16th-21st September

Metamaterials 2013
Bordeaux, France

7th International Congress on Advanced Electromagnetic Materials in Microwaves and Optics

Programme

http://congress2013.metamorphose-vi.org
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With our great pleasure we welcome you to the 7th International Congress on Advanced Electromagnetic Materials in Microwaves and Optics (Metamaterials 2013) in Bordeaux, France. This event is organised by the Virtual Institute for Artificial Electromagnetic Materials and Metamaterials (Metamorphose VI) and hosted by the Université de Bordeaux.

The Congress series, initiated by the European Network of Excellence Metamorphose and convened annually by the Metamorphose VI, is widely recognised as the prime event in the metamaterial community. Owing to 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 presenting the latest results in the rapidly growing fields of metamaterials and their applications. The good traditions of the Congress, established and nurtured by its preceding editions, held in Rome (2007), Pamplona (2008), London (2009), Karlsruhe (2010), Barcelona (2011), and St. Petersburg (2012), will be further strengthened and advanced by the Bordeaux event.

This year Congress is very special for us because it coincides with the 20th anniversary of the former International Conference on Complex Media and Metamaterials (Bianisotropics) and 10th anniversary of the Rome International Workshops on Metamaterials and Special Materials for Electromagnetic Applications and TLC. These two main events have paved the way and laid a foundation for the Metamaterials Congress. A Tuesday Special Historical Session is held to celebrate these anniversaries and will set the stage for the future research advancements.

The Congress programme covers a broad range of research activities in artificial electromagnetic materials and surfaces for radio, microwave, terahertz, and optical frequencies as well as in acoustic, superconductor and quantum metamaterials. A balanced mix of plenary and keynote talks, invited, contributed and poster presentations, all subjected to rigorous peer review, encompasses diverse aspects of the fundamental theory, modelling, design, applications, fabrication and measurements.
The Congress is traditionally accompanied by the European Doctoral School on Metamaterials. This year school event is devoted to bottom-up fabrication of metamaterials.

We would like to thank our sponsors and all colleagues who have helped with the Congress organisation and offered their scientific and technical contributions.

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

Sergei Tretyakov, General Chair
Alexander Schuchinsky, General Co-Chair
Filiberto Bilotti, Chair of the Steering Committee
The field of metamaterials has literally exploded in the past few years, and it currently spans a wide range of exciting research activities in RF, THz, optics and UV, as well as other wave regimes, including thermal, mechanical and acoustic waves. In this context of great expansion, and in a moment in which the field has reached an important level of maturity in terms of impact and applications, it is a great honor to chair the technical program committee of this meeting, at a time in which we also celebrate the 20th anniversary since the first Bianisotropics meeting, the direct parent of this conference series.

We have put together a truly exciting program, with three plenary sessions hosting some of the most active players in the field of metamaterials, eight special sessions with keynote speakers focusing on the most recent and hot trends in the area, an impressive collection of confirmed invited speakers, three parallel oral sessions and three full poster sessions. The selection process has been hard, but we believe to have done a good job at preparing a balanced and exciting program that will hopefully draw the interest of the audience up until the last talk on Thursday evening. We are also happy to host two special evening events, one to celebrate the 20th anniversary of the first Bianisotropics meeting, another one to shed light on the interest of funding agencies and high-impact journals in our field of research.

I would like to thank all the TPC members, the special session organizers, the reviewers and the technical staff for their terrific job in putting together this scientific program. As traditional for this meeting, we had a serious review process of all submitted papers, which have been rated by at least two reviewers to make sure that the program really presents the most exciting new research in the field. We do hope that you will enjoy the exciting program ahead of us, and that the oral and poster sessions will be stimulating for the whole community. The sessions and presented topics are very cross-disciplinary, and we have a fabulous set to help enjoying it, a beautiful city with an amazing culture. We hope the meeting will stimulate fruitful discussions for the future of this field of research, during the coffee-breaks, lunches and the poster sessions.

Without taking any more time, hope you will enjoy the meeting and Bordeaux!

Andrea Alù,
Chair of the Technical Programme Committee
Dear Colleagues!

