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5th International Congress on Advanced Electromagnetic Materials in Microwaves and Optics

Programme

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Foreword

It is our great pleasure to welcome you to the **5th International Congress on Advanced Electromagnetic Materials in Microwaves and Optics** -**Metamaterials 2011**-, organized by the **Virtual Institute for Artificial Electromagnetic Materials and Metamaterials** (*Metamorphose VI*).

Over the past five years, the Congress series, initiated by the European Network of Excellence *Metamorphose*, has established itself as the prime event in the metamaterial community. Addressing the multidisciplinary nature of artificial electromagnetic materials, the Congress brings together researchers and engineers working in material science and electromagnetic theory, optics and microwaves, physics of solids and acoustics, nanofabrication and device design. This provides a unique forum for discussions of the latest advances in the explosively growing area of metamaterials and their applications. The preceding editions of the Congress, held in Rome (2007), Pamplona (2008), London (2009), and Karlsruhe (2010) have gained the high reputation to these meetings and developed good traditions which we are happy to follow and advance.

The Congress programme covers a wide scope of research in artificial electromagnetic materials and surfaces for RF, microwave, terahertz, and optical ranges, and encompasses various aspects of their fundamental theory, modelling, design, applications, fabrication and measurements. The recent advances in metamaterials for acoustic waves are also reviewed. The programme contains a balanced combination of plenary and keynote talks, invited, contributed and poster presentations, all subjected to rigorous peer review. Special sessions address the key topics of the latest developments.

The Congress is traditionally accompanied by the European Doctoral School on Metamaterials. This year school event is focused on engineering applications of metamaterials.

The success of the conference series allows Metamorphose Virtual Institute, as a non-for-profit international association, to offer financial support to a number of participants and particularly students, operate European Doctoral Programme on Metamaterials (EUPROMETA) and provide other services to the community.

We would like to thank our sponsors and all colleagues who have helped with the organization of this event and offered their scientific and technical contributions.

Sergei Tretyakov
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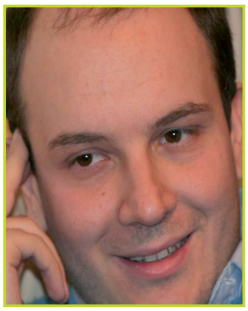

Preface

It is well-established that metamaterials permit for engineering the electromagnetic properties by purposefully designing meta-atoms and their respective arrangement. Whereas in the infancy of metamaterial research both the meta-atoms and the metamaterial itself were essentially planar structures with limited degrees of freedom in design there is now much progress towards the fabrication of genuine three-dimensional structures. The design spectrum gets even wider if the underlying materials are active, controllable, and nonlinear. This evolution requires pushing nanostructuring technologies, numerical modeling and experimental characterization techniques towards their limits. Sort of well-established theoretical approaches have to be double-checked with respect to their applicability and novel fabrication technologies have to be introduced being a combination of chemical processes controlled by self-organization and conventional top-down methods of nanofabrication. These requirements provide the chance for a fruitful and close collaboration of scientist from many branches of science as advanced technology, material science, plasmonics, linear and nonlinear optics, computational physics, and chemistry to name only a few.

The **Congress on Advanced Electromagnetic Materials in Microwaves and Optics**, which is now in its fifth year, has played a crucial role in these developments and in providing researchers from these different fields an exciting podium for discussions. Almost 500 contributions coming from many areas of physics and engineering have been submitted to this year's conference.

In contrast to conferences with a narrower scope reviewing and selecting papers as well as assembling the conference program was not a straight-forward task.

Thus I have to express my sincere and deep gratitude to all TPC members and the Review Board for their assistance, work, and support. I am also grateful to the Steering Committee and to the Local Organizing Committee for their help and active involvement in forming the scientific program. Finally, I would like to thank all colleagues involved in creating and maintaining the Internet platform of the Congress, which has been extremely useful in organizing our work.

Thanks to all these efforts, this Fifth International Congress on Advanced Electromagnetic Materials in Microwave and Optics can offer you three Plenary and eight Keynote Talks given by renowned experts. Three Special Sessions on 'hot' topics as well as 39 Oral and three Poster Sessions with almost 300 contributions in total, coming from many countries around the world, will hopefully provide a broad overview of the current "state of the art" in metamaterial science and technology. We hope you will enjoy the meeting and find it was a good opportunity for sharing ideas and visions with many old and new friends. We also hope that novel exciting projects will emerge from the talks given and from the discussions with your colleagues.

Falk Lederer
Chair of the Technical Program Committee

Welcome Message

Dear Friends and Colleagues,

Welcome to Metamaterials 2011 in Barcelona

It is our pleasure to host this **5th edition of the International Congress on Advanced Electromagnetic Materials in Microwaves and Optics**, a conference that has been consolidated as an international reference meeting in the field of Metamaterials, covering the whole range of the electromagnetic spectrum (also including acoustics and other emerging areas) and a wide range of disciplines.

This year, the conference is locally organized by the Centre **CIMITEC** (Universitat Autònoma de Barcelona) and held in the city of Barcelona, in a well communicated Venue (Hotel Barceló Sants) with appropriate spaces and facilities to host the conference.

I wish you enjoy the technical program and your stay in Barcelona as well. I would like to encourage all participants (especially those visiting the city for the first time) to discover our city. Barcelona is worldwide famous for the modernist architecture, mainly represented by the Temple of *Sagrada Familia* and *Parc Güell* (both due to the Architect Antonio Gaudí), among others. I am sure that the conference participants will have the opportunity of visiting these famous places and other attractive zones of Barcelona (Gothic area, Ramblas, harbor…) during the conference. For this reason, in the Social Event we will visit another jewel (and symbol) of Catalonia, the Montserrat Abbey (located 50 km. from Barcelona), followed by a dinner in a leisure complex in the territories of a Middle Ages monastery, where part of our traditions will be shared with all the participants.

It has been our aim to create the appropriate atmosphere to enhance the interchange of ideas and scientific discussions among the participants, so that you can say that this conference has been technically very beneficial at its end, and a good experience to remind in future.

To end this message, I would like to thank all the people contributing to make this conference a success, including our sponsors and Institutions that have given support to the conference, with special emphasis to our University.

Enjoy the Conference!

Ferran Martín
Chair of the Local Organizing Committee

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Location

Barcelona is Spain's second largest city, with a population of nearly two million people (more than 4.000.000 including the outlying areas), and the capital and largest city of Catalonia.

The city, located on the north-eastern Mediterranean coast of Spain, is world wide famous for the modernist architecture, mainly represented by Antoni Gaudi's works, like the temple of Sagrada Familia and Parc Güell.

You can enjoy Barcelona in a lot of ways: take a walk along the Ramblas, visit one of the multiple museums, have a drink in a bar next to the beach, go shopping, or taste some tapas at the Barri Gòtic (old town). Barcelona is more than just a single city. Explore it and have a good time!

The Conference Venue is placed in a centric location of Barcelona and well connected with other parts of the city by underground (Metro), trains and buses. It is situated in the neighbourhood of Sants, formerly an industrial town on the plain bordering Barcelona, known as Santa Maria de Sants. The main artery of the neighbourhood is Carrer de Sants, popularly known as Carretera de Sants, which unites Plaça d'Espanya with the neighbouring municipality of L'Hospitalet de Llobregat. It is one of the most commercial streets in Barcelona.

Metamaterials 2011

10th-15th October

Barcelona

Conference Venue

The Congress activities will take place at the **first floor of Hotel Barceló-Sants**.

There are **three rooms for the lectures**: Barcelona B, Sants-Montjuïc and Sarrià-Sant Gervasi, and another one for poster sessions and coffee breaks (Barcelona A).

Exhibition will be held at the foyer.

Lunches will be in "La Cantina de L'Estació", also located at the first floor of the Hotel.

Barceló

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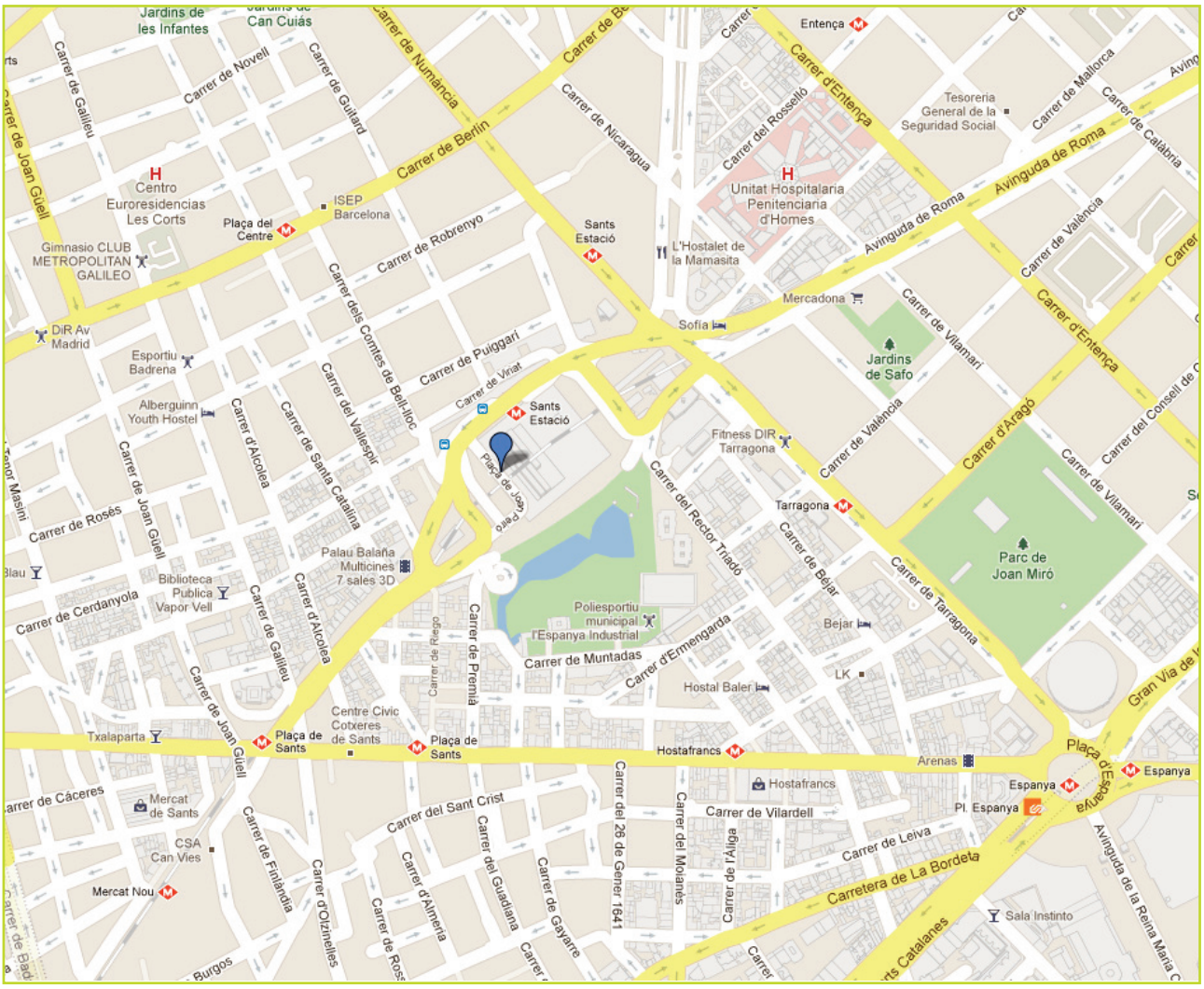

Social Events

Monday, 10 October ▸ 18:10 h. ▸ **Welcome Reception** ▸ Hall of Hotel Barceló-Sants, Ground Floor

Wednesday, 12 October ▸ 17:30 h. ▸ **Visit to Montserrat and Conference Banquet**

Montserrat is a mountain chain near Barcelona, which presents a peculiar aspect. Formed of pink conglomerate sedimentary rock, Montserrat or "serrated mountain" attracts a million of visitors annually. There we can find the Benedictine abbey of Santa Maria de Montserrat, where is hosted the Virgin of Montserrat, a black Madonna popularly known as "La Moreneta", patroness of Catalonia.

After the visit to Montserrat, we are going to move to **Món Sant Benet**, a leisure complex in the territories of a middle Ages monastery, to have the **Conference Banquet**. Before the dinner we will have a **castells** (human towers) exhibition, performed by Castellers de Sabadell. Castells have been recently declared by UNESCO to be amongst the Masterpieces of the Oral and Intangible Heritage of Humanity. There will be another exhibition of a Catalan traditional dance: ***ball de bastons*** (stick dance)

Montserrat ▸

▴ Castellers

▾ Món Sant Benet

▸ Ball de Bastons

Sunday, 9th October

17:00 – 20:00 Sunday Registration

Monday, 10th October

07:30 - 09:00 Monday Registration ▸ Registration Desk, Secretariat

09:00 - 09:30 **Opening Ceremony** ▸ Room Barcelona A+B

09:30 - 13:00 **Plenary Session** ▸ Room Barcelona A+B

Plenary Session Part I

Session Chair ▸ **Ferran Martín**, *Universitat Autònoma de Barcelona, Spain*

09:30 - 10:30

Photonic metamaterials: Challenges and opportunities

Costas M. Soukoulis, *Foundation for Research Technology Hellas, Greece, and Iowa State University, USA*

In the last decade, a new area of photonics research has emerged, that has given the ability to produce materials with entirely novel electromagnetic properties. Known as metamaterials for their ability to take beyond conventional materials. Clearly, the field of metamaterials can develop mould-breaking technologies for a plethora of applications, where control over light (or more generally electromagnetic radiation) is a prominent ingredient-among them telecommunications, solar energy harvesting, biological and THz imaging and sensing, optical isolators and polarizers. In this talk, I give an introduction into this emerging field, review recent progress, and highlight remaining challenges and opportunities.

10:30 - 11:00 Coffee break ▸ Foyer

Plenary Session Part II ▸ Room Barcelona A+B

Session Chair ▸ **Sergei Tretyakov**, *Aalto University, Finland*

11:00 - 12:00

Metamaterials for active photonics and energy conversion

Harry A. Atwater, *California Institute of Technology, USA*

Metamaterials have compelling potential applications in active photonics and solar energy conversion. Highly compliant substrates allow generation of actively tunable metamaterials based on split ring resonators with frequency tunability over several resonant linewidths, and applications in sensing and spectroscopy. Metamaterials can also enable control of light-matter interactions in solar energy conversion.

12:00 - 13:00

Metamaterial-inspired engineering of electrically small antennas from microwave to optical frequencies

Richard W. Ziolkowski, *University of Arizona, USA*

In electrically small antenna applications, active metamaterial constructs have been introduced to increase the bandwidths at low frequencies and overcome losses at high frequencies. The theoretical designs of many of these systems and their simulated performance characteristics have been confirmed experimentally. These concurrences between theory and experiment will be highlighted.

13:00 - 14:30 Lunch ▸ La Cantina de l'Estació, Hotel Barceló Sants

Plasmon Polariton Optics

14:30 - 16:10 ▸ Room Barcelona B

Session Chair ▸ **Francisco Jose Garcia-Vidal**, *Universidad Autonoma de Madrid, Spain*

14:30 - 15:10 **Resolving light-matter interactions on the nanoscale** Keynote

L. (Kobus) Kuipers, *FOM Institute AMOLF, The Netherlands*

Nir Rotenberg, *FOM Institute AMOLF, The Netherlands*

We present our recent results on the local investigations near nanostructures of light fields and their interactions with matter.

15:10 - 15:40 **How to tame light at the nanometer scale? Either shape the structure or the illumination** Invited

Romain Quidant, *ICFO-The Institute of Photonic Sciences, Spain*

We present our latest advances in the nanoscale control of light using plasmonic nanostructures and their application to the control of single emitters and optical cloaking.

15:40 - 16:10 **Shaping of light in metamaterials and plasmonic structures** Invited

Yuri Kivshar, *Australian National University, Australia*

We review our recent theoretical and experimental results on the light shaping in plasmonic structures and nano-structured metamaterials. In particular, we discuss several effects associated subwavelength nanofocusing and shaping of light in plasmonic structures, nanofocusing of polychromatic plasmon beams, and the generation of Airy plasmons.

16:10 - 16:30 Coffee break ▸ Room Barcelona A

Monday, 10th October

RF and Microwave Metamaterials 1

14:30 - 16:10 ▸ Room Sants-Montjuic

Session Chair ▸ **Silvio Hrabar**, *University of Zagreb, Croatia*

14:30 - 14:50 **Optimal power transfer by coupled resonant coils** Oral

Laszlo Solymar, *Imperial College London, UK*
Ekaterina Shamonina, *Imperial College London, UK*

Assuming one transmitter and N-1 magnetically coupled receivers located in arbitrary positions a method is presented for finding the load impedances that optimize the total amount of power absorbed by the receivers. Auxiliary conditions are discussed.

14:50 - 15:10 **Metamaterial inspired microwave focal plane array** Oral

Wangren Xu, *Tufts University, USA*
David Shrekenhamer, *Boston College, USA*
Suresh Venkatesh, *University of Utah, USA*
David Schurig, *University of Utah, USA*
Sameer Sonkusale, *Tufts University, USA*
Willie Padilla, *Boston College, USA*

We present a metamaterial inspired detector array for room-temperature detection of gigahertz radiation. The system is implemented on printed circuit board and we characterize the sensitivity and radiation pattern. The metamaterial unit cell is loaded by an impedance matching circuit to tune the resonance strength and frequency of the metamaterial to account for variations in fabrication. The proposed sub-wavelength pixel shows enhanced detection sensitivity of -61dBm.

15:10 - 15:30 **Squint-free leaky-wave radiation with non-Foster artificial transmission lines** Oral

Hassan Mirzaei, *University of Toronto, Canada*
George Eleftheriades, *University of Toronto, Canada*

A novel leaky-wave antenna is presented, where the leaky-wave radiation is obtained by periodically loading a host transmission line with non-Foster negative capacitors. This type of loading, while making the antenna fast, preserves the non-dispersive nature of the host transmission line, thus, the beam-squinting can be effectively eliminated over a broad frequency range.

15:30 - 15:50 **Noise in periodic electrical lattices** Oral

Richard Syms, *Imperial College London, UK*
Laszlo Solymar, *Imperial College London, UK*

Passive electrical lattices can allow forward and backward wave propagation. Considerable attention has been paid to propagation loss arising from the finite conductivity. Here we show that loss is inevitably accompanied by noise, that noise must propagate as a wave, and demonstrate methods of calculating its power spectral density.

15:50 - 16:10 **Cylindrical Free-Space Transmission-Line Metamaterials: A Numerical Study** Oral

Justin G. Pollock, *University of Alberta, Canada*
Ashwin K. Iyer, *University of Alberta, Canada*

This paper presents a new hollow cylindrical metamaterial composed of radially orientated negative-refractive-index transmission-line (NRI-TL) boards. The NRI-TL board orientation introduces radially inhomo-geneous permeability and permittivity, whose profiles are extracted from full-wave simulations using a discrete multilayer approximation. Full wave simulations show that a vertical electric line source placed near a single metamaterial layer produces interesting radiation phenomena, including increased directivity and radiated power, as well as excitation of the dipolar resonant mode of the cylindrical shell.

16:10 - 16:30 Coffee break ▸ Room Barcelona A

Symmetry Properties of Metamaterials

14:30 - 16:10 ▸ Room Sarrià-Sant Gervasi

Session Chair ▸ **Mario Silveirinha**, Universidade de Coimbra, Portugal

14:30 - 15:10 **Plasmonic metamaterials with low spatial symmetry and their applications** Keynote

Gennady Shvets, *UT-Austin, USA*
Chihhui Wu, *UT-Austin, USA*
Nihal Arju, *UT, USA*
Alexander Khanikaev, *UT, USA*

Low Spatial Symmetry (LSP) plasmonic structures is a novel building block of optical metamaterials. In this talk I will discuss the potential of LSP metamaterials as platforms for optical devices designed to produce broad-band slow light, transform light polarization, enhance nonlinear effects, and enable highly-sensitive infrared bio-sensing. Fano resonances in LSP metamaterials will be discussed, and experimental results presented. Both metal and dielectric-based metamaterials will be discussed. The results of optical characterization of ordered and disordered arrays will also be presented.

15:10 - 15:30 **Strong chiral properties of helically-structured metamaterials in THz range** Oral

Igor Semchenko, *Francisk Skorina Gomel State University, Belarus*
Sergei Khakhomov, *Francisk Skorina Gomel State University, Belarus*
Elena Naumova, *Institute of Semiconductor Physics, Russian Academy of Sciences, Siberian Division, Russia*
Victor Prinz, *Institute of Semiconductor Physics, Russian Academy of Sciences, Siberian Division, Russia*
Sergey Golod, *Institute of Semiconductor Physics, Russian Academy of Sciences, Siberian Division, Russia*
Vitaliy Kubarev, *Institute of Nuclear Physics, Russian Academy of Sciences, Siberian Division, Russia*

In this paper on an example of the sample developed by a group from Institute of Semiconductor Physics (Novosibirsk), analytical simulation and numerical modeling of chiral properties of artificial anisotropic structure formed by microhelices is carried out. It is shown, that such artificial periodic structure can show giant chirality in Hz range. The rotation angle of polarization plane of transmitted electromagnetic wave and circular dichroism of structure are compared with experimental results.

15:30 - 15:50 **Numerical MoM treatment of cloak with cyclic symmetry** Oral

Arnab Bhattacharya, *Université Catholique de Louvain, Belgium*
Enrica Martini, *University of Siena, Italy*
Stefano Maci, *University of Siena, Italy*
Christophe Craeye, *Université Catholique de Louvain, Belgium*

A numerical analysis technique based on Array Scanning Method (ASM) for cyclic symmetry cylindrical cloaks is presented along with Method of Moments (MoM) for 1D periodic structures used for treating the periodicity along the axis of the cloak. The numerical analysis for a cloak presented in the literature is discussed.

15:50 - 16:10 **Cooperative asymmetry induced transparency in ensembles of interacting plasmonic resonators** Oral

Stewart Jenkins, *University of Southampton, UK*
Janne Ruostekoski, *University of Southampton, UK*

We develop a theory of Cooperative Asymmetry Induced Transparency (CAIT) in a finite array of interacting meta-molecules. In contrast with similar EIT like phenomena in meta-materials that can be described by meta-molecules acting independently, CAIT relies on cooperative interactions to form the high quality modes on which the transparency depends.

16:10 - 16:30 Coffee break ▸ Room Barcelona A

Monday, 10th October

Plasmonic Metamaterials 1

16:30 - 18:10 ▸ Room Barcelona B

Session Chair ▸ **Vladimir Shalaev**, *Purdue University, USA*

16:30 - 17:00 **Resonant multiple scattering by metamaterial clusters** Invited

Ivana Sersic, *FOM Institute AMOLF, Netherlands*
A. Femius Koenderink, *FOM Institute AMOLF, Netherlands*

Metamaterials are composed of very strongly scattering subwavelength objects that can give rise to magnetic analogons of plasmonic antennas, plasmon hybridization and extraordinary transmission. We present a new fully electrodynamic theory for magneto-electric point scatterers that provides quantitative cross sections, resonance linewidths, and reflection and transmission coefficients for arbitrary clusters of objects like split rings. We confirm these quantitative predictions in scattering experiments.

17:00 - 17:20 **Glimpsing non-radiative plasmonic dark modes in the near field: exciting the unexcitable** Oral

Worawut Khunsin, *Max-Planck-Institute für Festkörperforschung, Germany*
Jens Dorfmüller, *Max-Planck-Institute für Festkörperforschung, Germany*
Moritz Eßlinger, *Max-Planck-Institute für Festkörperforschung, Germany*
Ralf Vogelgesang, *Max-Planck-Institute für Festkörperforschung, Germany*
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Falk Lederer, *Friedrich-Schiller-Universität Jena, Germany*
Harald Giessen, *Universität Stuttgart, Germany*
Klaus Kern, *Max-Planck-Institute für Festkörperforschung & École Polytechnique Fédérale de Lausanne, Germany & Switzerland*

We present near-field mapping of a system of coupled nanoantennas composed of bright and dark plasmonic modes. We identify the governing geometrical and illumination parameters that affect the excitation and the structure of the induced dark mode. Based on the insights we obtain in this study, we demonstrate, in the nearfield, how the destructive interference in a plasmonic system occurs that causes EIT-like effect. Our findings have potentials in the fundamental study of excitation mechanism in plasmonic nanostructures and will serve as a design guideline for plasmonic sensors.

17:20 - 17:40 **Surface plasmon polariton flat lenses** Oral

Muamer Kadic, *Institut Fresnel – CNRS; Aix-Marseille Universite, France*
Sebastien Guenneau, *Institut Fresnel – CNRS; Aix-Marseille Universite, France*
Stefan Enoch, *Institut Fresnel - CNRS; Aix-Marseille Universite, France*
Anantha Ramakrishna, *Indian Institute of Technology, India*

We extend designs of perfect lenses to the focussing of surface plasmon polaritons (SPPs) propagating at the interface between two anisotropic media of opposite permittivity sign. We identify the role played by the components of anisotropic and heterogeneous tensors of permittivity and permeability, deduced from a coordinate transformation, in the dispersion relation governing propagation of SPPs. We illustrate our theory with three-dimensional finite element computations for focussing of SPPs by perfect flat lense. Finally, we propose a design of a flat SPP lens consisting of metamaterial in a periodic fashion (hexagonal array) on a metal plate. This new design open the way to experiments.

17:40 - 18:10 **Metamaterials and flow of photons and electrons** Invited

Nader Engheta, *University of Pennsylvania, USA*

In this paper, I give an overview of our recent efforts in my group in the areas of optical metamaterials and their roles in taming photons and electrons. I discuss our recent progress on design of building blocks of optical metamaterials with specific bulk properties, optical metatronics, extreme-parameter metamaterials, one-way flow of photons, graphene metamaterials and transformation optics, and nonlinear phenomena in certain metamaterial nanostructures. Physical insights into these results are given and future directions are speculated.

18:10 - 20:10 **Welcome Reception** ▸ Hall, Ground Floor

Fabrication of Metamaterials 1

16:30 - 18:10 ▸ Room Sants-Montjuic

Session Chair ▸ **Thomas Pertsch**, Friedrich Schiller University Jena, Germany

16:30 - 17:10 **Recent experimental progress in 3D optical metamaterials and transformation optics** Keynote

Tolga Ergin, *Karlsruhe Institute of Technology (KIT), Germany*
Joachim Fischer, *Karlsruhe Institute of Technology (KIT), Germany*
Andreas Frölich, *Karlsruhe Institute of Technology (KIT), Germany*
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Nicolas Stenger, *Karlsruhe Institute of Technology (KIT), Germany*
Michael Thiel, *Nanoscribe GmbH, Germany*
Martin Wegener, *Karlsruhe Institute of Technology (KIT), Germany*

In this paper, we review our recent experimental progress regarding three-dimensional metamaterials and transformation-optics architectures. In particular, we present several variations of our previously introduced gold-helix metamaterials as compact broadband circular polarizer. Furthermore, we discuss our polarization-independent visible-frequency invisibility cloak that has been enabled by three-dimensional stimulated-emission-depletion direct-laser-writing optical lithography.

17:10 - 17:30 **Self-assembly as fabrication tool: Plasmonic particles organized in nanostructured polymer matrices** Oral

Clemence Tallet, *Centre de Recherche Paul Pascal – CNRS, France*
Julien Vieaud, *Centre de Recherche Paul Pascal – CNRS, France*
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Frederic Nallet, *Centre de Recherche Paul Pascal – CNRS, France*
Ashod Aradian, *Centre de Recherche Paul Pascal – CNRS, France*
Virginie Ponsinet, *Centre de Recherche Paul Pascal – CNRS, France*

We study the organization and the optical properties of gold nanoparticles self-assembled in poly-mer matrices. Both disordered and ordered nanocomposites are studied. A detailed description of their structure is obtained using scattering and microscopy techniques. Spectroscopic ellipsometry is used to determine the refractive indices, which are then confronted to effective medium models. This work aims at demonstrating the potential of self-assembly as fabrication tool for new optical materials.

17:30 - 17:50 **Amorphous multilayer meta-material based on cluster of nanoparticles and polymer thin films** Oral

Toralf Scharf, *École polytechnique fédérale de Lausanne, Switzerland*
Jose Dintinger, *École polytechnique fédérale de Lausanne, Switzerland*
Houda Sellame, *École polytechnique fédérale de Lausanne, Switzerland*

We present a material concept based on nanoparticles clusters sandwiched between polymer lay-ers and arranged in a thin film stack to combine. In this way we achieved to combine plasmonic resonances and multilayer interference and realized thin film bulk materials with unconventional optical properties. The technology is based on spin coating and polymerization and leads to high quality films with specific optical features. Samples with a variety of parameters were prepared and characterized by angle resolved spectroscopy. We present details how cluster concentration and multilayer interference influence the optical properties if such metamaterials.

17:50 - 18:10 **Optimization of silver for a 200 nm Fishnet grating** Oral

Iris Bergmair, *PROFACTOR GmbH, Austria*
Maria Losurdo, *Institute of Inorganic Methodologies and of Plasmas - IMIP-CNR, Italy*
Giovanni Bruno, *Institute of Inorganic Methodologies and of Plasmas - IMIP-CNR, Italy*
Michael Bergmair, *Johannes Kepler University, Austria*
Babak Dastmalchi, *Johannes Kepler University, Austria*
Uwe Hübner, *Institute of Photonic Technology, Germany*

Monday, 10th October

Raluca Penciu, *Foundation for Research Technology Hellas , Greece*
Nianhai Shen, *Ames Laboratory and Iowa State University, USA*
Costas M. Soukoulis, *Foundation for Research Technology Hellas , Greece*
Michael Mühlberger, *PROFACTOR GmbH, Austria*
Kurt Hingerl, *Johannes Kepler University, Austria*

In this paper we show the fabrication of a silver Fishnet aiming at the visible regime using Nanoimprint Lithography (NIL). One main problem for such materials is the silver quality and its degradation. We report on the fabrication of silver structures and its manipulation of grain size using plasma processes to reduce silver oxide and to improve the silver stability on air.

18:10 - 20:10 **Welcome Reception** ▸ Hall, Ground Floor

Applications of Metamaterials 1

16:30 - 18:10 ▸ Room Sarrià-Sant Gervasi

Session Chair ▸ **Alex Schuchinsky**, *Queen's University Belfast, UK*

16:30 - 17:00 **Engineering nonlinearities in plasmonic nanorod metamaterials** Invited

Anatoly Zayats, *King's College London, UK*

Plasmonic metamaterials based on aligned nanorods provide an opportunity to engineer nonlinear optical response by controlling the interaction between plasmonic modes of individual nanorods as well as with active material embedded in the array. In this talk we will overview nonlinear optical properties of such bare and hybrid gold nanorod arrays in weak and strong coupling regimes as well as taking into account the effect of nonlocal electromagnetic interactions in the array.

17:00 - 17:30 **Integrated linear and nonlinear metaphotonics** Invited

Allan Boardman, *University of Salford, UK*
Peter Egan, *University of Salford, UK*
Rhiannon Mitchell-Thomas, *University of Salford, UK*
Martin McCall, *Imperial College London, UK*

Integrated metamaterial-driven waveguide devices are of growing importance for potential applications in the health, environment and energy sectors and in the possible design of new computing techniques. The latter will be introduced through the new history editor involving space-time transformations optics. This paper will address both linear and nonlinear waveguide complexities, under the general heading of integrated metaphotonics heading. The results will demonstrate how strong linear modal control emerges from metamaterial choices and how even weak nonlinearity creates new forms of beam and pulse formation. For all the cases analysed, both waveguide complexity and the role of magnetooptics will be introduced.

17:30 - 17:50 **High speed terahertz modulation from metamaterials with embedded high electron mobility transistors** Oral

David Shrekenhamer, *Boston College, USA*
Saroj Rout, *Tufts University, USA*
Andrew Strikwerda, *Boston University, USA*
Chris Bingham, *Boston College, USA*
Richard Averitt, *Boston University, USA*
Sameer Sonkusale, *Tufts University, USA*
Willie Padilla, *Boston College, USA*

We have designed and demonstrated the performance of a novel terahertz (THz) device resulting from hybridization of metamaterials (MMs) with pseudomorphic high electron mobility transistors (HEMTs), fabricated in a commercial gallium arsenide (GaAs) process. Monolithic integration of transistors into each unit cell permits modulation at the metamaterial resonant frequency of 0.46 THz. Characterization is performed using a THz time-domain spectrometer (THz-TDS) and we demonstrate modulation values over 30%, and THz modulation at frequencies up to 10 megahertz (MHz).

17:50 - 18:10 **Intrinsic performance of dual-gate FET dual-band distributed mixers with composite right/left-handed transmission lines** Oral

Javier Mata-Contreras, *Universidad de Malaga, Spain*
Teresa Martin-Guerrero, *Universidad de Malaga, Spain*
Carlos Camacho-Peñalosa, *Universidad de Malaga, Spain*

Composite Right/Left-Handed Transmission Lines (CRLH-TLs) have been recently used to design active distributed mixers with new performance like, for instance, dual-band frequency response. However, these circuits present a poor local oscillator to radiofrequency isolation and require an external coupler to inject both signals into the mixer, as conventional ones also do. These draw-backs can be removed by using dual-gate FETs instead of single-gate ones. In this contribution the intrinsic performance of dual-band distributed mixers based on dual-gate FETs is assessed by simulating a simplified mixer model.

18:10 - 20:10 **Welcome Reception** ▸ Hall, Ground Floor

Tuesday, 11th October

Advanced Metamaterials and their Applications

08:20 - 10:00 ▸ Room Barcelona B

Session Chair ▸ **Ekaterina Shamonina**, *Imperial College London, UK*

08:20 - 09:00 **Zero-permeability nonlinear split-ring metamaterials for magnetic resonance imaging applications** Keynote

Manuel Freire, *University of Seville, Spain*
Marcos Lopez, *University of Seville, Spain*
Jose Algarin, *University of Seville, Spain*
Volker Behr, *University of Würzburg, Germany*
Peter Jakob, *University of Würzburg, Germany*
Ricardo Marques, *University of Seville, Spain*

Nonlinear split-ring metamaterial slabs with zero permeability can reject the weak radiofrequency magnetic field coming from tissue in magnetic resonance imaging systems and at the same time can avoid the distortion of the strong excitation field. This can help to increase the signal-to-noise-ratio of the image.

09:00 - 09:20 ~~**Application of nanotechnology in the plasmonic enhancement of the solar-to-electric energy conversion by bacteriorhdopsin**~~ ~~Oral~~

Chun-Wan Yen, *Georgia Institute of Technology, USA*

This paper was not presented at the conference (Withdrawal).

Recently, we have successfully constructed a simple solu…without bR film preparation and external bias. Furthermore, we used plasmonic properties of silver nano-particles (AgNPs) to enhance the flux of blue photons, which can shortcut the photocycle of bR and increase the production of protons. By kinetic measurement, we observed that the plasmonic field effect of AgNPs can greatly accelerate the recovery of bR ground state and the decay of bR intermediate. From the results of photocurrent measurement, the plasmonic enhanced photocurrent can be as high as 25 nA cm-3, 15 times higher that that of pure bR. This value of photocurrent density is also orders of magnitude higher than previous reports. This mechanism was further verified by spectroscopic and kinetic studies.

