that in carbon nanotube devices. The latter is important for the proposed graphene's applications in sensors and electronics.

[1] K.S. Novoselov, A.K. Geim, S.V. Morozov, D. Jiang, Y. Zhang, S.V. Dubonos, I.V. Grigorieva, and A.A. Firsov, *Science* **306**, 666 (2004).
[2] A.A. Balandin, S. Ghosh, W. Bao, I. Calizo, D. Teweldebrhan, F. Miao, and C.N. Lau, *Nano Letters*, 8, 902 (2008); S. Ghosh, I. Calizo, D. Teweldebrhan, E.P. Pokatilov, D.L. Nika, A.A. Balandin, W. Bao, F. Miao, and C. N. Lau, *Appl. Phys. Lett.* **92**, 151911 (2008).
[3] I. Calizo, A.A. Balandin, W. Bao, and C.N. Lau, *Nano Letters* **7**, 2645 (2007).
[4] D. Teweldebrhan and A.A. Balandin, *Appl. Phys. Lett.* **94**, 013101 (2009).
[5] Q. Shao, G. Liu, D. Teweldebrhan, A.A. Balandin, S. Rumyantsev, M. Shur, and D. Yan, *IEEE Electron Device Letters* **30**(2), (2009).

Development of Reliable and High Power MEMS Varactors

Blondy P., Stefanini R., Courreges S., Pothier A., Orlianges J.C., Crunteanu A., Chatras M.

XLIM Research Institute, CNRS, Universite de Limoges, 123 Avenue Albert Thomas, 87060 Limoges – France

RF-MEMS are expected to have a major impact on future telecommunication systems and radio frequency components. Indeed, they combine the advantages of mechanics, like linearity, low loss, and low power consumption, but also the integration, collective fabrication process and small size that are typical properties of microelectronics.

However, poor reliability and incomplete understanding of all degradation mechanisms present in these components have hindered fast and practical implementation of these devices into RF and microwave subsystems.

This talk will present the effort currently carried in our institute towards the development of low cost, highly reliable RF MEMS switched capacitors arrays. XLIM has developed an original technique using an air gap device that strongly reduces charge injection and trapping into dielectric layers, thus increasing dramatically the lifetime and overall degradation of MEMS properties.

The first part of the presentation will be devoted to the presentation of the concept in itself and the resulting properties of the fabricated structures. The methods and test benches that have been developed to assess the reliability of the devices will be outlined. Next, the effects of applied microwave power on reliability will be shown and the latest results on power handling will be presented.

In a second part, we will show the potential applications of this technology to several microwave components such as planar filters, cavities and tunable antennas. High Q, 10% tuning, microwave cavities around 5 GHz, with Qs exceeding 500 in the worst case have been fabricated and tested. Also, 200 MHz to 400 MHz tunable filters will be shown with low loss and medium power handling. Lastly, the talk will include high Q, 27 GHz, surface mounted cavities, with Qs between 500 and 700 for all states.

Detonation Nanodiamond - the Promising Material for MEMS/NEMS Applications

Dideykin A.T.

Ioffe Physical-Technical Institute RAS, 194021 St.-Petersburg, Russia

Detonation nanodiamond (DND) is the material that consists of the amount of single crystalline diamond particles of about 4-5 nm in size. The technology for its synthesis is based on the condensation of the excessive carbon of the explosive substances into diamond nano crystals under conditions of the detonation wave. It was found that each DND particle contains the single crystalline diamond core, the transition layer of disordered diamond-like carbon and the graphite- like shell of several atomic layers thick. The shape of the particle is quasi-spherical, sometimes, with the signs of the facets (depends upon the thickness of the graphite-like shell). The thickness of the graphite like (onion like) shell can be modified by annealing in vacuum, in neutral atmosphere or by electron beam treatment. The surface of DND particle usually contains the carboxyl (COOH) functional groups that can be replaced for other molecular fragments by appropriate chemical treatment.

Today this remarkable material is available as the industrial product with wide range of applications. The main applications of DND are the fine polishing abrasives, the add-ons to the oils and greases, the component of the polymer composites and the protecting nanodiamond-metallic galvanic coatings, precursors for CVD diamond films.

The extreme hardness, chemical stability and sharp size distribution make DND particles to be very attractive for the future applications in MEMS/NEMS technologies. They can help to reduce friction between the parts of MEMS, or play the part of building blocks for NEMS, probably, in combination with carbon nanotubes (CNT) and the electron beam as the assembling tool.

The main issues for the further broaden the application area of DND to the MEMS/NEMS technologies, medicine, biology, fine chemical technology, electronics, etc. are the insufficient level of the purification from the chemically resistive impurities and the agglomeration of DND into the stable aggregates of 100 -500 nm in size. Solving the abovementioned problems undoubtedly, will make DND to become one of the basic carbon materials, along with CNT and grapheme, for future nanotechnologies.

MEMS Markets overview

Eloy J.-C., Robin L., Mounier E.

**Yole Développement, Lyon, F-69006*

This paper will highlight the trends for the years to come for the different MEMS markets. We will present our latest analysis for the 2008 – 2014 MEMS markets forecasts (at the chips and equipments/materials levels).

The impact of the financial crisis on the different MEMS will be discussed. In particular, driving applications for MEMS (automobile and consumer) will be analyzed. Today, an important part of the MEMS market is driven by the growth of consumer applications, which is quite new in "MEMSland". The next years will certainly see the dominant growth of consumer applications compared to automotive, industrial and/or medical business. Although it is strongly impacted by the economic crisis, consumer is a strong driving force for the MEMS industry to have more integrated devices at lesser cost (cell phones with gyro-based optical stabilization modules, pico-projectors ...).

There are also very interesting new emerging MEMS devices which could have market growth for the years to come:

- Multi-frequency oscillators: application is the replacement of several quartz oscillators in order to have integrated solutions for consumer products
- Micro-fuel cells
- Silicon micro-motors
- Auto-focus, microzoom

The markets for these devices will be presented and discussed.

A focus will also be made on the MEMS equipment and materials market as well with market forecasts for specific MEMS processing tools such as DRIE, wafer bonders.

At last, the different business models for the MEMS industry will be presented and discussed.

MEMS for Practical Applications

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Application oriented MEMS (Micro Electro Mechanical Systems) developments by open collaboration with industry have been pursued in Tohoku University. A slim facility in which 20mm silicon wafers are processed using home made equipments has been used for MEMS prototyping. The facility is shared by many laboratories and more than 100 companies have dispatched full time researchers for collaborative development and technology transfer since approximately 30 years ago. Access to accumulated knowledge has been important for efficient development of MEMS. Three examples of commercialization in this collaboration are described below.

Electrostatically levitated rotational gyroscope has been developed for the purpose of motion control and navigation [1]. A 1.5 mm diameter silicon ring which is electrostatically levitated by digital control using capacitive position sensing and electrostatic actuation is rotated at 74,000 rpm. The rotation is based on the principle of a variable capacitance motor. The inertia measurement system (Tokyo Keiki Inc. MESAG (Micro Electrostatically Suspended Accelerometer Gyro)) using the rotational gyroscope can measure two axes rotation and three axes acceleration simultaneously with high precision (sensitivity 0.01 deg/s and 0.2mG respectively).

MEMS switch which uses a thermal bimetal actuator for making contact to multi-springs was developed [2]. The springs have electrical connections to the backside using the electrical feedthrough in a glass. This switch has been used for latest high speed LSI testers (Advantest Inc. T-2000).

Silicon micromachined two-dimensional galvano optical scanner was developed [3] and commercialized (Nippon Signal, Eco Scan). The optical scanner has been used as 3D-imager by using time of flight of laser light for the purpose of surveillance for example in airport. The scanner is being applied for laser projector used in portable IT systems as well.

[1] T. Murakoshi, Y. Endo, K. Sigeru, S. Nakamura and M. Esashi, *Jpn. J. Appli. Phys.* **42**, Part 1, 2468-2472 (2003).

[2] Y.Liu, X.Li, T.Abe, Y.Haga and M.Esashi, in Proc. of MEMS' 2001, Interlaken, Switzerland, 2001, pp.220-223.

[3] N.Asada, H.Matsuki, K.Minami and M.Esashi, *IEEE Trans. on Magnetics* **30**, 4647-46496 (1994).

Smart Sensors: Advantages and Pitfalls

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For almost 50 years, silicon sensors have been on the market. There have been many examples of success stories for simple silicon sensors, such as the Hall plate and photo-diode. These have found mass market applications. The development of micromachining techniques brought pressure sensors and accelerometers into the market and later the gyroscope. These have also achieved mass-market. The remaining issue is how far to integrate. Many of the devices on the market use a simple sensor with external electronics or read-out electronics in the same package (system-in-a-package). However, there are also many examples of fully integrated sensors (smart sensors) where the whole system is integrated into a single chip. If the application and the device technology permit this, there can be many advantages. A broader look at sensors shows a wealth of integrated devices. The critical issues are reliability and packaging if these devices are to find the applications. A number of silicon sensors and actuators have shown great commercial success, but still many still have to find their way out of the laboratory. This paper will examine the development of the technologies, some of the success stories and the opportunities for integrated Microsystems as well as the pitfalls.

Surface Characterization for MEMS/NEMS Materials and Processes

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The controlled etching of micro/nano structures is important for a variety of technological applications, including MEMS fabrication. XeF_2 is an isotropic and selective vapor phase etchant used to etch Si and metals in MEMS and other devices. For more efficient process control in manufacturing, and better device functioning and reliability in products, it is important to understand etching mechanisms at the molecular level. In this study we explore the surface and gas phase chemistry of XeF_2 etching of metallic films. In-situ XPS is used to analyze the surface composition of etched films while morphology of the etched films is studied by AFM. Etch rates are determined from total pressure, quartz crystal microbalance, and other methods. Down stream mass spectrometry is used to identify the gas phase by-products in the etching process. Ion scattering methods have been used to measure the thickness of the films and the depth profile of the near surface species after etching. Ideas for process optimization and new etch chemistries will also be discussed.

Integration of Diverse Biological Materials in Micro/Nano Devices

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The reasons for integrating biological materials in micro/nano devices can be divided into two broad categories. First, these materials confer a specific functionality to the devices; second, the devices can be used to characterize the materials with high precision and resolution. This presentation describes key examples of our work on biomaterial integration that fall under one of these two categories.

We use the polysaccharide chitosan for immobilization of DNA and proteins in micro- fabricated sensors to make them responsive to a particular sample. Chitosan has some unique properties, including the ability to be electrodeposited and to bind biomolecules covalently. Two types of devices were functionalized in this manner: a microcantilever sensor and an optical sensor. In some cases, the use of chitosan was shown to improve the detection signal by a factor of 100 compared to devices without chitosan.

We have developed a method for depositing tobacco mosaic virus on micro scale electrodes in order to increase the effective surface area. This approach was used to fabricate micro batteries with enhanced capacity. Consequently, the capacity was increased by a factor of 6 compared to devices with planar electrodes.

In some cases, biomaterials are incorporated into micro/nano devices for characterization purposes rather than functionalization. For example, we have demonstrated the culturing of bacteria in microfluidic test platform. The growth of bacteria over time is measured optically to provide information about the bacterial response to different stimuli. In a related demonstration, bacterial enzymes are assembled in a fluidic channel and their products under varying conditions are detected with a microcantilever sensor. The use of microfabricated devices for these experiments enables high-density, high-throughput measurements of the biomaterials to be performed.

Three-dimensional Photonic Crystals based on Opal-semiconductor and Opal-metal Nanocomposites

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Photonic crystals (PCs) are materials with a periodical modulation of dielectric permeability on the scale of the order of the light wavelength. The photonic band structure of such materials is determined by the PC lattice period and symmetry and also by the dielectric contrast, i.e., the ratio between dielectric permeabilities of the components that comprise the PC. Similar to the forbidden band gap structure of atomic crystals, the PCs have frequency regions (photonic band gaps - PBGs) in which light propagation inside the PCs is suppressed in one direction or all crystallographic directions (a complete PBG). It is just the PBG that allows control of spontaneous emission and leads to light localization. This opens up the way to application of PCs in optical communication and information transmission systems, laser technology, quantum computers, etc.

The report describes methods of fabrication of three-dimensional PCs based on opal-filler (semiconductor or metal) nanocomposites and experimental demonstration of an ultrafast control of light beams in such 3D PCs. We demonstrate the possibility to control light beams in 3D PCs based on opal-Si and opal-VO_2 nanocomposites. A photoinduced change in the modulation depth of the PC dielectric permeability and, hence, the change in the PBG position and width was achieved in optical experiments with the femtosecond resolution by subjecting the electron subsystem of the semiconductor (Si, VO_2) PC component to a laser pulse. We succeeded in achieving the highest parameters for 3D PCs, i.e. PBG switching of not more than 30 fs in the opal-Si composites, and an extremely large (~25 meV) ultrafast (~500 fs) PBG shift caused by a photoinduced phase transition in VO_2 in the opal-VO_2 composites.

The periodicity of dielectric constants in opals is accompanied by a periodicity of acoustic impedance. The elastic coupling between a-SiO_2 spheres composing opal films brings forth 3D periodic structures which, in addition to a PBG, are predicted to exhibit complete phononic band gaps. The influence of elastic crystal vibrations on the photonic band structure was studied by injection of coherent hypersonic wave packets generated in a metal transducer by subpicosecond laser pulses. These studies showed that light was efficiently modulated by hypersonic waves. With such a photonic-phononic system, ultrafast manipulation and control of light beams by hypersonic waves in the structures having the complete 3D photonic and phononic gaps may become feasible, promising a new generation of acousto-optical devices.

The work was supported by the RFBR, RAS, and FASI.

MEMS-based Displays

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Coloration in nature is generally realized in two ways, through pigmentation or by means of controlling the flow of photons in thin optical films or/and 3D structures.[1,2] Iridescence (originated from the Greek word “irides” – “rainbows”) is an optical phenomenon caused by multiple reflections from multiple layers of optical films in which phase shift and interference of the reflections modulates the incident light by amplifying or attenuating certain wavelength more than others.

Recent developments in micro- and nano-fabrication and photonics allow one to fabricate structures that can mimic iridescence in nature by manipulating light in a controlled manner in MEMS/NEMS architectures, thus opening up a window for a variety of novel devices and applications. The Qualcomm mirasolTM reflective display is a high speed, electrostatically actuated, bistable MEMS device built on a transparent (e.g. glass) substrate.[2-5] Basic device consists of a suspended conductive membrane serving as a mirror, over a partially reflective optical stack. There is a few hundred nanometers wide gap between the two that is filled with air. Interference between light reflected from the mirror and from the partially reflective optical stack generates vibrant color. This revolutionary interferometric modulator (IMOD) technology offers significant benefits in viewability, ruggedness, and power reduction, which make it attractive for a wide variety of consumer electronics applications.

Using IMOD technology as a typical example, we will discuss key device concepts of capacitive MEMS [6]. Basic electromechanical physics of the device and reliability aspects will be addressed. The dielectric stack is an important element of capacitive MEMS. Therefore, the role of the dielectric and electronic transport effects during device operation will be reviewed, as well as materials and process related issues. Finally, fabrication principles of the devices, as well as the current status of the technology for large scale manufacturing will also be discussed.