It is a real pleasure to welcome you to Metamaterials 2013, the 7th edition of the International Congress on Advanced Electromagnetic Materials in Microwaves and Optics. The Conference has become over years a reference milestone in the field of Metamaterials, extending its scope to acoustics and other emerging areas.

This year the Congress is held in Bordeaux, France and is hosted by the University of Bordeaux on the Sciences and Technology Campus, in the charming domain of the Agora Conference Centre which was once a convent.

World famous for its wines, Bordeaux is also a historical and touristic city. Walking around the historical centre, you will discover the remains of the old Roman city of Burdigala, the impressive gates of the middle-age walls, the rich architecture of the 18th Century or the modern gardens of the river front with the popular “water-mirror”. You will enjoy the delices of the local cuisine and the friendly atmosphere of the cafés. The weather in September is usually very nice.

We do hope that the Conference will offer an excellent opportunity to present and discuss with your colleagues and friends the most recent advances in the field of Metamaterials. We will do our best to create an excellent atmosphere and make this Conference a memorable event.

Last but not least, on behalf of the Organizing Committee, I wish to thank the University of Bordeaux, the Metamorphose Virtual Institute, the sponsors and supporting companies who made possible the organization of this Conference.

Looking forward to meeting you in Bordeaux,

Philippe Barois, Chair of the Local Organizing Committee
Bordeaux, France

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Bordeaux is an ancient and historic land of majestic chateaux and superb vineyards. The rise of colonial trade together with the growth of the wine industry contributed to Bordeaux’ incredible expansion during the 18th Century.

Today, with a population of 750,000, the historic port city has matured into a 21st Century metropolis, whilst protecting and restoring its 18th Century “golden age” buildings and monuments. In the vineyards, from the medieval village of Saint Emilion to the elegant chateaux of the Médoc and Graves, a keen desire to achieve excellence has shaped a unique cultural landscape, with world-renowned wines and distinctive architecture, featuring gems from several centuries, including leading contemporary designers.

The Bordeaux area also includes wild islands scattered along the largest estuary in Europe, the Dune du Pyla with its amazing view over the Banc d’Arguin and the Atlantic Ocean, as well as oyster-farmers’ huts and chic holiday homes around Arcachon and Cap-Ferret.
Bordeaux, France

An ancient city, founded 2,000 years ago

A classical city with a rich heritage dating back to the Enlightenment

A modern city of Research, Innovation and Technology

A safe city where it feels good to live and to stroll
The Agora Conference Center is situated on the Sciences and Technology Campus of the University of Bordeaux in Talence. Located in the beautiful setting of an old convent, it offers modern and fully equipped conference facilities surrounded by pleasant natural gardens. The Grand Auditorium retains the architecture inspired by the Cistercian monasteries of the former chapel and is adorned by the beautiful stained-glass windows designed by the French glassmaker master Gabriel Loire. The bell-tower is reminiscent of the Roman campaniles of northern Italy. Access by tram (line B, station Forum) is fast and easy from the Bordeaux city centre. A large selection of hotels, shopping areas and historical sites are only 20 minutes away from the Agora Center. Plenty of cafés and restaurants will be happy to welcome you in the heart of the historical quarter where you will enjoy the charming and friendly atmosphere of Bordeaux.
Bordeaux, **France**

**Conference Venue**

![L'Agora du Haut-Carré](image)

![L'espace Agora du Haut-Carré](image)
Metamaterials 2013

Sunday, 15th September

15:00 – 18:00  Sunday registration

Monday, 16th September

07:30 – 09:15  Monday registration

09:15 – 09:30  Opening ceremony

Plenary session 1

09:30 – 10:30  Plenary session 1
Session chairperson: Andrea Alù

09:30 - 10:30  Metamaterials Beyond Electromagnetism

Martin Wegener, Karlsruhe Institute of Technology, Germany
We review our as well as other groups recent progress on metamaterials and coordinate-transformation based architectures for thermodynamics, acoustics, elastostatics, and elastodynamics. We focus on the counterparts of negative-index metamaterials and invisibility cloaking in electromagnetism