09:20 - 09:40 **Some applications of MTMs based on non-Foster active loads** Oral

Mirko Barbuto, *"Roma Tre" University, Italy*
Alessio Monti, *"Roma Tre" University, Italy*
Filiberto Bilotti, *"Roma Tre" University, Italy*
Alessandro Toscano, *"Roma Tre" University, Italy*

In this contribution, we propose a novel approach to dramatically improve the operation bandwidth of a Split Ring Resonator (SRR) by loading its external gap with an active non-Foster circuit. The theoretical aspects, as well as some applications in the field of electrically small microwave antennas, enhanced microwave transmission, and microwave absorbers are presented.

09:40 - 10:00 **Four different sign combinations of density and modulus** Oral

Sam Hyeon Lee, *Yonsei University, Korea*
Jong Jin Park, *Yonsei University, Korea*
Seung Hwan Lee, *Yonsei University, Korea*
Choon Mahn Park, *Anyang University, Korea*
Yong Mun Seo, *Myongji University, Korea*
Chul Koo Kim, *Yonsei University, Korea*

We present a dispersive new acoustic metamaterial consisting of Helmholtz resonators and membranes, which exhibited all the four sign combinations of the constitutive parameters; namely density negative (NG), modulus negative(BNG), double negative (DNG), and double positive (DPS).This acoustic metamaterial exhibits some important extreme properties including infinite stiffness and zero density.

10:00 - 11:20 Coffee break + **Poster Session 1** ▸ Room Barcelona A

Nanoplasmonics: Design and Fabrication

08:20 - 10:00 ▸ Room Sants-Montjuic

Session Chair ▸ **Alexandra Boltasseva**, *Purdue University, USA*

08:20 - 08:50 **Nanoplasmonics: New design concepts for nanoscale optical cavities** Invited

Stefan Maier, *Imperial College London, UK*

The design of nanoplasmonic cavities exploiting coherent processes such as sub- and superradiance as well as Fano-type interactions will be discussed, under the framework of plasmon hybridization theory. In such cavities, interactions between bright and dark localized plasmon modes lead to a complex mode spectrum, which can be visualized using electron energy loss spectroscopy. First implementations fabricated using electron beam lithography will be presented. Furthermore, it will be shown how the concept of transformation optics can be utilized for the design of nanoresonators with a broadband absorption spectrum, showing high promise for light harvesting over the whole visible and infrared range of the spectrum.

08:50 - 09:20 **Optical transmission through hole arrays in optically thin metal films** Invited

Luis Martin-Moreno, *Instituto de Ciencia de Materiales de Aragón CSIC & Universidad de Zaragoza, Spain*
Sergio G. Rodrigo, *University of Rochester, USA*
Alexey Yu. Nikitin, *Instituto de Ciencia de Materiales de Aragón CSIC &Universidad de Zaragoza, Spain*
Alexandre V. Kats, *Institute for Radiophysics and Electronics, Ukrainian Academy of Sciences, Ukraine*
Ivan S. Spevak, *Institute for Radiophysics and Electronics, Ukrainian Academy of Sciences, Ukraine*
Francisco Jose Garcia-Vidal, *Universidad Autónoma de Madrid, Spain*

We present a theoretical study on the extraordinary optical transmission through square hole arrays in a metal film, focusing on the dependence on the metal thickness. More precisely, we will study the crossover from the (now canonical) optically thick films to the case of optically thin films. We show that, as the thickness of the metal film decreases the extraordinary optical transmission peak redshifts, due to the coupling of light with the short-range surface plasmons. Remarkably, the ratio between the maximum and minimum values of the transmittance is high even for metal thicknesses as small as one skin depth.

09:20 - 09:40 **Bottom-up fabrication of metamaterials by metallic nanoparticle self-organization** Oral

José Dintinger, *Ecole fédérale polytechnique de Lausanne, Switzerland*

In this paper, the bottom-up fabrication of metamaterials by self assembly of metallic nanoparti-cles into spherical clusters is discussed. The refractive index of silver nanoparticle composites with different concentrations, from dispersed to randomly packed nanoparticles, is measured by spec-troscopic ellipsometry, demonstrating high permittivity values in the visible. As a potential meta-material building block, nanoparticle spherical assemblies are prepared by a method based on oil in water emulsion and their optical properties are characterized.

09:40 - 10:00 **Sub-picosecond polarization conversion with plasmonic crystals** Oral

Polina Vabishchevich, *Lomonosov Moscow State University, Russia*
Varvara Komarova, *Lomonosov Moscow State University, Russia*
Maxim Shcherbakov, *Lomonosov Moscow State University, Russia*
Tatyana Dolgova, *Lomonosov Moscow State University, Russia*
Andrey Fedyanin, *Lomonosov Moscow State University, Russia*

Ultrafast polarization state alteration is observed in optical response of a plasmonic nanograting by means of sub-picosecond time-resolved polarimetry. Simultaneous measurement of Stokes parame-ters as a function of time with a time-gate of 130 fs reveals a significant conversion of polarization state in a single pulse when the incident polarization is oriented at 45 to the sample's optical axis. The effect is attributed to the excitation of the long-living surface plasmon-polaritons under the plas- monic bandgap condition.

10:00 - 11:20 Coffee break + **Poster Session 1** ▸ Room Barcelona A

Tuesday, 11th October

Planar Metamaterials 1

08:20 - 10:00 ▸ Room Sarrià-Sant Gervasi

Session Chair ▸ **Harald Giessen**, **University of Stuttgart, Germany**

08:20 - 08:50 **Resonance hybridization in asymmetric split-ring resonator arrays - and detection of organic molecular Fano resonances** Invited

Nigel Johnson, *University of Glasgow, UK*
Basudev Laharir, *University of Glasgow, UK*
Richard De La Rue, *Univeristy of Glasgow, UK*
Ce Lang, *City University of Hong Kong, China*
Scott McMeekin, *Glasgow Caledonian University, UK*

We utilise a plasmon resonance hybridization model to understand the working of an array of A-SRR resonators (or nano-antennas) and show, by both experiment and simulation. We also show that, when PMMA is used as an organic probe on top of the A-SRR array, the phase and amplitude of a characteristic molecular Fano resonance associated with PMMA changes according to the spectral position of the trapped mode and the plasmonic reflection peaks. We further extend the study to show the quantitative effects of double A-SRRS and their resulting multiple trapped modes.

08:50 - 09:20 **Adiabatic gradient index plasmonics** Invited

Jason Valentine, *Vanderbilt University, USA*
Thomas Zentgraf, *University of California, Berkeley, USA*
Yongmin Liu, *University of California, Berkeley, USA*
Maiken Mikkelsen, *University of California, Berkeley, USA*
Xiang Zhang, *University of California, Berkeley, USA*

We demonstrate an approach to realize gradient refractive index transformations in plasmonic systems by adiabatically tailoring the modal index. This is accomplished through smooth height variations in a dielectric cladding layer, thus minimizing parasitic scattering and reflections. We experimentally demonstrate this concept by examining plasmonic Luneburg and Eaton lenses.

09:20 - 09:40 **Transferable low-attenuation scaffold based on transparent conductive oxide nanoparticles for nanoplasmonics and optical metamaterials** Oral

Zoran Jaksic, *University of Belgrade, Serbia*
Jelena Buha, *Swiss Federal Laboratories for Materials Science and Technology, Switzerland*
Jovan Matovic, *Vienna University of Technology, Austria*
Slobodan Vukovic, *University of Belgrade, Serbia*

We report on functionalized nanomembrane-based plasmonic structures transferable to various substrates, but also used as freestanding media. Carbon nanotubes were utilized to reinforce the structure, while indium tin oxide and zinc oxide nanoparticles were utilized as the plasmonic part. Dip coating and drop coating were used for the deposition.

09:40 - 10:00 **Self-complementary metasurface for designing a new kind of frequency selective surface** Oral

Julián David Ortiz Cárdenas, *Universidad Nacional de Colombia, Colombia*
Juan Domingo Baena Doello, *Universidad Nacional de Colombia, Colombia*
Ricardo Marqués Sillero, *Universidad de Sevilla, Spain*
Francisco Medina Mena, *Universidad de Sevilla, Spain*

A self-complementary metasurface is studied in this paper. The unit cell consists of a split ringresonator and its complementary counterpart. Numerical simulations demonstrate that this structurebehaves like a very selective band-pass filter for one linear polarization and like a band-stop filter for the orthogonal polarization at the same frequency range.

10:00 - 11:20 Coffee break + **Poster Session 1** ▸ Room Barcelona A

Poster Session 1

10:00 - 11:20

Room Barcelona A

1. ~~How long does it take?~~

Wei Hsiung Wee, *Imperial College London, UK*
John Pendry, *Imperial College London, UK*

Since the “perfect lensing” takes time to develop, a natural question to ask is “how long does it take?”. While this has been analysed previously, the anaylsis only applies for the simple (epsilon=muapprox-1) slab lens. This work is an attempt to provide a universal framework applicable to any general perfect lens.

2. Three-dimensional invisibility cloaking operates at terahertz frequencies

Fan Zhou, *Northwestern University, USA*
Yongjun Bao, *Northwestern University, USA*
Wei Cao, *Oklahoma State University, USA*
Colin Stuart, *Northwestern University, USA*
Jianqiang Gu, *Oklahoma State University, USA*
Weili Zhang, *Oklahoma State University, USA*
Cheng Sun, *Northwestern University, USA*

In this paper we aim to explore novel approach of using dielectric material with gradient index to manipulate terahertz (THz) waves. As an example, we demonstrated such gradient index material could enable invisibility in broadband THz frequencies, so called cloaking. Transformation optics technique was used to design the index distribution, which can bend electromagnetic wave and make it propagate in the desired manner. The scalable and parallel 3D lithography (microstereo-lithography) technique was employed in the cloak fabrication process and shows the strong capa-bility and potential in fabricating THz metamaterial with complex structures. Finally the invisibil-ity was characterized by reflection terahertz time-domain spectroscopy (THz-TDS).

3. Fabrication and characterization of 3D nanocomposites made of glass doped with nanoparticles for plasmonic applications

Marcin Gajc, *Institute of Electronic Materials Technology, Poland*
Andrzej Kłos, *Institute of Electronic Materials Technology, Poland*
Barbara Surma, *Institute of Electronic Materials Technology, Poland*
Ryszard Diduszko, *Institute of Electronic Materials Technology, Poland*
Andrey Nikolaenko, *University of Southampton, UK*
Nikolay I. Zheludev, *University of Southampton, UK*
Dorota A. Pawlak, *Institute of Electronic Materials Technology, Poland*

In this paper metallodielectric nanocomposites, obtained by directional growth of glass fibers with incorporated silver nanospheres, silver nanowires and indium tin oxide (ITO) nanoparticles have been investigated. Description of novel fabrication process together with structural/optical characterization results will be presented.

4. Terahertz metamaterial consisting of three-dimensional microcoils

Stefan Waselikowski, *Universität Freiburg, Germany*

In this paper we present a metamaterial consisting of 3D submillimeter-sized coils fabricated with an automated wire-bonder. The response of the structure is characterized by terahertz (THz) time- domain spectroscopy and numerical simulations. Depending on the light polarization fundamental and higher order electric or magnetic resonances can be excited. As a first step towards active tunability of the metamaterial, we demonstrate tuning of the q-factor and resonance frequency by variation of the winding pitch of the coils.

5. Fabrication and characterization of crystallized magnetoferritin as an artificial magnetic metamaterial

Thomas Schwarze, *Technische Universiät München, Germany*
Mitsuhiro Okuda, *H. H. Wills Physics Laboratory, UK*
Rupert Huber, *Technische Universiät München, Germany*
Jean-Charles Eloi, *H. H. Wills Physics Laboratory, UK*
Florian Brandl, *Technische Universiät München, Germany*
Lukas Dreher, *Technische Universität München, Germany*
Martin S. Brandt, *Technische Universität München, Germany*
Dirk Grundler, *Technische Universiät München, Germany*
Walther Schwarzacher, *H. H. Wills Physics Laboratory, U.K.*

We synthesized magnetic nanoparticles in the central cavity of a cage-shaped protein and fabrica-ted periodic three-dimensional arrays using the protein's ability to self-assemble. The crystal's dy-namic magnetic properties were observed by electron paramagnetic resonance in the GHz fre-quency regime. The crystals are superparamagnetic at higher temperatures but an isotropic reso-nance is observed at 5 Kelvin.

5. Describing the transition in the effective optical properties from 2D to 3D metamaterials: A simple extension of the Maxwell-Garnett rule

Olivier Merchiers, *Centre de Recherche Paul Pascal – CNRS & University of Bordeaux, France*
Yves Borensztein, *Institut des Nanosciences de Paris, France*
Ashod Aradian, *Centre de Recherche Paul Pascal – CNRS & University of Bordeaux, France*

We propose and study a straightforward extension of the Maxwell-Garnett mixing rule, which makes it possible to encompass the effective properties of two-dimensional metamaterials, three-dimensional metamaterials and all intermediate situations. We apply this to the situation of a system of spherical resonators (gold nanoparticles) embedded in a host medium, in contact with a substrate. We study the continuous transition taking place from two-dimensional to fully three-dimensional effective properties, as a function of the system thickness. Our extension allows to study the effect of a depletion or accumulation of resonators near the substrate boundary, where surface effects due to image charges dominate. More generally, we are able to take into account any non-uniform distribution of resonators in the thickness and compute the outcome on the effective properties.

6. Influence of randomness on the effective dielectric function of metal-dielectric composites for metamaterial purposes

Jordi Sancho-Parramon, *Rudjer Boskovic Institute, Croatia*
Vesna Janicki, *Rudjer Boskovic Institute, Croatia*
Hrvoje Zorc, *Rudjer Boskovic Institute, Croatia*

The effective dielectric function of metal-dielectric composites consisting of spherical particles randomly distributed in a matrix is numerically investigated. The study shows that local field fluctuations may critically affect the composite performance for metamaterial applications. Randomness significantly modifies the effective dielectric function of composites consisting of metal inclusions embedded in dielectric matrix. The effect is less remarkable for dielectric inclusions in a metal matrix.

7. Proposal for new method to design all-dielectric photonic metamaterials using an analytical approach

Eric Cassan, *Université Paris Sud, France*
Khanh-Van Do, *Université Paris Sud, France*
Xavier Le Roux, *Université Paris Sud, France*
Charles Caër, *Université Paris Sud, France*
Delphine Marris-Morini, *Université Paris Sud, France*
Nicolas Izard, *Université Paris Sud, France*
Laurent Vivien, *Université Paris Sud, France*

We propose a new analytical approach to the study of all-dielectric metamaterials allowing the prediction of the optical index maps and the required hole drilling distributions making light follow prescribed paths. The method will be applied to proof-of-concept structures based on the silicon-on-insulator technology. Light propagation will be studied using FDTD simulation to verify light trajectories, study the influence of extended light beams, and evaluate the robustness of the semi-classical approach based on equations of Hamiltonian optics. The presented results will show that the proposed method can be used for the straightforward design of new optical functionalities within the photonic metamaterial regime.

8. A length-independent method to retrieve the effective parameters of materials and determine the interactions in metamaterial-structures

Alireza Ajami, *RWTH Aachen, Germany*
Hammam Shakhtour, *RWTH Aachen, Germany*
Dirk Heberling, *RWTH Aachen, Germany*

A novel method to retrieve the effective electromagnetic parameters (permittivity and permeability) is proposed. The advantage over the existing methods is that the length of the material under test (MUT) should not be strictly smaller than the wavelength. This makes it possible to retrieve the effective electromagnetic parameters of a metamaterial consisting of any number of cells. Consequently the effect of the interactions between the cells in a long structure can be studied without length-disturbance. The method is determined and its length-independency is proved. The interactions between the cells of two metamaterials (consisting of 2 and 10 cells) are discussed and the deviation of their effective electromagnetic parameters, which is caused by the interactions, is presented.

9. ~~Non-periodic homogenization of acoustic metamaterials using the method of matched asymptotic expansions~~

Pierre-Henri Cocquet, *Onera, The French Aerospace Lab, France*
Abderrahmane Bendali, *IMT, Institute of Mathematics of Toulouse – INSA, France*
Sébastien Tordeux, *INRIA Bordeaux Sud-Ouest, France*

This paper was not presented at the conference (No show).

In this paper we study the scattering of a plane wave by N bo elta$ tends to 0 and N grows to infinity with the method of matched asymptotic expansions. We assume that the bodies are embedded into a bounded domain of $\R^{3}$ according to some distribution function allowing to consider both periodical and non-periodical distribution of bodies. The homogenized refractive index of the metamaterial is then found by interpreting the expansion of the scattered field outside the zone filled by the bodies as the Born approximation corresponding to the effective material.

10. Accuracy of homogenization models for finite high-impedance surfaces located in the proximity of a horizontal dipole

Filippo Costa, *University of Pisa, Italy*
Olli Luukkonen, *Aalto University, Finland*
Constantin Simovski, *Aalto University, Finland*
Agostino Monorchio, *University of Pisa, Italy*
Sergei Tretyakov, *Aalto University, Finland*
Peter de Maagt, *European Space Agency, The Netherlands*

The accuracy of different homogenization models is analyzed in the case of a dipole antenna located very close to a finite high-impedance surface (HIS). In the different models, the periodic structure is replaced by a homogeneous boundary condition with different degrees of accuracy. It is shown that the expressions for the input impedance of HIS, that are used to compute the reflection phase diagram for normal incidence, do not provide the sufficient accuracy needed for this type of near-field problems. The accuracy of the homogenization model can be gradually improved by taking into account the spatially dispersive terms due to the grounded substrate and to the frequency-selective surface (FSS) grid. Further, it is shown that by accurately modeling the spatial dispersion in such HIS structures, one is able to reproduce correctly the presence of TE sur-face waves that play important role in the operation of a HIS-based antenna. Indeed, the bandwidth of the HIS-based antenna over which it presents a good return loss and broadside patterns can be extended by using the these surface waves propagating on the HIS favorably.

11. Optical magnetic response in three-dimensional metamaterial of upright plasmonic meta-molecules

Wei Ting Chen, *National Taiwan University, Taiwan*
Chen Jung Chen, *National Taiwan University, Taiwan*
Pin Chieh Wu, *National Taiwan University, Taiwan*
Shulin Sun, *National Taiwan University, Taiwan*
Lei Zhou, *Fudan University, China*
Guang-Yu Guo, *National Taiwan University and National Chengchi University, Taiwan*
Chinh Ting Hsiao, *National Taiwan University, Taiwan*
Kuang-Yu Yang, *National Taiwan University, Taiwan*
Nikolay I. Zheludev, *University of Southampton, UK*
Din Ping Tsai, *National Taiwan University. National Applied Research Laborator. Academia Sinica, Taiwan*

Fabrication of 375x375 vertical U-shape nano gold rings (110 nm x 60 nm x 40 nm) on a fused silica substrate has been successfully implemented by a novel e-beam lithography double exposure process. Plasmonic resonance modes of such particles are investigated by finite-element simulations and optical measurements, which are in excellent agreement with each other. Results show magnetic field solely depends on the resonance mode showing either enhanced between two prongs of vertical U-shape nano ring or enhanced around two prongs of vertical U-shape gold ring.

12. Electrically thin asymmetric chiral metamaterial circular polarizer

Mehmet Mutlu, *Bilkent University, Turkey*
Ahmet E. Akosman, *Bilkent University, Turkey*
Andriy E. Serebryannikov, *Hamburg University of Technology, Germany*
Ekmel Ozbay, *Bilkent University, Turkey*

In this paper, we numerically and experimentally demonstrate an asymmetric chiral metamaterial circular polarizer constructed by using four double-layered U shaped split ring resonators, mutually rotated by 90°. The sizes of the electrically and magnetically excited rings are different, which allows for equalizing the orthogonal components of the electric field at the output interface with ±90° phase difference. As a result, left hand circular polarization and right hand circular polarization are obtained in transmission at 5.1 GHz and 6.4 GHz, respectively.

13. ~~Surface plasmon polaritons in enantiomeric chiroplasmonic structures due to bianisotropy~~

Roland Tarkhanyan, *Institute of Radiophysics & Electronics, Armenia*

This paper was not presented at the conference (No show).

A new class of surface plasmon polaritons supported in ident c structures is presented. The existence of two distinct Fa d polarization properties is predicted.

14. Magnifying absolute instruments for homogeneous region

Tomas Tyc, *Masaryk University, Czech Republic*

We propose several magnifying absolute optical instruments that create magnified stigmatic images, either virtual or real, of optically homogeneous three-dimensional spatial regions.

15. Flexible metamaterials at visible frequencies and applications

Andrea Di Falco, *University of St Andrews, UK*
Yang Zhao, *University of Texas at Austin, USA*
Andrea Alu, *University of Texas at Austin, USA*

We discuss our recent results regarding the realization and characterization of metamaterials on flexible substrates at visible wavelengths (Metaflex). We outline the fabrication procedure and show the electromagnetic response for different plasmonic structures. We also report on the verification of Fano resonances on Metaflex, which yields to ultra-narrow spectral features in flexible plasmonic surfaces, and on the realization of a flexible metamaterial with response independent on polarization and angle of incidence.

16. Temporally shaping pulses with a metamagnetic metamaterial

Dean Brown, *UES, Inc. - AFRL, USA*
Mark Walker, *GDIT - AFRL, USA*
Augustine Urbas, *AFRL, USA*

Excitation in optical spectroscopy and photo-induced processes like second harmonic generation depend on temporal properties of ultrafast pulses. In this work, we demonstrate that metamaterials can be fabricated to have very large spectral dispersion properties that can positively affect both the temporal envelope an ultrafast pulse and the phase of each spectral component.

17. Magnetic excitations in silver nanocrescents in the blue spectral range: experiments versus calculations

Andriy Shevchenko, *Aalto University, Finland*
Roman Khakimov, *Aalto University, Finland*
Victor Ovchinnikov, *Aalto University, Finland*
Matti Kaivola, *Aalto University, Finland*

We verify numerically the presence of resonant magnetic excitations in the blue spectral region in silver crescent-form nanoresonators. The resonances originate from plasmon modes that resemble electric quadrupole excitations. We also identify another resonance in the red, which has a magnetic dipole character. These results support our previous experimental findings.

18. Saturation of the resonance of the complementary SRR

Julián David Ortiz Cárdenas, *Universidad Nacional de Colombia, Colombia*
Vicente Delgado, *Universidad de Sevilla, Spain*
Juan Domingo Baena Doello, *Universidad Nacional de Colombia, Colombia*
Ricardo Marqués Sillero, *Universidad de Sevilla, Spain*

It is well known that the Split Ring Resonator (SRR) reachs a saturation value of the resonant frequency when its size is scaled down. In other works the complementary SRR was proposed as an electric resonator. Here it is demonstrated that a similar saturation phenomenon happens to the complementary SRR.

19. ~~Magneto-optical properties of nickel nanostructured arrays~~

Antony Murphy, *Queen's University Belfast, UK*
William Hendren, *Queen's University Belfast, UK*
John McPhillips, *Queen's University Belfast, UK*
Ron Atkinson, *Queen's University Belfast, UK*
Robert Pollard, *Queen's University Belfast, UK*

This paper was not presented at the conference (No show).

Nanostructured metamaterials consisting of nickel nanowire or nanotube arrays embedded in alumina have been fabricated. The anisotropic magneto-optical properties of the metamaterials were studied using a Kerr polarimeter in the polar configuration. A finite element approach has been developed which can effectively model the Kerr effects of the nanostructured materials.

20. ~~Flat-top perfect bright solitons in epsilon-near-zero nonlinear metamaterials~~

Carlo Rizza, *University of L'Aquila, Italy*
Alessandro Ciattoni, *CNR-SPIN, Italy*
Elia Palange, *University of L'Aquila, Italy*

This paper was not presented at the conference (No show).

We analytically investigate transverse magnetic (TM ions of Maxwell's equations, propagating through nonlinear metamaterials whose linear dielectric permittivity is very close to zero and whose effective nonlinear Kerr parameters can be tailored to achieve values not available in standard materials. In these epsilon-near-zero nonlinear metamaterials, an unusual optical regime can be achieved, regime where linear and nonlinear polarization can be comparable at feasible and realistic optical intensities. The novel regime can strongly affect the beam spatial dynamics and is able to support flat-top solitons.

21. Is the perfect electromagnetic conductor the most general truly isotropic medium?

Carlos Paiva, *Technical University of Lisbon, Portugal*
Sérgio Matos, *Instituto Superior de Ciências do Trabalho e da Empresa - IUL, Portugal*

The perfect electromagnetic conductor (PEMC) is a paradigmatic medium in electromagnetics. It was introduced, using differential forms, as a truly isotropic medium. In this paper we will show, using spacetime algebra, that the PEMC is just an extreme case of a more general class of Tellegen media that are truly isotropic – that of Minkowskian isotropic media (MIM). A PEMC is shown to be a MIM that corresponds to an ideal electromagnetic conductor.

22. Extreme subwavelength electric GHz metamaterials

Paul W. Kolb, *Laboratory for Physical Sciences, USA*
Thomas S. Salter, *Laboratory for Physical Sciences, USA*
Jonathan A. McGee, *Laboratory for Physical Sciences, USA*
H. Dennis Drew, *University of Maryland, USA*
Willie J. Padilla, *Boston College, USA*

By increasing the capacitive coupling between the "electrodes" of adjacent resonators and by adding inductive meander lines to connect the electrodes, we are able to lower the resonant frequency of electric GHz metamaterials to obtain an extreme ratio of wavelength to resonator size of about 30.

23. Chiral media based on periodic distribution of cranks. The four cranks resonator

Gregorio J. Molina-Cuberos, *Universidad de Murcia, Spain*
Ángel J. García-Collado, *Universidad Católica San Antonio, Spain*
Ismael Barba, *Universidad Valladolid, Spain*
Ana C. Cabeceira, *Universidad Valladolid, Spain*
José Represa, *Universidad Valladolid, Spain*
José Margineda, *Universidad Murcia, Spain*

A new structure consisting of four cranks, as the unit cell, to produce electromagnetic activity at microwave frequencies is proposed. A chiral medium is build by means of a 2D periodical distribution of the unit cell in printed circuit boards. By using a free-wave experimental setup, we have found that the medium presents electromagnetic rotatory dispersion and circular dichroism at the X-band frequency range. The maximum on the rotation angle is observed at the end of the band with a magnitude of around 170 deg. Numerical studies confirm the experimental results and allow to study the phenomena in the Ku band, where another small resonance is found.

24. Reflection properties of mushroom-type surfaces with loaded vias

Chandra S. R. Kaipa, *University of Mississippi, USA*
Alexander B. Yakovlev, *University of Mississippi, USA*
Stanislav Maslovski, *Universidade de Coimbra Polo II, Portugal*
Mario G. Silveirinha, *Universidade de Coimbra Polo II, Portugal*

In this paper we study the reflection phase characteristics of mushroom-type surfaces with impedance loadings (as lumped loads) at the junction of vias and metallic elements (patches and ground plane). The analysis is carried out using the nonlocal homogenization model for the mushroom structure with a generalized additional boundary condition for loaded vias. It is observed that the reflection characteristics obtained with the homogenization model strongly depend on the type of the load (inductive or capacitive), and are in a good agreement with the full-wave simulation results.

25. ~~An effective medium approach for metafilms and its application for multilayered metamaterials~~

Jiangfeng Zhou, *Los Alamos National Laboratory, USA*
Hou Tong Chen, *Los Alamos National Laboratory, USA*
Thomas Koschny, *Iowa State University, USA*
Antoinette Taylor, *Los Alamos National Laboratory, USA*
Costas Soukoulis, *Iowa State University, USA*
John O'Hara, *Los Alamos National Laboratory, USA*

This paper was not presented at the conference (No show).

We propose an effective medium approach to analyze single and multilayered metamaterials by modeling each layer as a homogenous thin film, or metafilm. The electromagnetic properties of single-layered metamaterial, or metafilm, can be described by effective permittivity and permeability through a thin film approximation. Employing a transfer matrix method, these metafilms can be assembled into multilayered metamaterials to realize certain functionalities. We demonstrate numerically that this approach provides an alternative interpretation of metamaterial-based perfect absorption, showing that the underlying mechanism a modified Fabry-Perot resonance. The approach also suitably explains metamaterial anti-reflection and electromagnetic tunneling. This method provides a general approach applicable for decoupled or weakly coupled multilayered metamaterials.

26. On the homogenization problem by means of surface integral equations

Ramón Paniagua-Domínguez, *Instituto de Estructura de la Materia - CSIC , Spain*
Jose Antonio Sánchez-Gil, *Instituto de Estructura de la Materia - CSIC, Spain*
Mário G. Silveirinha, *Universidade de Coimbra, Portugal*

In this paper we present a new formulation of the homogenization problem based on surface integral equations. The homogenization is based on the excitation of the structure with a macroscopic source. In our formulation the whole response of the system to the excitation is included in the definition of the effective permittivity, which accounts for spatial dispersion phenomena.

27. Conical refraction for new classes of biaxial metamaterials

Sérgio Matos, *Instituto Superior de Ciências do Trabalho e da Empresa - IUL, Portugal*
Carlos Paiva, *Instituto Superior Técnico, Portugal*

The study of conical refraction for media other than biaxial non-magnetic crystals has never been considered in the literature – as far as the authors are aware. Hence, in this paper, we investigate how conical refraction can arise for broader classes of biaxial metamaterials using a new classifi-cation scheme previously developed by the authors. Namely, conical refraction is shown to occur for media with both electric and magnetic anisotropies. Furthermore, this same effect is analyzed for a special class of biaxial bianisotropic media.

28. On the accuracy of surface integral equation formulations for left-handed materials

Marta G. Araújo, *University of Vigo, Spain*
José Manuel Taboada, *University of Extremadura, Spain*
Javier Rivero, *University of Extremadura, Spain*
Fernando Obelleiro, *University of Vigo, Spain*

Several left-handed material (LHM) spheres with different constitutive parameters are analyzed employing different integral-equation formulations based on the Method of Moments. The combined normal formulation (CNF), the combined tangential formulation (CTF), the Poggio-Miller-Chang-Harrington-Wu-Tsai formulation (PMCHWT) and the electric and magnetic current combined field integral equation (JMCFIE) are tested in order to assess their accuracy and suitability for dealing with LHM's. The results point out that the JMCFIE formulation is the most stable and reliable proposal.

29. Micromagnetic studies of quasistatic and dynamic properties of densely packed hexagonal nanodisk arrays

Dmitry Berkov, *Innovent Technology Development, Germany*
Nataliya Gorn, *Innovent Technology Development, Germany*

We present an example of micromagnetic simulations for an arrays of thin platelets (hexagonal lattice of nanodisks) which are promising candidates for magnetic metamaterials. Comparing our results with experimental data obtained by different measurements techniques, we show that simulations represent a reliable tool for prediction of static and dynamic properties of such metamaterials.

30. ~~Coherent response of resonators in metamaterials~~

Elena Semouchkina, *Michigan Tech University, USA*
Fang Chen, *Michigan Tech University, USA*
Arash Hosseinzadeh, *Michigan Tech University, USA*

This paper was not presented at the conference (No show).

George Semouchkin, *Penn State University, USA*
Michael Lanagan, *Penn State University, USA*

This paper discusses the conditions for obtaining a coherent response of resonators in metamateri-als, in particular, in arrays of resonators used in cloaking devices, where such response is required to satisfy the transformational optics concepts. We show that the desired response can be provided at the so called anti-bonding interaction between coupled resonators.

31. ~~Feynman formulae for dynamics of quantum (quasi) particles in inhomogeneous semi-conductors~~

Yana Butko, *Bauman Moscow State Technical University, Russia*
Oleg Smolyanov, *Lomonosov Moscow State University, Ru*

This paper was not presented at the conference (No show).

We present a new mathematical method to describe the dy ose mass is variable. This method allows to represent solutions of evolutionary equations with the help of a limit of n-fold iterated integrals of some elementary functions, when n tends to infinity (such represen-tations are called Feynman formulae). Feynman formulae can be used for direct calculations and computer modeling of the considered dynamics. The results, presented in this note, can be useful for investigations of inhomogeneous semiconductor devices and liquid crystals. The considered method also allows to describe quantum evolution on curved spaces, which can be useful for the investigation of nonplanar nano-structures.

32. Numerical modeling of transmission of electromagnetic waves through the 3d magnetic opal-based metamaterial structures in waveguides at millimeter waves

Galina Makeeva, *Penza State University, Russia*
Oleg Golovanov, *Penza State University, Russia*
Anatoly Rinkevich, *Institute of Metal Physics, Russia*
Martha Pardavi-Horvath, *The George Washington University, USA*

The 3D magnetic metamaterials based on the opal matrices of close packed SiO2 spheres with magnetic nanoparticles infiltrating in voids between the spheres have interesting and potentially useful electromagnetic properties at GHz and THz frequencies, tunable by external bias magnetic field [1]. The ferromagnetic resonance and waveguide transmission and reflection measurements were performed on magnetic opals at millimeter (mm) waves, demonstrating the tunability of the RF signal at resonance [1]. The goal of the present work is the accurate electromagnetic modeling of the effect of magnetic field on the scattering of the electromagnetic waves (EMW) on 3D magnetic opal-based metamaterial structures in waveguide at mm waves.

33. A novel and efficient numerical scheme employing characteristic basis functions for the modelling of optical properties of plasmonic nanorods array

Arash Rashidi, *Northeastern University, USA*
Hossein Mosallaei, *Northeastern University, USA*
Raj Mittra, *Penn State University, USA*

In this paper we introduce a set of Characteristic Basis Functions (CBFs) for efficient representa-tion of the currents induced on the elements in a 2D array of plasmonic nanorods. The use of these functions leads to a relatively small and well-conditioned matrix, only a 2×2 size for the normally incident plane wave. We show that the shape of the current can be found by solving a relatively small truncated array, 11×11 array for instance, and the level of the current can be computed by taking advantage of the fast convergence of the Galerkin testing integral in spectral domain circumventing the oscillatory behaviour of the solution in spatial domain.

34. Resonant frequencies of split ring resonator in respect of angle between slits

Vojislav Milosevic, *Institute of Physics Belgrade, Serbia*
Branka Jokanovic, *Institute of Physics Belgrade, Serbia*

In this paper we proposed the method for calculation of resonant frequencies of split-ring resonators (SRRs) as a function of the angle between slits. Method is based on transmission line (TL) approach.

35. ~~Transport and localization in disordered systems with metamaterials~~

Ara Asatryan, *University of Technology, Sydney, Australia*
Yurii Bliokh, *Technion, Israel*
Lindsey Botten, *University of Technology, Sydney, Australia*
Mike Byrne, *University of Technology, Sydney, Australia*
Valentin Freilikher, *Bar-Ilan University, Israel*
Sergey Gredeskul, *Ben Gurion University of the Negev, Israel*
Ilya Shadrivov, *Australian National University, Australia*
Yurii Kivshar, *Australian National University, Australia*
Franco Nori, *RIKEN Japan and University of Michigan, Japan, USA*
Ross McPhedran, *University of Sydney, Australia*

This paper was not presented at the conference (No show).