[1] P. Vukusic, “Manipulating the flow of light with photonic crystals” Physics Today, Oct 2006, p. 82

[2] J. B. Sampsell, "Causes of Color: Especially Interference Color," Proceedings of the Fourteenth IST Color Imaging Conference, 2006, p.90

[3] J.B. Sampsell, “MEMS-based display technology drives next-generation FPDs for mobile applications”, Information Display, June 06, p.24

[4] M.W. Miles, “Toward an iMoD ecosystem”, Hilton Head 2006 – A solid-state sensors, actuators and Microsystems workshop, June 2006

[5] M.W. Miles, E. Larson, C. Chui, M. Kothari, B. Gally, and J. Batey “Digital paper for refractive displays”, SID, 2002.

[6] D.Felnhofer, K.Khazeni, M. Mignard, Y.J. Tung, J.R. Webster, C. Chui, and E.P. Gusev, *“Device physics of capacitive MEMS”*, Microelectronics Engineering, 84, 2007, p. 2158

High Temperature Stable Au/Sn and Cu/Sn Interconnects for 3D Stacked Applications

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The desire to directly integrate MEMS with ASICs in a 3D stack is the main motivation behind the development of a bonding technology suitable for both interconnects and seal rings. SLID (Solid-Liquid Inter Diffusion) bonding processes based upon Au/Sn and Cu/Sn (high melting point metal/low melting point metal) is therefore investigated [1]. The benefit of such a non-eutectic metallurgy is that the bond will initially form at the melting point of Sn (232°C) whereas the final intermetallic compound (IMC) AuxSnx and CuxSnx will have a higher melting point. This allows for subsequent bonding cycles in the case of chip stacking, or if interconnections and seal rings are bonded at different steps in the process steps. For these scenarios, it is important that the initial bonding material can withstand high temperatures without being compromised.

This work presents an alternate method to achieve fluxless bonding in SLID Au/Sn and Cu/Sn bonding process instead of vacuum bonding, which may complicate time and temperature control. Thus, in order to protect the metal surfaces from oxidizing at elevated temperatures, a pre-bonding annealing process is employed to form a thin layer of IMC on the Cu or Sn surface [2] where micro-thickness sandwich-multilayers are electroplated to form interconnects and seal rings. It is important to keep the protective IMC layer intentionally thin as not to interfere with the inter-diffusion process during bonding. To evaluate the bond strength, test dies bonded to Au and Cu patterned substrates are subjected to SEM/EDX bond line analysis and shear testing at both room and elevated temperatures. For the Cu/Sn samples, the measured shear strength is comparable to conventionally SLID bonded interconnects. For the Au-Sn samples no bond delamination was observed up to 380°C which is 100°C higher than the eutectic point.

Furthermore, since the SLID bonding process neither is a collapsible, nor a reflow process, the height uniformity of the electroplated interconnects will significantly affect the bond quality and yield. For 3D MEMS/ASIC heterogeneous integration, a sealing ring is usually required in conjunction with interconnects, which makes the uniformity of the deposited metal even more critical [3]. New results using electroplating process control together with mask optimization will be presented.

[1] H. Huebner, S. Penka, B. Barchmann, M. Eigner, W. Gruber, M. Nobis, S. Janka, G. Kristen, and M. Schneegans, *Microelectronic Engineering* **83**, 2155-2162, 2006

[2] K. Wang, K. Aasmundtveit, and H. Jakobsen, "Surface Evolution and Bonding Properties of Electroplated Au/Sn/Au," Proceedings of The 2nd Electronics System-Integration Technology Conference (ESTC), 2008

[3] H. Liu, E. M. Husa, Z. Ramic, A. Munding, K. Aasmundtveit and N. Hoivik, "Uniformity requirements for electroplated Cu-Sn interconnects used in heterogeneous 3-D MEMS/ASIC stacks", in Proceedings of IMAPS Nordic, IMAPS, 2008.

Development of DRIE for the Next Generation of MEMS Devices

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The Bosch process [1] has been fundamental in enabling the commercialisation of MEMS devices. Before this pioneering technique, plasma processing mainly used a combination of gases in a continuous mode to etch material with limitations in etch rate and selectivity [2]. Since the initial granted patent in 1994 [1], which enabled faster etch rates with enhanced selectivity to be obtained compared to non switching techniques [2,3], the development of the switched approach has allowed etch rates to increase by more than 200% along with enhanced control of profile and other measured parameters.

Each MEMS device has its own unique requirements and utilising DRIE (Deep Reactive Ion Etching) equipment to attain these specifications is challenging. Advancements for some key areas such as targeting etch rate for micro-fluidic applications, controlling sidewall roughness inherent with the Bosch technique for optical applications or submicron requirements and achieving high aspect ratios (HAR) for devices such as infrared detectors or sensors is necessary for the next generation of devices.

This paper will describe how DRIE processing can be developed further to meet the targets for the growing plethora of MEMS devices. The Bosch process can be regarded as comprising of three phases; deposition, deposition removal and silicon etch, this paper will consider ways to optimise each phase of the process and equipment to target the device requirements. In detail, methods to increase etch rate for increased throughput and methods to tackle the increased aspect ratio required for next generation devices will be discussed.

[1] F. Laermer and A. Schlip, German Patent DE4241045 (1994).
[2] B.N. Chapman, *Glow Discharge Processes*, New York, Wiley Press (1980).
[3] A.A. Ayon, R. Braff, C.C. Lin, H.H. Swain and M.A. Swain, *Journal of the Electrochemical Society* **146** (1), 339-349 (1999).

Ultra Low Power Sub-100nm Laterally Actuated Nano-Electro-Mechanical (NEM) Switch in an Industry Standard Process Flow for Logic and Memory Applications

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Power-performance trade-offs in ultra scaled Complementary Metal Oxide Semiconductor (CMOS) technology increasingly constrain functionality gains from generation to generation. However, such constraints may be circumvented by the use of NEM switches. They have several attractive features: i) high on current, ii) practically zero off state current iii) ultra-steep sub-threshold slope, iv) high temperature operation, v) radiation immunity and vi) compatibility with inexpensive substrates such as glass and quartz. However, many challenges must be solved first: i) stiction; ii) suitable metallic contacts; iii) wear; iv) reliability; v) switching speed. Several research groups have shown promising NEMS simulation results1-5. A few have reported experimental results on vertically-actuated cantilever-based structures with a single actuation electrode6-8. However, these conventional switches with single actuation electrode, suffer from impact bouncing and long settling time due to release vibrations. In this work, we introduce for the first time the characteristics of the laterally-actuated, double-electrode NEM logic switches. The lateral NEM technology has two key advantages: 1) Device footprint is independent of the beam width and is a function of the beam thickness – usually much smaller than its width – leading to smaller area2. 2) In contrast to vertical actuation, lateral NEM designs enable implementation of symmetrical electrode structures suitable for logic gate fabrication. This symmetry is exploited here for double-electrode switches, which is a key step towards our objective of energy-reversible (ER) NEM logic gates3. ER gates have several advantages over conventional (CMOS-like) NEM gates, including supply voltage, switching energy, and reliability3. In addition, double-electrode switches and ER gates do not suffer from the long settling time (after turn-off) that decreases the switching speed of single-electrode structures.

We report the first experimental demonstration of ultra low power Nano-Electro-Mechanical (NEM) switches with the following attributes: lateral actuation, double electrode, sub-100nm dimension, vertical metallic contact, industry standard flow, zero off state current, low operating voltage (4.25V) and fairly large hysteresis window (~5V). These attributes present NEM switch as a promising building block for ultra low power logic and memory devices. Use of an industry standard flow holds promise for added functionality in existing CMOS platform via hybrid integration.

[1] H. Kam, et. al. *IEDM* 2005; [2] K. Akarvardar et. al. *IEDM* 2007; [3] K. Akravardar, et. al. *DRC* 2008; [4] M. Li, et. al. *Nature Nanotechnology* **2**, 114, 2007; [5] H. Dadgour, et. al. 44th Annual Conference on Design Automation 306, 2007; [6] S. Bhunia, et. al. Conference on Asia South Pacific Design Automation, 86, 2007; [7] W.W. Jang, et. al. APL **92**, 103110 (2008); [8] L. Duraffourg, et. al. APL **92**, 174106 (2008).

Low Temperature Processes for MEMS Device Fabrication

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High temperatures typical in semiconductor and conventional MEMS fabrication limit the material choices of MEMS structures and there is wide interest in post-CMOS processing and for compatibility with aluminium metallization. This paper reviews some of the low temperature processes and techniques available for MEMS fabrication and describes some characteristics of these techniques and practical process examples.

Silicon direct bonding with subsequent high temperature annealing is a standard method for fabrication of silicon-on-insulator wafers for MEMS and sensor applications. We have a long experience in low-temperature silicon direct bonding based on plasma activation of bonding surfaces and several activation processes have been developed for our plasma tools. Strong bonding can be achieved even in 200°C which enables the bonding of wafers with metal structures. This echnology has been utilized e.g. in wafer-scale packaging and MEMS device fabrication.

Silicon dioxide is one cornerstone of silicon based MEMS fabrication. However, thermal growth of oxide and low pressure chemical vapour deposition (LPCVD) of oxide typically require higher temperature than what is desired for many applications. Plasma enhanced chemical vapour deposition (PECVD) offers a low temperature (< 200°C) option for silicon dioxide and silicon nitride deposition. These processes can be tailored to deposition temperatures between 100-200°C. These films are relatively free of pinholes for thicknesses above 100 nm and the thickness uniformity is around ±1%.

A modern alternative for the growth of other oxides is the atomic layer deposition (ALD) method. Insulating Al_2O_3 and semi-insulating TiO_2 layers can be grown at temperatures down to about 110°C. In addition to utilizing the electrical, optical and chemical properties of the pure oxides, by using Al_2O_3/TiO_2 nanolaminate layers, the electrical (dielectric constant, resistivity) and optical (refractive index) properties can be accurately tailored.

To replace silicon as a mechanical material we have studied the use of low temperature materials like co-sputtered amorphous metal alloys. Mo-Si-N films offer good stability and excellent elastic properties compared to metals. The electrical properties of amorphous metals are better than what is achievable with polycrystalline silicon films.

Finally, one of the key issues in the fabrication of surface-micromachined MEMS is the release of the mechanical structures. Sacrificial oxides are typically removed with aqueous solutions of hydrofluoric acid or with anhydrous HF-vapor. Polymers such as photoresist or polyimides offer a low temperature solution as a sacrificial layer material. It can be dry-released in oxygen plasma at temperatures below 150°C. Also the stiction of released structures, can be avoided by a dry release processes.

As a practical example of the use of these techniques the basic characteristics of a MEMS switch and other devices fabricated at VTT are presented.

Pull-in Dynamics of Electrostatically Actuated Bistable Curved Microbeams

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Instability of equilibrium of electrostatically driven MEMS devices, commonly referred to as pull-in instability, is encountered as a basic instability mechanism limiting the operational range of micro actuators. In these devices, increase of the actuation voltage is accompanied by a nonlinearly (in terms of deflections) increasing electrostatic force which cannot be balanced by typically linear or weakly nonlinear elastic restoring force beyond the pull-in point while one-to-one dependence between the voltage and the stable deflection is observed.

In this work we first present a few examples of the devices exhibiting multiple stable configurations at the same voltage (bistability [1,2] and multistability [3,4]). The multistability is possible in the case of non-monotonous dependence of the actuation force on the deflection [3] or highly nonlinear stiffening characteristic of the restoring elastic force [1,2]. Stability properties of an initially curved clamped–clamped microbeam actuated by a distributed electrostatic force is analysed in more details. Under static operation, this structure exhibits sequential snap-through buckling and electrostatic pull-in instability, as was shown theoretically and experimentally in [4]. Here, the results of theoretical investigation of the transient pull-in dynamics of the electrically actuated initially curved micron scale beam are presented. Reduced-order Galerkin and consistently constructed lumped models of the shallow Euler–Bernoulli arch were built and account for the distributed nonlinear electrostatic forces and nonlinear squeezed film damping as well as inertial loading. Rigorous phase plane analysis for various beam configurations is carried out using the single degree of freedom model and the dynamic snap-through and dynamic pull-in conditions are evaluated. Lumped model results are verified by numerical analysis, and the influence of various parameters on the stability is investigated.

Results of the work are relevant to a broad variety of applications including RF and optical switches, shutters and diffractive devices and can be used by MEMS designers for analysis of these kinds of devices.

[1] S. Krylov and Y. Bernstein. *Sensors and Actuators A* **130-131**, 497-512 (2006).

[2] S. Krylov, B. R. Ilic, D. Schreiber, S. Seretensky and H. Craighead. *J. Micromech. Microengr.* **18**, 055026 (2008).

[3] T. Shmilovich and S. Krylov. *Proc. IEEE MEMS'07*, 675-678 (2007).

[4] Y. Gerson, S. Krylov, B. Ilic and D. Schreiber. *Proc. IEEE MEMS'08*, 463-466 (2008).

Description of the Nano/Microelectromechanical Systems RTD Targets of the Russian Federation Programmes

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Dear Colleagues,

I would like to thank the organizing committee for the given opportunity to speak about micro-nanosystems.

Let me say a few words about this field's terminology formed in Russia. In general the terms coincide with European ones, but there is a term typical for our country.

The term "Microsystem Technique" got used in Russia's official documents after adoption of Critical Technologies List on federal level in 1996.

In 2001 Russian Fund of Technological Development (RFTD) of the Ministry of Industry, Science and Technologies of the Russian Federation held a competition on the subject: "New Generation Devices Development on the Basis of Microelectromechanical Systems" (E-mail: gubarev@minstp.ru).

The competition (by 5 projects) was conducted in following directions:

- Micromachines: power and motion sources, force drives and mechanisms.
- Microbiochemical systems: microdosers, micropumps, microvalves, microreactors and microfermentors.
- Microtelecommunication systems: controlled microelectromechanical radiocomponents, adaptive microelectrooptomechanical "bench".
- Analytical microsystems.

The developed devices are intended for use in Medicine and Biochemistry, Telecommunications, Industrial Automation, Space Industry, Motor Transport, Environment Monitoring.

At the beginning of 2002 Russian Agency on Control Systems (RACS, http://www.rasu.gov.ru) held a common competition on the fulfillment of research, experimental-design and technological tests in 2002 on the following sections of the federal aim-oriented program "National Technological Basis" for 2002-2006
(by 30 projects):

- Microelectronic technologies;
- Telecommunications technology;
- Computing systems technology ;
- Radio electronic, microwave and accustoelectronic technology.

The following projects were included in the list of the competitive projects on the section "Microelectronic Technology"(concerning Microsystem Technique and Nanoelectronics):

- The development of production technology of micromechanical elements for Microsystem technique on silicon technology.
- The development of base production technology of micromechanical elements for Microsystem technique on fiberglass technology.
- The development of device-technological base of production of intellectual nanotechnological complexes for nanoelements and terrobit micromechanical storage devices creation.
- The development of device-technological base of zond and ionic nanotechnologies of formation of elements with sizes less than 10 nm.
- The development of device-technological base of nanotechnological elements on the basis of nanotube carbon structures formation.