10:30 - 11:00  Coffee Break

Oral sessions (Monday morning)

11:00 - 12:30  Active, non-Foster, PT-symmetry metamaterials

11:00 - 12:30  Chiral Metamaterials I

11:00 - 12:30  Microwave & RF metamaterials

11:00 - 12:30  Special session I.1: Active, non-Foster, PT-symmetry metamaterials
Organizer: Vincenzo Galdi
Session chairperson: Vincenzo Galdi
11:00 - 11:30  Non-Foster Element and Dispersion Engineering Approaches to Bandwidth Enhancements in Active Metamaterial-Inspired Structures  
Invited oral

Richard W. Ziolkowski, University of Arizona, USA

Recent applications of non-Foster elements to overcome impedance and directivity bandwidth restrictions imposed by fundamental physics limits associated with passive elements will be described. The relationships between this active element approach at lower frequencies and gain material-based dispersion engineering approaches for optical metamaterial structures will be described.

11:30 – 12:00  Active Nanorod Metamaterials: Loss, Gain and Polarisation Effects  
Invited oral

Anatoly Zayats, King’s College London, United Kingdom

We will discuss active functionalities achievable with plasmonic nanorod metamaterials exhibiting hyperbolic dispersion. Control of gain, loss and nonlinear effects associated with metamaterial constituents will be overviewed. Polarisation manipulation with and its nonlinear control in the metamaterials will also be discussed. Nanorod metamaterials provide flexible and universal platform for designing active nanophotonic components.

12:00 - 12:15  Using PT-Symmetry in Plasmonic Systems for Switching and Dynamic Memory Applications  
Oral

Anatole Lupu, IEF, University Paris Sud, France
Henri Benisty, Laboratoire Charles Fabry, CNRS, Univ. Paris-Sud, France
Aloyse Degiron, IEF, University Paris Sud, France

We address the potential of a coupled plasmonic waveguides system with gain featuring a PT symmetry configuration for the realization of switching and dynamic memory applications based on a non-reciprocal modal behavior. The possibility for a perfect switching operation in such a non-conservative layout combining loss and gain is demonstrated. The positive role of losses allowing to lower the total amount of gain required for switching is particularly emphasized.

12:15 – 12:30  Complex-Coordinate Transformation Optics and PT-Symmetric Metamaterials  
Oral

Giuseppe Castaldi, University of Sannio, Department of Engineering, Italy
Silvio Savoia, University of Sannio, Department of Engineering, Italy
Vincenzo Galdi, University of Sannio, Department of Engineering, Italy
Andrea Alù, The University of Texas at Austin, Department of Electrical and Computer Engineering, USA
Nader Engheta, University of Pennsylvania, Department of Electrical and Systems Engineering, USA

We introduce a complex-coordinate extension of the transformation-optics approach which enables for the generation and modeling of a general class of metamaterials with balanced loss and gain characterized by parity-time (PT) symmetry. The proposed approach allows for the metamaterial-based interpretation and physical implementation of wave-objects (e.g., complex-source-points) and resonant states residing in complex-coordinate spaces.
11:00 - 12:30  **Oral session I.1: Chiral Metamaterials**  
Session chairperson: Femius Koenderink

### 11:00 – 11:30  **THz Control Using Chiral Metamaterials**  
**Invited oral**

**Maria Kafesaki,**  *Foundation for Research and Technology Hellas (FORTH), Institute of Electronic Structure and Laser (IESL), Greece*

**George Kenanakis,**  *FORTH-IESL, Greece*

**Eleftherios Economou,**  *FORTH-IESL, Greece*

**Costas Soukoulis,**  *FORTH-IESL and Iowa State University, USA*

We demonstrate giant optical activity, circular dichroism and negative refractive index response in THz chiral metamaterial structures fabricated on flexible polyimide substrates. Incorporating properly photoconducting silicon in the structures, tunable and switchable chiral response is achieved and demonstrated.