In this paper, we present results of our recent analyti ort and localization of classical waves in randomly layered s anded elements. We develop a general analytical approach for describing the localized and ballistic re-gimes in disordered media with dispersion and absorption. We discuss the analogy between the propagation of light in metamaterials and charge transport in graphene super-latices.

36. Bloch modes of optical fishnet metamaterials: A "microscopic" model

Jianji Yang, *Laboratoire Charles Fabry de l'Institut d'Optique, France*
Christophe Sauvan, *Laboratoire Charles Fabry de l'Institut d'Optique, France*
Philippe Lalanne, *Laboratoire Charles Fabry de l'Institut d'Optique, France*
Haitao Liu, *Nankai University, China*

We theoretically study fishnet metamaterials at optical frequencies. In contrast to earlier works, we provide a microscopic description by tracking the transversal and longitudinal flows of energy through the fishnet mesh composed of intersecting subwavelength plasmonic waveguides. The analysis is supported by a semi-analytical model based on surface-plasmon coupled-mode equations. The model provides accurate formulas for the fishnet refractive index, including the real-negative and imaginary parts. The model simply explains how the surface plasmons couple at the waveguide intersections and it shines new light on the fishnet negative-index paradigm at optical frequencies. Extension of the theory for loss-compensated metamaterials with gain media is also presented.

37. Resonant tunneling of light in nanostructures: Gradient dielectric vs metallic foils?

Oleg Volpian, *M.F. Stelmakh Research Institute – Polus, Russia*
Alexander Shvartsburg, *Joint Institute of High Temperature, Russia*
Anatoly Kuzmichev, *National Technical University – Kiev Polytechnical Institute, Ukraine*

The results of analysis of propagation and tunneling of light through thin film dielectrics with nanogradient n(z)/epsilon(z) across the film, are presented. The influence of giant artificial heterogeneity-induced non-local dispersion, stipulated by the subwavelength gradient and curvature of distribution epsilon(z), is studied. Formation of cut-off frequency, separating the traveling and tunneling regimes of waves propagation through the transparent dielectric with epsilon > 0, but grad(epsilon).

38. Analysis of metamaterial slab of magnetodielectric spheres

Boris Tomasic, *Air Force Research Laboratory, USA*
Kristopher Kim, *Air Force Research Laboratory, USA*
Naftali Herscovici, *Air Force Research Laboratory, USA*

In this paper we analyze an extremely large, one-layer slab consisting of magnetodielectric spheres. The theory of vector spherical harmonics and the vector addition theorem with infinite array approximations were used to determine the sphere scattering coefficients, and subsequently the homogeneous medium constitutive parameters. The method requires very little memory and is more accurate as array size increases, rendering the method applicable to extremely large array problems.

39. Ferroelectric metamaterials: towards a refractive index control

Stefano De Zuani, *University of Padova, Italy*
Marco Natali, *University of Padova, Italy*
Denis Garoli, *University of Padova, Italy*

Here we report on the use of lead zirconate titanate (PZT) - a well known electro-optic ceramic - to realize electrically tunability of fishnet metamaterials.

40. Integrated acoustic and electromagnetic analysis of cylindrical anisotropic metamaterials

Jorge Carbonell, *Universidad Politécnica de Valencia, Spain*
Daniel Torrent, *Universidad Politécnica de Valencia, Spain*
José Sánchez-Dehesa, *Universidad Politécnica de Valencia, Spain*

Anisotropic characteristics of cylindrically corrugated microstructures are analyzed in terms of their acoustic and electromagnetic behaviours paying special attention to their differences and similarities. A simple analytical model has been developed using effective medium theory to understand the anisotropic features of both types of waves in terms of radial and angular components of the wave propagation velocity. The anisotropic constituent parameters have been obtained by measuring the resonances of cylindrical cavities, as well as from numerical simulations. This permits to characterize propagation of acoustic and electromagnetic waves and to compare the fundamental anisotropic features generated by the corrugated effective medium. Anisotropic coefficients match approximately in both application fields but other relevant parameters explain significant differences in the behaviour of both types of waves.

41. An integral equation approach to model gain media at optical frequencies

Nilufer Ozdemir, *Université Catholique de Louvain, Belgium*
Christophe Craeye, *Université Catholique de Louvain, Belgium*

An integral equation approach is being developed to model gain media at optical frequencies. The approach is based on modeling the effect of active optical materials such as organic dye molecules by equivalent sources inside a passive medium under external illumination. As an initial step, the equivalent sources are approximated as electric current sources that are proportional to the tested electric field intensity inside the passive medium due to external illumination at the pumping frequency. A more elaborate model needs to be developed to relate the equivalent sources at the frequency of operation to the tested field at the pumping frequency to represent the effect of dye molecules inside the passive medium.

42. Bloch theory and metadispersion

Enrica Martini, *University of Siena, Italy*
Giovanni Maria Sardi, *University of Siena, Italy*
Francesco Caminita, *University of Siena, Italy*
Stefano Maci, *University of Siena, Italy*

An innovative method for the characterization of dispersion in metamaterials realized by stacked planar periodic surfaces is presented. The analysis procedure performs a full wave analysis of the constituent planar periodic surface and uses analytic formulas from Bloch theory to determine the dispersion characteristics of the overall artificial medium.

43. Biaxial negative magnetic permeability support magnetic surface polariton mode

Yu-Hang Yang, *National Tsing Hua University, Taiwan*
Leng-Wai Un, *National Tsing Hua University, Taiwan*
Hsin-Cheng Lee, *National Tsing Hua University, Taiwan*
Ta-Jen Yen, *National Tsing Hua University, Taiwan*

We provide a dispersion equation of magnetic surface polariton mode supported by an anisotropic magnetic material. We requires controlling three frequency-dependent constituent parameters properly, so that then we design a biaxial magnetic metamaterial (PBMM) accordingly. The realization of the MSP mode is evidenced by both analytical calculation and numerical simulation.

44. ~~Metamaterial properties of arrays of rectangular magnetic dots~~

Roberto Zivieri, *Department of Physics, Ferrara, Italy*
Federico Montoncello, *Department of Physics, Ferrara, Italy*
Loris Giovannini, *Department of Physics, Ferrara, Italy*
Fabrizio Nizzoli, *Department of Physics, Ferrara, Italy*
Silvia Tacchi, *Department of Physics, Perugia, Italy*
Marco Madami, *Department of Physics, Perugia, Italy*
Gianluca Gubbiotti, *Department of Physics, Perugia, Italy*
Giovanni Carlotti, *Department of Physics, Perugia, Italy*
Adekunle Adeyeye, *Department of Electrical & Computer*

This paper was not presented at the conference (No show).

In this paper we study the magnonic band structure of c . We estimate amplitude of modes magnonic band and the group velocity in the long wavelength limit for a vanishing separation which is an important property to identify the behavior of a one-dimensional quasi-continuous magnonic metamaterial.

45. Nano films of linear-chain carbon with embedded metal and nonmetal atoms: Data Mining modeling

Victor Abrukov, *Chuvash State University, Russia*
Valeriy Kochakov, *Chuvash State University, Russia*
Sergey Abrukov, *Chuvash State University, Russia*

In this paper we aim to present a new nano material: nano films of linear-chain carbon with embedded metal and nonmetal atoms and results of its modelling by means of Data Mining tools.

46. Cloaking performance of a transmission-line cloak in free space and in the near field of a horn antenna

Joni Vehmas, *Aalto University, Finland*
Pekka Alitalo, *Aalto University, Finland*
Sergei Tretyakov, *Aalto University, Finland*

A new design of a volumetric transmission-line-based cloaking structure is studied numerically and experimentally. The cloaking performance is demonstrated using simulations of the total scattering cross section and simulations and measurements of the radiation pattern of a horn antenna with the cloak placed in the near field of the antenna.

47. A broadband carpet cloak realized by dielectric cylinders

Di Bao, *Queen Mary University of London, UK*
Wenxuan Tang, *Queen Mary University of London, UK*
Christos Argyropoulos, *Queen Mary University of London, UK*
Efthymios Kallos, *Queen Mary University of London, UK*
Yang Hao, *Queen Mary University of London, UK*

In this paper, a carpet cloak made from nonmagnectic dielectric cylinders is designed, simulated and tested experimentally. By manipulating the periodicity of the dielectric cylinders, it is possible to achieve the required dielectric map and therefor the propagate direction of the electromagnetic waves. The cloak is tested with open-end waveguide from 7 to 9 GHz . Open end waveguide is feeded as excitation to demonstrate that it can work with all incident angle. The experiment results are in good agreement with the simulation results.

48. ~~A plasmonic resonant metalens for breaking the diffraction barrier in the visible~~

Fabrice Lemoult, *Institut Langevin - ESPCI ParisTech & CNRS, France*
Mathias Fink, *Institut Langevin - ESPCI ParisTech & CNI*
Geoffroy Lerosey, *Institut Langevin - ESPCI ParisTech &*

This paper was not presented at the conference (No show).

In this paper we propose an approach for focusing and imaging beyond the diffraction limit in the visible range using a plasmonic resonant metalens, that is an array of resonant silver nanorods.

49. All kinds of cloaks, all kinds of transformations: a general theory of transformation mechanics

Paul Kinsler, *Imperial College London, UK*
Martin McCall, *Imperial College London, UK*
Alberto Favaro, *Imperial College London, UK*

The diverse collection of electromagnetic cloaks includes object, carpet, and exterior cloaks— even space-time ``event" cloaks. Other transformation optics devices are field-concentrators, super-scatterers, and ray-geodesic imagers. We show how to generalize transformation optics, and make it applicable to any kind of wave propagation, such as acoustic or water waves.

50. Scaling slabs based on transformation optics for immersion lenses and angular filters

Carlos Garcia-Meca, *Universidad Politécnica de Valencia, Spain*
Ruben Ortuño, *Universidad Politécnica de Valencia, Spain*
Francisco Jose Rodriguez-Fortuño, *Universidad Politécnica de Valencia, Spain*
Javier Marti, *Universidad Politécnica de Valencia, Spain*
Alejandro Martinez, *Universidad Politécnica de Valencia, Spain*

We discuss two applications of compressing/expanding slabs based on transformation optics. The first one is an immersion lens that, unlike conventional ones, is flat, reflectionless, and introduces no distortion. The second application is a spatial filter whose response is a scaled version (in angle) of that of an infinite dielectric slab.

51. Highly directive antennas based on a slim Luneburg lens

Carolina Mateo-Segura, *Queen Mary University of London, UK*
Angela Demetriadou, *Imperial College, UK*
Yang Hao, *Queen Mary University of London, UK*

Transformation optics has emerged as a useful tool to control the behaviour of electromagnetic fields and thus offers potential for designing novel antenna structures. In this contribution, a new antenna system based on a slim flat Luneburg lens located above a radiating source printed on a ground plane is proposed. The permittivity map of the transformed lens able to convert the non-directive beam radiated by a single source to a highly-directive beam with low side-lobe level is calculated. Numerical simulations based on CST Microwave Studio are performed to illustrate the proposed antenna system performance in comparison with a common Fabry-Perot cavity antenna. Results confirm the high-directivity, low side-lobe level and steering capability of the proposed antenna.

52. Investigation on subwavelength focusing properties of metal-dielectric multilayer

Cristian Della Giovampaola, *University of Siena, Italy*
Matteo Albani, *University of Siena, Italy*
Filippo Capolino, *University of California - Irvine, USA*

We present a planar multilayered structure composed of metal-dielectric layers which is capable to enhance the near-field at optical frequencies by adding contributions to the evanescent spectrum of the transmitted field, thus generating an electrically narrow field spot after the last interface. Numerical simulations have shown the possibility of achieving subwavelength resolution when using the proposed multilayer as a near field lens.

53. ~~A high resolution 8.5 MHz magnetic meta-lens~~

Clara Rivero-Baleine, *Lockheed Martin Missiles and Fire Control, USA*
Christina Drake, *Lockheed Martin Missiles and Fire Control, USA*
Zhi Hao Jiang, *The Pennsylvania State University, USA*
Clinton P. Scarborough, *The Pennsylvania State University, USA*
Douglas H. Werner, *The Pennsylvania State University, USA*
Pingjuan L. Werner, *The Pennsylvania State University, USA*
Stephen Aiken, *Lockheed Martin Missiles and Fire Control, USA*

This paper was not presented at the conference (Withdrawal).

In this paper, we present two isotropic magnetic metamaterial lens (meta-lens) designs operating at 8.5 MHz for magnetic imaging applications. Both meta-lenses have an effective isotropic permeability _eff=-1 at 8.5 MHz. These magnetic meta-lenses enhance the evanescent fields, producing strong magnetic fields and sharp sub-wavelength resolution at the image plane. Measurements of a fabricated meta-lens are in good agreement with the full-wave simulations. The most advanced design employs a unit cell that is more than four times smaller than the first design to improve the imaging resolution.

54. Non-linear transformation optics

Luzi Bergamin, *KB&P GmbH, Switzerland*
Sergei Tretyakov, *Aalto University, Finland*

The concept of transformation optics is extended to non-linear media. It is shown that transformation optics can be generalized to include arbitrary non-linear response. In a systematic expansion, transformation optics favors implicit constitutive relations in terms of energy densities D.E and B.H rather than E^2 and H^2. As an example, the Kerr non-linearity is studied in some details.

55. The transformation optics of chiral metamaterials

Simon Horsley, *University of St Andrews, UK*

The geometrical interpretation of electromagnetism in transparent media (transformation optics) is extended to include media with isotropic, inhomogeneous chirality. It is found that both reciprocal and non–reciprocal chiral media may be described in terms of geometry through introducing the property of space–time torsion into the Maxwell equations. I then show how such a formalism may be applied to the design of optical devices.

56. Application of transformation optics concept for the design of an ultra-directive emission

Paul-Henri Tichit, *University of Paris Sud, France*
Shah Nawaz Burokur, *University of Paris Ouest, France*
Dylan Germain, *University of Paris Sud, France*
André de Lustrac, *University of Paris Sud, France*

This paper deals with the modelling, practical implementation and characterization of an ultra-directive antenna around 10 GHz. The design of the antenna is based on transformation optics concept by transforming a radiating cylindrical space into a rectangular one. Metamaterials pre-senting electric and magnetic resonances are used to achieve the transformation.

57. Cloaking a 3-d arbitrary shaped domain

Alessandro Veltri, *Centre de Recherche Paul Pascal, France*

In this presentation we will describe a straightforward method to design the electromagnetic cloak of a 3d-generic star domain whose surface is defined just by a set of points distributed over it.

58. Performance of multi-segment nanolens for a near-field transport in the visible domain

Pavel Voroshilov, *National Research University of Information Technologies, Mechanics and Optics, Russia*
Atiqur Rahman, *Queen Mary University of London, UK*
Yuri Kivshar, *The Australian National University, Australia*
Pavel Belov, *Queen Mary University of London, UK*

We analyze capabilities and functionalities of a multi-segment superlens recently suggested by S. Kawata et al. [Nature Photonics 2, 438 (2008)] for long-distance transport of color images with subwavelength resolution. We study the performance of three-segment nanolens structures by analyzing numerically both transmission and reflection coefficients and by employing the full-wave simulations for a particular source arrangement. We observe that such a stacked structure offers limited subwavelength imaging performance due to operation with coherent sources only within narrow frequency band, typically 3-5% wide.

59. Engineering antenna radiation patterns via quasi-conformal transformations

Carlos Garcia-Meca, *Universidad Politécnica de Valencia, Spain*
Alejandro Martinez, *Universidad Politécnica de Valencia, Spain*
Ulf Leonhardt, *University of St Andrews, UK*

We use a combination of conformal and quasi-conformal mappings to engineer isotropic optical devices that modify the omnidirectional radiation pattern of a point source. For TE waves, the designed devices are also non-magnetic. The flexibility of the proposed technique, higher than that achieved with conformal mappings, is illustrated with some examples.

Special Session

Fano Phenomena and electromagnetically Induced Transparency in Complex Multiresonant Metamaterials

11:20 - 13:00 ▸ Room Barcelona B

As the sophistication of electromagnetic metamaterials is increasing, there is a growing number of quantum-mechanical phenomena that can be effectively emulated by these new emerging structures. One such phenomenon is the Fano Resonance that was originally observed in atomic systems and later in the solid state. In the context of metamaterials, Fano resonances provide an effective method of radiation lifetime engineering that enables ultra-sharp spectral lines and extremely high electromagnetic field enhancements. The other related phenomenon is the so-called Electromagnetically Induced Transparency. Both phenomena are observed in complex metamaterials supporting several resonances with vastly different radiative lifetimes. The five invited talks in this session will examine the fundamental physics behind these multi-resonant phenomena, such as nonlinear effects and the effects of disorder, as well as several exciting applications such as ultra-sensitive linear and nonlinear spectroscopies. The universality of Fano Resonances across the entire electromagnetic spectrum will be highlighted in this Session by drawing on the examples ranging from optical to microwave physics.

Organizer ▸ **Gennady Shvets**, *University of Texas at Austin, USA*

Session Chair ▸ **Gennady Shvets**, *University of Texas at Austin, USA*

11:20 - 11:40 **Tunable transparency window with meta-molecules utilizing superconducting dark resonators** Invited

Cihan Kurter, *University of Maryland, USA*
Philippe Tassin, *Iowa State University, USA*
Lei Zhang, *Iowa State University, USA*
Thomas Koschny, *Iowa State University, USA*
Costas M. Soukoulis, *Iowa State University, USA*
Alexander P. Zhuravel, *National Academy of Sciences of Ukraine, Ukraine*
Alexey Ustinov, *Karlsruhe Institute of Technology, Germany*
Steven M. Anlage, *University of Maryland, USA*

We have developed a high quality factor microwave-frequency meta-molecule to demonstrate a classical optical phenomenon analogous to electromagnetically induced transparency (EIT). The two-dimensional design employs two planar Nb split rings acting as dark resonators symmetrically placed around a thick Au strip acting as a bright resonator.

11:40 - 12:00 **Engineering resonances in THz metamaterials** Invited

Carsten Rockstuhl, *Friedrich-Schiller-Universität Jena, Germany*
R. Singh, *Los Alamos National Laboratory/ Oklahoma State University, USA*
S.-Y. Chiam, *National University of Singapore, Singapore*
C. Menzel, *Friedrich-Schiller-Universität Jena, Germany*
A. A. Bettiol, *National University of Singapore, Singapore*
W. Zhang, *Oklahoma State University, USA*
F. Lederer, *Friedrich-Schiller-Universität Jena, Germany*

We review our recent activities on THz metamaterials and disclose the measures that can be put in place in order to engineer the quality factor of their resonances. This leads to a systematic investigation on the impact of the intrinsic material properties.

12:00 - 12:20 **Fano resonance and light localization in disordered metamaterials** Invited

Salvatore Savo, *University of Southampton, UK*
Nikitas Papasimakis, *University of Southampton, UK*
Nikolay Zheludev, *University of Southampton, UK*

We present the first experimental study of light localization in disordered planar metamaterials. The statistics of the near field intensity are investigated and and the role of subradiant and superradiant modes is discussed.

Tuesday, 11th October

12:20 - 12:40 **Applications of plasmonic oligomers, metamaterials, and nanoantennas** Invited

Harald Giessen, *University of Stuttgart, Germany*

We present an overview of 2D and 3D plasmonic oligomers, metamaterials, and nanoantennas which are utilized for different purposes e.g. perfect absorbers, sensors for liquids and gases and broadband circular polarizers.

12:40 - 13:00 **Symmetry breaking and nonlinear effects in PIT metamaterials** Invited

Shuang Zhang, *University of Birmingham, UK*
Kevin O'Brien, *University of California, Berkeley, USA*
Thomas Zentgraf, *University of California, Berkeley, USA*
Yong-Shik Park, *University of California, Berkeley, USA*
Xiang Zhang, *University of California, Berkeley, USA*

Second and third harmonic generations were experimentally investigated in plasmon induced transparency (PIT) metamaterials with unit-cells consisting of coupled radiative bright and non-radiative dark plasmonic elements. We will discuss these nonlinear phenomena and in particular their correlation to the effect of symmetry breaking and field enhancement.

13:00 - 14:30 Lunch ▸ La Cantina de l'Estació, Hotel Barceló Sants

RF and Microwave Metamaterials 2

11:20 - 13:00 ▸ Room Sants-Montjuic

Session Chair ▸ **Filiberto Bilotti**, *"Roma Tre" University, Italy*

11:20 - 11:50 **Differential transmission lines loaded with split ring resonators (SRRs) and complementary split ring resonators (CSRRs)** Invited

Jordi Naqui, *Universitat Autònoma de Barcelona, Spain*
Miguel Durán-Sindreu, *Universitat Autònoma de Barcelona, Spain*
Armando Fernández-Prieto, *Universidad de Sevilla, Spain*
Francisco Mesa, *Universidad de Sevilla, Spain*
Francisco Medina, *Universidad de Sevilla, Spain*
Ferran Martín, *Universitat Autònoma de Barcelona, Spain*

In this paper, it is demonstrated that complementary split ring resonators (CSRRs) and split ring resonators (SRRs) can be used to control the propagation in differential transmission lines. Specifically, it is shown that by etching CSRRs in the ground plane of a microstrip differential pair, the common (even) mode can be efficiently suppressed, this being of interest for common mode noise rejection. It is also demonstrated that the differential (odd) mode can be suppressed by merely etching SRRs in the upper substrate side, be-tween the pair of transmission lines. These results are of interest in applications where differential lines are used, for instance, high speed digital circuits.

11:50 - 12:20 **An update of progress in non-Foster metamaterials** Invited

Silvio Hrabar, *University of Zagreb, Croatia*
Igor Krois, *University of Zagreb, Croatia*
Ivan Bonic, *University of Zagreb, Croatia*
Aleksandar Kiricenko, *University of Zagreb, Croatia*

The underlying physics and possible applications of non-Foster metamaterials are reviewed. Several state-of-the-art examples of extremely broadband 1D and 2D active ENZ and MNZ metamaterials developed at University of Zagreb are presented and some new research directions are highlighted.

12:20 - 12:40 **Applications of artificial transmission lines with active negative reactances to design of ultra-wideband microwave devices** Oral

Dmitry Kholodnyak, *St. Petersburg Electrotechnical University, Russia*
Vyacheslav Turgaliev, *St. Petersburg Electrotechnical University, Russia*
Alexander Rusakov, *St. Petersburg Electrotechnical University, Russia*
Pavel Turalchuk, *St. Petersburg Electrotechnical University, Russia*
Irina Vendik, *St. Petersburg Electrotechnical University, Russia*

Advantages of artificial transmission lines with negative reactances are considered as applied to design of ultra-wideband microwave devices. The use of specific dispersion properties of the right- and left-handed transmission lines consisting of negative reactances to achieve flat 0°, 90°, and 180° phase characteristics over a wide frequency range is demonstrated. Potential applications are outlined and illustrated by some examples. Practical implementation of negative reactances as negative impedance converters based on a pair of transistors is discussed.

12:40 - 13:00 **Microstrip/CPW differential lines for common-mode suppression** Oral

Armando Fernandez-Prieto, *University of Seville, Spain*
Francisco Medina, *University of Seville, Spain*
Francisco Mesa, *University of Seville, Spain*
Silon Qian, *Heriot-Watt University, UK*
Jia-Sheng Hong, *Heriot-Watt University, UK*

This paper reports on differential printed transmission lines which yield a very good matching for differential-mode and strong rejection for the common-mode. The new differential lines are inspired on the concept of metamaterial transmission lines. Circuit model predictions, electromagnetic simulations and experimental results are quite satisfactory.

13:00 - 14:30 Lunch ▸ La Cantina de l'Estació, Hotel Barceló Sants

Tuesday, 11th October

Theory of Metamaterials 1

11:20 - 13:00 ▸ Room Sarrià-Sant Gervasi

Session Chair ▸ **Nicolae Panoiu**, *University College London, UK*

11:20 - 12:00 **Inherent noncausal features in the Maxwell-Garnett homogenization of metamaterials** Keynote

Andrea Alu, *The University of Texas at Austin, USA*
Arthur D. Yaghjian, *Research Consultant, USA*
Robert A. Shore, *AFRL/RYHA, USA*
Mario G. Silveirinha, *University of Coimbra, Portugal*

We explain the noncausal features that arise in the homogenization of metamaterial arrays using standard point-dipole approximations. We are able to relate these noncausal features to the approximations commonly used in Maxwell-Garnett homogenization approaches, and we show that these anomalous effects may become particularly significant for the important case of densely packed metamaterial arrays.

12:00 - 12:20 **Does the magnetic permeability satisfy the Kramers-Kronig relations for passive media?** Oral

Mario Silveirinha, *Universidade de Coimbra, Portugal*

One of the most debated features of the extracted effective permeability of structured media is that often, even in case of very low loss, it may exhibit an anti-resonant frequency response that is inconsistent with the Kramers-Kronig's formulas for passive media. Here we critically analyse such features and study the restrictions of the dispersive behaviour of the magnetic permeability in the spectral range where its usual physical meaning is preserved.

12:20 - 12:40 **Assigning effective parameters to amorphous metamaterials** Oral

Stefan Mühlig, *Friedrich-Schiller-Universität Jena, Germany*
Christoph Menzel, *Friedrich-Schiller-Universität Jena, Germany*
Thomas Paul, *Friedrich-Schiller-Universität Jena, Germany*
Carsten Rockstuhl, *Friedrich-Schiller-Universität Jena, Germany*
Falk Lederer, *Friedrich-Schiller-Universität Jena, Germany*

We summarize our efforts to assign effective parameters to amorphous metamaterials. To this end we rely on a multipole analysis of the scattered field of individual meta-atoms. If only electric and magnetic dipole moments contribute to the scattered field, effective parameters can be assigned to the metamaterial by considering these multipole moments and an adequate filling fraction for the bulk metamaterial. Results are compared to rigorous simulations of amorphous metamaterials and the predictive accuracy of the method is evaluated.

12:40 - 13:00 **Wave impedance retrieving via Bloch modes analysis** Oral

Andrei Andryieuski, *Technical University of Denmark, Denmark*
Sangwoo Ha, *Australian National University, Australia*
Andrey Sukhorukov, *Australian National University, Australia*
Radu Malureanu, *Technical University of Denmark, Denmark*
Yuri Kivshar, *Australian National University, Australia*
Andrei Lavrinenko, *Technical University of Denmark, Denmark*

The main bottleneck in the restoration of electromagnetic effective parameters is con-nected to the impedance retrieving. The S-parameters method gives the input (Bloch) im-pedance, which, being then used for permittivity and permeability determination, causes some fundamental physics principles violation, like antiresonance behaviour with Im( ) and wave effective parameters of lossy and lossless metamaterials. In some examples when the passivity is violated we made further analysis and showed that the concept of impedance retrieving through the volume averaging experiences limitations and needs to be revisited.

13:00 - 14:30 Lunch ▸ La Cantina de l'Estació, Hotel Barceló Sants

Tunable and Tailorable Metamaterials

14:30 - 16:10 ▸ Room Barcelona B

Session Chair ▸ **Philippe Lalanne**, *Institut d'Optique Théorique et Appliquée - CNRS, France*

14:30 - 15:10 **Tailorable nonlinear metamaterials** Keynote

Martti Kauranen, *Tampere University of Technology, Finland*
Robert Czaplicki, *Tampere University of Technology, Finland*
Hannu Husu, *Tampere University of Technology, Finland*
Jouni Mäkitalo, *Tampere University of Technology, Finland*
Goëry Genty, *Tampere University of Technology, Finland*
Henna Pietarinen, *Tampere University of Technology, Finland*
Mariusz Zdanowicz, *Tampere University of Technology, Finland*
Kalle Koskinen, *Tampere University of Technology, Finland*
Roope Siikanen, *Tampere University of Technology, Finland*
Joonas Lehtolahti, *University of Eastern Finland, Finland*
Janne Laukkanen, *University of Eastern Finland, Finland*
Markku Kuittinen, *University of Eastern Finland, Finland*

Defects give rise to effective quadrupole effects in second-harmonic generation from metal nanostructures. Samples with improved quality, however, allow the desired dipole limit to be reached. This opens the path for tailorable nonlinear metamaterials, as demonstrated by varying the ordering of anisotropic metal nanoparticles in an array.

15:10 - 15:30 **Voltage controllable metamaterials infiltrated by liquid crystal** Oral

Fuli Zhang, *Northwestern Polytechnical University, China*
Qian Zhao, *Tsinghua University, China*
Jingbo Sun, *Tsinghua University, China*
Eric Lheurette, *Université des Sciences et Technologies de Lille, France*
Ji Zhou, *State Tsinghua University, China*
Didier Lippens, *Université des Sciences et Technologies de Lille, France*

In this paper, we report on the experimental demonstration of voltage tunable metamaterial operating under normal incidence at microwave frequencies via nematic liquid crystal. Two types of metamaterial structures, the short wire pair and fishnet prototype, were used for the realization of the variation of effective permeability and effective index, respectively. The results shows, under low external bias voltage, a reversible frequency shift around 400 MHz, for the frequency band presenting the metamaterial properties.

15:30 - 15:50 **Tunable nonlinear response of coupled resonators** Oral

Kirsty Hannam, *Australian National University, Australia*
David A Powell, *Australian National University, Australia*
Ilya V Shadrivov, *Australian National University, Australia*
Yuri S Kivshar, *Australian National University, Australia*

We investigate the effect of tuning various linear properties of two coupled split-ring resonators (SRRs) via altering their relative positions. We also study the nonlinear properties of the coupled SRRs and the tunability of their collective nonlinear response.

15:50 - 16:10 **Interactions in planar metamaterials and their use for active tuning** Oral

Igal Brener, *Sandia National Labs & Center for Integrated Nanotechnologies, USA*
A. Gabbay, *Sandia National Labs & Center for Integrated Nanotechnologies, USA*
X. Miao, *Sandia National Labs & Center for Integrated Nanotechnologies, USA*
B.S. Passmore, *Sandia National Labs, USA*
J. Reno, *Sandia National Labs & Center for Integrated Nanotechnologies, USA*
J.R. Wendt, *Sandia National Labs, USA*

Tuesday, 11th October

A. Gin, *Sandia National Labs & Center for Integrated Nanotechnologies, USA*
M.C. Wanke, *Sandia National Labs, USA*
M.B. Sinclair, *Sandia National Labs, USA*
E.A. Shaner, *Sandia National Labs, USA*
D.J. Shelton, *CREOL, University of Central Florida, USA*
J.C. Ginn, *Sandia National Labs & Center for Integrated Nanotechnologies, USA*
D.W. Peters, *Sandia National Labs, USA*
G.D. Boreman, *CREOL, University of Central Florida, USA*
S. Vangala, *University of Massachusetts Lowell, USA*
W. Goodhue, *University of Massachusetts Lowell, USA*

We explore strong coupling between metamaterial resonators and different types of absorbers placed in proximity to these resonators. Very clear anticrossing behaviour and level splitting is observed when IR phonons interact with metamaterials. More complex dipole transitions can be designed using semiconductor bandgap engineering. We show experimentally the coupling between metamaterial resonances and intersubband transitions and highly doped layers in semiconductor heterostructures and discuss this mechanism for electrical tuning of metamaterials throughout the optical infrared spectral region.

16:10 - 16:30 Coffee break + **Poster Session 1 (continuation)** ▸ Room Barcelona A

Plasmonic Metamaterials 2

14:30 - 16:10 ▸ Room Sants-Montjuïc

Session Chair ▸ **Nader Engheta**, *University of Pennsylvania, USA*

14:30 - 15:00 **Surface plasma wave enhanced infrared detection** Invited

S. C. Lee, *University of New Mexico, USA*
S. Krishna, *University of New Mexico, USA*
S. R. J. Brueck, *University of New Mexico, USA*

Surface plasma waves (SPW) offer an attractive enhancement for quantum-dot infrared photodetectors (QDIPs). We demonstrate strong enhancement in the detectivity (30×) for both top-surface metal photonic crystal (holes in a Au film) and back surface corrugated metal films. The corrugated metal film is particularly attractive for incorporation in a standard focal plane array processing sequence. The first fully operation SPW focal plane array camera is demonstrated. The long term vision is to encode both spectral and polarization information in a FPA readout greatly increasing the information content of infrared cameras.

15:00 - 15:30 **Multi-spectral plasmon induced transparency with hybridized metamaterials** Invited

Alp Artar, *Boston University, USA*
Ahmet Ali Yanik, *Boston University, USA*
Arif Engin Cetin, *Boston University, USA*
Hatice Altug, *Boston University, USA*

We experimentally and theoretically demonstrate an approach enabling construction of a scalable multi-layered metamaterial media supporting multispectral plasmon induced transparency A perturbative model incorporating hybridization and mode coupling is introduced to explain the observed novel spectral features.

15:30 - 15:50 **Plasmonic wormholes** Oral

Tieh-Ming Chang, *Institut Fresnel, France*
Muamer Kadic, *Institut Fresnel, France*
Guillaume Dupont, *Institut Fresnel, France*
Sebastien Guenneau, *Institut Fresnel, France*
Stefan Enoch, *Institut Fresnel, France*

We describe two types of toroidal invisible metamaterials for SPPs. One is a handlebody bridging remote holes: it works as a plasmonic counterpart of electromagnetic wormholes. The other is a ring bridges two disconnected metal surfaces. We demonstrate the electromagnetic field inside these metamaterials does not disturb the propagation of SPPs.

15:50 - 16:10 **Plasmonic metamaterails for enhanced photovoltaics** Oral

Christopher Tabor, *USAF Research Lab, USA*
Cory Knick, *UES Inc., USA*
Shane Juhl, *USAF Research Lab, USA*
Michael Durstock, *USAF Research Lab, USA*

In this paper the authors focus on two mechanisms to increase organic photovoltaic performance using plasmonic metamaterials: (1) light guiding into bloch mode resonances of a patterned metal surface and (2) near-field enhancements of the photo-physical properties of photo-responsive organic species. Our current work displays improvements in the photovoltaic performance, both in the device photo-physics and potentials for increases in off-angle photovoltaic response.

16:10 - 16:30 Coffee break + **Poster Session 1 (continuation)** ▸ Room Barcelona A

Applications of Metamaterials 2

14:30 - 16:10 ▸ Room Sarrià-Sant Gervasi

Session Chair ▸ **Thomas Zentgraf**, *University of Paderborn, Germany*

14:30 - 15:00 **Transforming light with optical metamaterials** Invited

Vladimir M. Shalaev, *Purdue University, USA*
A. V. Kildishev, *Purdue University, USA*
Z. Jacob, *Purdue University, USA*
A. Boltasseva, *Purdue University, USA*
S. Xiao, *Purdue University, USA*
V. P. Drachev, *Purdue University, USA*
X. Ni, *Purdue University, USA*
G. V. Naik, *Purdue University, USA*
J. Y. Kim, *Purdue University, USA*
E. E. Narimanov, *Purdue University, USA*

We review the exciting field of optical metamaterials (MMs) and discuss the recent progress in developing tunable and active MMs, nanolasers, artificial optical magnetism, loss-free negative-index MMs, broadband cloaking, and new means for engineering the photonic density of states with MMs.