In 2000 Russia's Ministry of Higher Education opened training for engineers of a new speciality - 201900 **"Microsystem Engineering".**

In 2002 the Ministry of Education held an additional competition of projects devoted to 'Micro- and Nanosystem TECHNIQUE" and "Electronics" (subprogram) (by 130 projects). Main competition directions were:

- Fundamental Micro- and Nanosystem Technology;
- Special Microsystem Technology;
- Nanotechnology Processes;
- nanoelements and terrobit micromechanical storage devices creation.
- The development of device-technological base of zond and ionic nanotechnologies of formation of elements with sizes less than 10 nm.
- The development of device-technological base of nanotechnological elements on the basis of nanotube carbon structures formation.
- Methods of Nanodiagnostics;
- Micro- and Nanosystem Technology Components;
- Micro- and Nanomachines.

In Russia the problems of microsystem technique are illustrated by the scientific-technical and scientific-production journal **"**MICROSYSTEM TECHNIQUE**",** founded in 1999 (http: //www. microsystems.ru).

The interdisciplinary scientific, technical and production journal **"**MICROSYSTEM TECHNIQUE**"**is issued under the assistance of Russian Academy of Sciences. The purpose of the journal is to cover the modern status and perspectives of MICROSYSTEM TECHNIQUE development, to consider the problems of development and to introduce microsystems in various fields of science, technology and production. /…./

The year 2004 saw a new period of nano- and microsystem technique development in Russia; new terms were introduced.

In the Russian Federation nanotechnology development concept up to 2010, generally approved by the Government of the Russian Federation (November 18, 2004), there was introduced a term “Nanosystem Technique”.

Since 2006 the Ministry of Education and Science of the Russian Federation has been carrying out a program, according to the Russian Federation Critical Technologies Lists, affirmed by the President of the Russian Federation and united into priority direction “Nanosystems and Materials Industry”.

One of the Russian Federation critical technologies is “Mechanotronics and Microsystem Technique Creation Technologies”.

It should be mentioned that in 2005 the title of the magazine was broadened into “Nano- and Microsystem Technique”.

The main directions of microelectromechanical systems development are incorporated, first of all, by used materials are:

- Silicon (in all institutions of Russia);
- Silicon Carbide (St.-Petersburg, Samara, Taganrog);
- Ferroelectrical films (Novosibirsk, Rostov-na-Donu, Moscow).

At present Russian experts obtain interesting outcomes in the field of MICROSYSTEM TECHNIQUE. Recently the amount of Russian scientific institutions occupied by nanomechanics (nanotools and nanotubes) has been increased.

LIGA microtechnology is being developed now in Russia. Physical technological issues, requiring comprehension and solution, as well as the product examples and the areas of process application, are developed by the experts of Kurchatov Source of Synchrotron Radiation.

Besides, a new method of three-dimensional MEMS and their fabrication has been proposed and developed in Russia (Saratov). This new approach is based on fiberglass technology.

In 2007 the following Russian official documents and institutions were presented:

- President’s initiative «Nanoindustry Development Strategy»;
- Governmental council of nanotechnology;
- Russia’s Nanotechnology Corporation.

Russian sciences were presented at Micro@Nanosystems Parallel Session at Information & Communication Technologies Conference in the EU's 7th Framework Programme of 2007 and 2008 (Moscow).

According to the experts, the development of microsystem technique for scientific and technical progress can have the same consequences as the emerging of microelectronics rendered the formation and modern status of leading fields of science and engineering.

Microwave and Millimetre Wave Devices Based on Micromachining of III-V semiconductors

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Micromachining of III-V compound semiconductors is a very exciting but less explored alternative to manufacture high performance microwave and millimetre wave circuits. GaAs micromachining is very interesting also due to the possibility for monolithic integration of micromachined passive circuit elements with active devices manufactured on the same chip. The MBE or MOCVD epitaxially grown layers of III-V compound semiconductor heterostructures provide flexibility and precision in micromachining. These layers have sharp interfaces and due to different alloy composition, they can be etched by wet or dry techniques with excellent selectivity. The system GaAs/$Al_xGa_{1-x}As$ can be used for this purpose. Specific dry and wet etching systems exhibit etching rates of GaAs orders of magnitude higher then for $Al_xGa_{1-x}As$ and vice versa (if $x \geq 0.5$). Most commonly AlGaAs is used as an etch stop layer for GaAs.

The paper will present the development of millimetre wave filters, broadside and endfire antennae and direct (video-type) receiver modules based on micromachining of III-arsenides. The receiver modules have both the antenna (folded slot or Yagi-Uda type) as well as the monolithic integrated Schottky diode supported on the same 2μm thin GaAs membrane. The demonstrators have been developed for frequencies up to 60 GHz but the developed technologies can be employed for receiver modules working in the sub-millimetre frequency range.

The development of technologies based on micromachining and nano-processing of wide band gap III-nitride semiconductors (GaN/Si and AlN/Si) for manufacturing FBAR and SAW resonators for GHz applications will be also presented. Very recent results obtained by the authors, especially those regarding the first FBAR resonators on thin GaN/Si membranes with a thickness less then 0.5μm, are very promising for applications in the 3-6 GHz frequency range.

Monocrystalline-silicon Microwave MEMS Devices: Multi-stable Switches, W-band Phase Shifters, and MEMS Tuneable Frequency-selective Surfaces

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The most robust MEMS components utilize monocrystalline silicon as the structural material for the moving parts. Beside its yield strength exceeding steel by a factor of 2-3, monocrystalline silicon maintains its elastic properties upon large stress levels even when exposed to elevated temperatures, in contrast to metals which plastically deform [Petersen1982]. This advantage, in combination with silicon offering the largest variety of wafer-scale micromachining processes to shape it, make it the best suitable material for integrated components which have to move mechanically reliable for billions of cycles during their life time [KovacsBook1998]. Monocrystalline silicon has been successfully applied for robust pressure sensors, accelerometers, micromirror arrays [Niklaus2002] and microrelays [OMRON1999].

This paper presents a summary of innovative RF and microwave MEMS devices fabricated at the Royal Institute of Technology, employing monocrystalline silicon as structural and dielectric material to construct microwave MEMS devices with extraordinary performance:

(1) mechanically multi-stable switch mechanisms with static zero power consumption, embedded completely inside the signal line of a coplanar waveguide for minimal insertion loss, fabricated by a single-mask metal-coated monocrystalline-Si core SOI RF MEMS process: Figure 1 shows the basic concept of the mechanically interlocking mechanism based on two moving cantilevers, SEM pictures of fabricated 2port and 3port devices, and measured S-parameters.

(2) 4.25bit phase shifter with best performance (Δφ/loss/bit, reflections, IL) ever reported in the W-band (Figure 2): every stage of the multi-stage phase shifter consists of a high-resistivity Si block moving vertically above a 3D micromachiend coplanar waveguide by a MEMS electrostatic actuator to change the wave propagation speed in the transmission line. The blocks and the suspending mechanical springs are fabricated out of the same monocrystalline Si material. The effective dielectric constant of a block can be tailor-made by varying the etch hole pattern of the block, to enable stages of 15°, 30° and 45° (75 GHz). Performance data: 4.25bit, IL=3.5dB(75GHz) and 4.1dB(110GHz); RL=17dB(75GHz) and

12dB(110GHz); IL/bit=0.82dB(75GHz) and 0.96dB(110GHz); Δφ/loss=71°/dB(75GHz) and 98°/dB(110GHz); total length=5.5mm. The devices are fabricated by transfer bonding a SOI wafer to a Si substrate, and by defining the moving blocks/springs in the device layer of the transferred wafer.

(3) MEMS tuneable frequency-selective surfaces by distributed tuneable capacitors with embedded MEMS electrostatic actuators (Fig 3): a monocrystalline Si core, cladded on both sides by a gold layer, is transfer-bonded by polymer wafer-bonding to a low-loss microwave glass substrate with metal reflecting layers. The polymer layer is removed after fixating the moving parts with electroplated posts, resulting in a tuneable structure. Localized tuning of the elements results in a phase gradient in the electrical resonance frequency, so that it can be utilized as tuneable phase-shifter or as tuneable reflective surface for indirect beam steering with a single element.

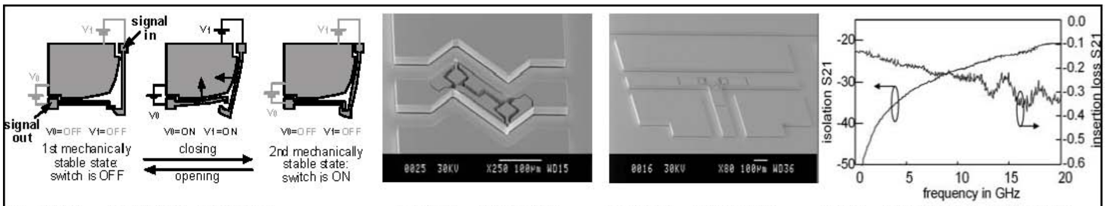

Figure 1: (a) switch mechanism (b) two-port device (c) three-port device (d) S parameters 2port device

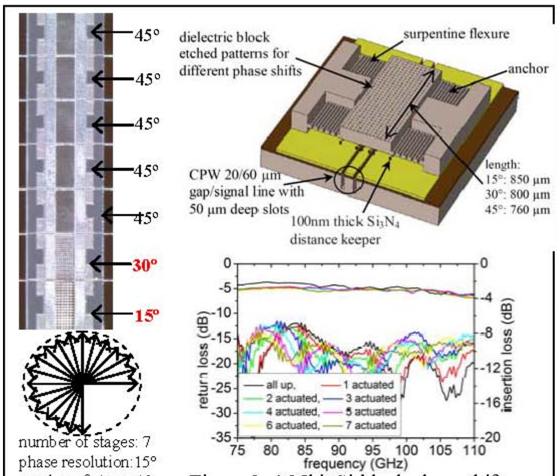

Figure 2: 4.25bit Si-block phase shifter

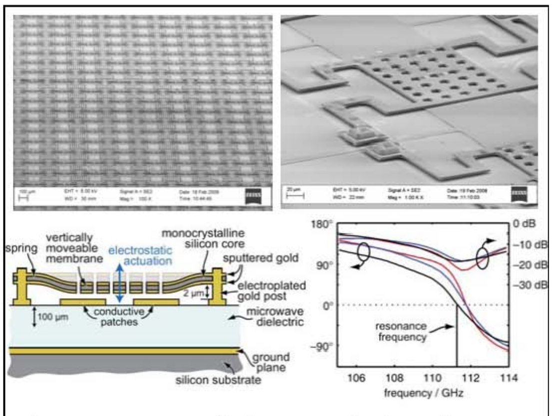

Figure 3: MEMS tuneable frequency-selective surface: SEM pictures array/single element; cross-section of an element; measured phase and magnitude of reflection coefficient

The Impact of Dielectric Material and Temperature on Dielectric Charging in MEMS Capacitive Switches

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The dielectric charging constitutes a major problem that still inhibits the wide application of commercialization of RF MEMS capacitive switches. The dielectric charging shifts [1] or narrows [2,3] the pull-in and pull-out windows leading always to stiction hence the devices failure. This effects occurs independently of the actuation scheme and has been attributed to charge injection during actuation.

Up to know several materials, such as SiO_2, Si_3N_4, AlN, $2O_3$, Ta_2O_5, have been proposed having in mind the deposition method maturity and the high dielectric constant. These materials consist of either covalent or ionic bonds, among which one is piezoelectric, a fact that significantly affects the charging processes. The presence or absence [6] of dielectric film as well as its expansion on the insulating substrate constitute a key issue parameter that influences the charging process. Finally, the device temperature [7] accelerates the charging and discharging processes by providing enough energy to trapped charges to be released and to dipoles to overcome potential barriers and randomize their orientation. The aim of the present work is to discuss in detail these issues and draw conclusions towards a better understanding of the effect of dielectric charging in RF MEMS capacitive switches.

[1] J. Wibbeler, G. Pfeifer, and M. Hietschold, *Sens. Actuators A, Phys.* **71**, 74 (1998).

[2] S. Melle, F. Flourens, D. Dubuc, K. Grenier, P. Pons, F. Pressecq, J. Kuchenbecker, J. L. Muraro, L. Bary, and R. Plana, in Proc. 33rd Eur. Microwave.Conf., Oct. 2003, pp. 37–40.

[3] P. Czarnecki, X. Rottenberg, R. Puers, and I. De Wolf, in Proc. MEMSWAVE, Jun. 2005, pp. 133–136.

[4] C. Goldsmith, J. Ehmke, A. Malczewski, B. Pillans, S. Eshelman, Z. Yao, J. Brank, and M. Eberly, in Proc. IEEE MTT-S Int. Microw. Symp., May 2001, vol. 1, pp. 227–230.

[5] G. M. Rebeiz, “RF MEMS,” in Theory, Design and Technology. Hoboken, NJ: Wiley, 2003, pp. 185–192.

[6] D. Mardivirin, A. Pothier, A. Crunteanu, B. Vialle and P. Blondy, *IEEE Trans. on Microwave Theory and Tech.* **57**, 231 (2009).

[7] G. Papaioannou, M. Exarchos, V. Theonas, G. Wang and J. Papapolymerou, *IEEE Trans. on Microwave Theory and Tech.* **53**, 3467 (2005).

RF MEMS/NEMS Technologies for Advanced Sensors and Scavengers

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In the field of Micro and Nanosystems, it is now understood that the advance in the field of knwoledge and in the field of technology is opening new paradigm concerning instrumentation that will be largely spread and wireless connected. In this context, the energy and the metrology will be two major issues. More precisally, it will be important to invent new generation of sensors featuring ultra low or zero power consumption, being able to sense diverse physical, chemical and biological quantities with enhanced resolution. Using Micro and Nanotechnologies, we believe that it will be possible to explore innovative ways fort he next generation of wireless sensors.

In this paper, we will investigate how the concept of Micro and Nano engineering of electromagnetic energy can be used to form new class of components for sensing or RF energy harvesting that will be very important for future generation of wireless sensor network. It will be shown that using the multi-physic coupling (i.e mechanical and electrical coupling), it will be possible to create millimeterwave pressure sensor featuring advanced sensitivity, highly sensitive dosimeter using the ability of RF MEMS/NEMS for dielectric charging or even power meter operating from 1nW to 1W that will be very important to introduce new functionnalities within the wireless architectures. It will be also shown that MEMS/NEMS will be used to develop gas sensor that could be involved in security and/or survey environnment applications. Additionnally, it will be shown that Micro and Nanoengineering will make possible the realization of innovative RF scavengers using Seebeck effect exhibited by Carbon nanotubes and the Ratchet Effect exhibited by Semi-conductor nanostructures.

It will be outlined that the new generation of sensors proposed are fully passive and will be read using RCS concept through FMCW millimeterwave radar.

Modeling of Dry Etching in Production of MEMS

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At present, microelectromechanical systems (MEMS) are widely used in various applications. As manufacturing technologies develop, the complexity of these devices grows as well as their influence to the cost of a final product. Therefore an optimization of MEMS manufacturing processes is of significant interest. Experiments of microchip fabrication are quite complicated and expensive and take a lot of time, so computer modeling seems like an attractive substitute which enables one to reduce the amount of work with real samples.