### 11:30 – 11:45  **Omega Transmission Lines**  
**Oral**

**Joni Vehmas,**  *Aalto University, Finland*

**Sergei Tretyakov,**  *Aalto University, Finland*

In this paper, we show how bi-anisotropic media with omega-type response can be realized using periodically loaded transmission lines. General conditions for the needed unit cell circuit block are derived. Also, an implementation is shown and analyzed.

### 11:45 – 12:00  **Non-dispersive Broadband Optical Activity In Interconnected 3D Chiral Metamaterials**  
**Oral**

**Hyun Sung Park,**  *KAIST, Republic of Korea*

**Teun-Teun Kim,**  *KAIST, Republic of Korea*

**Kyungjin Kim,**  *KAIST, Republic of Korea*

**Hyeon-Don Kim,**  *KAIST, Republic of Korea*

**Bumki Min,**  *KAIST, Republic of Korea*

We experimentally demonstrate that non-dispersive broadband optical activity can be realized with an interconnected 3D chiral metamaterial in which the meta-atom possesses four-fold rotational symmetry. For the proof of principle, experiments were conducted in the microwave regime and excellent agreement is found among analytic predictions, numerical simulations, and measurements for nondispersive broadband optical activity in the proposed metamaterials.

### 12:00 – 12:15  **Enhancing Optical Activity in Strongly Coupled Planar Chiral Metamolecules**  
**Oral**

**Sang Soon Oh,**  *Department of Physics, Imperial College London, UK*

**Teun-Teun Kim,**  *Mechanical Engineering, KAIST, Republic of Korea*

**Hyun-Sung Park,**  *Mechanical Engineering, KAIST, Republic of Korea*

**Rongkuo Zhao,**  *Department of Physics, Imperial College London, UK*

**Seong-Han Kim,**  *Advanced Photonics Research Institute, Republic of Korea*

**Bumki Min,**  *Mechanical Engineering, KAIST, Republic of Korea*

**Ortwin Hess,**  *Department of Physics, Imperial College London, UK*

We propose a new way of enhancing the optical activity of planar chiral metamaterials which employs strong coupling between chiral metamolecules to achieve extremely large optical activity. With microwave experiments and numerical simulations, we demonstrate that the strong coupling leads to significant
enhancement of a chirality parameter along with reduced ellipticity. To explain the
effect, we use a coupled $\Omega$-particle model which associates
the gap capacitance with chirality parameter of a double-Z metamaterial.

12:15 – 12:30 **Optical Activity for Twisted Sub-wavelength Hole Arrays** Oral

**Didier Lippens, Université de Lille, France**  
**Shengxiang Wang, Wuhan Textile University, China**  
**Frédéric Garet, Université de Savoie, France**  
**Magali Astic, Université de Savoie, France**  
**Eric Lheurette, Université de Lille, France**  
**Jean Louis Coutaz, Université de Savoie, France**

We show experimentally and numerically that cholesteric-type metal-dielectric
structures made of twisted sub-wavelength hole elliptical–shaped arrays, exhibit
optical activity. The experimental demonstration is carried out by means of time-
domain spectroscopy with a three layered structure operating around 0.5 THz. A
rotary power as high as 1000°/wavelength along with an ellipticity around 30 were
demonstrated experimentally, in good agreement with a full-wave analysis carried
out by numerical simulation in the frequency domain.

11:00 - 12:30 **Oral session I.2: Microwaves & RF Metamaterials I**
Session chairperson: Raj Mittra

11:00 – 11:30 **Superluminal Propagation in Metamaterials: Anomalous Dispersion versus Non-Foster Approach** Invited oral

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

This paper compares superluminal propagation based on anomalous dispersion
and recently introduced non-Foster approach. It is shown that non-Foster approach
offers simultaneous superluminal phase and group velocities that are extremely
broadband (achieved bandwidths vary from 1:20 (more than four octaves) to 1:400
(more than seven octaves)) in contrast to narrowband anomalous-dispersion
approach.