15:00 - 15:30 **Manipulate light polarizations by metamaterials: from microwave to visible** Invited

Wujiong Sun, *Fudan University, China*
Jiaming Hao, *Fudan University, China*
Qiong He, *Fudan University, China*
Lei Zhou, *Fudan University, China*

In this paper, we review our recent efforts in employing anisotropic metamaterials to manipulate electromagnetic wave polarizations, including conversions between different polarization states and rotations of polarization direction, in frequency domains ranging from microwave to visible. We first present a general theoretical analysis on the problem, and then discuss our experimental efforts in fabricating metamaterial samples and realizing the predicted polarization manipulation effects, in both reflection and transmission geometries.

15:30 - 15:50 **Transformation-optics and illusion-optics devices made of microwave metamaterials** Oral

Tie Jun Cui, *Southeast University, China*
Wei Xiang Jiang, *Southeast University, China*
Hui Feng Ma, *Southeast University, China*

In this paper, we present several transformation-optics and illusion-optics devices realized by microwave metamaterials, including three-dimensional (3D) ground-plane cloak, 3D Luneburg lens with flattened focal surface, two-dimensional (2D) shrinking device, and 2D material-convention device. Experiments demonstrate good performances of such devices.

15:50 - 16:10 **180° analogue S-band phase shifter based on composite right/left-handed transmission lines** Oral

Evgenia Zameshaeva, *St. Petersburg Electrotechnical University, Russia*
Dirk Stoepel, *Technical University Ilmenau, Germany*
Stefan Humbla, *Technical University Ilmenau, Germany*
Matthias Hein, *Technical University Ilmenau, Germany*
Irina Vendik, *St. Petersburg Electrotechnical University, Russia*

An analogue 0°-180° phase shifter based a tuneable composite right/left handed transmission line with a controllable dispersion relation and controlled by varactor diodes is presented. The device is implemented as a printed circuit board with surface-mounted components and demonstrates a flat phase shift across a fractional bandwidth of 25% at 2.7 GHz.

16:10 - 16:30 Coffee break + **Poster Session 1 (continuation)** ▸ Room Barcelona A

Fabrication and Experimental Characterization of Metamaterials

16:30 - 18:10 ▸ Room Barcelona B

Session Chair ▸ **Martin Wegener**, *Karlsruhe Institute of Technology, Germany*

16:30 - 17:10 **Nano-optics with electron beams: Probing the dispersion and local density of states of metamaterials with 10 nm resolution** Keynote

Albert Polman, *FOM institute AMOLF, Netherlands*

We introduce a new technique, angle- and polarization-controlled cathodoluminescence imaging spectroscopy, to determine the dispersion and local density of states in photonic metamaterials. We determine the full dispersion diagram of metal-insulator-metal waveguides with different dimensions and geometries and accurately map the plasmonic standing waves, and collect the angle-resolved radiation patterns.

17:10 - 17:40 **Drawn metamaterials - a scalable approach to fabrication** Invited

Boris Kuhlmey, *University of Sydney, Australia*
Alessandro Tuniz, *University of Sydney, Australia*
Elise Pogson, *University of Wollongong, Australia*
Roger Lewis, *University of Wollongong, Australia*
Simon Fleming, *University of Sydney, Australia*

We use optical fibre drawing techniques to produce hybrid polymer/metal fibres with modified electric and magnetic response in the THz. The technique can produce kilometres of metamaterial, and can be scaled for operation in the infrared and even potentially in the visible spectrum.

17:40 – 18:10 **Plasmonic nanoparticles assemblies: Preparation, structure and optical properties** Invited

Thomas Bürgi, *University of Geneva, Switzerland*
Alastair Cunningham, *University of Geneva, Switzerland*

Strategies to assemble plasmonic particles into larger entities are described. These include the use of surfactants leading to hierarchical organization of metal particles, the build-up of layered structures on flat substrates using polyelectrolytes and the fabrication of core-shell systems. The optical properties have been characterized and compared with simulations of the corresponding model systems.

18:10 – 19:10 **Discussion Forum** ▸ Room Barcelona B

Tuesday, 11th October

Photonic Crystals

16:30 - 18:10 ▸ Room Sants-Montjuïc

Session Chair ▸ **Maria Kafesaki**, *Foundation for Research and Technology Hellas (FORTH), Greece*

16:30 - 17:00 **Broadband time-reversal of optical pulses using a switchable photonic-crystal mirror** Invited

Yonatan Sivan, *Imperial College London, UK*
John B. Pendry, *Imperial College London, UK*

We propose a new time-reversal scheme for optical pulses which overcomes the limitations of exisitng schems. As examples, we demonstrate highly efficient and broadband reversal of pulses of 100 fs and 10 ps duration.

17:00 - 17:30 **Optics of CMOS compatible 3D photonic band gap crystals** Invited

Willem Vos, *University of Twente, Netherlands*
S. R. Huisman, *University of Twente, Netherlands*
L. A. Woldering, *University of Twente, Netherlands*
R. V. Nair, *University of Twente, Netherlands*
M. D. Leistikow, *University of Twente/ FOM Institute Amolf, Netherlands*
A. P. Mosk, *University of Twente, Netherlands*

We study optical properties of CMOS-compatible 3D silicon inverse woodpile photonic crystals in the near-infrared. Spectrally overlapping reflectivity peaks for both polarizations and many directions form the experimental signature of a photonic band gap with a relative bandwidth up to 16%.

17:30 - 17:50 **Enhanced electromagnetic wave transmission and Faraday rotation of a ferromagnetic metal layer embedded in dielectric slab** Oral

Kyle Smith, *University of Texas at San Antonio, USA*
Andrey Chabanov, *University of Texas at San Antonio, USA*

We report microwave measurements and numerical calculations of the electrodynamic properties of a cobalt layer embedded in dielectric slabs. We observe enhanced (up to 3 orders of magnitude) transmission and Faraday rotation as compared to that of the cobalt layer, suggesting its important applications in photonics.

17:50 - 18:10 **Out-of-plane resonances in dielectric and metallo-dielectric photonic quasi-crystal slabs** Oral

Armando Ricciardi, *University of Sannio, Italy*
Alessio Crescitelli, *University of Sannio, Italy*
Marco Consales, *University of Sannio, Italy*
Antonello Cutolo, *University of Sannio, Italy*
Giuseppe Castaldi, *University of Sannio, Italy*
Vincenzo Galdi, *University of Sannio, Italy*
Emanuela Esposito, *CNR-ICIB "E. Caianiello", Italy*
Andrea Cusano, *University of Sannio, Italy*

In this paper, we present a summary of recent results from our studies on out-of-plane resonances in dielectric and metallo-dielectric nanostructured photonic quasi-crystal slabs, with specific reference to the Ammann-Beenker (octagonal, quasi-periodic) tiling geometry. Our experimental results at infrared wavelengths are in good agreement with the numerical predictions from full-wave simulations based on a supercell approximation

18:10 – 19:10 **Discussion Forum** ▸ Room Barcelona B

Acoustic Metamaterials

16:30 - 18:10 ▸ Room Sarrià-Sant Gervasi

Session Chair ▸ **Jose Sanchez-Dehesa**, *Universidad Politecnica de Valencia, Spain*

16:30 - 17:00 **Seismic cloaks** Invited

Mohamed Farhat, *Institut Fresnel, France*
Sebastien Guenneau, *Institut Fresnel, France*
Stefan Enoch, *Institut Fresnel, France*
Michele Brun, *University of Cagliari, Italy*
Alexander Movchan, *University of Liverpool, UK*

We analyse cylindrical cloaks designed to control bending waves and coupled in-plane pressure and shear waves in elastic plates. Whereas electromagnetic cloaks require symmetric rank 2 tensors of permittivity and permeability, our approach is based upon the introduction of an asymmetric rank 4 tensor of elasticity and a scalar density.

17:00 - 17:30 **Acoustic metamaterials: A circuit approach** Invited

Nicholas Fang, *Massachusetts Institute of Technology, USA*

A dramatically increased capability of manipulating light and sound waves has stimulated the exploration of metamaterials. This is exemplified by cloaking devices to render the concealed object undetectable under the flow of light or sound, as well as superlenses to refocus waves and break the limit of diffraction. In this invited talk, we present our progress in theoretical and experimental approaches of acoustic metamaterials made by a set of acoustic circuit elements. We will also discuss the potential impact of these acoustic metamaterials to a wide spectrum of nonlinear effects in ultrasound.

17:30 - 17:50 **Topology optimized acoustic and all-dielectric optical cloaks** Oral

Jacob Andkjær, *Technical University of Denmark, Denmark*
Ole Sigmund, *Technical University of Denmark, Denmark*

We have numerically demonstrated that topology optimization can be used to find the layout of isotropic material in both electromagnetic and acoustic cloaks. Both optimized graded-index designs and optimized designs based on circular inclusions in a background material are presented.

17:50 - 18:10 **Frequency-selective surface cloaking for acoustic waves** Oral

Mohamed Farhat, *Friedrich-Schiller-Universitat Jena, Germany*
Pai Yen Chen, *University of Texas at Austin, USA*
Sebastien Guenneau, *Institut Fresnel - CNRS, Aix-Marseille Universite, France*
Stefan Enoch, *Institut Fresnel - CNRS, Aix-Marseille Universite, France*
Andrea Alu, *University of Texas at Austin, USA*

This contribution applies the concept of 'mantle cloaking', based on the use of appropriate ultrathin pseudo-surfaces that may act as a cloaking device for a finite range of frequencies, to acoustic waves. The physical principle underlying this technique consists in finding the optimal uniform surface impedance (Z=pressure/velocity for elastodynamic waves) that permits us to cancel the scattered field by a diffracting obstacle placed in the way of an impinging acoustical wave. Our numerical simulations performed for 2D and 3D geometries of both the near- and the far-fields show a significant reduction of the acoustic scattering cross-section over a relatively broad range of frequencies, confirming the possibility of designing surface acoustic cloaks (easier to manufacture and less cumbersome than their bulk counterpart). Potential applications lie in low-observability, camouflaging, non-invasive probing, and related applications.

18:10 – 19:10 **Discussion Forum** ▸ Room Barcelona B

Discussion Forum

Theoretical Foundations for Homogenization Theories

18:10 - 19:10

Room Barcelona B

Averaging of the Maxwell equations (MEs), i.e., the transition between the microscopic MEs to their macroscopic counterparts, is one of the main steps in electrodynamics. In spite of the fundamental importance of the averaging procedure, it is extremely rare presented in university courses and respective books; up to now there is no established consensus about how the averaging procedure has to be performed. The main goal of this discussion forum is to start creating a common basis for discussion of the mentioned above problem. Another goal is to establish the averaging procedure for the metamaterials, which is rather close to the case of compound materials but should include artificial magnetic response due to its inclusions shape and size. It is expected that the discussion will help us to elaborate an agreement about some basic principles for the averaging procedure (irrespective to the type of materials) which have to be satisfied. Any newly developed homogenization model has to correlate with these basic principles. Apparently, in case of absence of this evidence of correlation of a particular model with the basic principles the model could not be accepted as a creditable one. It is also expected that the discussion will help us to set more coherence in activities of different groups in their efforts to establish the averaging procedure for metamaterials. We start from the consideration of bulk materials, which means in vast majority of cases that we consider propagation of an electromagnetic wave far from the interfaces, where the eigenwave in the media is already formed and stabilized. In the second part we set a basic structure for discussion about boundary conditions and layered metamaterials. The discussion forum organizers have prepared some preliminary material for discussion, which can be found as an Arxiv preprint at http://arxiv.org/abs/1106.3835

Organizer Arkadi Chipouline, *FSU, Germany*

Session Chair Arkadi Chipouline, *FSU, Germany*

Carbon and Quantum Metamaterials 1

08:20 - 10:00 ▸ Room Barcelona B

Session Chair ▸ **Martti Kauranen**, *Tampere University of Technology, Finland*

08:20 - 08:50 **Control of emission and reflectance with metamaterials** Invited

M. Noginov, *Norfolk State University, USA*
T. Tumkur, *Norfolk State University, USA*
H. Li, *Norfolk State University, USA*
Yu. Barnakov, *Norfolk State University, USA*
G. Zhu, *Norfolk State University, USA*
C. Bonner, *Norfolk State University, USA*
M. Mayy, *Norfolk State University, USA*
P. Black, *Norfolk State University, USA*
Z. Jacob, *University of Alberta, Canada*
L. Alekseyev, *Purdue University, USA*
E. Narimanov, *Purdue University, USA*

We experimentally show that a broad-band singularity in the density of photonic states in metamaterials with hyperbolic dispersion enables two classes of interesting physical phenomena: (i) enhancement of spontaneous emission radiative rate, quantum yield and directionality, and (ii) strong reduction of reflectance off corrugated metamaterials surfaces.

08:50 - 09:20 **Graphene plasmonics** Invited

Javier Garcia de Abajo, *CSIC, Spain*
Frank H.L. Koppens, *ICFO-Institut de Ciéncies Fotóniques, Spain*
Darrick E. Chang, *California Institute of Technology, USA*
Suko Thongrattanasiri, *CSIC, Spain*

Graphene plasmons provide a suitable alternative to noble-metal plasmons because they exhibit much larger confinement and relatively long propagation distances, with the advantage of being highly tunable via electrostatic gating. We will discuss how these properties translate into strong light-matter interaction, total light absorption, and other exciting properties.

09:20 - 09:40 **Graphene-based Fourier optics** Oral

Ashkan Vakil, *University of Pennsylvania, USA*
Nader Engheta, *University of Pennsylvania, USA*

In this paper, we theoretically show that by tailoring specific conductivity distribution on graphene, one can create a region on this material to perform as a lens. Our numerical studies indicate that this “one-atom thick” lens obtains spatial Fourier transform of the optical signal similar to a standard optical lens in 3-dimensional optics. The possibility to create inhomogeneous patterns of effective index for SPP surface waves on the graphene may allow for reimplementation of Fourier optics devices on a monolayer of carbon atoms.

09:40 - 10:00 **Fluorescence enhancement in the vicinity of complex plasmonic nanostructures: A transformation optics approach** Oral

Alexandre Aubry, *ESPCI ParisTech - CNRS, France*
John Pendry, *Imperial College London, UK*

In this paper, the interaction of a dipole emitter (e.g molecule or quantum dot) with complex plasmonic nanostructures is investigated by means of transformation optics. The fluorescence enhancement as well as the quantum efficiency are derived analytically. Their spectral and spatial properties are analyzed in the perspective of future experiments.

10:00 - 11:20 Coffee break + **Poster Session 2** ▸ Room Barcelona A

Chiral Metamaterials

08:20 - 10:00 ▸ Room Sants-Montjuïc

Session Chair ▸ **Andrei Lavrinenko**, *Technical University of Denmark, Denmark*

08:20 - 08:50 **Science meets magic: Metamaterials** Invited

Ekmel Ozbay, *Bilkent University, Turkey*

The word "magic" is usually associated with movies, fiction, children stories, etc. but seldom with the natural sciences. Recent advances in metamaterials have changed this notion, in which we can now speak of "almost magical" properties that scientists could only dream about only a decade ago. In this article, we review some of the recent "almost magical" progress in the field of meta-materials.

08:50 - 09:20 **Experimental mapping of plasmonic patterns based on second harmonic generation microscopy** Invited

Ventsislav K. Valev, *Katholieke Universiteit Leuven, Belgium*
Alejandro V. Silhanek, *Katholieke Universiteit Leuven, Belgium*
Xuezhi Zheng, *Katholieke Universiteit Leuven, Belgium*
Claudiu G. Biris, *University College London, UK*
Ben De Clercq, *University of Hasselt, Belgium*
Vladimir Volskiy, *Katholieke Universiteit Leuven, Belgium*
Denitza Denkova, *Katholieke Universiteit Leuven, Belgium*
Nicolae C. Panoiu, *University College London, UK*
Guy A. E. Vandenbosch, *Katholieke Universiteit Leuven, Belgium*
Oleg A. Aktsipetrov, *Moscow State University, Russia*
Marcel Ameloot, *University of Hasselt, Belgium*
Victor V. Moshchalkov, *Katholieke Universiteit Leuven, Belgium*
Thierry Verbiest, *Katholieke Universiteit Leuven, Belgium*

We demonstrate that second harmonic generation (SHG) microscopy constitutes a unique, impor-tant, user-friendly and widely-applicable method for visualizing plasmonic hotspots in metamate-rials. Most importantly, though, SHG imaging has an impact, literally. Indeed, we prove that SHG imaging of samples can imprint the plasmonic patterns on the surface of the structures for subse-quent imaging with structural characterization techniques such as SEM or AFM. Consequently, the plasmonic patterns can be mapped with the resolution of scanning probe techniques and thus the limitations imposed by the diffraction of light can be removed altogether.

09:20 - 09:40 **Zero-backscattering self-dual object from two chiral particles** Oral

Antti Karilainen, *Aalto University, Finland*
Sergei Tretyakov, *Aalto University, Finland*

In this paper we study two canonical chiral particles as a possible element for composite media. We write the polarisation components for one chiral particle, and see that when combined with the second, we need only four of the ten components to describe the scattered field with good accuracy. For the normal incidence, the unit element scatters as a Huygens' source with in-plane isotropy for linear polarisation. The reason behind this zero-backscattering behavior is that the element is self dual with 90-degree rotational symmetry. The scattered fields from a circularly polarised field are studied in detail, and it is seen that the scattered field has also the Huygens' pattern and the polarisation is circular.

09:40 - 10:00 **Spatially resolved enhancement of chirality in planar and 3D chiral metamaterials** Oral

Martin Schäferling, *University of Stuttgart, Germany*
Daniel Dregely, *University of Stuttgart, Germany*
Mario Hentschel, *University of Stuttgart, Germany*
Harald Giessen, *University of Stuttgart, Germany*

We visualize the enhancement of optical chirality in the near-field regime of chiral metallic metamaterials. Different planar and three-dimensional geometries are analyzed. We show that two-dimensional structures are more suitable for practical applications as it is easier to access the superchiral fields, while three-dimensional structures show higher enhancement of optical chirality.

10:00 - 11:20 Coffee break + **Poster Session 2** ▸ Room Barcelona A

Tunable and Nonlinear Metamaterials

08:20 - 10:00 ▸ Room Sarrià-Sant Gervasi

Session Chair ▸ **Yuri Kivshar**, *Australian National University, Australia*

08:20 - 08:50 **Tuning interaction between metamaterial elements** Invited

David Powell, *Australian National University, Australia*

We give an overview of the issue of coupling between metamaterial elements, an important factor in understanding and characterising their behaviour. We describe the well known Lagrangian model to describe this interaction. We show how the interaction coefficients can be calculated, and illustrate the importance of losses and fabrication errors in the tuning behaviour.

08:50 - 09:20 **Dynamic tuning in metamaterials exhibiting electromagnetically induced transparency** Invited

Cihan Kurter, *University of Maryland, USA*
Alexander P. Zhuravel, *National Academy of Sciences of Ukraine, Ukraine*
Philippe Tassin, *Ames Laboratory-U.S. DOE, USA*
Lei Zhang, *Ames Laboratory-U.S. DOE, USA*
Thomas Koschny, *Ames Laboratory-U.S. DOE, USA*
Alexey V. Ustinov, *Karlsruhe Institute of Technology, Germany*
Costas M. Soukoulis, *Ames Laboratory-U.S. DOE, USA*
Steven M. Anlage, *University of Maryland, USA*

Metamaterials designed to display electromagnetically induced transparency (EIT) have potential applications in telecommunication because of their large phase shifts and delay-bandwidth products. Therefore, the ability to tune the performance of these metamaterials is crucial in terms of their functionality. Here we demonstrate a precise and sensitive control on EIT response of a mematerial composed of superconductor/normal metal hybrid structure through temperature and RF magnetic field.

09:20 - 09:40 **Active three-dimensional metal/semiconductor metamaterials including Ag gratings** Oral

Stephan Schwaiger, *Universitaet Hamburg, Germany*
Andreas Rottler, *Universitaet Hamburg, Germany*
Matthias Klingbeil, *Universitaet Hamburg, Germany*
Jochen Kerbst, *Universitaet Hamburg, Germany*
Ricardo Costa, *Universitaet Hamburg, Germany*
Aune Koitmae, *Universitaet Hamburg, Germany*
Markus Broell, *Universitaet Hamburg, Germany*
Yulia Stark, *Universitaet Hamburg, Germany*
Christian Heyn, *Universitaet Hamburg, Germany*
Detlef Heitmann, *Universitaet Hamburg, Germany*
Stefan Mendach, *Universitaet Hamburg, Germany*

We prepare three-dimensional metamaterials consisting of alternating layers of plasmonic silver gratings and optically active semiconductor quantum wells utilizing the concept of self-rolling strained layers. Finite difference time domain calculations which assume quantum well gain obtained from measurements reveal that pumping induced transparency is expected for these structures.

09:40 - 10:00 **Giant femtosecond optical nonlinearity of gold metamaterial nanostructures** Oral

Mengxin Ren, *University of Southampton, UK*
Baohua Jia, *Swinburne University of Technology, Australia*
Jun-Yu Ou, *University of Southampton, UK*
Eric Plum, *University of Southampton, UK*
Kevin MacDonald, *University of Southampton, UK*
Andrey Nikolaenko, *University of Southampton, UK*
Jingjun Xu, *Nankai University, China*
Min Gu, *Swinburne University of Technology, Australia*
Nikolay Zheludev, *University of Southampton, UK*

We demonstrate that magnitude and sign of the third-order nonlinear susceptibility of plasmonic metals like gold can be controlled by nanostructuring, leading to 100-fold enhanced ultrafast (less than 115fs) two-photon absorption for optical limiting and terahertz-bandwidth all-optical data processing.

10:00 - 11:20 Coffee break + **Poster Session 2** ▸ Room Barcelona A

Poster Session 2

10:00 - 11:20 ▸ Room Barcelona A

1. Wide and multi band fan shaped split ring resonator for radar

Mahmoud Abdalla, *MTC University, Egypt*
Mohamed Fouad, *MTC University, Egypt*

The paper presents a new simple and ultra thin (5.6% l0) wide/ multi bands metamaterial radar absorber. The new metamaterial absorber is based on the use of fan shaped split ring resonator. The theoretical concepts have been validated using the electromagnetic full save simulations. The results illustrate that the proposed metamaterial absorber can achieve dual band of radar absorption. Both bands have wider bandwidth compared to conventional rectangular split ring resonator (four times wider in one band and eight times wider in the second band). Also, the proposed metamaterial absorber can achieve almost -20 dB reflection coefficient for both the cases of co polarized and cross polarized incidence fields at the center frequency.

2. Dual-band circularly polarized RFID reader antenna employing metamaterial quadrature hybrid coupler

Youn-Kwon Jung, *Kyung Hee University, Republic of Korea*

A dual-band circularly polarized aperture coupled microstrip RFID reader antenna using a meta-material (MTM) quadrature hybrid coupler has been designed, fabricated, and measured. The proposed antenna is fabricated on an FR-4 substrate with relative permittivity of 4.6 and thickness of 1.6 mm. A dual-band (UHF and ISM) circularly-polarized RFID planar reader antenna with separate TX and RX ports is incorporated connected to the designed metamaterial (MTM) quadrature hybrid coupler. The measured 10dB bandwidth of the proposed antenna is 908 to 939 MHz (3.4%) and 2370 to 2540 MHz (7.0%). The maximum measured CP gain is 6.6 dBc at 920MHz (UHF) and 7.9dBc at 2.45GHz (ISM). The cross-polar gains near broadside of the RFID reader antenna are approximately less than -20dB compared with the co-polar gains in both bands. The proposed antenna presents isolation of 25dB and 38dB at each band.

3. Slot-loaded dual-layer artificial magnetic conductor

Ji Hwan Yoon, *Yonsei University, Republic of Korea*
Yohan Lim, *Yonsei University, Republic of Korea*
Young Joong Yoon, *Yonsei University, Republic of Korea*

A dual-band artificial magnetic conductor composed of two metallic patch layers with slot-loading is proposed. The slots inserted in the patches lengthen the current path on the patches, which increases the equivalent inductances. The equivalent circuit model of the dual-layer AMC is modified by the additional inductances due to the slot-loading, and the reflection phases calculated using the model is compared with full wave analysis results. The effects of the slot-loading on the reflection phase are discussed using the results. The method of controlling the reflection phase of the dual-layer AMC using slot-loading is expected to increase the degree of freedom in designing both AMC and electromagnetic gradient surface structures.

4. Study of the LSR-MTM antenna: Dual-band and dual-polarized approaches

Hammam Shakhtour, *RWTH Aachen, Germany*
Alireza Ajami, *RWTH Aachen, Germany*
Entlira Stavrou, *RWTH Aachen, Germany*
Dirk Heberling, *RWTH Aachen, Germany*

Microstrip patch antenna loaded with a series gap discontinuity and a 4-arm logarithmic spiral resonator (LSR) is investigated. Two structures are given, one is a dual-polarized metamaterial antenna (MTM). The other one is a dual-band MTM antenna. Both antennas are based on the LSR-MTM transmission line (TL) approach [1]. It is shown by comparison that a big reduction in antenna's size, compared to conventional patch antenna, could be achieved. Furthermore, simplicity of fabrication will turn out to be an advantage of such antennas. CST Microwave studio is used to simulate and optimize the proposed antennas. Measurement results are finally presented to verify functionality.

5. Sound blockage through closely spaced perforated layers

A. R. J. Murray, *University of Exeter, UK*
A. P. Hibbins, *University of Exeter, UK*

Transmission of sound through a pair of rigid plates each perforated with a sub-wavelength square array of circular holes and separated by a sub-wavelength gap is explored and compared with model predictions.

6. ~~Sound transmission through a rigid plate perforated with compound hole arrays~~

Hector Estrada, *Centro de Tecnologias Fisicas – CSIC/UPV, Spain*
Vicente Gomez-Lozano, *Centro de Tecnologias Fisicas – CSIC/UPV, Spain*
Antonio Uris, *Centro de Tecnologias Fisicas – CSIC/UPV, Spain*
Pilar Candelas, *Centro de Tecnologias Fisicas – CSIC/UPV, Spain*
Francisco Belmar, *Centro de Tecnologias Fisicas – CSIC/UPV, Spain*
Francisco Meseguer, *Centro de Tecnologias Fisicas – CSIC/UPV, Spain*

In this paper we present numerical results of sound transmission through plates perforated with a compound hole array consisting in two periodic arrays of holes. The model used is based on the rigid-solid assumption for the perforated plate. Multiple transmission peaks can be achieved and their locations can be controlled by the plate thickness, the array period and the hole size. The minima corresponding to the Wood anomalies can be replaced by a resonant transmission peak in the double array spectrum. A new minimum appears due to the destructive interference of both arrays.

7. Time reversed lasing system for coherent perfect absorption based on switchable micro-machined metamaterial mirrors

Wei Ming Zhu, *Nanyang Technological University of Singapore, Singapore*
Yuan Hsing Fu, *Nanyang Technological University of Singapore, Singapore*
Ji Fang Tao, *Nanyang Technological University of Singapore, Singapore*
Jing Hua Teng, *Institute of Materials Research and Engineering of Singapore, Singapore*
Xin Hai Zhang, *Institute of Materials Research and Engineering of Singapore, Singapore*
Hendrix Tanoto, *Institute of Materials Research and Engineering of Singapore, Singapore*
Hong Chen Guo, *Institute of Materials Research and Engineering of Singapore, Singapore*
Qing Yang Wu, *Institute of Materials Research and Engineering of Singapore, Singapore*
Tarik Bourouina, *Université Paris-Est of France, France*
Ai Qun Liu, *Nanyang Technological University of Singapore, Singapore*

In this paper a time reversed lasing system for switchable coherent perfect absorption (CPA) is designed and demonstrated. The perfect absorption condition of the time reversed lasing is controlled by the micromachined metamaterial mirrors. In experiment, the peak absorption is measured to be larger than 97%.

8. ~~Oblique incidence of drifting electrons upon a negative permittivity material: derivation of the dispersion equation~~

This paper was not presented at the conference (Withdrawal).

Laszlo Solymar, *Imperial College London, UK*
Ekaterina Shamonina, *Imperial College London, UK*

A two-dimensional analysis is performed by combining the equation of motion for electrons with Maxwell's equations which relate the fields and currents to each other. A dispersion equation is derived under the assumption that the electric field associated with drifting electrons sees a nega-tive permittivity. The dispersion equation derived can be used for testing the stability of the physi-cal situation. An instability can lead to oscillators and amplifiers in the THz region.

9. Investigation of negative refraction in composite ferrite-semiconductor prism for millimeter waveband

Aleksey Girich, *Institute of Radiophysics and Electronics - NASU, Ukraine*
Sergey Tarapov, *Institute of Radiophysics and Electronics - NASU, Ukraine*

The paper is devoted to experimental study of left-handed properties of prism-shaped metamaterial consists of ferrite and semiconductor bricks oriented in the staggered order in millimeter waveband. The negative refraction was revealed. The appearance of double negative frequency zone has been demonstrated experimentally and theoretically. Satisfactory agreement between experiment and numerical results is shown. The dependence of double negative zone position on the external magnetic field, caused by ferromagnetic resonance in ferrite elements has been detected and analyzed.

10. Cryogenic temperature measurement of THz meta-resonance in symmetric metamaterial superlattice

J. H. Woo, *Ewha Womans University, South Korea*
E. S. Kim, *Ewha Womans University, South Korea*
Boyoung Kang, *Ewha Womans University, South Korea*
E. Y. Choi, *Ewha Womans University, South Korea*
Hyun-Hee Lee, *Ewha Womans University, South Korea*
J. Kim, *Ewha Womans University, South Korea*
Y. U. Lee, *Ewha Womans University, South Korea*
Tae Y. Hong, *Yonsei University, South Korea*
Jae H. Kim, *Yonsei University, South Korea*
J. W. Wu, *Ewha Womans University, South Korea*

Symmetric THz metamaterial superlattice is introduced to investigate the temperature dependence of Q-factor of trapped and open modes. Contributions of radiative damping and Joule heating to the loss are identified in determining Q-factors. In the trapped mode, the Joule heating is found to be significantly suppressed at the cryogenic temperature.

11. Diffractive coupling in metamaterial arrays studied by terahertz nearfield imaging

Jan Wallauer, *University of Freiburg, Germany*
Markus Walther, *University of Freiburg, Germany*

We experimentally study coupling in planar metamaterial systems consisting of periodically arranged split-ring resonators (SRRs) by terahertz (THz) near-field imaging. For appropriate lattice periodic- ities the SRRs couple via their diffracted fields leading to an avoided crossing in their transmission spectra. Our measured electric and magnetic field maps of the resonant modes in the SRR arrays reveal hybridization between the plasmonic resonance and the lattice mode in this diffractive coupling regime.

12. Dual band textile antenna on EBG for WiFi applications

Mohamad Mantash, *IETR/University of Rennes 1, France*
Anne-Claude Tarot, *IETR/University of Rennes 1, France*
Sylvain Collardey, *IETR/University of Rennes 1, France*
Kouroch Mahdjoubi, *IETR/University of Rennes 1, France*

A complete study of a dual band textile antenna on Electromagnetic Band Gap (EBG) for WiFi applications is presented. A CPW G-shaped monopole antenna on EBG for dual band operation on textile (denim) is designed and characterized. Finally, experimental results for the antenna on EBG prototype using Shieldit Super electro-textile are presented and show that both the lower and the upper WiFi frequency bands are covered.

13. Multi layer artificial magnetic conductors for multiband antennas

Jerome Massiot, *ONERA, France*
Cedric Martel, *ONERA, France*

In this paper, we propose multi band reflectors based on high impedance surface (HIS). The HIS are composed of stacks of patches layers. The first part of this paper is about the design of a two-layer reflector and three-layer reflector. In a second part, performances of a multi layer HIS reflector is simulated using dipole antennas of different lengths. Finally the insertion of an inductive layer in the stack of capacitive layers of the HIS is discussed.

14. Control of the hot spot localization in graded plasmonic nano-antennae

Javier Munárriz, *Universidad Complutense de Madrid, Spain*
Andrey Malyshev, *Universidad Complutense de Madrid, Spain*

We consider nano-antennae comprising metallic nanospheres of different sizes organized in graded linear chains in the proximity of a heterointerface of two media with different refractive indices. We address the near field signal of the antennae under the excitation by evanescent waves and show that the response of the array is localized at a few nanospheres, creating a hot spot. We demonstrate that, even for a fixed wavelength, the position of the hot spot can be controlled by the angle of incidence of the excitation. This opens new opportunities to control electromagnetic energy localization and enhancement at nanoscale.

15. ~~Characterization of materials using rotating polarizer and analyzer spectroscopic ellipsometer~~

Sofyan Taya, *Islamic University of Gaza, Palestine*
Taher El-Agez, *Islamic University of Gaza, Palestine*

This paper was not presented at the conference (No show).

A spectroscopic ellipsometer in which the polarizer and the a[illegible]n the same angular speed is proposed. The light intensity received by the detector contains four components, one dc and three AC terms. The ellipsometric parameters and of a sample can be extracted from the AC Fourier coefficients without relying on the dc component. The characterization of bulk c-Si and a thin film of SiO2 on Si substrate using the proposed ellipsometer are shown. The effect of a hypothetical noise imposed on the signal is shown.

16. The use of metamaterials: A solution to improve the performance of radiofrequency coil for magnetic resonance imaging (MRI)?

Mohand Said Khennouche, *Universite Paris Sud 11, France*
Frederique Gadot, *Universite Paris Sud 11, France*
Andre de Lustrac, *Universite Paris Sud 11, France*
Marie Poirier Quinot, *Universite Paris Sud 11/CNRS, France*
Luc Darrasse, *Universite Paris Sud 11/CNRS, France*
Jean Christophe Ginefri, *Universite Paris Sud 11/CNRS, France*

In this paper we coupled a coil for Magnetic Resonance Imaging with metamaterials in order to increase its sensitivity and improve the RF magnetic field pattern. To radiation patterns of the coil and the coil associated with metamaterials are so compared. We present in this paper one configuration of the coil coupled with metamaterials and their first encouraging numerical results.

17. Radiation pressure forces and Mie scattering resonances over stratified spherical particles with negative refractive index layers

Leonardo A Ambrosio, *University of Campinas, Brazil*
Hugo E Hernández-Figueroa, *University of Campinas, Brazil*

We extend our previous analysis of optical forces over homogenous and lossless negative refractive index (NRI) spherical particles in order to include radiation pressure forces over stratified spherical particles with arbitrary-material layers, using the generalized Lorenz-Mie theory (GLMT) to observe the new resonance effects on the Mie scattering coefficients.

18. New fractal structures for frequencies close to the visible range

Radu Malureanu, *Danish Technical University, Denmark*
Alexandra Sandru, *"Politehnica" University of Bucharest, Romania*
Andrei Andryieuski, *Danish Technical University, Denmark*
Andrei Lavrinenko, *Danish Technical University, Denmark*

We present a new type of fractal resonator to be used in the red/NIR region. It presents high-transmission band in 795-825nm range. The stop band is in the 683-731 nm range. It can be used as an efficient sensor, both in transmission and reflection (sensitivity of 780nm/RIU). Also, the response is angle independent.