One of the important stages in a MEMS manufacturing process is dry etching with neutral gas. This processing type is required to remove parts (called sacrificial) which were used as a "mould" for the mechanical elements of the microdevice. Since this operation is performed at the last steps of processing then selectivity is one of the key issues in the choice of reactants. XeF_2 has a good selectivity in the etching of silicon/oxide systems, but it is relatively expensive for commercial production. Therefore it is important to optimize the efficiency of dry etching process with respect to etchant consumption.

Here we present a numerical model of dry etching of a cavity below a planar mechanical element (e. g. a mirror or a solid gear) through a set of holes in it. The model describes the evolution of etching profile connected to the molecular transport in the cavity and gas concentration in the reactor chamber.

Using the developed model we show that complex geometries of MEMS devices and low pressure of dry etching may lead to limitation of the etching rate by gas transport under mechanical elements, which means that etchant gas concentration is strongly inhomogeneous inside the etched cavities. From our numerical results, some criteria of distinction between the systems with and without transport limitation effect are provided.

Another important question is the influence of reactor parameters on the efficiency of etching process. For this goal we compare two types of the etching reactor: well-stirred (continuous-flow) reactor and batch (periodic) reactor using corresponding reactor models.

The adequacy of the above numerical simulations is determined by the choice of mathematical models for the considered processes and system components. Primarily, the choice of models is important for the following two problem elements: etchant gas transport inside the etched cavities and evolution of the cavities' shape and size. It was shown that diffusion model for the transport and string model for the cavities shape is the best choice for the problems discussed.

Electrochemical Models for the Redox Switching of Conjugated Polymers

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There has been considerable interest for using organic materials in electronic and electromechanical devices. Among organic materials, conjugated polymers (CPs) are proposed because of their ability to switch upon chemical or electrochemical doping between two states with different physical properties. In this communication, we present the electrochemical switching of two types of devices: a monolayer junction based on conjugated oligomers (COs) and electrochemical actuators.

We investigate the electron transfer properties of ultra-thin COs films by using electroactive probes having various redox potentials. Measurements clearly show that for redox probes with low redox potentials diode-like behaviour is observed and the current can flow in only one direction across these organic layers whereas, when the potential of the external redox probe increases, the transparency of the layers toward electron transfer in both direction increases [1-2]. We propose a mechanism allowing rationalizing these peculiar responses. A monolayer junction based on COs with a well defined metal/oligomer interface retaining reversible on/off switches capabilities controlled by the redox state of the COs would be of interest for molecular electronics.

We are also interested to study the electrochemical responses of CPs in the presence of room temperature ionic liquid for the development of electrochemical actuators [3]. Study of the electrochemistry helps determine the kinetics and thermodynamics that govern the transfer of electrical energy to or from the polymer, which in turn impact on actuator power density and electro-mechanical efficiency. We show that the CP electrochemical actuators behave as supercapacitor [4]. The charging/discharging kinetics has been studied.

[1] C. Fave, Y. Leroux, G. Trippé, H. Randriamahazaka, V. Noël, and J-C. Lacroix, *J. Am. Chem. Soc.* **129**, 1890 (2007).

[2] C. Fave, V. Noël, G. Trippé, H. Randriamahazaka, and J-C. Lacroix, *J. Phys. Chem. C* **112**, 18638 (2008).

[3] H. Randriamahazaka, C. Plesse, F. Vidal, C. Gauthier, C. Chevrot, and D. Teyssié. *Proceedings SPIE* **5385**, 294 (2004).

[4] H. Randriamahazaka, C. Plesse, D. Teyssié, and C. Chevrot, *Electrochim. Acta* **50**, 4222 (2005).

Advances in RF MEMS: Angular-Based Actuators for High-Yield Stress-Robust Designs

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RF MEMS metal-contact and capacitive switches offer key advantages in terms of linearity, loss, and power consumption compared to conventional solid-state switches. To date, they have been used extensively in a wide range of RF switching and reconfigurable networks with excellent performance. Metal-contact switches to-date are typically based on a thick cantilever process (6-10 um), while capacitive switches are typically based on a fixed-fixed beam with thin metallization. Both designs have high sensitivity to either the residual stress or the stress gradient, and this causes a large variation in the pull-down voltage across a wafer. This, in turn, results in a variation in the contact or release forces and affects the switch reliability.

In this talk, we report on new RF MEMS switch designs with very low sensitivity to biaxial stresses or stress gradient [1,2]. The cantilever (thick metal) or fixed-fixed (thin metal) designs are based on a circularly symmetric geometry with arc-type springs placed between the anchors and suspended beam. The symmetry of these designs reduces the sensitivity to vertical stress gradients and therefore minimizes the initial displacement of the suspended beam. These novel designs also compensate for the effects of the residual biaxial stresses in the beam which can vary with temperature, and this results in a pull-in voltage slope versus temperature of only -50 mV/ºC from -5 ºC to 95ºC. The novel designs show excellent uniformity on a wafer-scale and can be “transported” from process to process with minor changes.

The angular actuators also result in very flat cantilevers and thin membranes, and therefore, one can build large area RF MEMS devices using this approach. This results in large contact force designs, and several prototypes with > 300 uN of contact force have been developed. These new actuators are excellent for high power, high reliability switches, and will be presented at the conference.

[1] I. Reines, B. Pillans and G. M. Rebeiz, “A Stress-Tolerant Temperature-Stable RF MEMS Switched Capacitor,” IEEE MEMS, Sorrento, Italy, Jan. 2009.

[2] H.Sedaghat-Pisheh, J.-M. Kim and G. M. Rebeiz, “Novel Stress-Gradient-Robust Metal-Contact Switch,” IEEE MEMS, Sorrento, Italy, Jan. 2009.

European Approach Towards Smart Systems and Public Private Partnerships

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Beyond the continuous miniaturisation of microsystems or MEMS towards NEMS, the current trend is to enrich them by adding intelligence, hence enabling those miniaturised systems to exhibit smart behaviour. This may provide not only to products but even to whole industrial sectors competitive advantage. Whereas microsystems focused on miniaturised sensors, including some processing and/or actuation, smart systems will provide additional functionalities. They will be able e.g. to diagnose a situation, to predict, to make decisions, will be context aware and able to communicate and interact with other smart systems and the environment. It is expected that smart systems will provide the building blocks of the future Internet of Things. The 7th Framework Programme of the European Union for Research and Technological Development supports this initiative by means of its ICT Workprogramme.

The European Technological Platform for Smart Systems Integration EPoSS – an industry driven initiative - comprising great many leading European industrial as well as academia players, is working according to a common Strategic Research Agenda in joining the forces of all those actors towards the implementation of the commonly elaborated vision for 2020 and beyond.

Furthermore, following the financial and economic crisis, the European Commission adopted the European Economic Recovery Package with the commitment to create three Public Private Partnerships (PPP): (1) Factories of the future, (2) Energy-efficient buildings and (3) Green cars. The objective is to promote the convergence of public interests with industrial commitment and leadership to define strategic research activities in key sectors

Numerical Continuation Methods for Non-linear MEMS Actuators and Oscillators

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Non-linearities play an important role in microelectromechanical systems (MEMS) design. In common MEMS electrostatic and thermal actuators, the force depends in an intrinsically non-linear way on voltage and displacement. Mechanical spring structures can cause additional non-linearities via material, geometrical and contact effects. Additionally, non-linear damping mechanisms can modify the dynamics of MEMS.

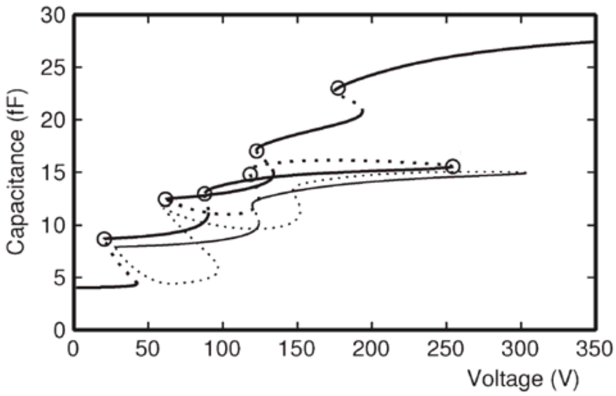

Figure 1. Solution paths and stability of an asymmetric see-saw capacitive MEMS device computed by numerical continuation [1].

In static actuators, non-linearities can lead to effects like instability and hysteresis. In dynamic devices like oscillators they can lead to anharmonicity, mixing and runaway. Therefore, it is essential for the efficient design and operation of MEMS devices to understand and model their effect. However, when there are many degrees of freedom, it becomes difficult to find all solutions of the non-linear equations. In these cases numerical continuation methods can be used as a powerful mathematical tool.

In this paper we will present several examples to illustrate how numerical continuation methods can be used efficiently to determine the static solution paths (see Fig. 1) of electrostatic MEMS actuators and their stability, extending on our previous work [1]. Moreover, we will show how numerical continuation can be applied to dynamic systems to determine the stability regime of a MEMS oscillator. The numerical continuation simulations will be performed both in MATCONT and by scripting in the finite element package COMSOL.

[1] J. Stulemeijer, J.A. Bielen, P.G. Steeneken and J.B. van den Berg, *J. Microelectromechanical Systems,* (2009).

3D Integration of MEMS and IC: Design, Technology and Simulations

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Wafer level packaging and 3D integration emerge as the solution for miniaturisation of future sensor systems. Densely packaged MEMS devices tightly integrated with their required IC chips and passives can add to the actuating or sensing functionalities of a system without increasing its size. However, most MEMS devices available on the market today are not readily prepared for such integration. Rather, most devices are designed to be mounted on a separate substrate with adhesive and wire bonds. A target within the EU funded project e-CUBES [1] has been to include MEMS devices in miniaturised sensor nodes. Various solutions for 3D integration of silicon based devices have been established to manufacture demonstrators with sensor nodes in the range of 1 cm^3. One of the demonstrators is a tire pressure monitoring system (TPMS) with two MEMS devices included: a pressure sensor and a bulk acoustic resonator (BAR). This paper describes the 3D integration of the TPMS. Research has been focused on technology development of through silicon via (TSV) and interconnect solutions applicable for these and similar MEMS devices. The mechanical aspect of the devices limits the range of usable technologies. New achievements within wafer thinning and wafer handling drive 3D integration of ICs forward, but a certain wafer thickness is crucial to achieve the required mechanical stability of MEMS pressure sensors. On the other hand, the TSV density and I/O count is quite low for most MEMS devices, which opens for alternative TSV and interconnect solutions to those tailored for IC 3D integration. MEMS sensors need to interact with the environment and such access must be ensured also when the sensors are 3D integrated. It was important to protect the inlet of the pressure sensor and to ensure a free surface for the BAR when stacking the silicon devices for the TPMS. A pressure sensor is especially sensitive to mechanical stress induced by the package as well as temperature changes. Stress induced from the package was minimized by choosing materials with well matched properties. This was important when choosing materials for the TSVs in particular. Thermal stress from neighbouring IC chips was estimated by simulations and possible hot spots were taken into consideration during the design of the stack.

[1] www.ecubes.org

Low Power Chemical Sensors for Safety and Security Applications

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Microsystems are undoubtedly the key solution for intelligent systems aiming at improving safety and security. Through MST technology it is possible to realize miniaturized chemical sensors with high sensitivity and selectivity suitable for portable equipment as well as for Wireless Sensor Networks. One of the key requirements for such applications is the minimization of power consumption. This is even more crucial when the sensor must work at elevated temperatures, such as the Metal Oxide chemical sensors that are widely used for the detection of hazardous and toxic gases.

In this work we present low power chemical sensors based on Porous Silicon Technology [1]. The use of Porous Silicon (PS) as a thermal isolation layer is an attractive alternative to Si_3N_4 or Si_3N_4/SiO_2, due to its very low thermal conductivity. Very high temperature rates (about $24^oC/mW$) have been obtained for classical type micro-hotplates with four supporting beams, demonstrating the very good thermal isolation achieved with suspended PS micro-hotplates. Moreover, there is another important advantage that stems from the use of Porous Silicon as material for the micro-hotplates. It permits us to implement alternative micro-hotplate designs [2], with two or even one supporting beam, which means that we can minimize the total area of the device as well as the power consumption. This possibility is very promising for the fabrication of low power sensor arrays.

Further power reduction can be achieved by using nanostructured catalytic materials being sensitive at lower temperatures [3] as well as by applying various measurement methodologies (pulsed mode vs constant temperature mode). A mixed-signal integrated circuit (IC) capable of handling up to four sensors and working at various modes has been designed and fabricated for this purpose. Measurements in various gas environments (NH_3, CO, NO) will be presented.

[1] C. Tsamis, A. Tserepi and A. G. Nassiopoulou, *Physica Status Solidi (a)*, **196**(2) (2003).
[2] R.Triantafyllopoulou, S. Chatzandroulis, C. Tsamis, A. Tserepi, *Microelectronic Engineering*, **83**, 1189 (2006).
[3] R. Triantafyllopoulou, X. Illa, O. Casals, C. Tsamis, A. Romano-Rodriguez and J.R. Morante, *Microelectronic Engineering,* **85**, 1116 (2008).

Challenges of Complete CMOS/MEMS Systems Integration

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Even before the term "MEMS" was coined and established, some of the early pioneers in this field envisioned ultimate monolithic integration of MEMS and ICs. Over three decades has passed and this is not yet a main stream technology in MEMS. However, the most significant MEMS products, like print-heads, ADI's accelerometers, TI's DPL, are utilizing monolithic integration. Their commercial success is the best evidence of this ultimate technological goal.

The first part of this presentation is an overview of early MEMS research and developments made in Russia (USSR) from 1971, which are not widely published and described in the western technical literature. Moscow Physics Engineering Institute was the first Russian organization where MEMS research was initiated in 1971. The number of world pioneering developments include: first monolithically integrated pressure sensor with amplifier (1972); first MEMS accelerometer (1974-75); microphone; sensors on bipolar and CMOS piezo-transistors (1975); IC circuits sensors (1975); detailed study and phenomenological model (later CAM) of anisotropic etching of silicon (1974-81); and a number of others. Among other Russian institutions participating in early MEMS works were: "Giredmet" (1976); "Nii Teplopribor" developed SOS pressure sensors (1973); "Component" (1976); "Electronpribor" in St. Petersburg developed together with MPhEI low cost pressure sensors and started its manufacturing in 1989; "Nii Physical Measurements" in Penza developed pressure sensors for Russian Shuttle – Buran; Technical University named after Bauman and Novisibirsk University made some research related to piezoresistive sensors (stating from late 1970s); later MIET was conducting a research in thin-film chemical sensors (1980s) and some other organizations.

Second part of the presentation is dedicated to the analysis of the challenges and historical reasons why monolithic integration of CMOS and MEMS is developing slower than it might be expected. Among the considered reasons are: specifics and historical evolution of micromachining technology toward processes more compatible with CMOS processing including dry versus wet processes, compatibility of materials and chemicals, compatibility of temperature regimes; enormously larger number of micro-mechanical "components" (structures) compared to the electronic components (transistors, etc.); orders of magnitude larger area of MEMS devices on the surface of the die / wafer; order of magnitude slower scaling of MEMS compared to CMOS; delay in introducing new generation of MEMS processing equipment for a larger wafer diameter; limited markets requiring very high volumes of MEMS products of the same kind; slow response on market demands to reducing the cost; lack of system approach to MEMS products commercialization. In the course of this analysis some real life examples are considered and some recommendations, solutions and forecasts are discussed.