19. A bio-imaging platform via split-ring resonators microscopy

Yueh-Chun Lai, *National Tsing Huang University, Taiwan*
Hsin-Cheng Lee, *National Tsing Huang University, Taiwan*
Cheng-Kuang Chen, *National Tsing Huang University, Taiwan*
Ta-Jen Yen, *National Tsing Huang University, Taiwan*

In this report, we built up a compact microscopic platform based on split-ring resonator (SRR). Owning advantages such as label-free, coupler-free, tunable spectrum range (from MIR to VIS) and longer detection length, the SRR microscopy (SRRM) is a strong competitor compared to the bulky surface plasmon resonance microscopy (SPRM) for biochemistry reaction detection in Bone marrow mesen-chymal stem cells (BM-MSCs). Our experimental results has successfully demon-strated its capability of constructing the refractive index distribution images of BM-MSCs and meanwhile, obtaining the information of functional groups from the target cells. Therefore, we expect that the SRR microscopy (SRRM) delivers much simple optical configuration and better pen-etration depth for truly whole-cell imaging applications.

20. ~~Metamaterial based biosensor for fast and sensitive detection~~

Semih Cakmakyapan, *Bilkent University, Turkey*
Humeyra Caglayan, *University of Pennsylvania, USA*
Kadir Aslan, *Morgan State University, USA*
Deniz Caliskan, *Bilkent University, Turkey*
Ekmel Ozbay, *Bilkent University, Turkey*

This paper was not presented at the conference (No show).

In this paper we showed that split ring resonators can b ong electromagnetic wave response, SRRs provide fast and sensitive detection, as well as reducing the bioassay time. It is shown that a typical ELISA test takes less than 2 minutes to complete by using split ring resonators and microwave heating, whereas the same test takes 70 minutes at room temperature.

21. Photonic crystal slabs for resonant photodetection

Stefan Kalchmair, *Vienna University of Technology, Austria*
Roman Gansch, *Vienna University of Technology, Austria*
Garrett D. Cole, *University of Vienna, Austria*
Hermann Detz, *Vienna University of Technology, Austria*
Aaron M. Andrews, *Vienna University of Technology, Austria*
Pavel Klang, *Vienna University of Technology, Austria*
Werner Schrenk, *Vienna University of Technology, Austria*
Gottfried Strasser, *Vienna University of Technology, Austria*

We present a photonic crystal slab (PCS) photodetector, designed for resonant absorption of infra-red light in quantum wells. With the PCS the photon lifetime in the detector active region is in-creased. This detector design allows extending the usable temperature range by at least 30K com-pared to a standard quantum well photodetector.

22. Metamaterial-based design of biological sensors operating at THz frequencies

Luigi La Spada, *"Roma Tre" University, Italy*
Filiberto Bilotti, *"Roma Tre" University, Italy*
Lucio Vegni, *"Roma Tre" University, Italy*

In this contribution, we present an omega-shaped electromagnetic resonator, which is of potential interest for THz biosensors. A new analytical model for such an inclusion-type is developed, considering the effects of the fringing capacitance. After the development of a proper parametric (analytical and numerical) analysis, we optimize the design in terms of selectivity and sensitivity for the operation of the biosensor at THz frequencies. The obtained biosensor exhibits an higher selectivity and sensitivity compared to similar devices already presented in the literature.

23. ~~Metamaterial loaded dual band microstrip patch antenna~~

Shyam S. Pattnaik, *National Institute of Technical Teachers' Training and Research, India*
J. G. Joshi, *National Institute of Technical Teachers' Training and Research, India*
S. Devi Pattnaik, *National Institute of Technical Teachers' Tr*

This paper was not presented at the conference (No show).

This paper presents a metamaterial multiple split ring reson ar microstrip patch antenna. The unloaded antenna resonates at 14.80 GHz. In loaded condition, it resonates at 6.03 GHz and 6.70 GHz due to magnetic coupling. The resonant frequency of the antenna can be controlled by varying number of split rings of MSRR and capacitance of the resonator.

24. Low-profile dual-band antenna based on meta-surfaces

Iñigo Liberal, *Public University of Navarra, Spain*
Iñigo Ederra, *Public University of Navarra, Spain*
Ramón Gonzalo, *Public University of Navarra, Spain*

A prototype for a dual-band metamaterial-inspired antenna is presented. The antenna consists of a dual-band dipole placed between two meta-surfaces, which are tuned to operate at both dipole bands. In this way, the dipole radiates at a different half-space at each frequency band. Antenna gains as high as 6.1dB and 7.6dB have been measured at the low- and high-frequency bands, re-spectively, while keeping a low-profile of 0.152 at the lowest resonant frequency.

25. Artificial magnetism and modes at millimeter waves in 3D lattices of titanium oxide microspheres

Salvatore Campione, *University of California Irvine, USA*
Sylvain Lannebere, *University of Bordeaux 1, France*
Ashod Aradian, *University of Bordeaux 1, France*
Matteo Albani, *University of Siena, Italy*
Filippo Capolino, *University of California Irvine, USA*

Complex modes and artificial magnetic properties of a 3D lattice made of titanium oxide microspheres are analyzed at millimeter waves. Effective permeability and refractive index from modal analysis, Maxwell Garnett homogenization, and scattering parameters retrieved from the Nicolson-Ross-Weir method and full wave simulations of finite thickness structures are compared.

26. Chirality arising from rotated square meshes

Celia Butler, *University of Exeter, UK*
Alastair Hibbins, *University of Exeter, UK*
Peter Hobson, *QinetiQ, UK*
Roy Sambles, *University of Exeter, UK*

Two subwavelength metallic meshes of square holes are placed in close proximity. One is rotated with respect to the other, despite each mesh being non-chiral, information is conveyed via the evanescent fields, and polarization conversion results - the system has become electromagnetically chiral.

27. Theory for ferrite-ferroelectric active ring resonator

Andrey Nikitin, *Saint Petersburg Electrotechnical University, Russia*
Alexey Ustinov, *Saint Petersburg Electrotechnical University, Russia*
Alexander Semenov, *Saint Petersburg Electrotechnical University, Russia*

A theory is developed for amplitude-frequency and phase-frequency characteristics of "active ring" resonator based on ferrite-ferroelectric layered structure. An active ring resonator (ARR) is a feedback circuit, the main parts of which are a ferrite-ferroelectric waveguiding structure and a microwave amplifier. It is shown that the amplitude-frequency (AFC) and the phase-frequency (PFC) characteristics of the ARR are determined by the dispersion law of the hybrid electromag-netic-spin waves (EMSWs) in ferrite-ferroelectric layered structure. It is demonstrated that the amplitude-frequency and phase-frequency characteristics of the active ring resonator are dual tunable. The dual tunability is achieved through changing the magnetic and/or electric bias fields. The quality factor of the resonance modes is controlled by the amplifier gain coefficient.

28. On the implementation of a robust algorithm which automates the synthesis of artificial transmission lines based on CSRRs

Ana Rodríguez, *Universidad Politécnica de Valencia, Spain*
Jordi Selga, *Universitat Autònoma de Barcelona, Spain*
Ferran Martín, *Universitat Autònoma de Barcelona, Spain*
Vicente E. Boria, *Universidad Politécnica de Valencia, Spain*

Recently, the authors of this paper have been able to automatically generate the layout for microstrip lines loaded with CSRRs. The method proposed in that paper, is working nowadays successfully for composite right/left-handed and negative permittivity unit cell lines. Several improvements have been introduced, and summarized in the present contribution.

29. Tunable microwave generator based on ferrite-ferroelectric film structure

Alexandr Kondrashov, *Saint-Petersburg Electrotechnical University, Russia*
Alexey Ustinov, *Saint-Petersburg Electrotechnical University, Russia*
Boris Kalinikos, *Saint-Petersburg Electrotechnical University, Russia*

Investigation of the microwave generator based on ferrite-ferroelectric metamaterial structure is reported. Possibility of auto-generation of complicated chaotic signals is experimentally observed. It is shown that a change of the direction and magnitude of the bias magnetic field leads to a change of chaos parameters in a wide range. Application of the electric bias field leads to a small increase of the fractal dimension.

30. Extraordinary transmission through nano-slits to actively control the optical near-field distribution

Abdoulaye Ndao, *CNRS-FEMTO-ST, France*
Quentin Vagne, *CNRS-FEMTO-ST, France*
Fadi Issam Baida, *CNRS-FEMTO-ST, France*
Jerome Salvi, *CNRS-FEMTO-ST, France*

We show a sub-wavelength confinement of the optical near-field through rectangular nano-slits sensitive to polarization. By switching the polarization, we can switch on/off sub-wavelength apertures to achieve a spatial control of the optical near-field distribution.

31. Wavelength-independent field enhancement in subwavelength gratings

Aliaksandra Ivinskaya, *Technical University of Denmark, Denmark*
Andrey Novitsky, *Technical University of Denmark, Denmark*
Dzmitry Shyroki, *Max Planck Institute for the Science of Light, Germany*
Maxim Zalkovskij, *Technical University of Denmark, Denmark*
Radu Malureanu, *Technical University of Denmark, Denmark*
Andrei Lavrinenko, *Technical University of Denmark, Denmark*

We show that lamellar metal gratings exhibit total transmission of incident radiation and strong nonresonant electric field enhancement in extremely subwavelength regime (in the nanometer-sized slits). With high accuracy the enhancement equals the ratio of the grating period to the slit width, it is independent on the wavelength and metal thickness.

32. Horn nano-antenna at near-infrared frequencies: Design and potential applications

Davide Ramaccia, *"Roma Tre" University, Italy*
Alessandro Toscano, *"Roma Tre" University, Italy*

Antennas working at near-infrared and optical frequencies are an emerging and innovating concept. The aim of this work, is to present a new type of nano-antenna: a nano-horn able to radiate, guide, and harvest efficiently the electromagnetic energy at near-infrared frequencies. Possible applications of the proposed horn nano-antennas are also discussed like, for instance, light-and thermal-emitting sources or detectors, photovoltaics and energy harvesting, spectroscopy, wireless secure communications, etc.

33. Thin-film solar cell enhanced by broadband plasmonic nanoantennas

Dmitry Morits, *Aalto University, Finland*
Constantin Simovski, *Aalto University, Finland*

We suggest a design solution of a thin-film solar cell enhanced in a very broad frequency band. The design is based on the recently invented cheap technology, which allows one to prepare large-area arrays of nanoantennas (NA) printed on a polyethylene or another cheap plastic film. Such arrays of NA operate as so-called plasmonic light concentrators for thin-film solar cells and the substrate of NA act as a Fabry-Perot resonator to prevent the reflection of the incident field. The significant advantage of this design is compatibility with the advanced technology which makes possible the large-area variant of plasmon-enhanced solar panels.

34. Controlling radiation patterns of plasmonics nano-antennae

Javier Munarriz, *Universidad Complutense de Madrid, Spain*
Andrey Malyshev, *Universidad Complutense de Madrid, Spain*
Victor Malyshev, *University of Groningen, Netherlands*
Jasper Knoester, *University of Groningen, Netherlands*

We study radiation patterns of plasmonic nano-antenna, formed by a linear chain of equally sized silver nano-spheres at a glass/indium tin oxide interface, excited by evanescent waves. We demonstrate that the radiation of the system is very directional and sensitive to polarization and angles of incidence of the excitation beam.

35. ~~Optical properties of a toroidal metallic resonator coupled to a dipolar emitter~~

Aloyse Degiron, *University of Paris-Sud and CNRS, France*
Tatiana Teperik, *University of Paris-Sud, France*

This paper was not presented at the conference (No show).

We report on the control of a dipolar emitter using a metallic re
that the emitter couples to the free electrons of the metal to
enhance the emission and the directivity at selected wavelengths. The small size of such structures
makes them attractive in the context of metamaterials, where they may be used as unit cells to control the local density of states in the vicinity of luminescent quantum dots and molecules.

36. Characterizing metamaterials using spectroscopic ellipsometry

Thomas Oates, *Leibniz – Institut für Analytische Wissenschaften, Germany*
Babak Dastmalchi, *Johannes Kepler University, Austria*
Kurt Hingerl, *Johannes Kepler University, Austria*
Iris Bergmair, *PROFACTOR GmbH, Austria*
Karsten Hinrichs, *Leibniz – Institut für Analytische Wissenschaften, Germany*

Traditionally ellipsometry is the method of choice for determining the dielectric function of iso-tropic bulk and composite materials. In recent years, the extension to generalized and Mueller matrix ellipsometry has facilitated the determination of the dielectric tensors of uniaxial and biaxial anisotropic materials. In this paper we investigate how the dielectric and permeability tensors of metamaterials may be characterized using spectroscopic ellipsometry. Fishnet metamaterials are measured in the IR range from 2500-9500 cm-1 and the optical parameters are extracted by inverting the measured data in a three layer model.

37. Experimental characterization method for metamaterials using an asymmetrical strip transmission line

Sandra Gómez, *Université de Bretagne Occidentale, France*
Patrick Quéffélec, *Université de Bretagne Occidentale, France*
Alexis Chevalier, *Université de Bretagne Occidentale, France*

An experimental technique for measuring the effective parameters of metamaterials is presented. The minimal size of the sample that produces a representative result is determined using electromagnetic simulations and the influence of the metallic parts of the measurement cell over the retrieved properties of the sample is analyzed.

38. Characterization of split-ring resonators using spectroscopic ellipsometry

Milka Jakovljevi, *University of Belgrade, Serbia*
Goran Isi, *University of Belgrade, Serbia*
Borislav Vasi, *University of Belgrade, Serbia*
Radoš Gaji, *University of Belgrade, Serbia*
Tom Oates, *Leibniz Institut für Analytische Wissenschaften - ISAS - e.V., Germany*
Karsten Hinrichs, *Leibniz Institut für Analytische Wissenschaften - ISAS - e.V, Germany*
Iris Bergmair, *PROFACTOR GmbH, Austria*
Kurt Hingerl, *Universität Linz, Austria*

Ellipsometric response of periodically arranged golden split-ring resonators at infrared frequencies is analyzed. Rigorous coupled wave analysis of the structure's optical response revealed excellent agreement with experimental data. The features in the ellipsometric spectra are discussed by analyzing the reflection spectra for p- and s-polarizations. It is shown that ellipsometry can be used to characterize the first few plasmonic modes of split-ring resonators.

39. Miniaturized narrowband microwave absorber based on double-negative metamaterial

Hongmin Lee, *Kyonggi University, South Korea*
Taejune Jo, *Kyonggi University, South Korea*

This paper presents a miniaturized microwave absorber for 2 GHz frequency band that utilizes properly arrayed double-negative metamaterial (MTM) unit cells. A MTM unit cell is constructed by two open complementary split-ring resonators (OCSRRs) and dual spiral resonators arrangement. The total size of the miniaturized MTM absorber unit cell was 7.4 mm x 7 mm x 2 mm. A spatial array of ab-sorber unit cells (13×3×2) exhibits a maximum absorbance of 93 % at 2.43 GHz.

40. Split-ring resonator loaded miniaturized slot for the slotted wave-guide antenna stiffened structure

Kelvin Nicholson, *Defence Science and Technology Organisation, Australia*
Wayne Rowe, *RMIT University, Australia*
Kamran Ghorbani, *RMIT University, Australia*
Paul Callus, *Defence Science and Technology Organisation, Australia*

The slotted waveguide antenna stiffened structure utilizes conventional hat-stiffeners in composite aircraft panels to implement antenna arrays. However, the slot dimensions are resonant thereby limiting the structural performance of the panel. This paper presents a method that achieves comparable gain from a miniaturized slot by means of a single SRR.

41. Microstrip band-stop filter design from a modified version of the split ring resonator

Juan de Dios Ruiz, *Universidad Politécnica de Cartagena, Spain*
Juan Hinojosa, *Universidad Politécnica de Cartagena, Sapin*

A microstrip resonator is proposed for its use in planar band-stop filters. The structure of the reso-nator is based on a modified version of the split ring resonator (SRR). Thus, the proposed topol-ogy, called open interconnected split ring resonator (OISRR), provides a small electric size which is attractive for compact band-stop filter design. In order to demonstrate the resonance and band-stop characteristics of the proposed OISRR, we have designed and fabricated a filter to produce approximately a band-stop at 2 GHz. Electromagnetic simulation and measurement results be-tween 300 kHz and 3 GHz are presented. A narrow band-stop is reasonably achieved with only one OISRR.

42. ~~A broadband ultra-thin metamaterial absorber based on the magnetic-dielectric substrate~~

Y Q Pang, *National University of Defense Technology of China, China*
H F Cheng, *National University of Defense Technology o*
Y J Zhou, *National University of Defense Technology of*
J Wang, *National University of Defense Technology of China, China*
L K Sun, *National University of Defense Technology of China, China*

This paper was not presented at the conference (No show).

Magnetic-dielectric substrates involving frequency selective surface (FSS) are employed to design broadband ultra-thin metamaterial absorbers.It is shown that the application of proposed magnetic-dielectric substrates allows one to broaden the absorption bandwidth with no extra thickness compared with the conventional dielectric substrates.

43. Negative refractive index characteristics of a uniaxial anisotropic -negative slab

Shotaro Nagai, *Yamaguchi University, Japan*
Atsushi Sanada, *Yamaguchi University, Japan*
Tsunayuki Yamamoto, *Yamaguchi University, Japan*
Hiroshi Kubo, *Yamaguchi University, Japan*

Negative refractive index characteristics of a uniaxial anisotropic slab with a negative component of the permeability tensor are first confirmed experimentally with a two-dimensional array of me-tallic spirals by near-field measurements at 4.5 GHz band. The measured refractive indices take negative values in accordance with numerical prediction.

44. Analysis of magnetic coupling in coaxial CRLH-TLs

Christoph Neumaier, *Spinner GmbH, Germany*
Martin Lorenz, *Spinner GmbH, Germany*
Natalie Spaeth, *Spinner GmbH, Germany*
Kai Numssen, *Spinner GmbH, Germany*
Erwin Biebl, *Technische Universität München, Germany*

The aim of this investigation are strongly coupled coaxial CRLH-TLs. For the proper prediction of the dispersion diagram, multiple coupling coefficients have to be taken into account. In this first step,we use the left-handed branch from full-wave calculations for the extraction of self-inductance, as well as mutual inductances for different configurations of our coaxial setup.

45. Performance enhancement of cut-wire-based metamaterial absorbers

Hiroki Wakatsuchi, *University of Nottingham, UK*
John Paul, *University of Nottingham, UK.*
Stephen Greedy, *University of Nottingham, UK*
Christos Christopoulos, *University of Nottingham, UK*

This study shows how performance of conductively lossy cut-wire-based (CW-based) metamaterial absorbers can be effectively improved with minor geometrical modifications. First, the reason for absorptance reductions found in short CW pairs is explained. Two approaches are then used for the enhancement of the absorbing behaviour.

46. Compact dual-band double-negative metamaterial design based on the combination of electric and magnetic resonators

Theodosios Karamanos, *Aristotle University of Thessaloniki, Greece*
Alexandros Dimitriadis, *Aristotle University of Thessaloniki, Greece*
Nikolaos Kantartzis, *Aristotle University of Thessaloniki, Greece*
Theodoros Tsiboukis, *Aristotle University of Thessaloniki, Greece*

The design of planar, double-negative metamaterials using electric/magnetic resonators is presented. The effective parameters of the new structures are extracted from the reflection/transmission coefficients, via the Kramers-Kronig relations, to solve the branching problem. The proposed idea is applied to the development of new multi-band, enhanced double-negative bandwidth or tunable metamaterials.

47. Optical properties of annular aperture arrays in plasmonic thin films

Joshua F. Einsle, *Queen's University Belfast, UK*
Jean-Sebastien Bouillard, *King's College London, UK*
Wayne Dickson, *King's College London, UK*
Anatoly V. Zayats, *King's College London, UK*

Nanoscale annular hole arrays form plasmonic crystals which allow the optical properties of metal films to produce such important effects such as enhanced transmission, filed enhancement and negative refraction index. In this paper we report on the optical characteristics resulting from variations in the geometrical parameters of annular aperture arrays. We discuss the role of the central pillar in the transmission of light through the crystal. Further investigations are performed on annular aperture arrays fabricated in multilayered thin metal films. Finally, plasmonic crystals with a nonsymmetric annular basis are optically characterized. By offsetting the central pillar, dark modes are accessed via Fano type resonance mechanisms.

48. ~~Anomalous extraordinary transmission in inductive arrays~~

Miguel Beruete, *Public University of Navarro, Spain*
Miguel Navarro-Cia, *Public University of Navarro, Spain*
Vitaliy Lomakin, *University of California-San Diego, USA*
Sergei A. Kuznetsov, *Novosibirsk State University, Russ*
Mario Sorolla, *Public University of Navarro, Spain*

This paper was not presented at the conference (No show).

In this paper we analyze a peak of transmission that can a c slab is added. The study is done by reducing the infinite periodic screen to a single unit cell inserted in an artificial waveguide of mutually perpendicular electric and magnetic walls. The modal distribution of this waveguide admits a direct translation to a simple lumped-elements equivalent circuit. With this procedure the analysis of the structure is straightforward. The results obtained with the equivalent circuited are checked with numerical calculations, with an outstanding agreement.

49. ~~Surface wave metamaterial structures for wakefield experiments~~

Alexei Kanareykin, *Euclid Techlabs LLC, USA*

This paper was not presented at the conference (No show).

Cherenkov radiation generated by a charged particle bun elds) can be used to design novel accelerating structures and b rials are planned to be used to prototype such devices in microwave range. We plan the results to be scaled to THz and optical frequency ranges as well.

50. Differences between metamaterial coupled resonator filters with SRR and NBSRR

Alejandro García-Lampérez, *Universidad Carlos III de Madrid, Spain*
Francisco Aznar-Ballesta, *Universidad Politécnica de Madrid, Spain*
Daniel Segovia-Vargas, *Universidad Carlos III de Madrid, Spain*
Vicente González-Posadas, *Universidad Politécnica de Madrid, Spain*

In this paper we study the differences in the frequency response using coupled SRR or coupled NBSRR in metamaterial band pass filters. Due to the topology, the charge distribution is different and this affects the coupling between adjacent resonators. This study is the starting point for the application of different coupled resonators in the metamaterial band pass filters.

51. Transmission through thick metallic structures with subwavelength annular holes from the enhancement and slow-wave perspectives

A.E. Serebryannikov, *Technische Universitaet Hamburg-Harburg, Germany*

We systematically study transmission through the thick metallic structures with the periodic subwavelength hole arrays, with the aim to show that changing the hole shape from circular to annular leads to the downshifting of the lowest-frequency passband, or the creating of a new one. Structures of three types are compared, for which a strong transmission enhancement and a relatively large group index of refraction can be obtained. They include the periodically stacked arrays of annular holes, the stacked arrays of circular holes with the long circular inserts, and the thick solid metallic screens with arrays of annular holes. In the last case, the basic features will be compared with those of a recently suggested squeezing mechanism.

52. Microwave antennae for broadband spectroscopy on magnonic metamaterials

Thomas Schwarze, *Technische Universität München, Germany*
Rupert Huber, *Technische Universität München, Germany*

Georg Dürr, *Technische Universität München, Germany*
Florian Brandl, *Technische Universität München, Germany*
Sebastian Neusser, *Technische Universität München, Germany*
Klaus Thurner, *Technische Universität München, Germany*
Dirk Grundler, *Technische Universität München, Germany*

We report on a technique allowing us to explore magnonic metamaterials by all electrical broad-band spectroscopy. The spectrometer setup and, in particular, different designs of tailored micro-wave antennae are presented. We show microwave devices which allow us to address both, magnonic crystals and magnonic metamaterials by covering different wave-length regimes. The antennae are operated at frequencies of several GHz to excite the ferromagnetic materials at wave vectors comparable to inelastic light scattering experiments.

53. In-situ generation of THz electromagnetic waves for studies of effective continuous properties of magnonic metamaterials

Rostislav Mikhaylovskiy, *University of Exeter, UK*
Euan Hendry, *University of Exeter, UK*
Volodymyr Kruglyak, *University of Exeter, UK*

We propose a novel technique of metamaterials characterization at THz frequencies based on the use of combined structures consisting of nonlinear crystals and metamaterials. The femtosecond optical pulses induce transient pulses of either nonlinear polarization or nonlinear magnetization that emit THz waves as well as have their own near fields. Both of the latter can be used to probe metamaterials adjacent to nonlinear crystals. In particular, we study the possibility to employ the inverse Faraday effect as a mechanism to generate transient pulses of magnetic field at THz fre-quencies. The field can be coupled to spins in magnonic metamaterials.

54. Measurements method of surface polariton fields distribution through the excitation of resonance in a single planar double split ring

Valery Butylkin, *Kotelnikov V.A. Institute of Radioengineering & Electronics - RAS, Russia*
Galina Kraftmakher, *Kotelnikov V.A. Institute of Radioengineering & Electronics - RAS, Russia*
Sergiy Prosvirnin, *Institute of Radio Astronomy - NASU, Ukraine*

It has been shown experimentally the possibility of using resonance in a single planar double split ring for investigating of field distribution and local polarization properties of surface polaritons supported by planar grating with parallel cut wires.

55. Fabrication techniques towards large area metamaterial devices

Ugo Cataldi, *University of Calabria, Italy*
Roberto Caputo, *University of Calabria, Italy*
Luciano De Sio, *University of Calabria, Italy*
Cesare Paolo Umeton, *University of Calabria, Italy*

Fabrication of samples showing plasmonic properties is a fundamental step towards the realization of devices exhibiting peculiar electromagnetic properties. Theoretical studies demonstrate that assemblies of Gold or Silver nanoparticles can be considered as building blocks (or meta-atoms) of a metamaterial; in this work we illustrate some fabrication techniques that can reveal useful for the realization of this kind of sample. In our experiments we used PDMS materials (and other photo-patternable polymers) in combination with Gold or Silver nanoparticles for realizing micro/nano structured devices. Field of application of such devices can include novel solar applications.

56. Atomic layer deposition for the fabrication of magnonic metamaterials

Rupert Huber, *TU München, Germany*
Thomas Schwarze, *TU München, Germany*
Paul Berberich, *TU München, Germany*
Thomas Rapp, *TU München, Germany*
Dirk Grundler, *TU München, Germany*

Atomic layer deposition (ALD) allows to conformally coat three-dimensionally prepatterned templates relevant for the creation of artificial materials. We explore ALD to prepare thin films of nickel as required for magnetic metamaterials. Using tailored pulse sequences of nickelocene NiCp$_2$ and gaseous precursors in the ALD growth chamber ferromagnetic material is obtained after, both, oxidization and reduction steps performed {em in situ}. For the first time we observe ferromagnetic resonance on ALD-grown Ni. The findings offer novel perspectives for magnonic devices with a three-dimensional surface topology operating in the GHz frequency regime.

57. Manipulation of photonic crystal nanostructures based on nanosphere lithography

Haesung Park, *Yonsei University, South Korea*
Gumin Kang, *Yonsei University, South Korea*
Dongheok Shin, *Yonsei University, South Korea*
Chansung Hwang, *Yonsei University, South Korea*
Seunghwa Baek, *Yonsei University, South Korea*
Minjung Choi, *Yonsei University, South Korea*
Hongmin Yoon, *Korea Advanced Nano Fab Center, South Korea*
Kyoungsik Kim, *Yonsei University, South Korea*

In this paper, we investigate optical absorption characteristic of highly ordered subwavelength 2D nanocone arrays which are fabricated by single-step deep reactive ion etching with nanosphere lithography. By changing reactive gas content, we successfully achieved various sidewall profiles which determine absorption characteristic of 2D nanocone array. Our total absorption measurement results show that the absorption of crystalline Si is improved from 68% to ~95% over a broad wavelength range of 400nm to 900nm with Si nanocone array.

58. Atom optics as alternative tool to plasmonic metamaterials

Pavel Melentiev, *Institute for Spectroscopy, Russia*
Anton Afanasiev, *Institute for Spectroscopy, Russia*
Victor Balykin, *Institute for Spectroscopy, Russia*

We review current status and perspectives of atom optics approaches for creation and characteriza-tion of plasmonic nanostructures manufactured on a substrate. Advantages and limitations of nano-lithography based on atom optics methods and its application in production of nanostructures with plasmonic properties is considered.

59. Gold nanostructures for optical metamaterials using genetically modified tobacco mosaic virus

Mime Kobayashi, *The Cancer Institute of the Japanese Foundation for Cancer Research, Japan*
Kiyotaka Shiba, *The Cancer Institute of the Japanese Foundation for Cancer Research, Japan*
Ichiro Yamashita, *Nara Institute of Science and Technology, Japan*
Yukiharu Uraoka, *Nara Institute of Science and Technology, Japan*
Satoshi Tomita, *Nara Institute of Science and Technology, Japan*

We report here the fabrication of gold nanostructures using genetically modified tobacco mosaic virus (TMV) as a template. 5-nm gold nanoparticles with small standard deviation in size are formed on the TMV fused with titanium (Ti) binding peptide, leading to realization of 3D optical metamaterials.

60. Magnetic and magneto-optical properties of RIB-sputtered ultra-thin Bi-substituted iron-garnet films for MPC applications

Viacheslav Kotov, *V.A. Kotel'nikov Institute of Radio-engineering and Electronics - RAS , Russia*
Vladimir Shavrov, *V.A. Kotel'nikov Institute of Radio-engineering and Electronics - RAS, Russia*
Vladimir Berzhansky, *V.I Vernadsky Taurida National University, Ukraine*
Andrey Karavainikov, *V.I Vernadsky Taurida National University, Ukraine*
Anatoly Prokopov, *V.I Vernadsky Taurida National University, Ukraine*
Alexander Shaposhnikov, *V.I Vernadsky Taurida National University, Ukraine*
Dmitry Balabanov, *Moscow Institute of Physics and Technology, Russia*
Vladimir Burkov, *Moscow Institute of Physics and Technology, Russia*

Magnetic properties, Faraday rotation (FR) and magnetic circular dichroism (MCD) effect of reactive ion beam sputtered (RIBS) ultra-thin Bi2.8Y0.2Fe5O12 films on Gd3Ga5O12 substrate for magnetic photonic crystal (MPC) applications were investigated. It was found the fine structure of substrate - film transitional layer including 5 nm nonmagnetic at room temperature sublayer, 3.5 nm magnetic sublayer of sharp changing composition (BiGdY)3(FeGa)5O12 with negative sign of MCD, and 2.5 nm magnetic sublayer with positive sign of MCD where the composition changed from (BiGdY)3Fe3.75Ga1.35O12 to Bi2.8Y0.2Fe5O12 followed by main part of film with nominal composition Bi2.8Y0.2Fe5O12.

61. 3-dimensional arrays of plasmonic nanospheres fabricated by Langmuir-Blodgett technique

Ludivine Malassis, *Universite Bordeaux, France*
Beatrice Agricole, *CNRS, France*
Philippe Barois, *CNRS, France*

In this paper we present a self-assembly technique that enables the fabrication of dense 3-dimensional lattices of plasmonic nanoparticles of sizes significantly shorter than the wavelength of visible light (i.e. lower than 100 nm). Compact monolayers of nanoparticles are first formed at the surface of water (Langmuir films) and transferred on to appropriate substrates (Langmuir-Blodgett layers). Bulk 3D materials are obtained over large areas (typically square centimetres) by successive transfer of identical monolayers. The distance between the metallic nanoparticles is ac-curately controlled by the thickness of a dielectric shall surrounding them. The quality of the final material is evidenced by scanning electron microscopy. It depends strongly on the surface chemis-try of the nanoparticles. Some optical properties of the fabricated materials are reported.

62. Aperiodic arrays of metal nanostructures with controllable adhesion for applications in metamaterials

Victor Ovchinnikov, *Aalto University, Finland*
Andriy Shevchenko, *Aalto University, Finland*

A method for fabrication of metal nanostructures with controllable adhesion on large-area substrates. Arrays of gold and silver nanostructures with feature size down to 15 nm were produced with this method. The measured optical spectra show that the nanostructures with and without an adhesion sublayer exhibit different optical responses.

63. Fabrication of metallic structures via multi-photon polymerization

Gabija Bickauskaite, *Foundation for Research and Technology Hellas, Greece*
Nikos Vasilantonakis, *Foundation for Research and Technology Hellas, Greece*
Konstantina Terzaki, *Foundation for Research and Technology Hellas, Greece*
Maria Kafesaki, *Foundation for Research and Technology Hellas, Greece*
Maria Vamvakaki, *Foundation for Research and Technology Hellas, Greece*
Maria Farsari, *Foundation for Research and Technology Hellas, Greece*

We present our research into the modeling and fabrication of three-dimensional (3D) nanostructures by direct laser writing, using an organic-inorganic hybrid polymer that can be selectively covered with metal. This material exhibits low shrinkage when structuring, metal binding affinity and ohmic conductivity when covered with metal, allowing the fabrication of three-dimensional conducting nanostructures.

64. Plasmonic properties of light sculptured structures including liquid crystals doped with metal nanoparticles

Luciano De Sio, *University of Calabria, Italy*
Ugo Cataldi, *University of Calabria, Italy*
Roberto Caputo, *University of Calabria, Italy*
Cesare Paolo Umeton, *University of Calabria, Italy*

Polymeric templates favour the self-organisation of liquid crystal materials doped with metallic nano-particles. A first spectroscopical characterization of the fabricated samples is reported. The plasmonic response obtained from the structures is polarization sensitive and can be somehow tuned by applying external fields. The research is oriented to the fabrication of devices with meta-material properties.

Special Session

Superconducting Metamaterials and Plasmonics

11:20 - 13:00 ▸ Room Barcelona B

Superconducting metamaterials have recently emerged to offer a radically new paradigm for sensing, data processing and information technologies. They will provide a dramatic reduction of losses, accompanied by access to the extreme sensitivity of the superconducting state to external stimuli and the exceptional nonlinearity of superconductors enabling low energy switching. Negative dielectric constants and dominant kinetic resistance also make superconductors intriguing plasmonic media. Moreover, a fundamental change in the nature of information carriers is produced by superconductivity: in some implementations it will be possible to switch from the classical excitations of conventional plasmonic and metamaterial devices to quantum excitations underpinned by flux quantization and quantum interference effects.

Organizer ▸ **Nikolay Zheludev**, *University of Southampton, UK*

Session Chair ▸ **Nikolay Zheludev**, *University of Southampton, UK*

11:20 - 11:40 **Artificial atoms and quantum metamaterials: Watching a Schrödinger's cat** Invited

Alexandre Zagoskin, *Loughborough University, UK*

The current progress in design, fabrication and control of mesoscopic solid-state qubits provides tempting opportunities for the realization of quantum metamaterials – controllably quantum coherent artificial media. We discuss their possible technological applications and - more importantly - their significance in the context of a direct probing of the quantum-classical boundary.

11:40 - 12:00 **Nonlinear modes and wave transmission in SQUID-based metamaterials** Invited

Giorgos P. Tsironis, *University of Crete, Greece*
N. Lazarides, *University of Crete, Greece*

A lattice of rf-driven superconducting quantum interference devices forms a metamaterial that may respond resonantly with a positive or negative effective magnetic permeability. When the lattice is driven in a fully nonlinear regime, nonlinear modes may be generated as intrinsically localized modes. Transmission studies show the appearance of multistability and chaos.

12:00 - 12:20 **Realising tunable, quantum and low-loss metamaterials and plasmonics with superconductors** Invited

Andrew Roger Buckingham, *University of Southampton, UK*
A. Tsiatmas, *University of Southampton, UK*
V. Savinov, *University of Southampton, UK*
V. A. Fedotov, *University of Southampton, UK*
P. A. J. De Groot, *University of Southampton, UK*
N. I. Zheludev, *University of Southampton, UK*

The use of superconductors over normal metals offers a significant reduction in Joule losses, providing interesting opportunities for metamaterials and terahertz plasmonics. Superconducting Josephson junction metamaterials and other metamaterial quantum interference devices are inherently nonlinear, making them promising candidates for use in sensor, switching and quantum information processing applications.

12:20 - 12:40 **Plasmonic behavior of deep sub-wavelength superconducting RF metamaterials** Invited

Cihan Kurter, *University of Maryland, USA*
Gennady Shvets, *University of Texas at Austin, USA*
Steven M. Anlage, *University of Maryland, USA*

We have designed and built ultra-small RF metamaterials with magnetically active spiral elements made of superconducting Nb films. RF transmission measurements on single, 1-D and 2-D arrays of spirals show robust magnetic response when Nb is in the superconducting state. Numerical simulations capture the main features of the experimental spectra.

12:40 - 13:00 **Superconducting artificial atoms as building blocks for quantum metamaterials** Invited

Alexey V. Ustinov, *University of Karlsruhe, Germany*

This presentation will review ideas and first experiments to develop quantum metamaterials comprised of networks of superconducting elements. The design flexibility of superconducting meta-atoms with Josephson junctions allows for utilizing small sizes down to the nanoscale while maintaining very low losses and frequency tunability.

13:00 - 14:30 Lunch ▸ La Cantina de l'Estació, Hotel Barceló Sants

Wednesday, 12th October

Superlenses

11:20 - 13:00 ▸ Room Sants-Montjuïc

Session Chair ▸ **Ross McPhedran**, *CUDOS, University of Sydney, Australia*

11:20 - 12:00 **Perfect lens based on ideal phase conjugating surfaces** Keynote

Stanislav Maslovski, *Universidade de Coimbra, Portugal*
Yuriy Rapoport, *Aalto University School of Electrical Engineering, Finland*
Sergei Tretyakov, *Aalto University School of Electrical Engineering, Finland*

It is known that two parallel sheets with the complex-conjugation transition condition act as a perfect lens, mimicking all the properties of a slab filled with an isotropic medium with permittivity and permeability both equal to -1. In this presentation we will discuss the physical meaning of the phase conjugating boundary conditions and outline possible approaches to practical realization of this superlens.

12:00 - 12:30 **Surface roughness of Ag film on the optical properties of metal-dielectric-metal film and super-resolution imaging** Invited

H Liu, *Institute of Materials Research and Engineering, Singapore*
B Wang, *Institute of Materials Research and Engineering, Singapore*
Eunice S P Leong, *Institute of Materials Research and Engineering, Singapore*
L Ke, *Institute of Materials Research and Engineering, Singapore*
J Deng, *Institute of Materials Research and Engineering, Singapore*
C. C. Chum, *Institute of Materials Research and Engineering, Singapore*
M. S. Zhang, *Data Storage Institute , Singapore*
L Shen, *Institute of Materials Research and Engineering, Singapore*
G. Y. Si, *National University of Singapore, Singapore*
Y. J. Liu, *Institute of Materials Research and Engineering, Singapore*
A Danner, *National University of Singapore, Singapore*
S. A. Maier, *Imperial College London, UK*
J. H. Teng, *Institute of Materials Research and Engineering, Singapore*

In this paper, we will discuss the seed layer assisted smooth Ag film deposition and the effect of the surface roughness on the surface plasmon resonance in thin Ag film, the reflectance spectra of Ag/MF2/Ag structure and the super-resolution imaging by using a Ag superlens. Ni and Ge are found to be the effective surfactant in forming smooth Ag film but Ag/Ni showed the most opti-mistic surface plasmon resonance. The Ag films deposited with and without seed layer were ap-plied to the near field superlens application. High image contrast and sub-50nm resolution imaging were demonstrated. The experimental results obtained on different Ag layers superlens agree well with the theoretical predications. The effect of surface morphology on the optical properties in metal-dielectric-metal (MDM) thin film was investigated and an empirical relationship was found between the optical properties and the Ag film structural properties.

12:30 - 13:00 **Proxiton-polaritons on metamaterial slabs of coupled split rings** Invited

Ekaterina Shamonina, *Imperial College London, UK*

In split-ring metamaterials, inter-element interactions result in propagation of magnetoinductive waves. These slow waves can couple to and influence the propagation of electromagnetic waves forming so-called proxiton-polaritons, similar to plasmon-polaritons in a bulk metal. Using our effective-medium model accounting for proxitons-polaritons, we are able to design SRR-based near field manipulating devices for arbitrary polarisation, in full analogy to a silver slab operating as a near-perfect lens for TM polarised light.

13:00 - 14:30 Lunch ▸ La Cantina de l'Estació, Hotel Barceló Sants

Planar Metamaterials 2

11:20 - 13:00 ▸ Room Sarrià-St. Gervasi

Session Chair ▸ **Jason Valentine**, *Vanderbilt University, USA*

11:20 - 11:50 **Non-reciprocal gyrotropic semiconductor-based metasurface not requiring magnetic bias** Invited

Dimitrios Sounas, *Ecole Polytechnique de Montreal, Canada*
Christophe Caloz, *Ecole Polytechnique de Montreal, Canada*

A non-reciprocal metasurface with gyrotropic properties similar to those of ferrites is presented. The constitutive element of the metasurface is a pair of parallel rings loaded with a unidirectional semiconductor-based lumped element. Contrary to ferrites, the metasurface does not require any biasing magnetic field. Full-wave simulations show that the metasurface rotates the polarization of a normally incident plane wave.

11:50 - 12:20 **Apertureless near-field optical microscopy investigations of long-range indirect interactions in unordered metamaterials** Invited

Ralf Vogelgesang, *Max-Planck-Institut für Festkörperforschung, Germany*
Warawut Khunsin, *Max-Planck-Institut für Festkörperforschung, Germany*
Jens Dorfmüller, *Max-Planck-Institut für Festkörperforschung, Germany*
Moritz Eßlinger, *Max-Planck-Institut für Festkörperforschung, Germany*
Carsten Rockstuhl, *Friedrich-Schiller-Universität Jena, Germany*
Falk Lederer, *Friedrich-Schiller-Universität Jena, Germany*
Björn Brian, *Chalmers University of Technology, Sweden*
Alexandre Dmitriev, *Chalmers University of Technology, Sweden*
Klaus Kern, *Max-Planck-Institut für Festkörperforschung, Germany*

Statistical near-field optical microscopy analysis of unordered metamaterials reveals long-range interactions between distant “metaatoms”, not observed with far-field optical spectroscopy. The system is characterized by a dense interaction matrix, in contrast to the sparse hopping-type interactions encountered in solid state materials.

12:20 - 12:40 **Metasurfaces with intertwined conductor patterns** Oral

Andrea Vallecchi, *University of Siena, Italy*
Alexander G. Schuchinsky, *Queen’s University Belfast, UK*

Metasurfaces comprised of interweaved periodic conductor patterns providing highly stable angular reflection and transmittance response with low cross-polarisation are explored. Two layouts of intertwined conductor patterns comprised of quadrifilar spirals and modified Brigid’s crosses are examined. Peculiar features enabled by the proposed interweaved array patterns and their potential for applications as metasurfaces are discussed.

12:40 - 13:00 **Asymmetric transmission in planar chiral metamaterials: microscopic explanation** Oral

Andrey Novitsky, *Technical University of Denmark, Denmark*
Sergei Zhukovsky, *University of Toronto, Canada*

Lorentz electron theory is a powerful approach for description of macroscopic parameters of a medium based on microscopic characteristics of the individual electron. For a planar array of chiral metallic split rings, we determine the averaged electron’s characteristics in a sprit ring and apply them to derive the permittivity tensor of the homogenized medium. The effective material parameters obtained describe anisotropic dichroic material, where electromagnetic waves are governed by enantiomeric and directional asymmetry — the signature property of planar chiral metamaterials.

13:00 - 14:30 Lunch ▸ La Cantina de l’Estació, Hotel Barceló Sants

Plasmonics Metamaterials 3

14:30 - 16:10 ▸ Room Barcelona B

Session Chair ▸ **Javier Garcia de Abajo**, *CSIC, Spain*

14:30 - 15:00 **Surface plasmon optics: from polarization control to negative refraction** Invited

Cyriaque Genet, *ISIS CNRS, France*
Thomas Ebbesen, *ISIS CNRS, France*

Tailoring surface plasmons by controlling the design of metal surfaces at the nanometer scale has allowed addressing the intimate relation between structures and optical properties of coupled light. In this context, we will show recent experimental results that demonstrate this link through structure designs and surface plasmon manipulations.

15:00 - 15:20 ~~**Plasmonic metamaterials utilising optical gain media**~~ ~~Oral~~

John McPhillips, *Queen's University Belfast, UK*
Wayne Dickson, *King's College London, UK*
Stephane Kena-Cohen, *Imperial College London, UK*
Daniel O'Connor, *King's College London, UK*
Antony Murphy, *Queen's University Belfast, UK*
J Levitt, *King's College London, UK*
K Suhling, *King's College London, UK*
Stephen Beckett, *Queen's University Belfast, UK*
Paul Stavrinou, *Imperial College London, UK*
Donal Bradley, *Imperial College London, UK*
Stefan Maier, *Imperial College London, UK*
Robert Pollard, *Queen's University Belfast, UK*
Anatoly Zayats, *King's College London, UK*

This paper was not presented at the conference (Withdrawal).

Metamaterials consisting of substrate supported gold nanorod arrays (GNRA) have been fabricated. We present investigations of plasmon-polariton loss compensation in GNRAs via a two-colour pump-probe arrangement using a guest-host gain medium, based on Forster energy transfer from a green host tris(8-hydroxy-quinolinato)aluminum (Alq3) to a red dopant 4-dicyanomethylene-2-methyl-6-(p-dimethyl-aminostyryl)- 4H-pyran (DCM).

15:20 – 15:40 **Angular tuning of plasmonic inter-particle coupling probed by spectroscopic ellipsometry** Oral

Kristof Lodewijks, *Katholieke Universiteit Leuven, Belgium*
Willem Van Roy, *IMEC, Belgium*
Gustaaf Borghs, *IMEC, Belgium*
Pol Van Dorpe, *IMEC, Belgium*

Localized surface plasmon resonances in metallic nanoparticles are known to be really sensitive to the polarization state of the incident electromagnetic wave which excites them. In this paper, we investigate the polarization dependence of localized surface plasmon resonances in gold nanorings on top of a continuous gold layer and a dielectric spacer. By scanning the incident angle in spectroscopic ellipsometry measurements, we tune the inter-particle coupling of the localized plasmon resonances.

16:10 - 16:30 Coffee break + **Poster Session 2 (continuation)** ▸ Room Barcelona A

Transformation Electromagnetics and Cloaking 1

14:30 - 16:10 ▸ Room Sants-Montjuïc

Session Chair ▸ Andrea Alu, The University of Texas at Austin, USA

14:30 - 15:00 **Hidden in plain sight** Invited

Baile Zhang, *Singapore-MIT Alliance for Research and Technology, Singapore*
Yuan Luo, *Massachusetts Institute of Technology, USA*
George Barbastathis, *Massachusetts Institute of Technology, USA*

Invisibility cloaking has attracted a lot of interest from both the general public and the scientific community because of its possible realization. Here we discuss the first realization of invisibility cloaking of a macroscopic object in visible light. The underlining mechanism is based on the incorporation of transformation optics in a conventional optical lens fabrication. A common anisotropic optical material -calcite- is used. This technique may open up the possibility of taking more transformation optics devices from concepts into practical applications.

15:00 - 15:30 **Macroscopic invisibility cloak of visible light** Invited

Shuang Zhang, *University of Birmingham, UK*
Xianzhong Chen, *University of Birmingham, UK*
Yu Luo, *Imperial College London, UK*
John Pendry, *Imperial College London, UK*
Jingjing Zhang, *Technical University of Denmark, Denmark*
Kyle Jiang, *University of Birmingham, UK*

We report the first realization of macroscopic volumetric invisibility cloak constructed from natural birefringent crystals. The cloak operates at visible frequencies, and is capable of hiding three-dimensional objects of the scale of centimetres and millimetres (which is 3-4 orders of magnitudes larger than the optical wavelengths in all three dimensions). Our work opens avenues for future applications with macroscopic cloaking devices.

15:30 - 15:50 **Field-based transformation optics** Oral

Andrey Novitsky, *Technical University of Denmark, Denmark*

Instead of common definition of the transformation-optics devices via the coordinate transformation we offer the approach founded on boundary conditions for the fields. We demonstrate the effectiveness of the approach by two examples: two-shell cloak and concentrator of electric field. We believe that the field-based approach is quite important for effective field control.

15:50 - 16:10 **Approaches to transformation optical devices in 3D** Oral

Nathan Landy, *Duke University, USA*
David Smith, *Duke University, USA*

We present several approaches to realizing Transformation Optical designs in three dimensions. We employ quasi-conformal transformations and chiral inclusions to mitigate the task of creating these devices. We verify the performance of each design via numerical ray-tracing and finite ele-ment simulation of a flattened Luneburg lens and an electromagnetic cloak.

16:10 - 16:30 Coffee break + **Poster Session 2 (continuation)** ▸ Room Barcelona A

Wednesday, 12th October

Theory of Metamaterials 2

14:30 - 16:10 ▸ Room Sarrià-Sant Gervasi

Session Chair ▸ **Raj Mittra**, *Penn State University, USA*

14:30 - 15:00 **Toroidal dipolar response in metamaterials: illusion or reality** Invited

Vassili Fedotov, *University of Southampton, UK*
Thomas Kaelberer, *University of Southampton, UK*
Nikitas Papasimakis, *University of Southampton, UK*
Vassili Savinov, *University of Southampton, UK*
Alexandra Rogacheva, *University of Southampton, UK*
Nikolay Zheludev, *University of Southampton, UK*

We will give a review of our recent and ongoing work in the filed of toroidal electrodynamics, where we have successfully been able to apply metamaterial approach and develop electromagnetic metamaterials the resonant response of which cannot be attributed to the excitation of conventional magnetic or charge multipoles and can only be explained by the existence of the induced toroidal dipole.

15:00 - 15:30 **Tensor circuit networks for transformation optics** Invited

Anthony Grbic, *University of Michigan, USA*
Gurkan Gok, *University of Michigan, USA*

In this presentation, we will describe transmission-line based metamaterials that can possess tensor con-stitutive parameters. The utility of tensor analysis in the design of such metamaterials will be shown. In addition, various microwave devices implemented using tensor transmission-line metamaterials will be demonstrated.

15:30 - 15:50 **Microscopic expression of chiral susceptibilities** Oral

Kikuo Cho, *Osaka University, Japan*

A first-principles derivation of susceptibilities including chiral ones is presented, and its relevance to the advanced study of metematerials is discussed. The quantum mechanical expression of the susceptibilities requires certain restrictions to the modeling in metamaterials study.

15:50 - 16:10 **Sum rules and physical limitations for passive metamaterials** Oral

Mats Gustafsson, *Lund University, Sweden*
Daniel Sjoberg, *Lund University, Sweden*

Bandwidth is an important parameter in many metamaterial applications. It has been shown that Herglotz functions and sum rules offer a powerful methodology to analyze the trade-off between bandwidth and design parameters. Here, this approach is described for the temporal dispersion of constitutive relations and high-impedance surfaces.

16:10 - 16:30 Coffee break + **Poster Session 2 (continuation)** ▸ Room Barcelona A

Plasmons

16:30 - 17:30 ▸ Room Barcelona B

Session Chair ▸ **Anatoly Zayats**, *King's College London, UK*

16:30 - 16:50 **Magneto-optical Kerr effect in magnetoplasmonic crystals** Oral

Andrey Grunin, *Lomonosov Moscow State University, Russia*
Nina Sapoletova, *Lomonosov Moscow State University, Russia*
Kirill Napolskii, *Lomonosov Moscow State University, Russia*
Andrey Eliseev, *Lomonosov Moscow State University, Russia*
Andrey Fedyanin, *Lomonosov Moscow State University, Russsia*

Strong modification of transversal magneto-optical Kerr effect (TKE) is experimentally observed in 1D and 2D magnetoplasmonic crystals due to resonant excitation of surface plasmon-polaritons. In one-dimensional structures the SPP excitation leads to appearance of Fano-type resonant features in the TKE spectrum.

16:50 - 17:10 **Channelling plasmons in nanostructured superconducting waveguides** Oral

Anagnostis Tsiatmas, *University of Southampton, UK*
A. Roger Buckingham, *University of Southampton, UK*
Vassili A. Fedotov, *University of Southampton, UK*
F. Javier Garcia de Abajo, *Instituto de Optica - CSIC, Spain*
Nikolay I. Zheludev, *University of Southampton, UK*

We show that superconductors are intrinsic low-loss plasmonic media able to support highly confined plasmonic excitations. We identify several promising superconducting waveguide configurations that provide nanoscale localization of plasmons at frequencies up to few THz and support their dispersion-less propagation for tens of centimetres.

17:10 - 17:30 **Angle resolved cathodoluminescence spectroscopy on plasmonic nanoantennas** Oral

Toon Coenen, *FOM institute AMOLF, Netherlands*
Ernst Jan Vesseur, *FOM institute AMOLF, Netherlands*
Femius Koenderink, *FOM institute AMOLF, Netherlands*
Albert Polman, *FOM institute AMOLF, Netherlands*

We present both radiation patterns and emission spectra for two antenna geometries, measured using a novel cathodoluminescence spectroscopy technique. We investigate the emission of a plasmonic Yagi uda antenna consisting of five gold nanoparticles and a plasmonic gold ridge resonator. For both geometries we find evidence for directional emission of light that depends strongly on the excitation position and emission wavelength.

17:30 - 20:30 **Visit to Montserrat** and **Conference Banquet**

Wednesday, 12th October

Planar Metamaterials 3

16:30 - 17:30

Room Sants-Montjuïc

Session Chair ▸ Ricardo Marques, Universidad de Sevilla, Spain

16:30 - 16:50 **Metamaterials as artificial electromagnetic boundaries in experimental geometries** Oral

Alastair Hibbins, *University of Exeter, UK*
Toby Basey-Fisher, *Imperial College London, UK*
Elizabeth Brock, *University of Exeter, UK*
James Edmunds, *University of Exeter, UK*
Euan Hendry, *University of Exeter, UK*
Roy Sambles, *University of Exeter, UK*
Ian Youngs, *Dstl, UK*

We present a summary of work being undertaken at Exeter associated with the use of metamaterials as artificial boundary conditions. Using experimental microwave techniques, and numerical and analytical modelling, we explore geometries including those that facilitate sub-wavelength confinement of surface waves and propagation in waveguides beyond their conventional frequency range.

16:50 - 17:10 **Realization of D'B' boundary in terms of metamaterial** Oral

Ismo Lindell, *Aalto University, Finland*
Ari Sihvola, *Aalto University, Finland*
Luzi Bergamin, *KB&P GmbH, Switzerland*
Alberto Favaro, *Imperial College London, UK*

In this paper we aim to find a realization for the D'B' boundary conditions requiring vanishing of the normal derivatives of the normal components of the D and B fields. Since the realization of the DB boundary requiring vanishing of the normal components of the D and B fields is known, it is shown that the realization of the D'B' boundary can be based on a layer of suitable metamaterial which makes the transformation from DB to D'B' boundary.

17:10 - 17:30 **Negative refraction by a two-sided mushroom structure with loaded vias** Oral

Chandra S. R. Kaipa, *University of Mississippi, USA*
Alexander B. Yakovlev, *University of Mississippi, USA*
Mario G. Silveirinha, *Universidade de Coimbra Polo II, Portugal*
Stanislav I. Maslovski, *Universidade de Coimbra Polo II, Portugal*

In this paper we show that the two-sided mushroom structure with inductive loadings (as lumped loads) at the junction of vias and metallic patches exhibits negative refraction. The transmission properties are analysed based on the nonlocal homogenization model for the mushroom structure with a generalized additional boundary condition for loaded vias. It is shown that it is possible to control the negative refraction angle by varying the inductive loads.

17:30 - 20:30 **Visit to Montserrat** and **Conference Banquet**

Applications of Microwave Metamaterials

16:30 - 17:30 ▸ Room Sarrià-Sant Gervasi

Session Chair ▸ **Manuel Freire**, *University of Seville, Spain*

16:30 - 16:50 **Dual-band printed dipole antenna loaded with open complementary split ring resonators (OCSRRs)** Oral

Francisco Javier Herraiz-Martínez, *Universitat Autònoma de Barcelona, Spain*
Jordi Bonache, *Universitat Autònoma de Barcelona, Spain*
Ferran Paredes, *Universitat Autònoma de Barcelona, Spain*
Gerard Zamora, *Universitat Autònoma de Barcelona, Spain*
Ferran Martín, *Universitat Autònoma de Barcelona, Spain*

A printed dipole antenna loaded with open complementary split ring resonators (OCSRRs) is proposed. The integration of these particles inside the dipole structure provides a dual-band performance. Furthermore, a dipolar-like radiation pattern is obtained at both working frequency bands. A prototype has been designed, manufactured and measured, showing good performance.

16:50 - 17:10 **Active tunable 1D periodic leaky wave antenna** Oral

Dushmantha Thalakotuna, *Macquarie University, Australia*
Ladislau Matekovits, *Politecnico di Torino, Italy*
Karu Esselle, *Macquarie University, Australia*
Stuart Hay, *Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia*

In this paper a novel periodic leaky wave antenna is introduced. Active devices inside the antenna give an additional degree of freedom to control the periodicity of the structure and thereby control the radiation angle.

17:10 - 17:30 **Efficiency limit of long-distance magneto-inductive power transfer** Oral

Richard Syms, *Imperial College London, UK*
Timmy Floume, *Imperial College London, UK*

The problem of optimising long-distance power delivery via magneto-inductive waveguides is considered, and limits to efficiency are derived. Arrangements for impedance matching are proposed, and it is shown that efficiency can be improved by operation off-resonance, when losses are minimum, using broadband matching transformers.

17:30 - 20:30 **Visit to Montserrat** and **Conference Banquet**

Thursday, 13th October

Antenna Applications

08:20 - 10:00 ▸ Room Barcelona B

Session Chair ▸ **Richard W. Ziolkowski**, *University of Arizona, USA*

08:20 - 08:50 **Some new strategies for practical realization of metamaterial-based devices** Invited

Raj Mittra, *Pennsylvania State University, USA; King Fahd University of Petroleum and Minerals, Saudi Arabia*

In this paper, we discuss some new strategies for designing devices such as lenses, cloaks, near-field imaging systems, etc., that are based on the use of dispersion-engineered materials aka Metamaterials (MTMs). Historically, the design of these devices has largely been based on the use of double-negative (DNG) type of materials that have been typically found to be highly dispersive, narrowband, angular-sensitive and polarization-dependent. Techniques for mitigating these problems with DNG materials are being actively researched, though successes have been rather limited to-date. In this paper, we look at some alternate strategies from a practioner's viewpoint that lead to the realization of MTM-devices which suffer little from the drawbacks alluded to above. Some illustrative examples of devices fabricated by using these new strategies are included in the paper.

08:50 - 09:20 **Circularly polarized metasurfing antennas** Invited

Gabriele Minatti, *University of Siena, Italy*
Francesco Caminita, *University of Siena, Italy*
Patrizio De Vita, *Ingegneria dei Sistemi - IDS, Italy*
Massimiliano Casaletti, *University of Siena, Italy*
Stefano Maci, *University of Siena, Italy*

We present a planar circularly polarized antenna based on transformation of a surface wave into a leaky wave. Such transformation is obtained by modulating the surface reactance using a dense texture of square sub-wavelength metal patches printed on a grounded dielectric slab. Experimental results are announced for the oral session.

09:20 - 09:40 **Nanoantenna-enhanced gas sensing in a single tailored nanofocus** Oral

Na Liu, *University of California Berkeley, USA*
Minglee Tang, *University of California Berkeley, USA*
Mario Hentschel, *Universität Stuttgart, Germany*
Harald Giessen, *Universität Stuttgart, Germany*
A. Paul Alivisatos, *University of California Berkeley, USA*

We demonstrate antenna-enhanced hydrogen sensing at the single-particle level. We place a single palladium nanoparticle near the tip region of a gold nanoantenna and detect the changing optical properties of the system upon hydrogen exposure.

09:40 - 10:00 **Design and analysis of dual-band EBG resonator antennas using millimetre-wave EBG structures for improved directivity and radiation bandwidth** Oral

Basit Ali Zeb, *Macquarie University, Australia*
Karu Esselle, *Macquarie University, Australia*

The design of a millimetre wave dual-band EBG resonator antenna is presented. Multiple source excitations are used to increase the antenna directivity and 3-dB radiation bandwidth in two frequency bands. By properly spacing the array feed elements, high directivity and low side-lobe levels are achieved without the appearance of grating lobes.out the appearance of grating lobes.

10:00 - 11:20 Coffee break + **Poster Session 3** ▸ Room Barcelona A

Theory of Superlensing

08:20 - 10:00 ▸ Room Sants-Montjuïc

Session Chair ▸ **Falk Lederer**, *Friedrich-Schiller-Universität Jena, Germany*

08:20 - 08:50 **Super-oscillating super-lens: imaging beyond the nearfield** Invited

M. Mazilu, *University of St Andrews, UK*
S. Kosmeier, *University of St Andrews, UK*
E. T. F. Rogers, *University of Southampton, UK*
K. Dholakia, *University of St Andrews, UK*
N.I. Zheludev, *University of Southampton, UK*

We demonstrate a new subwavlength resolution imaging paradigm that is capable of imaging objects placed beyond the nearfield of the imaging system.

08:50 - 09:20 **Metamaterial composites and super-resolution** Invited

Ross McPhedran, *University of Sydney, Australia*
Johan Helsing, *Lund University, Sweden*
Graeme Milton, *University of Utah, USA*

We consider the optical properties of composites containing metamaterial inclusions in a normal material matrix, with the scale size of inclusions much finer than the wavelength. We consider the case where these inclusions have sharp corners, and use analytic results of Hetherington and Thorpe to argue that it is then possible to deduce the shape of the corner (its included angle) by spectral measurements on absorptance of such composites, irrespective of the size of the inclusions with respect to the wavelength. We support these analytic arguments by highly accurate numerical results for the effective permittivity function of such composites, as a function of the permittivity ratio of inclusions to matrix, which show that this function has a continuous spectral component with limits independent of area fraction of inclusions, and the same for square and staggered square lattices.

09:20 - 09:40 **Scattering lens resolves nanostructure** Oral

Elbert G. van Putten, *University of Twente, Netherlands*
Duygu Akbulut, *University of Twente, Netherlands*
Jacopo Bertolotti, *University of Florence, Italy*
Ad Lagendijk, *FOM insitituut AMOLF, Netherlands*
Willem L. Vos, *University of Twente, Netherlands*
Allard P. Mosk, *University of Twente, Netherlands*

We demonstrate high-resolution focusing of visible light by a combination of scattering and active control of the incident wavefront. The resolution of the resulting lens is better than 100 nm.

09:40 - 10:00 ~~**Superdiffusion, focalisation and spatial filtering in 2D gain/loss periodic spatially modulated artificial materials**~~ ~~Oral~~

Muriel Botey, *Universitat Politècnica de Catalunya, Spain*
Ramon Herrero, *Universitat Politècnica de Catalunya, Spain*
Nikhil P Kumar, *Universitat Politècnica de Catalunya, Spain*
Ramon Vilaseca, *Universitat Politècnica de Catalunya, S*
Kestutis Staliunas, *Universitat Politècnica de Catalunya,*

This paper was not presented at the conference (No show).

We analyze light propagation through materials with a 2D periodical modulation of gain and loss. We predict mode locked states, superluminar regimes, non diffractive propagation of beams and super-iffusion due to angular gain dependence which allows simultaneous management of amplification and spatial frequency filtering, obtaining amplified, cleaned and focalized beams.

10:00 - 11:20 Coffee break + **Poster Session 3** ▸ Room Barcelona A

Thursday, 13th October

Extraordinary Transmission and Gratings

08:20 - 10:00 ▸ Room Sarrià-Sant Gervasi

Session Chair ▸ **Miguel Beruete**, *Universidad Publica de Navarra, Spain*

08:20 - 08:40 **Extraordinary transmission frequency tuning based on meander hole arrays** Oral

Victor Torres, *Public University of Navarre, Spain*
Miguel Beruete, *Public University of Navarre, Spain*
Miguel Navarro-Cía, *Public University of Navarre, Spain*
Francisco Falcone, *Public University of Navarre, Spain*
Mario Sorolla, *Public University of Navarre, Spain*

In this work, we present some modifications in the topology of typical subwavelength hole arrays to tune the frequency of the resonant peak associated to extraordinary transmission phenomena. By substituting the straight line between holes by a meander line it is possible to move the extraordinary transmission peak downward which also brings about an enlargement of the fractional bandwidth. This phenomenon is theoretically analyzed from an equivalent circuit perspective and demonstrated experimentally at the millimetre-wave regime. A wide range of applications may benefit from this, since now the extraordinary transmission happens far away from the onset of higher order diffracted modes.

08:40 - 09:00 **Electromagnetic tunneling in heterostructures containing single-negative and double-positive media** Oral

Giuseppe Castaldi, *University of Sannio, Italy*
Vincenzo Galdi, *University of Sannio, Italy*
Andrea Alú, *University of Texas at Austin, USA*
Nader Engheta, *University of Pennsylvania, USA*

In this paper, we deal with electromagnetic tunneling phenomena that can take place in certain classes of heterostructures composed of a single-negative slab suitably paired with one or two double-positive (possibly anisotropic) layers. In this framework, we also explore the sensitivity with respect to frequency and direction of the impinging wave, taking into account material dispersion and losses.

09:00 - 09:20 **Closed-form analysis of electrically thick diffraction gratings with internal structure** Oral

Francisco Medina, *University of Seville, Spain*
Guillaume Bigel, *Institut Polytechnique de Grenoble, France*
Francisco Mesa, *University of Seville, Spain*
Raul Rodriguez-Berral, *University of Seville, Spain*

This contribution reports on a very accurate analytical model for 1-D arrays of slits in thick screens having internal structure. The model is based on circuit-theory arguments. Full-wave numerical data and analytical results show a very good agreement up to the onset of the first diffraction order.

09:20 - 09:40 **Brewster angle for plasmonic gratings** Oral

Christos Argyropoulos, *University of Texas at Austin, USA*
Andrea Alù, *University of Texas at Austin, USA*
Giuseppe D'Aguanno, *AEgis Tech., USA*
Nadia Mattiucci, *AEgis Tech., USA*
Mark Bloemer, *Charles M. Bowden Facility, USA*

In this paper, we analyze the transmission properties of metallic gratings at optical frequencies. In particular, we show that an inherently ultra-broadband tunneling mechanism may be obtained based on impedance matching between the guided modes supported by ultranarrow slits and free-space TM plane waves impinging at an oblique angle. This phenomenon is the analogous of the well-known Brewster transmission for dielectric slabs, but it is obtained here for mostly opaque metallic gratings. We focus on the transmission of short pulses in time domain through such grating, showing that broadband signals may be transmitted with weak distortion, very different from typical extraordinary optical transmission based on resonant phenomena.

09:40 - 10:00 **Analytical model for periodic arrays of slits / strips printed on dielectric slabs: TE and TM polarizations** Oral

Raul Rodriguez-Berral, *University of Seville, Spain*
Francisco Mesa, *University of Seville, Spain*
Francisco Medina, *University of Seville, Spain*

This paper provides a systematic procedure to extract an equivalent circuit model to characterize the electromagnetic transmission and reflection properties of periodic arrays of slits or strips sandwiched between a pair of dielectric slabs. The method is valid for TE and TM polarization and for normal and oblique incidence

10:00 - 11:20 Coffee break + **Poster Session 3** ▸ Room Barcelona A

Poster Session 3 + Student Paper Competition

10:00 - 11:20 Room Barcelona A

The finalists of the **Student Paper Competition** will present their papers at the regular technical sessions in accordance with the Conference Program. In addition, they will be required to present their papers again at **this dedicated poster session**. The members of the Steering Committee will interact with the students during the poster presentation and will elect the winner. The winner of the best student paper will be announced at the Congress closing ceremony. The finalists are:

Clausiu Biris, *UK*
Pai-Yen Chen, *USA*
Antti Karilainen, *Finland*
Nathan Landy, *USA*
Hassan Mirzaei, *Canada*
Basit Ali Zeb, *Australia*

Poster Session 3

1. Grazing beaming in metallodielectric nanostructures

Juan J. Miret, *University of Alicante, Spain*
Slobodan Vukovic, *University of Belgrade, Serbia*
Zoran Jaksic, *University of Belgrade, Serbia*
David Pastor, *University of Valencia, Spain*
Carlos J. Zapata-Rodríguez, *University of Valencia, Spain*

We identified a family of nanostructured devices that can sustain subwavelength diffraction-free beams with grazing propagation. The basic configuration consists of a planar multilayered metal-dielectric arrangement deposited on a solid transparent substrate. Potential application in optical trapping and submicrochannel machining are outlined.

2. Ferrite-ferroelectric nonlinear microwave phase shifter

Alexey Ustinov, *St.Petersburg Electrotechnical University, Russia*
Boris Kalinikos, *St.Petersburg Electrotechnical University, Russia*
Gopalan Srinivasan, *Oakland University, USA*

A nonlinear microwave phase shifter based on ferrite-ferroelectric composite material has been studied for the first time. A principle of operation of the device is based on the linear and nonlinear control of the phase shift of the hybrid spin-electromagnetic waves propagating in the composite waveguide.

3. Nonlinear microwave devices based on magnonic crystals

Andrey Drozdovskii, *St. Petersburg Electrotechnical University, Russia*
Alexey Ustinov, *St. Petersburg Electrotechnical University, Russia*
Boris Kalinikos, *St. Petersburg Electrotechnical University, Russia*

A novel multifunctional nonlinear microwave spin-wave device utilizing a YIG-film magnonic crystal have been designed, fabricated and tested. A principle of operation of the device is based on a nonlinear frequency shift and a nonlinear damping of the carrier spin waves propagating in the magnonic crystal. The device performs several functions of microwave signal processing, namely, enhancement of signal-to-noise ratio and limiting or suppression of high-power signals.