Nanochip: A MEMS-based Ultra-High Data Density Memory Device

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Demand for higher capacity data storage has pushed conventional memory devices – magnetic discs, flash memory and optical storage devices – to the technological limits and attracted efforts to technologies that can provide both higher data density and higher capacity for storage devices. Probe storage technology utilizing AFM-type tips as read-write heads and MEMS micro-movers is a promising candidate for new memory devices.

A prototype of probe storage device (Millipede) utilizing polymer-based memory was demonstrated by IBM [1]. Writing bits is done by making indentations in the polymer by thermally-actuated cantilevers with sharp tips. Reading is based on thermal sensing. Slow writing, high power consumption, high temperature sensitivity and difficulties with data erasing are the main downsides of this approach.

Nanochip has developed a conceptual prototype of probe storage device (nanochip) utilizing ferroelectric memory and offering very fast read-write operations. Voltage pulses applied to the tips create local electric field capable of switching polarization of domains in a ferroelectric material – bits. Reading is achieved by sensing the charge associated with the bits. Multiple reading operations do not affect domain polarization. Data density of 1.9 Tb/in^2 has been demonstrated on multiple samples using 15 nm bits. Bit size can be reduced to 5-8 nm.

Fabricated prototypes have about 600 actuated cantilevers. Writing and reading was done at scanning speeds of 10-20 mm/s using only some of the cantilevers.

All major components and a conceptual prototype demonstrating basic functions of a memory device were built and tested. The results show that the major drawbacks of the earlier probe storage concepts can be overcome and bring the technology much closer to commercialization. Data densities of 2-4 Tb/in^2 can be achieved using the memory material and the recording technique developed by Nanochip.

[1] A. Pantazi et al. *IBM J. Res. Dev.* **52**(4-5), 493 (2008).

Combined Scanning Probe Microscopy and Micro/nano Raman Studies of Modern Nanostructures

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In this report, we demonstrate various applications of confocal Raman/fluorescence microscope integrated with Atomic Force Microscope (AFM). We report on "classical" applications of such combination, when 2D AFM and confocal Raman maps are acquired simultaneously from the *same* part of the sample, but "independently" one from another. Physical characterization and modification capabilities of AFM merge with chemical resolution of confocal Raman microscope and general capabilities of optical microscope to provide complete information about sample investigated. Diffraction limited resolution of 2D Raman maps is 200 nm. We demonstrate results on various promising nanoelectronics materials: graphene flakes, carbon nanotubes, semiconductor nanowires etc.

The ultimate goal of integrating AFM with Raman/fluorescence spectroscopy is to break diffraction limit and to bring spatial resolution of optical methods down to resolution of AFM (a few nm). We describe different ways of using light interaction with the apex of AFM cantilever to produce an optical signal originated from a substantially *subwavelength* sample area ($<50\times50$ nm^2) located *right below* apex of AFM probe. By scanning the AFM probe along the sample, getting 2D maps of Raman or fluorescence signals with subwavelength resolution (down to a few dozens of nm) is possible. We focus on the results of Tip Enhanced Raman Scattering (TERS) experiments – where Raman signal from narrow sample area below the metallized AFM tip is resonantly enhanced due to interaction with plasmons localized at the tip apex. The resulting resolution of 2D Raman mapping is about 60 nm that goes far beyond the optical diffraction limit. TERS data on carbon nanotubes, fullerenes, graphene and stressed Si structures is presented. We discuss experimental procedure and strict setup requirements for TERS experiments. Special emphasis is put on the difference between transmission (transparent samples) and reflection (opaque samples) TERS geometries.

Modelling of NEMS Based on Carbon Nanostructures

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At the present time a variety of nanoelectromechanical systems (NEMS) that employ carbon nanotube walls or graphene layers as movable elements are being developed [1]. The crucial issue for the design of such NEMS is the possibility to predict the system behavior at macroscopic operation times (more than 1 s) depending on the microscopic structure of the whole device and its components.

We developed a multi-level approach for studying the operation characteristics of the nanotube-based NEMS. In the framework of this approach, the tribological properties of NEMS were investigated depending on the parameters and microscopic structure of the system (temperature, length, interwall distance, structure of the walls/layers, defectness, etc.) through molecular dynamics simulations. The results of this study were then used to describe the dynamic behavior of the NEMS at long simulation times with the help of a phenomenological model.

For the use of NEMS it is essential to control the motion of the nanotube walls or graphene layers at long operation times. With molecular dynamics simulations, we demonstrated the possibility to control the motion of a functionalized nanotube wall with a non-uniform electric field. The characteristics of the control force required for the stationary operation of the NEMS were determined with the help of the phenomenological model.

Moreover, significant thermodynamic fluctuations were revealed in the considered NEMS. The fluctuations were shown to have a critical effect on the possibility of controlling the NEMS operation. Using the phenomenological model, it was demonstrated that the stability of the NEMS operation subject to the thermodynamic fluctuations can be achieved through increasing the amplitude of the control force and the NEMS size.

[1] Yu. E. Lozovik, and A. M. Popov. *Usp. Fiz. Nauk* **177**, 786 (2007).

Graphene: Properties and Modeling of Nanodevices

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As known graphite consists from coupled through weak, van der Waals forces graphene layers. But inside graphene layers the homopolar binding is very high. This gives the possibility to write by graphitic rods by splitting off graphite flakes. But several years ago the wonderful discovery was done by A.Geym team – single graphite monolayer, graphene with only one atom thick was experimentally obtained and its electronic properties were studied rather in detail now. Graphene is essentially harder than steel, its thermoconductivity is much greater than that for copper. But most wonderful are its electronic properties. The energy gap between valence and conductivity bands is identically equal to zero, effective masses both electrons and holes are also equal to zero. In result electrons and holes are described by Dirac equation but with zero mass. In result electrons in graphene penetrate with probability equal to one through any high potential barrier and backscattering for slowly varying potential barriers is impossible. This changes the effect of impurities by cardinal way, particularly weak localization become to be impossible. The last lead to some pecularities in creation of nanodevices based on graphene. From other hand the graphene has great potential for nanoelectronic and nanoelectromechnical system.

We studied the structure from two graphene layers independently gated .We predicted the existence of coherent phase and superfluidity in graphene bilayer originated from pairing of spatially separated electrons and holes. Bose condensation and Kosterlitz-Thouless transaition were predicted for bilayer graphene in strong normal magnetic field. The systems considered give the possibility to create nondissipative nanoelements for information transfer operating even at room temperatures.

Quantum dots, nanotransistors and new type of nanoelements based on graphene are discussed.

Calculations of nanoelements based on graphene by generalized density functional approach for system with “ultrarelativistic” electronic spectra is developed.

Possible NEMS based on graphene are analyzed.

[1] K. Geim, K. S. Novoselov. *Nature Materials* **6**, 183 (2007).
[2] Yu.E.Lozovik, A.A.Sokolik. *JETP Lett.* **87**(1), 55 (2008).
[3] Yu.E.Lozovik, S.P.Merkulova, A.A.Sokolik, *Physics-Uspekhi* 51(7), (2008).(translated from *Uspekhi fiz Nauk* **178**(7), 757 (2008).
[4] O.L. Berman, Yu.E. Lozovik, G.Gumbs, *Phys. Rev.* **B77**, 155433 (2008).
[5] O.L. Berman, Yu.E. Lozovik, G.Gumbs, *Phys. Rev.,* **B77**(15), 155433 (2008).
[6] O.L. Berman, R.Y. Kezerashvili, Yu.E.Lozovik, *Phys.Rev.* **B78**(3), 035135(2008).
[7] O.L.Berman, G.Gumbs, Yu.E.Lozovik, *Phys.Rev.* **B78**(8), 085401 (2008).
[8] Yu. E. Lozovik, et.al.(to be publ.)

Passive and Active Membranes for MEMS

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Results of complex investigations of flat and corrugated monolayer and multilayer micro- and nanosize composite membranes on the basis of Si_3N_4, BN, AlN, SiC, metals and polyimide are presented.

Different membrane constructions are examined [1], which ensures:

- high sensitivity to mechanical influences;
- control of intrinsic mechanical stresses and of membrane displacements by applying an electrical voltage;
- generation of electrical potential on membrane under mechanical deformations;
- storage of electrical charge on the "membrane-substrate" interface during long time;
- high selectivity of gas separation of oxygen and nitrogen when controlling air medium;
- stability under the influence of aggressive factors.

Results of investigations on multilayer Me/SiC/Si_3N_4 composite with artificial concentric and self-organizing radial ruffles are presented.

[1] A.V. Korlyakov, A.N. Krivosheeva V.M. Pasyuta, "Inorganic and organic nano- and microsize membranes for microsystem devices" in "Nanotechnology: physics, processes, diagnostics, devices", Edit. V.V. Luchinin, Yu.M. Tairov, Moscow, 2006, chapter 4, pp. 493 –516.

MEMS Composite Porous Silicon Crystalline Silicon Cantilever-array Biosensors: Continuous Sensing of Explosive and Chemical Warfare Agents

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The recent years have shown that homeland security capabilities and measures are lagging behind terrorist activities in the ability to trace explosives and non conventional warfare agents. The development of deployable, sensitive and informative means to detect today's threats is an expensive endeavor that requires the effective integration of know-how and technologies of numerous disciplines. One major obstacle in detection and identification of home made explosives and chemical warfare agents is their extremely low vapor pressure and lack of easily detectable signatures.

NEMS/MEMS sensors have the potential to become an effective platform for sensing a wide variety of substances in a continuous and parallel manner. NEMS/MEMS sensors have already proven to exhibit inherently high sensitivity. Nevertheless, they also lack the selectivity needed for such applications. Furthermore, low power and miniaturized readout is essential for field applications.

At Technion-Israel Institute of Technology we address the above issues. In our laboratories at Technion we develop micro cantilever sensor arrays that will provide a generic tool for sensing according to the following guidelines: the sensor is composed of large arrays of composite porous silicon/crystalline silicon cantilevers, each characterized by a low specificity high affinity sensing layer. Each crystalline cantilever sensor incorporates high nanostructure porous silicon surface that increase the surface area and thus its sensitivity. Smart sensing layers atop the high structure interact with the adsorbed molecules and amplify their induced signal on the cantilever. Selectivity is achieved through the use of different sensing layers and based on their specific reaction and interactions with the adsorbed molecules. External thermal stimuli are also used to differentiate between target molecules. Identification of specific target molecules will be achieved through response pattern recognition of the sensor array and is expected to provide a unique signature for each target species.

Low Frequency Noise in Nano-objects

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The low frequency (1/f and generation- recombination) limits sensitivity and determines the signal to noise ratio of gas, magnetic, acceleration, infrared (including terahertz), and many other sensors including MEMS/NEMS. The low frequency noise is also a powerful tool to study surface properties, material structural perfection, degradation, and deep levels in semiconductors. The decrease of the characteristic dimension of the sensors leads to the increase of the low frequency noise inversely proportional to the device volume or faster. Therefore, noise is one of the crucial factors, which determines the possibility of practical use of any sensor.

We review the noise properties of semiconductor nanowires (including Si, ZnO, GaN) and carbon nanotubes and show that the contribution of contact and surface can be minimized making the noise level comparable with the noise in bulk samples.

Recently the noise study in GAN nanowires showed that the level of 1/f and recombination-generation noise can be suppressed by ultraviolet radiation by up to an order of magnitude. This strong suppression of the noise is explained by the illumination changing the occupancy of traps responsible for noise [1].

The high sensitivity of the resistance and noise in the carbon nanotubes to the gas environment [2] shows a possible potential for their applications as chemical sensor.

[1] S.L. Rumyantsev, M.S. Shur, M.E. Levinshtein, A. Motayed, A.V. Davydov. *J. Appl. Phys.* **103**, 064501 (2008).

[2] S. Vijayaraghavan, S.Kar, S. Rumyantsev, A. Khanna, C. Soldano, N. Pala, R. Vajtai, K. Kanzaki, Y. Kobayashi, O. Nalamasu, M. S. Shur, P. M. Ajayan. *J. Appl. Phys.* **100**, 024315 (2006).

Low Cost Silicon Coriolis' Gyroscope paves the way to Consumer Inertial Measurement Unit

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During the last two years MEMS linear accelerometers have reinvented the way of playing a game, protecting your sensitive data on HDD, using your mobile devices smartly or making your washing machine less power hungry. Consumer and Industrial Markets have taken advantage from "The MEMS Consumerization Wave", driven by STmicroelectronics, which introduced a wide portfolio of two and three-axis motion sensors meeting customer requirements in terms of size, performances, quality and price.

What's next? More and more applications in the Consumer and Industrial markets are coming up with the need of sensing motion along multiple axes degree of freedom. Linear motion detection is requested to be combined with angular rate sensing along pitch, yaw and roll axis in the space to address a wide range of applications where four to six degree of freedom sensing feature is required. One example is related to Inertial Measurement Unit (IMU) or Inertial Navigation Unit (INU) where accelerometer and gyroscopes are each other complementary to detect linear and angular motion in several applications including image stabilization, enhanced user interface for mobile phones, games and pointers/remote controllers, pedestrian and car navigation for location based services and fitness/wellness people monitoring.

As seen for the accelerometer, once again size, performances and price are the driving factors for gyroscope success in Consumer & Industrial market.

This talk will provide an overview of the main gyroscope technologies (including electro-optic, mechanical, vibrating and micromachining ones) and applications today available in the Market, benchmarking the working principle and the key parameters relevant for Consumer and Industrial market applications.

In particular this talk will address the design and technology challenges addressed by STMicroelectonics to realize a stable and high resolution multiple axis compact Low Cost Silicon Gyroscope based on Coriolis' sensing force. It will also underline the challenge we are currently facing for the combination of the accelerometer and gyroscope in a single miniature module with all the signal conditioning required to run the specific algorithm.

Poster Session

Internal Stresses in Martensite Formation in Copper Based Shape Memory Alloys

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Shape memory alloys constitute a class of materials called smart materials which exhibit an unusual property, shape memory effect. The behaviour of these materials is evaluated by the structural changes caused by internal stresses in microscopic scale. Beta phases of copper based alloys have the disordered bcc structure, and undergo a solid state phase transition, martensitic transition following two types of ordered reactions called pre-martensitic transitions on cooling from high temperature. This transition occurs in two steps. First step is Bain distortion, and the second one is lattice invariant distortion. Both distortions are caused by the internal stresses in the material. The lattice invariant distortion involves the introduction of stacking sequences on one of the close packed $\{110\}_{\beta}$ planes of matrix called martensite basal plane. The formation and evolution of the layered structure in copper based ternary shape memory alloys consist of lattice invariant shears and shear mechanism.

The lattice invariant shears occurs, in two opposite directions, <110 > -type directions on the {110}-type basal plane. This kind of shear can be called as {110} <110 > -type mode and gives rise to the formation of layered structure.