4. Dimer and polymer metamaterials with both electric and magnetic coupling

A. Radkovskaya, *Moscow State University, Russia*
O. Sydoruk, *Imperial College London, UK*
E. Tatartschuk, *University of Erlangen-Nuremberg, Germany*
N. Gneiding, *University of Erlangen-Nuremberg, Germany*
C. J. Stevens, *University of Oxford, UK*

D. J. Edwards, *University of Oxford, UK*
Ekaterina Shamonina, *Imperial College, London, UK*

We tailor actively the dispersion curves of diatomic metamaterials with alternating electric and magnetic coupling and show that in 'dimer' metamaterials two resonance modes of the unit cell widen into two pass bands of slow waves, whereas in 'polymer' metamaterials a single pass band with entirely new properties appears.

5. Soft matter template containing metallic subunits dissolved in self-organized materials

Luciano De Sio, *University of Calabria, Italy*
Roberto Caputo, *University of Calabria, Italy*
Ugo Cataldi, *University of Calabria, Italy*
Cesare Umeton, *University of Calabria, Italy*

We report on the fabrication and characterization of a micro periodic structure realized in soft-composite materials containing metallic nanoparticles. These are used to infiltrate a passive polymer template, realized by combining an holographic curing setup and a microfluidic etching process.

6. Resonant three-wave interaction in the nonlinear anisotropic dielectric slabs

Oksana Shramkova, *Queen's University Belfast, UK*
Alex Schuchinsky, *Queen's University Belfast, UK*

The nonlinear interaction of waves in the anisotropic dielectric slabs illuminated by the plane waves of two tones is examined. A special case of Wolf-Bragg resonances at the combinatorial frequency is analyzed analytically and numerically. The dependencies of the intensities of the reflected and transmitted waves of combinatorial frequencies on the layer thickness are studied.

7. Reversible sub-ps optical switching of GaAs-AlAs microcavities

Georgios Ctistis, *University of Twente, The Netherlands*
Emre Yüce, *University of Twente, The Netherlands*
Alex Hartsuiker, *FOM Institute for Atomic and Molecular Physics (AMOLF), The Netherlands*
Maela Bazin, *Nanophysics and Semiconductor laboratory, CEA/INAC/SP2M, France*
Julien Claudon, *Nanophysics and Semiconductor laboratory, CEA/INAC/SP2M, France*
Jean-Michel Gérard, *Nanophysics and Semiconductor laboratory, CEA/INAC/SP2M, France*
Willem L. Vos, *University of Twente, The Netherlands*

We present ultrafast pump-probe reflectivity measurements on microcavities with a cavity resonance at telecom wavelengths. We demonstrate ultimate fast decrease and recovery of the cavity resonance due to the instantaneous electronic Kerr effect.

8. ~~The hybrid method of nonlinear transformational and complex geometrical optics for energy concentration in metamaterials~~

Allan Boardman, *University of Salford, UK*
Volodymyr Grimalsky, *Autonomous University of Morelo*
Yuriy Rapoport, *T. Shevchenko National University, Ukrai*

This paper was not presented at the conference (No show).

The algorithm of "nonlinear transformational optics" is p[illegible] con-centrator. "Superfocusing" is used, including both linear and nonlinear focusing. Matching of complex geometrical optic and full-wave solutions is provided. Possibilities of effective energy focusing and even a tendency to an occurrence of "hot spots" are shown.

9. Stop light and electrical control of the carbon nanotube-graphene structure

Igor Nefedov, *Aalto University, Finland*
Yurii Rapoport, *T. Shevchenko National University, Ukraine*

A mechanism of a light control in a combined graphene-carbon nanotube-dielectric structure is proposed. It is based on the change of the Fermi level in graphene, placed between layers supporting propagation of forward and backward waves, by electric bias field.

10. Vertically aligned carbon nanotubes - study of effective electric permittivity

Grzegorz Lubkowski, *Fraunhofer INT, Germany*

In this paper we aim to assign effective electric permittivity values to vertically aligned arrays of carbon nanotubes fabricated by the state-of-the-art manufacturing techniques. The effective constitutive parameters of this artificial medium depend on the density of the carbon nanotubes. The overview of the densities of the grown aligned carbon nanotubes reported in the literature is given in the paper. The effective parameters are modelled by Maxwell-Garnett homogenization formulas. Carbon nanotube forests form artificial lossy dielectrics with the real part of the effective electric permittivity between 1 and 2 in the optical and near-infrared range.

11. Nano-graphene and single-walled carbon nanotube electrical and optical conductivity properties by terahertz time-domain spectroscopy

Ehsan Dadrasnia, *Universidad Carlos III de Madrid, Spain*
Horacio Lamela Rivera, *Universidad Carlos III de Madrid, Spain*

This paper studies the graphene single-layer and single-walled carbon nanotube thin-films electrical and optical conductivity properties using terahertz time-domain spectroscopy. We analytically compare the graphene and single-walled carbon nanotube thin-films total transmission deposition on high resistivity silicon wafers as sheet conductivity function in same range terahertz spectroscopy of 0-3THz.

12. New tri-band AMC cell

Silva Pimenta Marcio, *LEAT, France*
Fabien Ferrero, *LEAT, France*
Philippe Ratajzack, *Orange-Labs, France*
Patrice Brachat, *Orange-Labs, France*
Jean-Marc Ribero, *LEAT, France*
Robert Staraj, *LEAT, France*

This article presents a novel tri-band Artificial Magnetic Conductor (AMC) cell. The relative simulated bandwidths are 1.3%, 1.1% and 2.7% at the central resonance frequencies of 1.150, 1.354 and 2.177 GHz respectively.

13. Highly non-linear RF metamaterials

Michael Wiltshire, *Imperial College London, UK*
David Smith, *Duke University, USA*

We report on the development and characterisation of nonlinear, varactor-loaded Swiss Roll metamaterial ele-ments. Single varactor elements show a strong power-dependent response, powerful second and third harmonic generation, and large hysteresis, whereas double varactor elements do not saturate or have a second harmonic signal, but display a large third harmonic.

14. Plasmonic nanoparticles self-organization in chiral liquid crystals

Melissa Infusino, *University of Calabria, Italy*
Antonio De Luca, *University of Calabria, Italy*
Alireza Rahimi Rashed, *University of Calabria, Italy*
Nicola Scaramuzza, *University of Calabria, Italy*
Giuseppe Strangi, *University of Calabria, Italy*
Roberto Bartolino, *University of Calabria, Italy*

In this work we are proposing a bottom-up approach for the assembling of a functional metamaterial based on gold nanoparticles-doped chiral smectic liquid crystal. Nanoparticles (NPs) inclusion in such a system does not compromise the typical periodic texture characterizing this liquid crystalline phase. On the contrary, first experimental observations clearly suggest that NPs present a periodic organization in the liquid crystal template, providing striking reconfigurable features under the action of external stimuli. In addition, bringing gain in these self-organized structures can lead to low-loss architectures where the plasmonic responses can be tailored and controlled.

15. UV and visible harmonic generation through enhanced transmission from GaAs-filled nano-cavities

Maria Antonietta Vincenti, *Nanogenesis Group - AEgis Technologies Inc., USA*
Domenico de Ceglia, *Nanogenesis Group - AEgis Technologies Inc., USA*
Vito Roppo, *Universitat Politècnica de Catalunya, Spain*
Michael Scalora, *Charles M. Bowden Research Center, USA*

A theoretical study of harmonic generation from a silver grating having slits filled with GaAs has been conducted. The enhanced transmission regime that guarantees high field localization inside the slits, and the phase-locking mechanism that take place between the pump and its harmonics allows enhanced harmonic generation under conditions of high absorption at visi-ble and UV wavelengths.

16. Active plasmonic devices based on epsilon-near-zero nonlinear metamaterials

Alessandro Ciattoni, *Consiglio Nazionale delle Ricerche, CNR-SPIN L'Aquila, Italy*
Carlo Rizza, *Università dell'Aquila, Italy*
Elia Palange, *Università dell'Aquila, Italy*

We theoretically propose and numerically investigate an active plasmonic device made up of a nonlinear epsilon-near-zero metamaterial slab of thickness smaller than 100 nanometers lying on a linear epsilon-near-zero metamaterial substrate. In free-space coupling configuration and total reflection condition, we predict that the system can be regarded as a memory unit whose binary state is accessible by measuring either the phase difference between incident and reflected waves or the power carried by the nonlinear plasmon wave along the slab-substrate interface, both quantities displaying multivaluedness and hysteresis.

17. Negative refraction and polarization filtering in a photonic crystal of metallic nanoshells

Christos Tserkezis, *University of Athens, Greece*
Nikolaos Stefanou, *University of Athens, Greece*

The extraordinary refractive properties of an fcc crystal of metallic nanoshells are studied by means of full-electrodynamic simulations by the layer-multiple-scattering method. The calculated isofrequency surfaces and corresponding group velocities show that the crystal exhibits all-angle negative refraction, which originates from the excitation of collective plasmonic modes. A thorough analysis of the band structure, in conjunction with corresponding transmission spectra of finite slabs of the crystal, reveals the existence of a single band extending over a narrow frequency region, which is formed from dipole plasmon modes of the individual nanoshells and can be excited, predominantly, by p-polarized incident light, leading to negative refraction and polarization filtering.

18. Exploration of surface waves on pseudo-plasmonic metamaterials

Helen Rance, *University of Exeter, UK*
Alastair Hibbins, *University of Exeter, UK*
John Roy Sambles, *University of Exeter, UK*

Some recent results from fundamental microwave studies of surface waves on pseudo-plasmonic metamaterial structures are presented. An exploration of both isotropic and anisotropic surfaces is undertaken and the potential to excite these modes via a novel "zig-zag" geometry is revealed.

19. Strong coupling of localized and surface plasmons to microcavity modes

Ralf Ameling, *University of Stuttgart, Germany*
Daniel Dregely, *University of Stuttgart, Germany*
Harald Giessen, *University of Stuttgart, Germany*

We strongly couple surface plasmon modes on a thin metal layer via localized plasmons of nanowires to photonic microcavity modes. The coupling becomes evident from an anti-crossing of the resonances in the dispersion diagram. We experimentally determine the dispersion by applying external pressure to the microcavity and find excellent agreement with simulations.

20. Electrodynamic theory of gain amplification for plasmonic nanoparticles coated with a layer of dye molecules

Vitaliy Pustovit, *Centre de Recherche Paul Pascal - CNRS and University of Bordeaux, France*
Filippo Capolino, *University of California Irvine, USA*
Ashod Aradian, *Centre de Recherche Paul Pascal - CNRS, France*

We here present a unified electrodynamic theory of the plasmonic response of metallic nanoparticles assisted by optical gain media, in the case of a nanoparticle coated with a shell of optically active dipoles (fluorescent molecules or quantum dots). We establish a complete description of the optical response based on Green's functions, which allows us to investigate high molecular coverages of the nanoparticle with either regular or random distribution of dye molecules, taking into account not only the interactions between nanoparticle (treated in a multipolar approach) and dye dipoles, but also between dyes molecules, either directly or via the nanoparticle. Our results show a strong amplification of the plasmonic resonance as well as significant modifications of the resonant lineshapes.

21. Loss compensation in metamaterials through embedding of negative impedance active transistor circuits

Wangren Xu, *Tufts University, USA*
Sameer Sonkusale, *Tufts University, USA*

This paper proposes an active transistor based loss compensation approach in metamaterials. As the CMOS and III-V technology continues its aggressive scaling to nanometer feature dimensions, with transit frequency (fT) reaching terahertz values, active transistor based circuits could be em-ployed in each unit cell of metamaterial structure for a variety of functions including loss compensation for ohmic and dielectric loss. The approach is feasible for metamaterials from microwave up to terahertz frequency range and is only limited by the fT of the technology. In this paper, we show results on a planar metamaterial composed of electrically coupled LC resonator (ELC) with resonance frequency at 2.62 GHz. Utilizing a 0.25 μm CMOS process, a negative impedance circuit is implemented to compensate for the ohmic and dielectric losses, improving the strength of resonance and increasing the quality factor Q from 11.21 to 2633.

22. Bistable transmission of nonlinear planar metamaterial with high structural symmetry via trapped-mode excitation

Sergiy Prosvirnin, *Institute of Radio Astronomy, Ukraine*
Vladimir Tuz, *Institute of Radio Astronomy, Ukraine*

We argue the possibility of realization of a polarization insensitive all-optical switching in a planar metamaterial composed of a 4-fold periodic array of two concentric metal rings placed on a substrate of nonlinear material. It is demonstrated that the switching may be achieved between essentially different values of transmission nearly the frequency of the high-quality-factor Fano-shape trapped-mode resonance excitation.

23. ~~Loss compensation in magnetic and negative index plasmonic nanocluster metamaterials~~

Andrea Vallecchi, *University of Siena, Italy*
Matteo Albani, *University of Siena, Italy*
Filippo Capolino, *University of California, Irvine, US*

This paper was not presented at the conference (No show).

We investigate the problem of loss compensation i periodical arrangements of three-dimensional (3D) plasmonic nanoclusters (NCs) coupled to a gain material incorporated into the nanostructure. The gain is described by a generic four-level system that in the linear regime yields an active constitutive relation for the gain material. Cross-section efficiencies of sample NC configurations whose constituent particles are differently embedded with the gain material as well as the retrieved effective parameters for 3D lattices of such inclusions are presented showing the possibility of loss compensation.

24. Two ways of liquid crystal tunability of optical fishnet metamaterials

Alexander Minovich, *Australian National University, Australia*

We propose two ways of tuning of the optical properties of a fishnet metamaterial infiltrated by liquid crystal. The first method is to control the hole mode of the structure and the second method is realised via the tuning of surface-plasmon polariton modes. We show that the last allows for more than 300 times refractive index enhancement.

25. Demonstration of enhancing second harmonic generation with doubly resonant metamaterial

Toshihiro Nakanishi, *Kyoto University, Japan*
Tetsuo Kanazawa, *Kyoto University, Japan*
Yasuhiro Tamayama, *Kyoto University, Japan*
Masao Kitano, *Kyoto University, Japan*

We investigate the enhancement of second harmonic (SH) generation in doubly resonant metamaterial, which consists of two resonators. We observe that the SH generation in the doubly resonant metamaterial is 4.6 times as large as that in a singly resonant metamaterial in microwave frequency region.

26. ~~Terahertz behavior of superconducting slot antenna filters~~

Odeta Limaj, *University of Rome "La Sapienza", Italy*
Stefano Lupi, *University of Rome "La Sapienza", Italy*

This paper was not presented at the conference (No show).

We theoretically investigated the optical properties o uctor metamaterials. The dependence on temperature of the resonant features showed a strong sensitivity to the physical properties of the superconducting film,such as the surface reactance, allowing for both active control of the metamaterial response and for characterization of the superconductor properties.

27. DB boundary based on resonant metamaterial inclusions

Davor Zaluski, *University of Zagreb, Croatia*
Damir Muha, *University of Zagreb, Croatia*
Silvio Hrabar, *University of Zagreb, Croatia*

Possible planar, single-layer, realization of the DB surface based on metamaterial inclusions is proposed.

28. Scattering of a width-modulated microstrip line for an arbitrary angle of incidence

Ladislau Matekovits, *Politecnico di Torino, Italy*
Yogeshwar Ranga, *Macquarie University, Australia*
Karu P. Esselle, *Macquarie University, Australia*
Mario Orefice, *Politecnico di Torino, Italy*

A parametric study of the scattering of an electromagnetic wave from a recently introduced periodic width-modulated microstrip line for arbitrary, i.e. normal and oblique, incidence is presented. The relationship between the analytically known dispersion characteristics (for grazing incidence) and the reflectivity of the structure is investigated for different values of the modulation constant and the incidence angle. The present study, carried out around the first stop band of the surface wave propagation, mainly aims to demonstrate the possibility of reduced virtual prototyping time of the geometry, when it's designed as a reflectarray element.

29. Bandwidth optimization for applications of metasurfaces in broadband circular polarizers

Yang Zhao, *University of Texas at Austin, USA*
Andrea Alu, *University of Texas at Austin, USA*

In this work, stacks of rotated plasmonic metasurfaces are used as building blocks to create broadband circular polarizers in the visible. A single metasurface is considered as the unit cell to retrieve effective ordinary and extraordinary refractive indices (ne and no), similar to what usually done in nematic liquid crystals. We apply Bloch theorem to a stack formed by rotated metasurfaces and show that these stacks can support propagating and evanescent circularly polarized modes over broad bandwidths, associated with the bandgaps of one of the retrieved effective refractive indices.

30. ~~Structured metamaterials for nanophotonic applications~~

S.W.R. Beckett, *Queen's University Belfast, UK*
W. Dickson, *King's College London, UK*
J. McPhillips, *Queen's University Belfast, UK*
R. Pollard, *Queen's University Belfast, UK*
A. V. Zayats, *King's College London, UK*

This paper was not presented at the conference (No show).

We investigated the plasmonic like resonances that exist in nanostructured metamaterials composed from arrays of gold nanorods. Experimental results were compared to simulations carried out using the effective medium approximation and full vectorial modelling.

31. Optical metamaterials with a negative index of refraction in the UV

Ruben C. Maas, *FOM institute AMOLF, The Netherlands*
James Parsons, *FOM institute AMOLF, The Netherlands*
Ewold Verhagen, *FOM institute AMOLF, The Netherlands*
Albert Polman, *FOM institute AMOLF, The Netherlands*

Metamaterials composed of Ag/Si3N4 and Ag/TiO2 multilayers were fabricated. Coupled plas-monic waveguide arrays were sculpted into miniature prisms using focussed ion beam (FIB) mill-ing. Negative refraction is observed.

32. Active loss mitigation and modes in an artificial material made of a 3D-lattice of plasmonic nanoshells

Salvatore Campione, *University of California Irvine, USA*
Matteo Albani, *University of Siena, Italy*
Filippo Capolino, *University of California Irvine, USA*

Complex modes and loss compensation are analyzed at plasmonic frequencies for a 3D-lattice made of nanoshells, modeled as electric dipoles. Gain materials are introduced in the shell dielectric region to compensate for metal losses. Effective refractive indexes from modal analysis and Maxwell Garnett homogenization theory are compared.

33. Tailoring plasmon resonances for applications in nanophotonics

Fernando López-Tejeira, *Instituto de Estructura de la Materia - CSIC, Spain*
Rogelio Rodríguez-Oliveros, *Instituto de Estructura de la Materia - CSIC, Spain*
Ramón Paniagua-Domínguez, *Instituto de Estructura de la Materia - CSIC, Spain*
Demetrio Macías, *Université de Technologie de Troyes, France*
José Antonio Sánchez-Gil, *Instituto de Estructura de la Materia - CSIC, Spain*

Complex metal nanostructures exhibit surface plasmon resonances that play a crucial role in a variety of electromagnetic phenomena. By means of the surface integral equation formulation, we have calculated the scattering properties of nanoparticles with different shapes, either isolated or interacting. Furthermore, we have made use of a bio-inpired stochastic technique in order to optimize particle design for some configurations of interest in nanophotonics.

34. ~~Local-to-propagating plasmon switching in thin gold nanogratings~~

Mikhail Dobynde, *Lomonosov Moscow State University, Russia*
Maxim Scherbakov, *Lomonosov Moscow State University, Russia*
Tatyana Dolgova, *Lomonosov Moscow State University, Russia*
Andrey Fedyanin, *Lomonosov Moscow State Unive*

This paper was not presented at the conference (No show).

Switching between surface plasmon polariton an thin gold nanograting is studied by means of linear spectroscopy and finite-difference time domain calculations. The switching occurs in visible spectral range of 600-800 nm and is controlled with the width of the nanograting slits. Experimental and numerical studies show that switching could be observed in the far-field optical response as well as in near-field electromagnetic energy distribution.

35. Frequency selective reflectors, magnetic walls and perfect optical absorbers based on new classes of metal and dielectric-loaded relief metamaterials

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Jun-Yu Ou, *University of Southampton, UK*
Takashi Uchino, *University of Southampton, UK*
Kevin MacDonald, *University of Southampton, UK*
Nikolay Zheludev, *University of Southampton, UK*

New classes of continuously metallic and 'dielectric-loaded' relief metamaterials (raised or in-dented sub-wavelength patterns on continuous, non-perforated metal surfaces) enable manipulation of reflected light intensity and phase in the visible-infrared range. Perfect absorption, colour control, field enhancement and optical magnetic mirror effects can be achieved and controlled through structural design.

36. Polarization-dependent plasmon resonances in sub-wavelength cruciform aperture arrays

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C. G. Biris, *University College London, UK*
E. J. Osley, *University College London, UK*
O. Gaathon, *Columbia University, USA*
R. M. Osgood, Jr., *Columbia University, USA*
N. C. Panoiu, *University College London, UK*
P. A. Warburton, *University College London, UK*

We have fabricated square arrays of sub-wavelength asymmetric cruciform apertures and measured their infra-red transmission spectra. The spectra display two transmission maxima whose amplitudes can be tuned by varying the in-plane polarization of the incident beam, and a wavelength at which the amplitude is invariant for all polarizations.

37. Coupling mechanisms in nano-U dimers

Natalia Gneiding, *University of Erlangen-Nuremberg, Germany*
Elena Krutkova, *University of Erlangen-Nuremberg, Germany*
Eugen Tatartschuk, *University of Erlangen-Nuremberg, Germany*
Oleksandr Zhuromskyy, *University of Erlangen-Nuremberg, Erlangen, Germany*
Ekaterina Shamonina, *Imperial College London, UK*

We explore the electric and magnetic coupling mechanisms in nano-U dimers comprising of two nano-U elements in the axial arrangement twisted by an arbitrary angle. We incorporate the effect of kinetic inductance due to the inertia of the electrons. Our approach should enable an effective design of metamaterial.

38. Suppression of specular reflection under surface plasmon-polariton resonance in terahertz

Mikhail Timchenko, *Usikov Institute for Radiophysics and Electronics, Ukraine*
Vladimir Gavrikov, *Institute of Radio Astronomy, Ukraine*
Yurii Kamenev, *Institute of Radio Astronomy, Ukraine*
Valerii Shulga, *Institute of Radio Astronomy, Ukraine*
Ivan Spevak, *Usikov Institute for Radiophysics and Electronics, Ukraine*
Alexandre Kats, *Usikov Institute for Radiophysics and Electronics, Ukraine*

We study the effect of the total suppression of the specular reflection (TSSR) caused by the resonance plasmon-polariton excitation on semiconductor in Terahertz. In our experiment the HCN laser radiation is incident from the air on the InSb surface with a periodic array of grooves and couples with eigenmode of the interface.

39. Eigenmode analysis of fishnet metamaterials

Masanobu Iwanaga, *National Institute for Materials Science, Japan*

Eigenmodes in a typical fishnet metamaterial have been clarified based on precise numerical analysis. The lowest mode in energy splits into two branches at in-plain wave vector of $k>0$. The lower branch is found to be the mode of in-plain negative group velocity, responsible for negative refraction in fishnet metamaterials.

40. Plasmonic nanosensor in the diagnosis and treatment of cancer

Saikat Das, *University of Eastern Finland, Finland*
Jari Turunen, *University of Eastern Finland, Finland*

We present a novel method based on silver nanoparticle-generated transient photothermal vapour nanobubbles. These intracellular plasmonic nanobubbles are effective in the diagnosis (by optical scattering) and treatment (by mechanical, nonthermal and selective destruction of target cells) of cancerous cells. Theoretical simulation of fused silica rod SPR sensors and optical fiber SPR sensors was carried out. Then these nanosensors were designed, fabricated and their sensitivities were measured experimentally. We introduce the nanosensors and describe how its size and environment can be harnessed to detect and treat cancer cells.

41. Broadband DNG response based on high-index materials embedded in a plasmonic host

João Costa, *Universidade de Coimbra, Portugal*
Mário Silveirinha, *Universidade de Coimbra, Portugal*

We show that a metamaterial formed by dielectric inclusions embedded in a plasmonic host may be characterized by simultaneously negative permittivity and permeability in a broadband frequency range. The electromagnetic response of the proposed metamaterial is mildly affected by the arrangement of the cylinders within the plasmonic host, and the metamaterial enables strong broadband negative refraction and superlensing.

42. Optical absorption and bistability of semiconductor quantum dot-metal nanoparticle dimers

Bintoro Nugroho, *University of Groningen, The Netherlands*
Alexander Iskandar, *Bandung Institute of Technology, Indonesia*
Victor Malyshev, *University of Groningen, The Netherlands*
Jasper Knoester, *University of Groningen, The Netherlands*

We perform a theoretical study of the optical response of a hybrid system comprised of a closely spaced semiconductor quantum dot (SQD) and a noble metal nanoparticle (MNP). We show the strong dipole-dipole SQD-MNP interaction results in the formation of narrow exciton-plasmon Fano resonances well as in bistability of the optical response. We provide a detailed analysis of the bistability phase diagram.

43. Near-field polarization control with plasmonic metamaterials

Maxim Shcherbakov, *Lomonosov Moscow State University, Russia*
Boris Tsema, *Lomonosov Moscow State University, Russia*
Mikhail Dobynde, *Lomonosov Moscow State University, Russia*
Anton Le, *Lomonosov Moscow State University, Russia*
Tatyana Dolgova, *Lomonosov Moscow State University, Russia*
Alexander Ezhov, *Lomonosov Moscow State University, Russia*
Andrey Fedyanin, *Lomonosov Moscow State University, Russia*

Polarization properties of planar optical metamaterials are studied by means of far-field optical spectroscopy and near-field optical microscopy. Local field maps of linear and circular dichroism measured with near-field optical microscope and calculated using FDTD method demonstrate strong polarization in the nanoscale regime.

44. ~~Surface enhanced imaging and IR spectroscopy of living cells on the basis of the effects of nanoplasmonics and photonics~~

Galyna Dovbeshko, *Institute of Physics - NASU, Ukraine*
Olena Gnatyuk, *Institute of Physics - NASU, Ukraine*
Olena Fesenko, *Institute of Physics - NASU, Ukraine*
Vasiliy Gorchev, *O.V. Palladin Institute of Biochemistry - NASU, Ukraine*
Sergey Karachin, *O.V. Palladin Institute of Biochemistry - NASU, Ukraine*
Elena Goncharuk, *Institute for Problems of Cryobiology and Cryomedicine - NASU, Ukraine*
Elena Pavlovich, *Institute for Problems of Cryobiology and Cryomedicine - NASU, Ukraine*

This paper was not presented at the conference (No show).

Vasiliy Moiseyenko, *Dnipropetrovsk National University, Ukraine*
Vladimir Gorelik, *P.N. Lebedev Physical Institute - RAS, Russia*

New approach for optical imaging, structural study and cells cultivation based on the effect of the enhancement of optical signals from biomolecules adsorbed on the nanostructured gold surface and photonic crystals is proposed. The rough gold surfaces fluorescence, enhanced fluorescence of biological molecules at the photonic crystals has been discussed.

45. Metamaterials for efficient and broadband transition from wave beams to evanescent packages

Constantin Simovski, *Aalto University, Finland*
Olli Luukkonen, *Aalto University, Finland*

We suggested and theoretically studied a planar plasmonic nanostructure which can be excited by a dielectric ridge waveguide and creates in a broad band a subwavelength spatial region where the field is locally enhanced. This spatial region is V-shaped and repeats the contour of the tapered structure. The frequency region where the effect holds covers nearly one half of the visible range. Over one quarter of the visible range a hot spot is formed in front of the structure apex.

46. Switchable directional filter based on defect-control by plasma discharge within a metallic EBG structure

Juslan Lo, *Université de Toulouse, France*
Jérôme Sokoloff, *Université de Toulouse, France*
Thierry Callegari, *Université de Toulouse, France*

In this paper, our aim is to investigate the use of localized plasma discharges within a metallic EBG structure. We showed that plasma discharges may be used to compensate defects within an EBG, and thus, to design a switchable directional filter based on metallic EBG.

47. Compact nonreciprocal optical dividers based on 2D photonic crystals

Victor Dmitriev, *Federal University of Para, Brazil*
Marcelo Kawakatsu, *Federal University of Para, Brazil*

We suggest and analyze a new nonreciprocal optical device based on 2D photonic crystals which fulfills simultaneously two functions: division of the input signal and isolation of the input port from two output ones.

48. ~~Inhomogeneous plasmonic-photonic crystals – does dimensionality matter?~~

Sergei Romanov, *University of Erlangen-Nuremberg, Germany*
Alexandra Romanova, *University of Erlangen-Nurem*
Alexander Korovin, *University of Erlangen-Nurember*
Ulf Peschel, *University of Erlangen-Nuremberg, Germany*

This paper was not presented at the conference (No show).

The optical properties of hybrid metal-dielectric plasmonic-photonic crystals depend on crystal dimensionality due to strongly inhomogeneous distribution of electromagnetic field. They can be described by the linear superposition of properties of plasmonic and photonic crystals and the interaction term represented by the interface function.

49. ~~Spontaneous parametric down-conversion in nonlinear photonic crystals~~

Vasilij Moiseyenko, *Oles' Gonchar Dnipropetrovs'k National University , Ukraine*
Mykhailo Dergachov, *Oles' Gonchar Dnipropetrovs'k National University, Ukraine*
Vladimir Shvachich, *Oles' Gonchar Dnipropetrovs'k National University, Ukraine*

Emission spectra of photonic crystals composed of synthetic opals and Ba(NO3)2, LiIO3, KH2PO4 contain a wide asymmetric band within 410–600 nm range with integral intensity nonlinearly depending on substance quantity in opal pores. Angular dependence of spectral intensity is observed. Spontaneous parametric down-conversion in spatially non-uniform nonlinear medium is proposed to be the emission origin.

50. Hard waveguides based on gap waveguide concept

Eva Rajo-Iglesias, *University Carlos III of Madrid, Spain*
Stefano Maci, *University of Siena, Italy*

A new geometry based on the concept of gap waveguide is proposed to allow the propagation of quasi-TEM modes in a rectangular waveguide within a wide band. The design is based in previous works which have used AMC on the walls of the waveguide to remove the cutoff condition, but the initial studies of the proposed modification provide for the first time enough bandwidth. Besides, the design has the advantage of gap waveguides of being a contact-less technology. The results can be seen as well as the horizontally-polarized version of the ridge gap waveguide.

51. ~~The one-dimensional dielectric photonic crystals with two combined superconducting defect~~

Nataliya Dadoenkova, *Donetsk Physical & Technical Institute - NASU, Ukraine*
Igor Lyubchanskii, *Donetsk Physical & Technical Institute - NASU, Ukraine*
Young Pak Lee, *Hanyang University, Korea*
Theo Rasing, *Radboad University of Nijmegen, Netherlands*

This paper was not presented at the conference (Withdrawal).

The one-dimensional dielectric photonic crystals with two complex defect layers, consisting of ultrathin superconducting and dielectric sublayers are theoretically studied. The pronounced difference in the transmittivity spectra of the photonic crystals with right-handed and left-handed positions of the superconducting defect sublayers with respect to the dielectric defect sublayer is demonstrated.

52. Three-dimensional photonic crystal for spatial filtering

Lina Maigyte, *Universitat Politecnica de Catalunya, Spain*
Titas Gertus, *Vilnius University, Lithuania*
Martynas Peckus, *Vilnius University, Lithuania*
Crina Cojocaru, *Universitat Politecnica de Catalunya, Spain*
Jose Trull, *Universitat Politecnica de Catalunya, Spain*
Valdas Sirutkaitis, *Vilnius University, Lithuania*
Kestutis Staliunas, *Universitat Politecnica de Catalunya, Spain*

It is well known that photonic crystals exhibit frequency band gaps. The main application of that property is that one can utilize it for a frequency filtering. Recently it has been proposed that angular band gaps in two and three-dimension photonic crystals can be similarly applied for a spatial filtering of light beams. The purpose of this paper is to experimentally demonstrate that photonic crystals can spatially filter the light.

53. A cross polarized antenna with reflector based on electromagnetic bandgap (EBG) material

Gunther Dehm-Andone, *University of Erlangen-Nuremberg, Germany*
Rainer Wansch, *Fraunhofer Institute for Integrated Circuits IIS, Germany*
Heinz Gerhäuser, *University of Erlangen-Nuremberg, Germany*
Robert Weigel, *University of Erlangen-Nuremberg, Germany*
Alexander Koelpin, *University of Erlangen-Nuremberg, Germany*

In this paper a gain improved cross polarized dipole antenna based on a Mushroom-Jerusalem-Cross hybrid electromagnetic bandgap (MJCH-EBG) structure is presented. For low frequencies these structures behave like metal surfaces. For a specific bandwidth at higher frequencies, that has to be dimensioned, they are highly resistive and represent a perfect magnetic conductor. This effect can be used to realize reflectors and to suppress surface waves at antennas. This helps to miniaturize these kind of antennas. Design, simulation, measurement and analysis is performed for this antenna at 10.7GHz.

54. Multiple Bragg diffraction effects in reflection spectroscopy of three-dimensional photonic crystals

V. G. Fedotov, *Saint Petersburg State University, Russia*
T. A. Ukleev, *Saint Petersburg State University, Russia*
A. Yu. Men'shikova, *Institute of Macromolecular Compounds - RAS, Russia*
N. N. Shevchenko, *Institute of Macromolecular Compounds - RAS, Russia*
A. V. Sel'kin, *Saint Petersburg State University, Russia*

We report the results of the theoretical and experimental studies of Bragg reflection spectra for three-dimensional photonic crystals possessing high dielectric contrast, with emphasis on the multiple Bragg diffraction effects. Opal-like photonic crystals made up of polystyrene microspheres are used as an example in our measurements. Numerical calculations of the reflection contours performed on the basis of the dynamical diffraction theory show a good agreement with the experimental data if a uniaxial strain along the sedimentation direction [111] of the opal crystal lattice is accounted for. We also demonstrate theoretically that the multiple Bragg diffraction effects can be observed at any angle of incidence, depending on the magnitude of the strain.

55. Wideband RCS reduction in a planar configuration using AMC structures

Juan Carlos Iriarte, *Public University of Navarra, Spain*
Jose Luis Martinez de Falcón, *Public University of Navarra, Spain*
Itziar Maestrojuan, *Public Univesity of Navarra, Spain*
Iñigo Liberal, *Public University of Navarra, Spain*
Ainara Rebollo, *Public University of Navarra, Spain*
Iñigo Ederra, *Public University of Navarra, Spain*
Ramon Gonzalo, *Public University of Navarra, Spain*

In this paper a combination of two different Artificial Magnetic Structures (AMC) properly com-bined in a chessboard like configuration are presented to reduce Radar Cross Section (RCS) in a wideband. Several designs can be seen in the literature reducing RCS in a narrow band or in sev-eral frequency bands, but presenting each of them narrow band behaviour. In this case, the design presented in the paper achieves more than a 40% working band.

56. Novel woodpile horn antennas

Irina Khromova, *Public University of Navarra, Spain*
Ramón Gonzalo, *Public University of Navarra, Spain*
Iñigo Ederra, *Public University of Navarra, Spain*
Karu Esselle, *Macquarie University, Australia*
Bas de Hon, *Eindhoven University of Technology, Holand*

Novel concept of feeding EBG horn antennas via evanescent fields is introduced. The principle of creating symmetrical all-dielectric pyramidal horn antennas based on woodpile structures is explained in detail. F band antennas based on the above mentioned concepts were designed, their Ku band scaled-up prototypes were fabricated and measured.