The product phases have the unusual complex structures called long period layered structures such as 3R, 9R or 18R depending on the stacking sequences on the close-packed planes of the ordered lattice.

Shape memory materials are deformed plastically in martensitic state; it keeps the deformed shape after releasing the deformed stress and spontaneously returns to the original, pre-deformation shape upon heating over the reverse transformation temperature. Shape memory elements cycle between the deformed and undeformed shapes against the temperature while using in the devices. These alloys can be used as actuator or sensor due to this property.

Metastable phases of copper-based shape memory alloys are very sensitive to the ageing effects, and heat treatments can change the relative stability and the configurational order of crystal planes. The parent phase is highly symmetric and the product phase is internally twinned and complex. Also, several types of microscopic deformation involving changes can occur in the stacking sequence of close-packed planes of material with martensite formation.

In the present contribution, x-ray diffraction and transmission electron microscopy studies were carried out on two copper based shape memory alloys.

Mismatch Problems in Heterostructures on the Base of IV-VI Semiconductors

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The mismatch problems are always important at the study of heterostructures. Our researches and their analysis show, that slackening of the big mismatch influence is possible by the change of composition profile in heterostructure without change of width relation of forbidden band in its areas, and also by doping of active areas by such impurities as Cr, V, Mn, Ca. The modeling experiments on doped single crystals carried out by us show that the elasticity module, critical elastic deformation and accordingly an elasticity limit essentially increase for definite impurities at doping level ~0.5÷1at.% correspondingly [1]. Both these factors allow us to postpone the appearance of strains relaxation and defects in active layers.

The mismatch study not only in heterostructures in semiconductor system IV-VI and at the growth of their epitaxial layers on the substrates BaF_2, NaCl, KCl, CaF_2 presents the essential interest [2]. If the layer of width by the order of several hundreds of angstroms has the ability to extend with deformation $\sim(1.5\div2)\cdot10^{-2}$ then it is possible to save corresponding increase of forbidden gap [3]. The increase of forbidden gap achieves ~100 meV at the given deformations for solid solutions PbSnTe, PbSnSe. If the layer is doped, for example, Cr, then its impurity level deeply penetrates in the forbidden band and carrier concentration essentially increases. The Cr impurity allows us to also form the additional resource in the supporting of elastic state, the widening of forbidden gap at simultaneous stabilization of Fermi level.

[1] A. Pashaev, O. Davarashvili, V. Aliyev, G. Darsavelidze, M. Enukashvili, V. Zlomanov. *Transactions of ANAS* **28**(5), 96 (2008).

[2] A. Pashaev, O. Davarashvili, V. Aliyev, M. Enukashvili, V. Zlomanov. *Georgian Engineering News* № 3, 53 (2008).

[3] A. Pashaev, O. Davarashvili, V. Aliyev, L. Bychkova, M. Enukashvili, V. Zlomanov. *Georgian Engineering News* № 4, 7 (2008)

Mechanical Stress in PECVD Silicon Oxide Films for MEMS Application

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PECVD silicon oxide films are widely used to create both electrical and mechanical elements in MEMS. For power MEMS, thicker oxide layers are often desired in order to obtain higher electrical and mechanical levels. However, the ability to deposit oxide film with thickness significantly greater than the current capability of a few micrometers is largely limited by the stress level present in the film.

In this study, we present mechanical stress evolution of PECVD silicon oxide films during and after post-deposition thermal cycling. Silicon oxide films 2.0 and 5.0 μm thick were deposited on silicon wafers in a plasma CVD reactor at 300°C. Mechanical stresses in films were evaluated from the measured curvature change using the Stoney equation. In situ wafer curvature was measured between room temperature and 530°C using a laser interferometer with an external thermo-chamber.

The overall mechanical stress state is determined by the superposition of two primary effects. The intrinsic (athermal) stress is generated during the deposition and is strongly related to the process parameters. The thermal stress only results from the temperature change between deposition and characterization and the difference in thermal expansion coefficients of the film and the wafer. It is found that the PECVD silicon oxide film stresses strongly depend on the processing history and thermal stresses annihilation are identified as the major mechanisms to control the mechanical behaviour of the oxide films. The dependence of residual stress on temperature is non-linear with significant hysteresis. This hysteresis reduced significantly during the subsequent thermal cycle. Thermal cycling is shown to result in major plastic deformation of the film and a switch from a compressive to a tensile state of stress; both athermal and thermal components of the net stress alter in different ways during cycling. These results provide a global information about the stress of the PECVD silicon oxide films and enable a rough stress control in a wide range.

MEMS Tunable Metamaterials for Beam Steering Millimeter Wave Applications

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We propose to combine concept of metamaterials, i.e. electrically small elements arrangement with engineered smart electro-magnetical properties, with MEMS fabrication technology enabling metamaterials' tunability. MEMS tunable high-impedance surface (HIS) [1] can be used as a component of millimeter wave phase shifter as a part of a phased array antenna, or as a smart reflective beam steering surface. Conventional HIS [2] consists of a capacitive array of metal patches on a dielectric wafer with a ground plane and has high effective surface impedance at a resonance frequency. Tuned with MEMS varactors, HIS can affect the phase factor of the propagation constant of waveguides or change direction of the reflected beam. Fabricated MEMS based HIS (Fig. 1) showed high-impedance resonance at 112 GHz. MEMS varactors are tuned with a bias voltage of 10-15 V.

Other types of metamaterials are studied for developing millimeter wave phase shifter and steerable leaky wave antennas on a chip for 79 GHz automotive radar application.

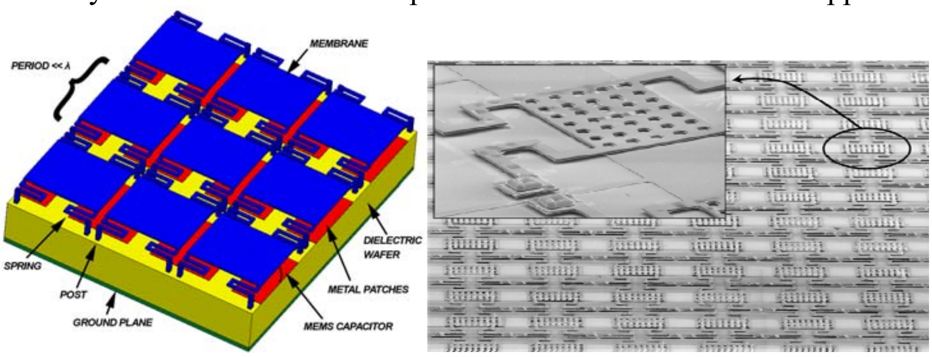

Fig. 1. MEMS tunable high-impedance surface: design and SEM image.

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 224197 and was carried out in the frame of TUMESA project (MEMS Tuneable Metamaterials for Smart Wireless Applications, 2008-2011).

[1] D. Chicherin, S. Dudorov, D. Lioubtchenko, V. Ovchinnikov, S. Tretyakov, A.V. Räisänen, *Microw. Opt. Tech. Lett.* **48**(12), 2570 (2006).

[2] D. Sievenpiper, *High-impedance Electromagnetic Surfaces*, Ph.D. dissertation, Dept. Elect. Eng., University of California at Los Angeles, CA, 1999.

Nanoionic Supercapacitors for New Technologies

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Reducing the energy consumption per 1 bit processing (ε) and supply voltage (V_{dd}) has been a major trend in micro- and nanoelectronics. Many high-tech directions require integrated circuits (ICs) which can meet other demands for performance, ε and failure rate f_{err} as compared modern general purpose processors: ε is primarily critical for self-powering wireless sensor networks, objects of nano- and microsystem engineering, etc. A typical IC in future deep-sub-voltage nanoelectronics will have the component density 10^{11}-10^{12} cm^{-2} and V_{dd} <0.3 V. The analysis of tendencies and prospects for the development of nanoelectronics and technologies associated with it reveals the emergence of a gigantic market for sub-voltage and deep-sub-voltage devices, and an increasing need in high-capacity capacitors of micron-scale size. Extensive investigations in the field of conventional high-capacity capacitors have not led to a considerable increase in their capacity density (δ_C), radiation and temperature hardness. In portable electronics, surface mount high-capacity capacitors stand out sharply against other components because of their large size. For future nanoelectronics and related technologies, the creation of impulse devices of micron-scale size for energy/charge storage with high δ_C has become urgent [1].

In the report, the arguments for the benefits using of all-solid state impulse supercapacitors with fast ion transport (FIT) at functional advanced superionic conductor (AdSIC)/electronic conductor (EC) heterojunctions (nanoionic supercapacitors) in future nanoelectronics, space technique, NEMS (MEMS), wireless, RFID and high-temperature electronics are presented. Our efforts in the IMT RAS are directed on the development of micron-scaled nanoionic supercapacitors with special interface design to provide the FIT in AdSIC/EC heterojunction. Interface engineering allows one to provide the conditions for synthesis of functional AdSIC/EC coherent heterojunctions; they are characterized by high δ_C and small time of response to applied external electric potential. In a model film device fabricated by 3-12 μm technology (Si-substrate, microscopically smooth electrodes, ~0.004 mm^3 volume), the value δ_C ≈100 μF/cm^2 (150°C) was obtained in frequency range up to 2 MHz. The behaviors of experimental devices are discussed. Crystal engineering methods and self-organization principles in AdSIC/EC nanosystems can become the basis for the creation of supercapacitors with record high frequency-capacity characteristics. Hetero-integration of nanoionic supercapacitors with CMOS and NEMS (MEMS) requires realization of cooperative academic/industrial R&D.

[1] A.L. Despotuli, and A.V. Andreeva. *Int. J. of Nanoscience* (2009).

Graphene Bilayer: Nanotribology and NEMS Applications

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Bilayer graphene can be a promising system for nanoelectromechanical devices, which combines good electrical conductivity of graphene flake and flexibility of interplane motion. In this work we investigate the tribological properties of bilayer graphene using first-principles calculations and consider its possible application for NEMS.

Two systems were considered: the infinite bilayer graphene and the finite graphene flake terminated with hydrogen atoms sliding along the infinite graphene layer. For the infinite system the calculated energy of interlayer binding is 24.4±0.2 meV per atom of sliding layer, for the system with the finite flake the obtained value of binding energy is 34.4±0.2 meV per carbon atom of the flake. These results are in agreement with recent experimental and theoretical data [1, 2]. The obtained values of maximum barriers for sliding with the accounting for the relaxation in the cases of commensurate and incommensurate layers' stacking are 9.1±0.1 meV/atom and 0.7±0.1 meV/atom, correspondingly. In the case of incommensurate stacking the barrier for sliding is substantially lower than in the commensurate case in accordance with [3]. In the commensurate case the effect of relaxation reduces the barriers for sliding by up to 60%. It should be noted that contrarily to commensurate case for the incommensurate system the account of relaxation increases barriers for some directions by several times.

It was shown that the conductivity of a double-wall carbon nanotube is dependent on the relative position of its walls [4], therefore one can expect that the conductivity of the bilayer graphene depends on the relative position of graphene layers. In this connection we propose the possible application of bilayer graphene as a nanoresistor. Several possible schemes of such nanoresistors based on different operation principles are proposed.

[1] R. Zacharia, H. Ulbricht, T. Hertel. *Phys. Rev. B* **69**, 155406 (2004).

[2] S. Grimme, C. Mck-Lichtenfeld, J. Antony. *J. Phys. Chem. C* **111**, 11199 (2007)

[3] Yu. Guo, W. Guo, C. Chen. *Phys. Rev. B* **76**, 155429 (2007).

[4] G.S. Ivanchenko, N.G. Lebedev, A.M. Popov, Yu.E. Lozovik, 8-th Biennal International Workshop Fullerenes and Atomic Clusters, Abstracts of Invited Lectures and Contributed Papers, StPetersburg, Russia, July 2-6, 2007, p.55.

Microfluidic Cell Separator for Microsensor of Live Bacterial Cells

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The rapid detection of live bacterial cells is essential for many applications, from environmental study and water quality monitoring to the detection of biological weapons [1]. However, it requires separation of live from dead cells, which could be performed by dielectrophoresis (DEP) in MEMS. DEP is resulted from the polarization effects in cells under specific frequency of applied non-uniform electric field. DEP force (FDEP) acting on a spherical cell in an electric field gradient is as follows [2, 3]: $FDEP = 2\pi\varepsilon m r^3 \, Re[K(\omega)] \, \nabla E^2$ (1), where r is the radius of cells, εm is the permittivity of the suspending medium, ∇ is the gradient operator, E is the root mean square of electric field, and Re [K (ω)] is the real part of the Clausius-Mossotti (CM) factor given by $K(\omega) = (\varepsilon^*p - \varepsilon^*s)/ (\varepsilon^*p + 2\varepsilon^*s)$ (2) with ε*p and ε*s being the complex permittivities of the bacterial cell and the surrounding medium, respectively. The complex permittivity is defined as $\varepsilon^* = \varepsilon - j\sigma/\omega$ (3), where ε is the permittivity, σ is the conductivity of the dielectric, ω is the angular frequency of the applied field, and $j=(-1)^{1/2}$. Selective separation of live and dead cells could be achieved by making use of a difference in the cell membrane conductivities. Using the two shell spheroidal model [3], we calculated that an optimal electrical frequency for DEP separation of live and dead bacterial cells in drinking water (with conductivity of 0.05 Sm^{-1}) is from 0.5 to 30 MHz. The geometric and fluidic designs of cell separator have been made using the modeling of the trajectories of live and dead cells during DEP separation in the microchannels by COMSOL® Multiphysics software. The cell separator for the biosensor of live bacterial cells in 1 mL of sample includes multiplex microchannels (10 μmwidth), DEP electrodes at the distance 40 μm, and 1000 sequential separation microcells (20×20 μm). Selection of specific material for microchannels can enhance DEP cell separation due to difference of dead and live cells surface hydrophobicities.

[1] Hughes MP, Hoettges KF. In: *Principles of Bacterial Detection: Biosensors, Recognition Receptors and Microsystems.* Mohammed Zourob, Souna Elwary, and Antony Turner, eds. Springer, NY, p. 895 (2008).
[2] Lapizco-Encinas B.H., Simmons B.A., Cummings E.B., Fintschenko Y. *Anal. Chem.* **76**(6), 1571 (2004).
[3] Suehiro J., Hamada R., Noutomi D., Shutou M., Hara M. *J. Electrostat.* **57**, 157 (2003).

Point-contact Gas-sensitive Nanosensors

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The novel fundamental concept [1, 2] based on application of point contact spectroscopy [3] to sensor research and development has been proposed. Point contacts (PC) have been discovered to present excellent and unprecedented characteristics when used as gas sensors. The novel concept has been tested successfully and opens the way to useful applications.

Copper and aluminium point contacts were investigated in gas media such as NO_x, HCl, H_2S and human breath. They reveal high sensitivity to these gases: the measured signal increases by 2-3 orders of magnitude upon gas exposure. Sensor parameters are fully restored when gas action ceases. Stable reproducibility of experimental results was observed after several exposure cycles onto the investigated point contacts.

The effect of gas sensitivity of point heterocontact (PHC) between carbon single walled nanotubes (SWNT) and a gold microwire was demonstrated for the first time. Au-SWNT heterocontact sensors exhibit high sensitivity to NH_3 and NO_2 vapors with fast response and relaxation and demonstrate that these two gases can be distinguished based on the direction of charge transfer between the analyte and the SWNTs. The mechanism of sensing is associated with formation of a thin conductive channel between Au and SWNT, but the sign of the resistance change is controlled by the SWNT.

The outstanding properties of PC and PHC sensors, such as superior sensitivity, fast response and short relaxation time provide the direct way to introduce point-contact sensors into the area of analysis of human breath gas. Novel TCNQ derivatives-based sensors were successfully applied for diagnostics of gastric ulcer and show promising results to find proliferative changes in stomach. The obtained results are of particular practical interest for development of noninvasive diagnosis of human diseases.

[1] G.V. Kamarchuk, O.P. Pospelov, A.V. Yeremenko, E. Faulques, and I.K. Yanson. *Europhys. Lett.* **76**(4), 575 (2006).

[2] G.V. Kamarchuk, I.G. Kolobov, A.V. Khotkevich, I.K. Yanson, A.P. Pospelov, I.A. Levitsky, and W.B. Euler. *Sensors and Actuators B* **134**, 1022 (2008).

[3] Yu.G. Naidyuk, and I.K. Yanson. Point-Contact Spectroscopy (Springer Verlag, New York, 2004).

Bionanohybrids Formed by Carbon Nanotubes:DNA for Biosensing

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Bionanohybrids based on single-walled carbon nanotubes (SWNT) attract the particular interest of scientists due to their promising application for creating the new generation biosensors. The first step that should be made in this direction is realization of biocompatibility of carbon nanotubes which can be resolved by a surface noncovalent functionalization of nanotubes with water soluble polymers, for example with DNA. We have studied hybrids of carbon nanotubes with fragmented native DNA or synthetic polynucleotides using spectroscopic methods, AFM and computer modeling [1]. The second important step in elaboration of biosensors is biofunctionalization of this nanomaterial for recognition of only one type of the target biomolecule. For this purpose we applied enzyme (glucose oxidase (GOX)) which was immobilized on SWNTs. To get over the difficulty with decreasing of enzymes activity after their direct adsorption onto the surface of nanotubes we suggested a new approach which implies using the polymer as an interlayer between GOX and nanotube. As such a polymer we proposed a DNA which wraps around tubes. The adsorption of the enzyme on DNA-wrapped nanotube was tested by the AFM which demonstrated native globular structure of GOX on the nanotube surface.

The luminescence intensity of semiconducting nanotubes in SWNT:DNA:GOX bionanohybrids was used for glucose detection. Adding small injections of glucose (1μL, 1 mM) into solution leads to quenching of the luminescence intensity of semiconducting nanotubes. The decreased nanotubes luminescence with rising glucose concentration in such small doses demonstrates the oxidizing activity of the enzyme after immobilization on the nanotube. Such a method for enzyme immobilization onto the nanotube surface can be applied for detection of glucose, lactate and others.

[1] V.A. Karachevtsev, G.O. Gladchenko, M.V. Karachevtsev, V.A. Valeev, V.S. Leontiev and O.S. Lytvyn. *Chem. Physic. & Phys. Chem.* **9**, 2010 (2008).

Thread-like Anisotropic Transparent Crystals of Carbon

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Two of three allotropic modification of carbon - diamond and fullerene (ordinary it name fullerit) - are transparent and both have cubic crystalline structure. As diamond, and fullerenes, as against graphite, are non-conductors. Colorless transparent isotropic crystals of diamond are characterized by a parameter of two-refraction above 2.3 whereas reddish transparent isotropic crystals of fullerene C_{60} - parameter of two-refraction it is less 1.90. In diamond the atoms are connected by means of only tetrahedronic sp^3 – hybridized states of carbon, and in a molecule of fullerene - by means of only sp^2 - hybridized states. If the diamond is formed at superhigh pressure and increased temperatures, fullerenes are formed in conditions of extremely high gradients as on temperature and pressure.

Here we represent a new state of transparent carbon as it thread-like crystals, the synthesis those is carried out at atmospheric pressure and temperatures close to $1000^{O}C$. The transparent threads of carbon painted in various colors (red, brown, light-blue etc.), are formed at thermal exposure of powders of carbon and silicon as well as at thermal transformation various organic molecules. Painted macrothreads in obtained products are found out by a diameter up to 80 mkm and length more 30 mm and are allocated by means of optical microscopy. The distinctive feature of carbon macrothreads is that they are formed of great number of threads of a smaller diameter and consequently have the specific ending.

According to crystal-optical analysis these thread-like crystals are anisotropic with a parameter of two-refraction (1,575). According to X-ray diffraction analysis thread-like crystals have original hexagonal crystalline structure with the following parameters: a = 0.498 nm and c = 0.826 nm.

The chemical composition of threads was appreciated with the help X-ray spectral analyzer (Camebax). It is established, that a basic element of threads is the carbon. These threads very nice in different organic solvents are dissolved. Threads and their toluene solutions by means of IR – and mass-spectroscopy as well NMR 13 are investigated.

Mechanism of growth of colored carbon threads (or rope) from carbon and hydrocarbons will be discussed.

Nanosilver-based Materials for Industrial Applications

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Over the last decades silver nanoparticles, structures up to 100 nm in size, were extensively investigated and have found applications in catalysis, optics, electronics and other areas of science and technology due to their unique size-dependent optical, electrical and magnetic properties. It would be fair to say that at the moment most of silver nanoparticles industrial applications is connected with their usage as antibacterial/antifungal agents, making nanosilver one of the fastest growing product categories in the nanotechnology industry [1].

The paper deals with the consideration of silver nanoparticles as a commercially viable addition for using in paint, textile and water treatment industry with the results of recently conducted antimicrobial and cytotoxicological assays.

Our MIC assays have shown that quantitatively nanosilver was less effective against E. coli, S. aureus, B. subtilis and P. phoeniceum than silver ions. However silver nanoparticles due to their mechanism of continuous release of enough concentration of Ag ions from the nanoparticle form can be more suitable in most appropriate industrial applications than silver ions.

The tests conducted have demonstrated that synthesized silver nanoparticles added to water paints, cotton/synthetic fabrics, fibrous water treatment sorbents show a pronounced antibacterial/antifungal effect. Our MTT test results obtained using NIH-3T3, HEP-G2, A-549, PC-12, and Colo-320 cells have shown that silver nanoparticles with concentrations of ~1-10 ppm entering the body from air or liquid suspensions can present a potential risk to human health. On the other hand most of silver-based materials used in industry are unlikely to present a direct health risk, as in case of sufficient bounding of nanosilver to the material the exposure potential will be negligible.

[1] Buzea C., Pacheco II, Robbie K. Nanomaterials and nanoparticles: Sources and toxicity. Biointerphases 2(4):MR17-MR71 (2007)

Characterization of Ferroelectrics for Microwave Applications

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Paraelectric state ferroelectric films are the basis for development of a new class of controlling microwave devices, which employ their nonlinear properties (tunable filters, phase shifters, delay lines, etc.). The analysis of general requirements on parameters of ferroelectric elements to provide their effective use on microwave is presented.

Procedures and results of small signal measurements of parameters of ferroelectric films and structures on their base in the frequency range (1-70) GHz are considered. The use of electrodeless measurements in parallel with measurements of FE film elements with metal electrodes (varactors, transmission lines) makes it possible to evaluate separately the dielectric and metal losses of elements.

Power handling capability is one of the main characteristic of microwave devices. Results of experimental investigations and simulation of the non-linear response of ferroelectric films to a high level of the microwave signal are presented. Two different techniques were used to estimate the non-linear response of ferroelectric films to microwave signal: i) measurements of the anharmonic response to pulsed microwave signal; ii) intermodulation distortion measurements (IMD). Mechanisms defining the power handling capability of ferroelectric microwave devices under microwave power were experimentally identified and theoretically described. Results obtained allow us to establish the power handling capability of ferroelectric devices and estimate the signal distortion corresponding to any operating level of microwave power.

The time required to tune microwave devices under controlling pulses is the important parameter for tunable microwave devices. Procedures and results of measurements of switching and relaxation time (down to 1ns) for different types of ceramics and thin film ferroelectric elements are analysed and the possible mechanisms of nature of the “slow” relaxation and the ways of its suppression are considered. The possibility to create the fast acting microwave devices on the base of ferroelectric films is demonstrated.

[1] N.K. Pervez, P.J. Hansen, and R.A. York. *App. Phys. Lett.* 85, 4451 (2004).
[2] O.Yu. Buslov, A.A. Golovkov, A. Kozyrev et al. *IEEE Trans. on MTT* 55, 2951 (2007).

Carbon Nanotube Based Pressure and Gas Sensors

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Electrical properties of multi-wall carbon nanotubes (MWNTs), both pristine and decorated by Ti and TiO_2 nanoparticles, were investigated as a function of temperature and gas pressure (gases: oxygen, nitrogen, argon). First, thin (50-100 nm) Ti electrode pairs with ~1μm separation were fabricated by a lift-off technique on thermally oxidized Si substrates. Then, multi-wall carbon nanotubes grown by CVD (2-5 μm long and 20-30 nm in diameter) were deposited onto Ti electrode pairs using ac dielectrophoresis (DEP) process from aqueous solutions and annealed in vacuum to reduce the contact resistance and obtain ohmic contacts. Subsequently, for decoration by Ti particles, very thin (~1 nm) Ti layer was deposited over MWNTs by sputtering resulting in formation of nanoparticles over MWNTs surface. TiO_2 nanoparticles were synthesized over MWNTs by $TiCl_4$ hydrolysis. TiO_2-decorated MWNTs were deposited onto Ti electrodes using the same DEP and annealing procedures. Electrical measurements were performed in a vacuum chamber at gas pressures and substrate temperatures ranging from 0.001 to 3 Torr and 20 to 200°C, respectively. Current through MWNTs as a function of voltage and time was measured in a 2 terminal configuration (bias 0.5 – 1 V) at different temperatures and gas pressures, including in pulsed regime. The sensitivity *S*, defined here as a relative change of resistance for a given gas pressure, was found to depend strongly on temperature. Two kinds of effects were observed when gas was injected into the vacuum chamber, previously under high vacuum. First, fast increase of current (up to $S = 0.1$) was observed for all samples as the gas (N_2, O_2 or Ar) was injected. This can be attributed to electrothermal effect: under applied bias, metallic nanotubes are heated by electric current (estimates give ΔT=50-100°C) and their resistance increases. When the gas is in, it cools down rapidly the nanotube resulting in fast increase of a current through the tube. This effect depends mainly on pressure and, to less extent, on the gas. Second, much slower decrease of current was observed for decorated nanotubes when O_2 is injected. This was attributed to charge transfer occuring during interaction of oxygen with Ti or TiO_2 particles, withy higher sensitivity observed for Ti. These results show that MWNTs (pristine and/or decorated by metal or metal oxide particles) can be used as pressure and gas (oxygen, in the case) sensing devices.

Physical Limits for Scaling of Electronic Devices

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Scaling of electronic devices in integrated circuits (ICs) and in MEMS sensors has both technological and physical limits. In this paper we discuss some physical limits for miniaturization of devices and paths in semiconductor ICs and MEMS. Prognoses of the development of the semiconductor industry (ITRS) foresee that sizes of electronic devices in ICs circuits will be smaller than 5 nm in the course of 15 years.

There are at least four physical limits: (1) electrostatics; it leads to degradation of a very thin and narrow channel causes by electrical potential; (2) electron tunneling through a insulation (oxide) between a source and a drain inside a CMOS; (3) spread of doping atoms in a semiconductor material; (4) quantization of electrical and thermal conductance in nanowires (formed by narrow paths and channels).

The theoretical quantum unit of electrical conductance ($G_0 = 2e^2/h$) in one-dimensional system (e.g. nanowire) was predicted by Landauer in his theory of electrical conductance. The total electrical conductance of a nanowire is given by formula: $G = NG_0$, where N is the number of transmission channels. For conductors and semiconductors the conductance quantization in units of $G_0 = 2e^2/h = (1/12.9\ \text{k}\Omega)^{-1}$ was measured in many experiments. In our experiments the quantization of conductance was evident.

It is generally known that limits for speed-up of digital circuits, especially microprocessors, are determined by thermal problems. There are several analogues between the electrical G_E and the thermal G_T conductance of a nanostructure. However an analyze of thermal conductance is more complex than electrical conductance because of contribution either phonons or electrons in heat exchange. Quantized thermal conductance in one-dimensional systems was predicted theoretically for ballistic transport of electrons and phonons. Quantized thermal conductance G_T was confirmed experimentally. The quantum of thermal conductance: $G_{T0} = (\pi^2 k_B{}^2/3h)T = 9.5\times10^{-13}T$ depends on the temperature. At $T = 300$K value of $G_{T0} = 2.8\times10^{-10}$ [W/K].

In small structures, like a path in an IC, a dissipated energy is quite large. At the supply voltage $V_{\text{sup}} = 1.3$ V for the 1st step of conductance quantization (G_0) the current in the circuit $I = 100$ µA (e.g. $I = 250$ µA for the 3rd step). The power dissipation in terminals of nanowires is $P = I^2/G_{E0} = 130$ µW for the 1st step ($P = 270$ µW for the 3rd step). One ought to notice that the density of electric current in nanowires is extremely high.

Nano-structured Materials for Thermoelectric Devices

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Thermoelectric devices have the limited field of application because of their relatively low performance, is of the order of 10%. The efficiency of conventional thermoelectric materials has reached asymptotic limit in recent decades. There are a number of technological problems which, in principle, can be solved by thermoelectric methods. One of them is a creation of thermal shutter which is extremely necessary to decrease heat leak through current leads of high-temperature superconducting power transmission lines, superconducting magnets, etc. Experiments with current leads supplied with Peltier elements confirmed the feasibility of this approach. However the efficiency of the best thermoelectric cooling materials based on Bi-Te-Sb is not enough due to low thermodynamic limit of refrigerating factor $T/\Delta T<4$ and low Ioffe parameter $Z\leq 0.003\ K^{-1}$.

The phenomenology of thermoelectricity is developed for macroscopic homogeneous media. It underlies (Onsager's principle) and it is a branch of the linear non-equilibrium thermodynamics, which is based on the microscopic description of diffusion processes only. Only macro-inhomogeneity (Thomson effect) is considered by thermoelectric theory as small corrections. The theory of optimization of highly doped semiconductor thermoelectric materials has been developed based on Ioffe-Stilbans model within the framework of the thermoelectric theory. Therefore, the present theory does not describe in principle the effects of micro/nano-inhomogeneities which have been attributed as "anomalous". However, the modern technologies allow to transfer "anomalous" effects into the category of normal, reliably reproduced thermoelectric effects. It was shown theoretically and confirmed experimentally that at micro/nano-inhomogeneities, in particular at contacts and p-n junctions, there are an additional thermoelectric effects allowing cardinally increase efficiency of thermoelectric conversion. It is shown that nano-structured materials with discovered polar ballistic addition predominating over diffusion thermoelectric effects allow to solve the problem of creation of efficient thermoelectric shutter.