57. Directional beaming from a corrugated row of holes at the end of an EBG crystal

Yaser Abdo, *Royal Military College of Canada, Canada*
Reza Chaharmir, *Communications Research Centre Canada, Canada*
Jafar Shaker, *Communications Research Centre Canada, Canada*
Yahia Antar, *Royal Military College of Canada, Canada*

In this paper, it is shown how a corrugated row of holes can be used as a leaky wave antenna to radiate a broadside directional beam. The interface of a square lattice of metal vias, which has a bandgap around 30 GHz, is modified by adding a row of holes to excite a surface mode. The surface mode is coupled to a leaky mode which radiates into free space by corrugating the holes. The radiation pattern of the corrugated row of holes was calculated to show its directivity and radiation efficiency.

58. Nucleation and growth of superlattices of metallic

Antonio Iazzolino, *University of Bordeaux, France*
Julie Angly, *University of Bordeaux, France*
Jacques Leng, *University of Bordeaux, France*
Jean-Baptiste Salmon, *University of Bordeaux, France*

We study, by an original microfluidic techniques, the assembly of metallic nanoparticles (gold, silver) that can act as locally resonant structures (for their plasmonic response) on a lattice in order to create super-lattices. Such a superstructure could be a good candidate for metamaterials working in the visibile range.

Special Session
Magnonics

11:20 - 13:00 ▸ Room Barcelona B

The session will highlight the state of the art and recent advances in the emerging field of magnonics, with a special attention to the novel opportunities arising from the possibility to tailor and control spin wave resonances in nano-scale magnetic structures for the research fields of magnonic and electro-magnetic metamaterials and associated technologies.

Organizer ▸ **Volodymyr Kruglyak**, *University of Exeter, UK*
Session Chair ▸ **Volodymyr Kruglyak**, *University of Exeter, UK*

11:20 - 11:40 **Magnonic crystals and their metamaterials properties - theoretical considerations** Invited

Maciej Krawczyk, *Adam Mickiewicz University, Poland*
M. Mruczkiewicz, *Adam Mickiewicz University, Poland*
R. V. Mikhaylovskiy, *University of Exeter, UK*
J. W. Klos, *Adam Mickiewicz University, Poland*
S. Mamica, *Adam Mickiewicz University, Poland*
M. L. Sokolovskyy, *Adam Mickiewicz University, Poland*
V. V. Kruglyak, *University of Exeter, UK*

Composite materials with a periodic arrangement of magnetic inclusions (magnonic crystals, MC) can show properties not found in bulk samples. The effective continuous properties of MC for spinwaves are defined. We calculated also the effective permeability of magnonic meta-materials formed by MC.

11:40 - 12:00 **Spin waves band structure in planar Magnonic Crystals** Invited

Gianluca Gubbiotti, *CNR-IOM, Italy*
S. Tacchi, *Consorzio Nazionale Italiano di Struttura della Materia (CNISM), Italy*
M. Madami, *Consorzio Nazionale Italiano di Struttura della Materia (CNISM), Italy*
G. Carlotti, *Consorzio Nazionale Italiano di Struttura della Materia (CNISM), Italy*

The application of Brillouin light scattering to study the spin waves band structure of planar one- and two-dimensional magnonic metamaterials, consisting of arrays of interacting ferromagnetic elements is reviewed. The dispersion curves of collective spin modes are characterized by periodical oscillations determined by the width of the artificial Brillouin zone.

12:00 - 12:20 **Transmission of GHz spin waves through periodically nanopatterned ferromagnets** Invited

S. Neusser, *Technische Universität München, Germany*
G. Duerr, *Technische Universität München, Germany*
F. Brandl, *Technische Universität München, Germany*
R. Huber, *Technische Universität München, Germany*
T. Schwarze, *Technische Universität München, Germany*
Dirk Grundler, *Technische Universität München, Germany*

We have coupled electromagnetic waves in the GHz frequency regime to collective spin excitations in ferromagnetic thin films which are periodically patterned on the nanoscale. In a short period antidot lattice we find spin-wave propagation between two collinear coplanar waveguides with velocities of up to several km/s.

12:20 - 12:40 **Magnonic band-gap meta-materials (one-dimensional and two-dimensional magnonic crystals) for magnetic field detection with very high sensitivity** Invited

Mitsuteru Inoue, *Toyohashi University of Technology, Japan*

We discuss a magnonic crystal which is an artificial magnetic material for the propagation of magnetic waves. A magnonic crystal with one-dimensional or two-dimensional structure can be used as an extremely sensitive three-dimensional magnetic field sensor that is functional at room temperature.

12:40 - 13:00 **Electric field control of surface spin waves** Invited

Robert L. Stamps, *University of Glasgow, UK*
K. Livesey, *University of Colorado, USA*
V. Gunawan, *Universitas Diponegoro, Indonesia*

A mean field theory is used to calculate spin wave frequencies for canted antiferromagnets with magnetoelectric coupling to a ferroelectric polarisation. Effects of electric fields on magnetic resonance frequencies and nonreciprocities are discussed. Possibilities for hybrid magnetoelectric modes in multilayer geometries are examined.

13:00 - 14:30 Lunch ▸ La Cantina de l'Estació, Hotel Barceló Sants

Thursday, 13th October

Nonlinear Metamaterials

11:20 - 13:00 ▸ Room Sants-Montjuic

Session Chair ▸ **Falk Lederer**, *University of Jena, Germany*

11:20 - 11:40 **Ultrafast pump-probe spectroscopy of a dual band negative index metamaterial** Oral

Keshav Dani, *Los Alamos National Laboratory, USA*
Zahyun Ku, *University of New Mexico, USA*
Prashanth Upadhya, *Los Alamos National Laboratory, USA*
Rohit Prasankumar, *Los Alamos National Laboratory, USA*
Steve R. J. Brueck, *University of New Mexico, USA*
Antoinette J. Taylor, *Los Alamos National Laboratory, USA*

In this paper we study the nonlinear optical response of a dual band negative index metamaterial device with two color pump probe spectroscopy. We measure and numerically reproduce its properties versus probe wavelength, pump fluence and probe polarization. Thereby, we demonstrate its utility as a nanoscale structurally tunable, subpicosecond all-optical modulator.

11:40 - 12:00 **Resonant plasmonic nonlinearities of the fishnet metamaterials** Oral

Maxim Shcherbakov, *Lomonosov Moscow State University, Russia*
Joerg Reinhold, *Friedrich Schiller University Jena, Germany*
Christian Helgert, *Friedrich Schiller University Jena, Germany*
Arkadi Chipouline, *Friedrich Schiller University Jena, Germany*
Thomas Pertsch, *Friedrich Schiller University Jena, Germany*
Andrey Fedyanin, *Lomonosov Moscow State University, Russia*

Second- and third-harmonic generation with the fundamental wave exciting electric and magnetic plasmonic resonances inside the negative-index fishnet metamaterial is studied in the angular and spectral domain.

12:00 - 12:20 **MEMS controlled EIT coupling in metamaterial** Oral

Wu Zhang, *Nanyang Technological University of Singapore, Singapore*
Wei Ming Zhu, *Nanyang Technological University of Singapore, Singapore*
Ji Fang Tao, *Nanyang Technological University of Singapore, Singapore*
Yuan Hsing Fu, *Data Storage Institute of Singapore, Singapore*
Ai Qun Liu, *Nanyang Technological University of Singapore, Singapore*
Jing Hua Teng, *Institute of Materials Research and Engineering of Singapore, Singapore*
Hendrix Tanoto, *Institute of Materials Research and Engineering of Singapore, Singapore*
Er Ping Li, *Institute of High Performance Computing of Singapore, Singapore*

A switchable EIT-like metamaterial is designed and tested. The metamaterial unit cell is reshaped through micro-electro-mechanical systems (MEMS) technology. By MEMS switching, the electromagnetically induced transparency (EIT) effect is simulated in the design. The EIT-like effect in metamaterial can be applied in slow light, optical switch and tunable filter.

12:20 - 12:40 **Nano-electromechanical switchable photonic metamaterials** Oral

Jun-Yu Ou, *University of Southampton, UK*
Eric Plum, *University of Southampton, UK*
Liudi Jiang, *University of Southampton, UK*
Nikolay Zheludev, *University of Southampton, UK*

We introduce mechanically reconfigurable electrostatically-driven photonic metamaterials (RPMs) as a generic platform for large-range tuning and switching of photonic metamaterial properties. Here we illustrate this concept with a high-contrast metamaterial electro-optic switch exhibiting relative reflection changes of up to 72% **in the optical part of the spectrum.**

Thursday, 13th October

12:40 - 13:00 ~~**Linear and non-linear dark whispering gallery modes in nanowire plasmonic cavities**~~ ~~Oral~~

Claudiu G. Biris, *University College London, UK*
Nicolae C. Panoiu, *University College London, UK*

This paper was not presented at the conference (Withdrawal).

In this paper we investigate numerically the formation of linear and non-linear, dark whispering gallery modes in plasmonic cavities made of Au nanowires. We employ a method based on multiple scattering the-ory to show that micron-sized plasmonic cavities allow for the formation of subradiant whispering gallery modes. We further demonstrate that these modes are highly sensitive to variations in geometrical parameters, leading to a high degree of tuneability of the optical response of the plasmonic system.

13:00 - 14:30 Lunch ▸ La Cantina de l'Estació, Hotel Barceló Sants

GHz and THz Metamaterials

11:20 - 13:00 ▸ Room Sarrià-St. Gervasi

Session Chair ▸ **Ekmel Ozbay**, *Bilkent University, Turkey*

11:20 - 11:40 **Analog of electromagnetically induced transparency in a hybrid metamaterial** Oral

Peter Weis, University of Kaiserslautern, Germany
Juan Luis Garcia-Pomar, *University of Kaiserslautern and Fraunhofer IPM, Germany*
René Beigang, *University of Kaiserslautern and Fraunhofer IPM, Germany*
Marco Rahm, *University of Kaiserslautern and Fraunhofer IPM, Germany*

We present a theoretical and experimental study on the coupling process of a split ring resonator metamaterial to dielectric substances. We show that the behavior can be similar to electromagnetic induced transparency or plasmonic induced transparency. We provide an analytic model and evidence its validity by numerical calculations and experiments.

11:40 - 12:00 **Polarisation insensitive single band, dual band and broadband THz metamaterial absorbers** Oral

James Grant, *University of Glasgow, UK*
Yong Ma, *University of Glasgow, UK*
Qin Chen, *University of Glasgow, UK*
Shimul Saha, *University of Glasgow, UK*
Ata Khalid, *University of Glasgow, UK*
David Cumming, *University of Glasgow, UK*

We present the design, simulation and experimental verification of single band, dual band and broadband polarisation insensitive resonant metamaterial absorbers in the THz region. All meta-material absorbers consist of a metal/dielectric spacer/metal structure allowing us to maximize ab-sorption by varying the dielectric material and thickness hence the effective electrical permittivity and magnetic permeability.

12:00 - 12:20 **Trapping the light in a crossed wire mesh: broadband and ultra-subwavelength waveguiding** Oral

Tiago Morgado, *Universidade de Coimbra, Portugal*
João Marco, *Universidade de Coimbra, Portugal*
Mário Silveirinha, *Universidade de Coimbra, Portugal*
Stanislav Maslovski, *Universidade de Coimbra, Portugal*

In this paper we study both theoretically and experimentally the exotic waveguiding properties of ultra-compact metamaterials formed by crossed metallic wires, revealing their superior bandwidth, tolerance to absorption and reduced physical size. In particular, the proposed structured waveguide supports highly confined plasmons with entangled dispersion. The studied waveguide supports such waves over a much wider range of frequencies as compared to other known solutions based on spoof surface plasmons or semiconductor plasmonic-type waveguides.

12:20 - 12:40 **Metamaterial-based gradient index lens for strong focusing in the THz frequency range** Oral

Jens Neu, *University of Kaiserslautern and Fraunhofer IPM, Germany*
Bernd Krolla, *University of Kaiserslautern and Fraunhofer IPM, Germany*
Oliver Paul, *University of Kaiserslautern, Germany*
Benjamin Reinhard, *University of Kaiserslautern, Germany*
René Beigang, *University of Kaiserslautern and Fraunhofer IPM, Germany*
Marco Rahm, *University of Kaiserslautern and Fraunhofer IPM, Germany*

We present the design, fabrication and experimental investigation of a three-layer metamaterial-based gradient index lens that focuses THz radiation to spot diameters of approximately one wavelength at a center frequency of 1.3 THz. The operation bandwidth of the lens was 300 GHz. We compared the experimental data to numerical calculations.

12:40 - 13:00 **Design of a composite right / left-handed slab-type material composed of multilayer metallic patterns** Oral

Tsunayuki Yamamoto, *Yamaguchi University, Japan*
Hiroshi Kubo, *Yamaguchi University, Japan*
Masayuki Watanabe, *Yamaguchi University, Japan*
Atsushi Sanada, *Yamaguchi University, Japan*

In this paper, a composite right/left-handed (CRLH) slab-type material excited by plane wave is proposed. It is composed of multilayer metallic patterns between dielectric substrates. The equiva-lent circuit is shown to design a balanced CRLH material. The balanced CRLH characteristics are measured. Next the CRLH material composed of four kinds of cells with different dispersion rela-tion is designed. The propagating direction of wave through the material is also measured. It is confirmed that the propagating direction can be controlled from -10 deg. to +8 deg. by the fre-quency of the input plane wave.

13:00 - 14:30 Lunch ▸ La Cantina de l'Estació, Hotel Barceló

Thursday, 13th October

Experimental Characterization of Metamaterials

14:30 - 16:10 ▸ Room Barcelona B

Session Chair ▸ **Ralf Vogelgesang**, *Max Planck Institute for Solid State Research, Germany*

14:30 - 14:50 **Electron energy loss spectroscopy on lithographically defined photonic metamaterials** Oral

Felix von Cube, *Universität Bonn and Research Center Caesar, Germany*
Nils Feth, *Karlsruher Institut für Technologie (KIT), Germany*
Stephan Irsen, *Research Center Caesar, Bonn, Germany*
Stefan Linden, *Universität Bonn and Karlsruher Institut für Technologie (KIT), Germany*

We investigate the spatial and spectral distribution of plasmonic modes on different metamaterial building blocks via STEM-EELS. Our samples have been fabricated utilizing electron-beam lithography on TEM compatible substrates. Experimental data for the four lowest-order plasmonic modes of split-ring resonators and complementary split-ring resonators are presented.

14:50 - 15:10 **Spectroscopic ellipsometry of the fishnet metamaterial** Oral

Babak Dastmalchi, *Johannes Kepler University, Austria*
Iris Bergmair, *PROFACTOR GmbH, Austria*
Thomas Oates, *Leibniz Institut für Analytische Wissenschaften - ISAS - e.V., Germany*
Karsten Hinrichs, *Leibniz Institut für Analytische Wissenschaften - ISAS - e.V., Germany*
Michael Bergmair, *Johannes Kepler University, Austria*
Kurt Hingerl, *Johannes Kepler University, Austria*

Spectroscopic ellipsometry has great potential for the characterization of optical metamaterials, particularly under oblique incidence. Here we present a method based on Berreman's 4x4 matrix formalism combined with oblique incidence retrieval methods to reproduce the ellipsometric response of Fishnet metamaterial. The existence of spatial dispersion is also discussed.

15:10 - 15:30 **Free space polarizability measurement method** Oral

Lukas Jelinek, *Czech Technical University in Prague, Czech Republic*
Jan Machac, *Czech Technical University in Prague, Czech Republic*

A simple and precise method for free space polarizability measurement of electrically small particles is presented. The method is based on a measurement of the scattering parameters of a waveguide loaded by a particle, and on knowledge of the dipolar polarizabilities of two calibration standards.

15:30 – 15:50 **Gain assisted and gain functionalized core-shell nanoparticles: A multi-pronged approach to compensate loss in metamaterials** Oral

Antonio De Luca, *University of Calabria, Italy*
Melissa Infusino, *University of Calabria, Italy*
Isabel Pastoriza-Santos, *Universidade de Vigo, Spain*
Marcin Grzelczak, *Universidade de Vigo, Spain*
Lucia Curri, *University of Bari, Italy*
Marinella Striccoli, *University of Bari, Italy*
Giuseppe Strangi, *University of Calabria, Italy*

Optical losses in meta-structures based on metal subunits represents a central topic towards the fabrication of metamaterials in the visible range, since most of the extra-ordinary electromagnetic properties expected in these structured systems are shadowed by unavoidable absorptive effects. In this paper we report experimental studies aimed to demonstrate effective chemical and physical approaches to mitigate the radiation damping effect by means of "gain assisted" and "gain functionalized" core-shell metal nanospheres selected as metamaterial building blocks. A multiscale strategy has been utilized to compare these two systems, showing that in both cases partial loss compensation can be obtained.

15:50 - 16:10 ~~**Characterization of IR metamaterials by polarimetric scatterometry**~~ ~~Oral~~

~~Stephen Nauyoks~~, *US Air Force Institute of Technology, USA*
~~Jason Vap~~, *US Air Force Institute of Technology, USA*
~~Thomas Fitzgerald~~, *US Air Force Institute of Technology, USA*
~~Michael Marciniak~~, *US Air Force Institute of Technology, USA*

This paper was not presented at the conference (Withdrawal).

We apply the technique of polarimetric scatterometry to characterize infrared metamaterials using full Mueller-matrix polarimetry, scatterometry throughout both the transmission and reflection hemispheres, and spectrally at tunable wavelengths of 4.4-9.7 microns. We are able to characterize metamaterial samples both at and away from their resonances, and have begun initial measurements.

16:10 - 16:30 Coffee break + **Poster Session 3 (continuation)** ▸ Room Barcelona A

Thursday, 13th October

Theory of Metamaterials 3

14:30 - 16:10 ▸ Room Sants-Montjuïc

Session Chair ▸ **Costas M. Soukoulis**, *Iowa State University, USA*

14:30 - 15:00 **Bloch wave and particle resonances in stacked dogbone arrays** Invited

Alex Schuchinsky, *Queen's University Belfast, UK*
Andrea Vallecchi, *University of Siena, Italy*
Filippo Capolino, *University of California Irvine, USA*
Alexey Shitvov, *Queen's University Belfast, UK*

The resonance transmission in the stacked arrays of the dogbone shaped conductor pairs is discussed. It is shown that its spectrum consists of the intrinsic resonances of individual pairs and Bloch wave resonances in the whole stack. The effects of the layer spacing and unit cell topology are explored.

15:00 - 15:20 **Modelling photothermal effect in a planar metamaterial absorber** Oral

Xi Chen, *Royal Insitute of Technology (KTH), Sweden*
Jing Wang, *Royal Insitute of Technology (KTH), Sweden*
Yiting Chen, *Royal Insitute of Technology (KTH), Sweden*
Jiaming Hao, *Royal Insitute of Technology (KTH), Sweden*
Min Yan, *Royal Insitute of Technology (KTH), Sweden*
Min Qiu, *Royal Insitute of Technology (KTH), Sweden*

The ultrasensitive photothermal heating in a plasmonic nanostructure irradiated by a pulsed white-light source is elaborated with a heat transfer model, which is subsequently solved with a finite-element method. The simulation results not only agree with our observation, but also provide more detailed temperature transition in the complex system.

15:20 - 15:40 **Treating the scattering problem at the interface between two metamaterials** Oral

Philippe Lalanne, *Institut d'Optique, France*
Wojtech Smigaj, *Institut d'Optique, France*
Jianji Yang, *Institut d'Optique, France*
Thomas Paul, *Institute of Solid State Theory and Condensed Matter Optics, Germany*
Carsten Rockstuhl, *Institute of Solid State Theory and Condensed Matter Optics, Germany*
Falk Lederer, *Institute of Solid State Theory and Condensed Matter Optics, Germany*

We use the Bloch-mode orthogonality to derive simple and accurate closed-form expressions for the scattering coefficients at an interface between two periodic media, a computationally-challenging electromagnetic scattering problem that can be solved only with advanced numerical tools.

15:40 - 16:10 **The impedance of metamaterials and nanoplasmonic structures** Invited

Carsten Rockstuhl, *Friedrich-Schiller-Universität Jena, Germany*
Thomas Paul, *Friedrich-Schiller-Universität Jena, Germany*
Shakeeb Bin Hasan, *Friedrich-Schiller-Universität Jena, Germany*
Christoph Menzel, *Friedrich-Schiller-Universität Jena, Germany*
Thomas Kaiser, *Friedrich-Schiller-Universität Jena, Germany*
Wojciech Smigaj, *Univ. Paris-Sud, France*
Thomas Pertsch, *Friedrich-Schiller-Universität Jena, Germany*
Philippe Lalanne, *Univ. Paris-Sud, France*
Falk Lederer, *Friedrich-Schiller-Universität Jena, Germany*

We discuss our efforts to assign an effective impedance to metamaterials while considering the field profile of the Bloch modes supported by the bulk structure. We show that an unambiguous introduction is only possible for carefully designed metamaterials for which at their interface only a single Bloch mode is excited.

16:10 - 16:30 Coffee break + **Poster Session 3 (continuation)** ▸ Room Barcelona A

Transformation Electromagnetics and Cloaking 2

14:30 - 16:10 ▸ Room Sarrià-St. Gervasi

Session Chair ▸ **Tomas Tyc**, *Masaryk University, Czech Republic*

14:30 - 15:00 **Collection and concentration of light by touching spheres: A transformation optics approach** Invited

Antonio I. Fernandez-Dominguez, *Imperial College London, UK*
Stefan A. Maier, *Imperial College London, UK*
John B. Pendry, *Imperial College London, UK*

A general three-dimensional transformation optics approach is presented that yields analytical expressions for the relevant electromagnetic magnitudes in plasmonic phenomena at singular geometries. This powerful theoretical tool reveals the broadband response and superfocusing properties of touching metal nanospheres and provides an elegant physical description of the prominent field enhancement that takes place at the point of contact between a spherical nanoparticle and a flat metallic surface.

15:00 - 15:30 **Sub-diffraction-limited imaging in the far-field** Invited

Susanne C Kehr, *University of St Andrews, UK*
Yun Gui Ma, *National University of Singapore, Singapore*
Sahar Sahebdivan, *University of St Andrews, UK*
Andrea Di Falco, *University of St Andrews, UK*
Thomas Philbin, *University of St Andrews, UK*
Aaron J. Danner, *National University of Singapore, Singapore*
Tomas Tyc, *Masaryk University Brno, Czech Republic*
Ulf Leonhardt, *University of St Andrews, UK*

Perfect imaging in the far-field becomes possible in refractive-index-profile devices such as e.g. Maxwell's fish-eye that can be described in transformation optics by a spherical geometry. We present experimental results in the microwave regime, which show sub-wavelength imaging with a positive refractive-index profile at several wavelengths away from the objects.

15:30 - 15:50 **Towards macroscopic optical invisibility devices: the geometrical optics of complex materials** Oral

Yaroslav Urzhumov, *Duke University, USA*
David Smith, *Duke University, USA*

Recently, a path towards macroscopic, transparent optical cloaking devices that may conceal objects spanning millions of wavelengths has been proposed. In this paper, we offer further analysis and improvements to the concept using the method of geometrical optics extended to complex photonic media with an arbitrary dispersion relation. Aberrations caused by the non-quadratic part of the dispersion relation are demonstrated quantitatively in a numerical experiment. An analytical argument based on the scalability of the eikonal phase is presented, which points towards a solution that removes this type of aberration in each order of the k-perturbation theory, thus restoring the perfect cloaking solution.

15:50 - 16:10 **Cloaking dielectric spheres by a shell of metallic nanoparticles** Oral

Mohamed Farhat, *Friedrich-Schiller-Universitat Jena, Germany*
Stefan Muhlig, *Friedrich-Schiller-Universitat Jena, Germany*
Carsten Rockstuhl, *Friedrich-Schiller-Universitat Jena, Germany*
Falk Lederer, *Friedrich-Schiller-Universitat Jena, Germany*

We describe a metamaterial made of randomly arranged silver nanospheres that is placed as a shell around a dielectric sphere with the purpose of cloaking it. The device is studied rigorously by full wave simulation and approximately by treating the shell of silver nanospheres within the Maxwell-Garnett theory. By both means it is concisely shown that such a metamaterial shell significantly reduces the visibility of the dielectric sphere. Advantages and disadvantages of such a cloak when compared to other implementations are disclosed.

16:10 - 16:30 Coffee break + **Poster Session 3 (continuation)** ▸ Room Barcelona A

Millimeter-Wave and THz Metamaterials

16:30 - 18:10 ▸ Room Barcelona B

Session Chair ▸ Carsten Rockstuhl, Friedrich-Schiller-Universität Jena, Germany

16:30 - 17:00 **Negative- and Zero-Index Metamaterials at terahertz frequencies** Invited

Eric Lheurette, *IEMN - Université de Lille 1, France*
Shenxiang Wang, *IEMN - Université de Lille 1, France*
Frédéric Garet, *IMEP -LAHC Université de Savoie, France*
Jean-Louis Coutaz, *IMEP -LAHC Université de Savoie, France*
Didier Lippens, *IEMN - Université de Lille 1, France*

In this article, we present the design, fabrication and characterization of double negative metamaterials for the terahertz operating spectrum. Special attention is paid to the near-zero index condition which corresponds to the case of simultaneous infinite phase and non vanishing group velocities. The metamaterial structures are made of metallic films patterned with sub-wavelength elliptical apertures separated by benzocyclobuthene (BCB) layers. The negative index properties have been experimentally demonstrated both indirectly, by means of a retrieval procedure from reflection (R) and transmission (T) characterization of a slab device and directly by angular measurements at the wedged interface of a prism-like structure. Both these experiments were carried out using Time Domain Spectroscopy (TDS).

17:00 - 17:30 **THz manipulation and superlensing using polaritonic metamaterials** Invited

Maria Kafesaki, *Foundation for Research and Technology Hellas (FORTH), Greece*
Alejandro Reyes-Corronado, *Foundation for Research and Technology Hellas (FORTH), Greece*
Stavroula Foteinopoulou, *University of Exeter, UK*
George Kenanakis, *Foundation for Research and Technology Hellas (FORTH), Greece*
Nikos Katsarakis, *Foundation for Research and Technology Hellas (FORTH), Greece*
Maria A. Acosta, *CSIC-Universidad de Zaragoza, Spain*
Rosa I. Merrino, *CSIC-Universidad de Zaragoza, Spain*
Victor M. Orera, *CSIC-Universidad de Zaragoza, Spain*
Victor Myroshnychenko, *CSIC, Spain*
Javier De Abajo, *CSIC, Spain*
Eleftherios N. Economou, *Foundation for Research and Technology Hellas (FORTH), Greece*
Costas M. Soukoulis, *Foundation for Research and Technology Hellas (FORTH), Greece and Iowa State University, USA*

In this paper we discuss and demonstrate the potential of composite metamaterials made of polaritonic rods in a host to exhibit negative refraction and subwavelength imaging resolution in the THz regime, giving thus the ability to those structures to be used in a variety of THz manipulation components.

17:30 - 17:50 **Experimental polarization-independent dual-band metamaterial with a negative refractive index in the millimetre range** Oral

Carlos Garcia-Meca, *Universidad Politécnica de Valencia, Spain*
Miguel Navarro-Cia, *Universidad Pública de Navarra, Spain*
Miguel Beruete, *Universidad Pública de Navarra, Spain*
Alejandro Martinez, *Universidad Politécnica de Valencia, Spain*
Mario Sorolla, *Universidad Pública de Navarra, Spain*

We fabricate and characterize a polarization-independent fishnet metamaterial displaying two different negative-index bands at millimetre wavelengths. The backward-wave nature of both bands is confirmed by direct measurement of the structure phase response. Finally, we numerically show the existence of negative refraction in a prism made up of this metamaterial.

17:50 - 18:10 **Controllable metamaterials for THz applications** Oral

Irina Vendik, *St. Petersburg Electrotechnical University, Russia*
Orest Vendik, *St. Petersburg Electrotechnical University, Russia*

Mikhail Odit, *St. Petersburg Electrotechnical University, Russia*
Dmitry Kholodnyak, *St. Petersburg Electrotechnical University, Russia*
Svetlana Zubko, *St. Petersburg Electrotechnical University, Russia*
Margarita Sitnikova, *St. Petersburg Electrotechnical University, Russia*
Pavel Turalchuk, *St. Petersburg Electrotechnical University, Russia*
Kirill Zemlyakov, *St. Petersburg Electrotechnical University, Russia*
Dmitry Kozlov, *St. Petersburg Electrotechnical University, Russia*
Irina Munina, *St. Petersburg Electrotechnical University, Russia*
Vyacheslav Turgaliev, *St. Petersburg Electrotechnical University, Russia*
Y. Park, *Samsung Advanced Institute of Technology, Korea*
J.E. Kihm, *Samsung Advanced Institute of Technology, Korea*
Chang-Won Lee, *Samsung Advanced Institute of Technology, Korea*

The paper presents a review of controllable metamaterials (MTM) for THz applications. More than 150 original papers have been analyzed. The following MTMs are under discussion: SRR based MTM, all-dielectric MTM, ferroelectric based MTM, ferromagnetic based MTM, liquid crystal based MTM, MTM for the wave polarization control, and layered metal-dielectric struc-tures. Different methods of control have been analyzed: by electric field, by magnetic field, optical control, and by temperature. In conclusion, assessment of the MTMs considered is given.

18:10 - 18:40 **Closing Ceremony** ▸ Room Barcelona B

Carbon and Quantum Metamaterials 2

16:30 - 18:10 ▸ Room Sants-Montjuïc

Session Chair ▸ **Mikhail Noginov**, *Norfolk State University, USA*

16:30 - 16:50 **Radiative heat transfer assisted by carbon nanotubes** Oral

Igor Nefedov, *Aalto University, Finland*
Constantin Simovski, *Aalto University, Finland*

We propose a new paradigm of the radiation heat transfer between two bodies which enables strong photon tunneling for micron-thick gaps. The idea is based on the use of carbon nanotube-based metamaterials, which transform all evanescent waves into propagating ones.

16:50 - 17:10 **Quantum levitation in nanowire materials** Oral

Stanislav Maslovski, *Universidade de Coimbra, Portugal*
Mário Silveirinha, *Universidade de Coimbra, Portugal*

In this work we demonstrate how the Casimir repulsion mechanism proposed by Boyer (the repulsion between a perfect electric and a perfect magnetic conductor) can be mimicked within a structure formed by cut silver nanorods. In particular, we consider a metallic piston that is perforated by vertical nanorods and may slide on them, and show that the repulsive Casimir force exerted on the piston in this structure is strong enough to prevent the piston from falling off the nanorods.

17:10 - 17:30 **Atomic-scale mantle cloak using a graphene monolayer** Oral

Pai-Yen Chen, *University of Texas at Austin, USA*
Andrea Alù, *University of Texas at Austin, USA*

Following our recent findings on making ultra-thin and moderately broadband mantle cloaks using metasurfaces, we investigate the possibility to apply these concepts to the thinnest possible cloak, composed of a single layer of graphene atoms, operating in the far-infrared spectrum. We show that an atomically thin graphene monolayer may drastically suppress the scattering of a given object, while at the same time preserving the moderately broad bandwidth of operation typical of mantle cloaks.

17:30 - 17:50 **Perfect tunneling in semiconductor heterostructures** Oral

Lukas Jelinek, *Czech Technical University in Prague, Czech Republic*
Juan Domingo Baena, *National University of Colombia, Colombia*
Jan Voves, *Czech Technical University in Prague, Czech Republic*
Ricardo Marques, *University of Seville, Spain*

We study the phenomenon of perfect tunneling (tunneling with unitary transmittance) in a 1D semiconductor heterostructure using a formal analogy of the electromagnetic wave equation and the Schrodinger equation. The Kane model of a semiconductor is used and it is shown that this phenomenon can indeed exist, resembling all the interesting features of the corresponding phenomenon in classical electromagnetism in which metamaterials are involved.

17:50 - 18:10 **Modal interactions in mushroom-type metamaterials with thin metal/graphene patches** Oral

Alexander B. Yakovlev, *University of Mississippi, USA*
George W. Hanson, *University of Wisconsin-Milwaukee, USA*

In this paper, we study the modal characteristics of mushroom-type surfaces with thin metal/graphene patches (more generally, resistive film patches). The dispersion equation for natural modes is obtained from a nonlocal homogenization model with a generalized additional boundary condition at the connection of vias to thin metal patches. It is observed that by varying the metal thickness (or equivalently the surface conductivity) the modal spectrum is significantly perturbed and the modal interaction of complex modes (in the sense of modal transformation) occurs.

18:10 - 18:40 **Closing Ceremony** ▸ Room Barcelona B

Dielectric and Non-Resonant Metamaterials

16:30 - 18:10 ▸ Room Sarrià-St. Gervasi

Session Chair ▸ Steven Brueck, University of New Mexico, USA

16:30 - 17:00 **Titanium nitride as plasmonic material for visible wavelengths** Invited

Gururaj V. Naik, *Purdue University, USA*
Jeremy L. Schroeder, *Purdue University, USA*
Timothy D. Sands, *Purdue University, USA*
Alexandra Boltasseva, *Purdue University, USA*

Transition metal nitrides such as titanium nitride show metallic properties at optical frequencies. We report that these materials can be better alternatives to conventional plasmonic materials such as gold and silver for metamaterial applications in the visible range.

17:00 - 17:30 **All-dielectric infrared metamaterials** Invited

Michael Sinclair, *Sandia National Laboratories, USA*

We describe the design, fabrication, and characterization of an all-dielectric metamaterial operating in the thermal infrared. The dielectric metamaterials is based on cubic dielectric resonators fabricated from Tellurium. The metamaterial exhibits a magnetic resonance near 10 microns wavelength and an electric resonance at a slightly shorter wavelength.

17:30 - 17:50 **3D non-resonant-inclusion metamaterials** Oral

D. Bruce Burckel, *Sandia National Laboratories, USA*
Joel R. Wendt, *Sandia National Laboratories, USA*
Eric A. Shaner, *Sandia National Laboratories, USA*
Igal Brener, *Sandia National Laboratories, USA*
Michael B. Sinclair, *Sandia National Laboratories, USA*

Membrane projection lithography (MPL) is a fabrication approach capable of creating submicron-scale metamaterial structures. Here MPL is combined with interferometric lithography (IL) to create IR metamaterials with non-resonant inclusions. Furthermore, we use standard contact lithography to create device structures such as waveguides and interferometers.

17:50 - 18:10 **Antiferromagnetic response of dielectric nanoparticles coupled to split-ring resonators** Oral

Andrey Miroshnichenko, *The Australian National University, Australia*
Boris Luk'yanchuk, *Data Storage Institute, Singapore*
Stefan Maier, *Imperial College London, UK*
Yuri Kivshar, *The Australian National University, Australia*

We analyze optically-induced antiferromagnetic response of a novel hybrid metal/dielectric structure consisting of a silicon nanoparticle coupled to multilayer stacks of split-ring resonators, and observe a strong antiferromagnetic resonance with a staggered pattern of the induced magnetization field. A periodic array of such elements will support a novel type of spin waves.

18:10 - 18:40 **Closing Ceremony** ▸ Room Barcelona B