Gas Sensors Based on Microtechnology and MEMS Platforms

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This paper deals with constructions, technologies, characteristics and applications of the following gas microsensors: integrated hydrogen sensors based on MISFET with Pd-Ta_2O_5-SiO_2-Si structure, thermosensor, heater and test element; nano-on-micro metal oxide sensor operating at pulse heating with improved selectivity to ammonia; thermocatalytic micromachined gas sensors with nano-materials based on Pd/Pt doped YSZ; MEMS platforms based on SiO_2-Si_3N_4 films for gas sensors; alumina MEMS platforms for impulse semiconductor and IR gas sensors. These sensors have been developed and investigated during the last years.

NEMS based on interaction of the walls of carbon nanotubes

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We consider new types of NEMS based on carbon nanotubes. Ultra high frequency nanoresonator based on the relative vibrations of the walls of carbon nanotubes is proposed. The resonator could be used for the detection of mass of nano-objects with atomic resolution. The scheme of mass nanosensor is suggested. The resonance can be determined through registering a change in the gate-nanotube capacity, which depends on the amplitude of vibrations of the wall with the attached nano-object. The change in the capacity causes the change in the current through the nanotube that can be measured. The principle schemes of memory cell [1] and nanothermometer [2] based on interaction of the walls of carbon nanotubes are also considered.

Density functional theory is used to compute the interaction energy of the walls of carbon nanotubes as a function of their relative position (see [3] for details of calculation technique). The computed interaction energy curves are fitted analytically and further exploited in the calculations of the frequencies of small relative vibrations of the walls. These frequencies are found to be in the range 70−700 GHz and do not depend on the length of the walls for nanoresonator with the vibrating wall which is shorter than fixed one.

To estimate the sensitivity of mass detection by the proposed mass nanosensor and the Q-factor of the resonance, molecular dynamics simulations of the resonator based on the (9,0)@(18,0) DWNT have been performed. The estimated values of the Q-factor are Q=160 at 77 K and Q=540 at 4.2K, with the mass sensitivity of 4.5 and 1.3 carbon atoms at 77K and 4.2K respectively.

Recent advances in techniques for creation of nanotube-based nanoelectomechanical systems are discussed.

[1] E. Bichoutskaia, A.M. Popov, Y.E. Lozovik. *Materials Today* **11**, 38 (2008).
[2] E. Bichoutskaia, A.M. Popov, Y.E. Lozovik, G.S. Ivanchenko, N.G. Lebedev. *Phys. Lett. A* **366**, 480 (2007).
[3] E. Bichoutskaia, M.I. Heggie, A.M. Popov, Yu.E. Lozovik, *Phys. Rev. B* **73**, 0454359 (2006)

Structure Property of $Al_xGa_{1-x}As/GaAs(100)$ Autoepitaxial Heterostructures

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Production of $Al_xGa_{1-x}As$ solid solutions in the form of chemical compound is an extremely actual problem, and properties of such compounds deserve careful study using various methods. Modification of fundamental properties of the semiconductor systems, will inevitably lead to a modification of energy gap width, transition from nondirect to direct band semiconductor, an inverse sequence of energy bands, complicating of optical spectra [1].

The tested samples produced in Ioffe Physical-Technical Institute St. Petersburg represent $Al_xGa_{1-x}As$/GaAs (100) heterostructures grown with a research objective of processes of autodoping for reaching of the peak concentration of a carbon acceptor. Therefore given experiments were provided at lower temperature and a minimum relation of 5 and 3 groups depending on a composition of a solid solution. Samples were grown by MOCVD installation «EMCORE GS 3/100»

Analyzing the data gathered using methods of X-ray diffraction, scanning electron microscope and IR-spectroscopy, it is possible to make the important deductions about structure of the autoepitaxial $Al_xGa_{1-x}As$ solid solutions. Autoepitaxial $Al_xGa_{1-x}As$ films, as well as disordered homomorphous solid solutions, have sphalerite structure, that is well enough tracked in case of growth of homoautoepitaxial GaAs/GaAs (100) structures - as from X-ray diffraction results follows, that lattices of solid solution and a substrate are perfectly matched. However essential difference is that the lattice parameter of an autoepitaxial film though is increased with growth of concentration of Al atoms in a metal sublattice, but it is still has less value, than at GaAs and this fact contradict to well known Vegard's law. This data, gained at first from the analysis of effects of X-ray diffraction, is also proved by the IR-spectroscopy method, proceeding from data about frequencies and intensities of TO and LO phonons of the basic modes.

[1] E.P. Domashevskaya, P.V. Seredin et al. *Fizika i Technika Poluprovodnikov* **39**, 354 (2005).

Biosensors Based on the Nanostructured Silicon: Development and Practical Application

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In this report the principle new instrumental method of the biochemical diagnostics of the bovine leucosis and mycotoxycosis through the registration of the formation of the specific immune complexes (Ag-Ab) with the help of biosensor based on the nanostructured silicon is proposed. The principle of the measurements based on the determination of the photosensitivity of the surface (Figure).

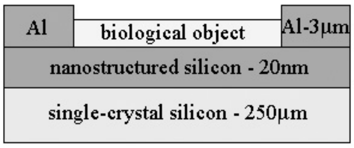

Figure. Scheme of the photo resistor on the base of the nanostructured silicon.

We used boron doped single-crystal silicon square wafers with resistivity of 1 Ohm*cm. The surface of the wafers was not polished. Nanostructured silicon layers were prepared by the stain etching in HF: HNO_3 solution at the room temperature and the natural day-time illumination. Thickness of layer nanostructured silicon is changed from 3 up to 60 nm. It was supervised by parameters of technological process at chemical modification of a surface of single-crystal silicon and was defined with the help of the Auger electronic spectroscopy. Contacts by the area 1 mm^2 and thickness 0.3 microns received with the help of a method of magnetron sputtering of In with use of a metal mask. At the formation of the immune complex (retrovirus proteins – specific Ab or specific Ab-some mycotoxin) it is observed the low changes of the current in the dark regime but in case of the illumination the current increases in 2-5 times depends on Ab or mycotoxin concentrations in sample to be analyzed. Actually the main processes in the proposed biosensor connected with the light excitation and the generation of the electrons and with the next electron interaction on the active surface of the nanostructured silicon.

This biosensor may be applied for the determination of the concentration of different substances which may form the specific complex in the result of the bioaffine reactions. In spite of the traditional methods of the proposed one may provide the express control of the milk quality as direct on the farm and during its processing as well as at the currying out the biochemical diagnostics of bovine leucosis in the field conditions with the minimum consumption of materials and procedure fulfillment.

MEMS and NEMS on Basis of Fibrous Composites

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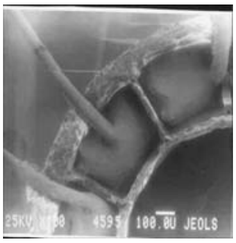
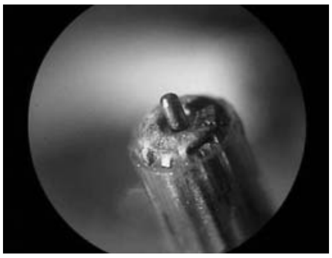
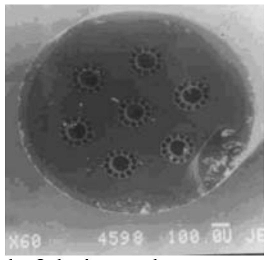
Indisputably, microelectronics is the mother of the MEMS/NEMS technologies. Unfortunately, the majority of developed MEMS and NEMS devices inherited from microelectronics technologies not only of merit but also deficiencies one of which is their planarity. Recently developed devices on the flexible base and also devices with the moving elements on the hinges, in principle, remain geometrically flat. With this micro- and nanomechanisms (motors, actuators, sensors, etc.) they are not divided with the base (from silicon or another material) large part of which (volume and mass) functionally is not used and has usual of macro sizes (dimensions of a chip). As a result, these ultra modern planar technologies are helpless with the creation of powerful autonomous 3D-devices with the overall sizes (1–10) mm^3. The author makes the attempt to estimate the prospects for development and fabrication of topology complex 3D MEMS/NEMS, for example, flaying microrobot and elastic micro motor on the basis of fibrous composites—ultra high aspect-ratio glass structures with predetermined 3D micro and nano-topologies and embedded wires.



Stator of synchronous micromotor

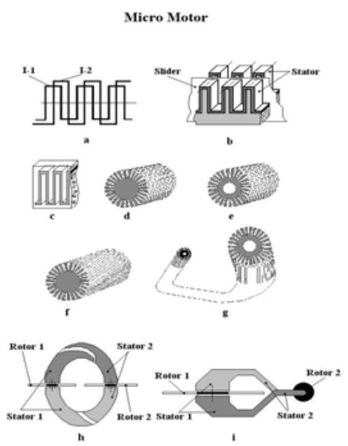


3-fh synchronous motor with NdFeB rotor

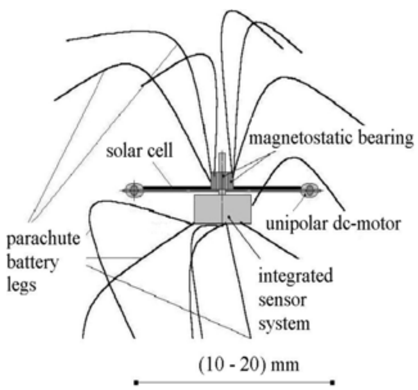


Batch fabricated stators or x-ray guides, or photon crystal

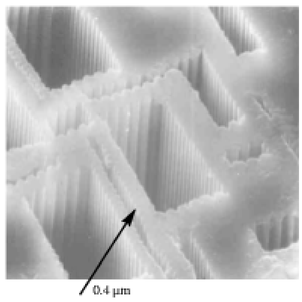
Projects



Elastic micromotors and helicopters



Flying microrobot



X-ray masks

The New Ferroelectric Sensors Material on the Base of Nanocomposites $PbSe+PbSeO_3$

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The oxidation of lead selenide structures prepared in the form of powdered samples is investigated.

Thus, the oxidation kinetics of powdered PbSe samples in a dry air stream was investigated by X-ray diffractometry and the chemical shift method. The analysis of the data obtained permitted us to draw the following inferences: Only the lead selenide phase occurs inside the PbSe sample. As the temperature increases, the volume of the $PbSeO_3$ phase on the PbSe surface increases proportionally to the decrease in the content of the PbSe phase. No phases except for PbSe and $PbSeO_3$ are found in the studied samples upon heat treatment at the above temperatures and times.

The optical properties of lead selenide powders are investigated by Fourier-transform IR spectroscopy at room temperature, as well as at temperatures of 723 and 773K. The diffuse reflection spectra of the initial and heated powders of the PbSe compound are measured. It is revealed for the first time that the surface of the initial and heated samples of the PbSe compound contains a layer of amorphous biselenite $Pb(HSeO_3)_2 \cdot nH_2O$.

Thus, in this work, we for the first time measured the IR diffuse reflection spectra of the $PbSeO_3$ compound and revealed that the surface of both the initial and heated powders of the PbSe compound contains a layer of amorphous biselenite $Pb(HSeO_3)_2 \cdot nH_2O$. Therefore, an increase in the conductivity, including the photoconductivity, in these materials prepared in the form of powders or thin films in contact with air can be associated with the appearance of the proton conduction in the surface layer.

Electrochemical cells in the form of pressed pellets and polycrystalline films prepared from the $PbSe+PbSeO_3$ two-phase composite are investigated by impedance spectroscopy. The complex analysis of the electrical properties revealed the ferroelectric phase transition in the system under investigation at a temperature $T_c \approx 343K$.

This investigation allows to conclude the perspectives of using nanocomposites $PbSe+PbSeO_3$ the sensor materials.

SnO_2 – based Film with a Filamentary Nanomorphology for Gas Sensors Materials

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Metal-oxide polycrystalline semiconductors have found a wide use in fabrication of gas-sensitive sensors [1]. It should be noted that materials based on tin dioxide are most promising due to a number of advantages [2]. The aim of this work was to investigate the sensitivity of tin dioxide–based nanostructured metal oxides to polar gas molecules by impedance spectroscopy.

It is demonstrated that, in principle, it is possible to prepare polycrystalline films of the based SnO_2 with one-dimensional nanoparticles on the surface and to fabricate highly sensitive gas sensors on their base.

Nanostructured polycrystalline films were grown on Al_2O_3 ceramic substrates by the hydropyrolytic method described in detail in our earlier work [3].

Under the conditions providing the vapor–liquid–crystal mechanism, we fabricated the SnO_2–based nanocrystalline films with a filamentary morphology.

The mismatch of the crystal lattice parameters of the substrate and the deposited film leads to the formation of a granular material with a mean grain size of ~25–100 nm.

Polycrystalline films based on the SnO_2 oxide with a filamentary nanostructured surface morphology can possess a high sensitivity to different gas molecules, especially to polar molecules.

It was demonstrated that, in principle, it is possible to determine the contribution from the impedance of gas molecules adsorbed on the surface to the impedance of a sensor based on the tin dioxide.

[1] W. Göpel. *Sens. Actuators, Ser. B* **18-19**, 1–21 (1994).
[2] A.M. Gas'kov M.N. Rumyantseva. *Neorg. Mater.* **36**(3), 369 (2000).
[3] V.V. Tomaev, L.N. Gar'kin, V.P. Miroshkin, V.A. Moshnikov. *Fiz.Khim. Stekla* **31**(2), 331 (2005) [*Glass Phys. Chem.* (Engl. transl.) **31**(2), 246 (2004)].

Solar Fullerenes and Carbon Nanotubes

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Fullerenes and carbon nanotubes have become a major field in condensed matter physics and chemistry. However, the large-scale production of these materials with high yield and selectivity is still a crucial problem. Conventional methods for the synthesis of fullerenes, such as electric arc discharge and laser ablation, fail when the process is being scaled up to higher power levels.

The solar vaporization process seems to be more promising using the solar reactor, in which a graphite rod contained under vacuum pressure behind a hemispherical quartz window is directly irradiated with peak solar concentration ratios exceeding 7000 suns and the vaporized carbon (at temperatures above 3300K) is swept out by Ar, quenched, and collected in a filter bag. The key parameters characterizing this process are the carbon soot mass flow rate and the desired product yield. The former is a function of the target temperature, whereas the latter is a function of specific reactor variables such as fluid flow patterns, residence times, and concentration of the carbon vapor in the carrier gas, target temperature, and temperature distribution in the cooling zone.

Catalytic filamentous carbon (CFC) can be produced by the solar thermal decomposition of hydrocarbons in the presence of small metal catalyst particles. Solar furnace experiments confirmed that nanotubes can be obtained using Co/MgO catalyst for CO and CH_4H_2 and those nanofibers can be obtained on Ni/Al_2O_3 catalyst for CO, CH_4, CH_4H_2, and C_4H_{10}. A solar chemical reactor, used for such experimental runs, consists of a quartz tube containing a fluidized bed of catalyst and Al_2O_3 grains. A secondary reflector, composed of a two-dimensional CPC coupled to an involute, provides uniform irradiation on the tubular reactor. CFC formed typically has the following properties: surface area 100 to 170m^2/g, pore volume 0.4 to 0.8 cm^3/g, micropore volume 0.004 to 0.008 cm^3/g, and average pore diameter 10 to 40 nm.

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Oral Contributions

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