11:30 – 11:45 **Tunable Flat Lens with Liquid Metal Metamaterial** Oral

**Weiming Zhu, EEE, Nanyang Technological University, Singapore**

In this paper, we demonstrate tunable flat lens with liquid metal. The flat lens
consists of 9 x 9 split ring resonators (SRR), which can be controlled individually by
a ternary-notation control system. Each SRR metamaterial unit cell is formed by
liquid metal (mercury) with approximately 1.5 µL, which offer high flexibility in
geometry reconfiguration. In experiment, it demonstrates freely tuning of the sub-
wavelength focus point at 20-cm focus length, which is approximately 10 times of
the incident wavelength.

11:45 – 12:00 **Capacitor-Connected Grids as One-Dimensional UWB Data Transfer Channels** Oral

**Yue Li, Department of Engineering, University of Oxford, UK**  
**Christopher W.T. Chan, Department of Engineering, Oxford University, UK**  
**Christopher J. Stevens, Department of Engineering, Oxford University, UK**
This paper reports on a new metamaterial waveguide, the capacitor-connected grid (CCG). It is constructed by introducing additional electric coupling into traditional purely magnetically coupled MIWs. The largest experimental fractional bandwidth achieved was up to 193.5%, which closely approaches the 200% maximum limit of an UWB channel. This shows great potential of CCG structures for improving bandwidth performance over traditional MIWs.

12:00 – 12:15 Metamaterials Microwave Measurement Using an Original Adjustable Height Stripline Oral

Sandra Gomez, Lab-STICC Université de Bretagne Occidentale, France
Patrick Quéffélec, Lab-STICC Université de Bretagne Occidentale, France
Alexis Chevalier, Lab-STICC Université de Bretagne Occidentale, France

We propose a broadband measurement method (1–6 GHz), for measuring the electromagnetic properties of metamaterials. Here, an original adjustable height strip transmission-line was developed, which allows characterizing several layers of metamaterial. The influence on the measured parameters of the number of unit cells in the sample has been studied.

12:15 – 12:30 Endoscopically Compatible MR-Safe Magneto-Inductive Imaging Catheter Oral

Richard Syms, Imperial College London, United Kingdom
Ian Young, Imperial College London, UK
Munir Ahmad, Imperial College London, UK
Simon Taylor-Robinson, Imperial College London, UK
Marc Rea, Imperial College NHS Trust, UK

Endoscopic compatibility of a catheter-based RF receiver for magnetic resonance imaging is demonstrated. The receiver is based on a self-terminating magneto-inductive waveguide, and constructed as a thin-film circuit on a catheter scaffold. Segmentation and figure-of-eight elements provide protection against transmitter B1 and E fields, respectively. MRI and simulated magnetic resonance cholangio-pancreatography are demonstrated in a 1.5 T field.

12:30 – 14:00 Lunch break (Monday)

Oral sessions (Monday afternoon 1)

14:00 - 15:30 Bottom-up and Self-Assembled Metamaterials
14:00 - 15:30 Nanoantennas
14:00 - 15:30 Microwave and RF Metamaterials II
14:00 - 15:30 Special session I.2: Bottom-up and Self-Assembled Metamaterials

Organizer: Philippe Barois
Session chairperson: Philippe Barois
14:00 – 14:30 What Materials Science Can Give to Metamaterials and What Metamaterials Can Give to Materials Science Invited oral

Dorota Anna Pawlak, Institute of Electronic Materials Technology, Poland

Utilizing directional solidification as a method for manufacturing metamaterials and plasmonic materials will be discussed. We developed two methods: (i) method based on directionally-grown self-organized eutectic structures; and (ii) NanoParticles Direct Doping method (NPDD) based on directional solidification of dielectric matrices doped with various nanoparticles.

14:30 – 14:45 Optically Anisotropic Self-Assembled Plasmonic Nanocomposites Oral

Clemence Tallet, CNRS-Univ. Bordeaux, CRPP, France
Kevin Ehrhardt, CNRS-Univ. Bordeaux, CRPP, France
Julien Vieaud, CNRS-Univ. Bordeaux, CRPP, France
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Ashod Aradian, CNRS-Univ. Bordeaux, CRPP, France
Virginie Ponsinet, CNRS-Univ. Bordeaux, CRPP, France

We study the relation between structure and optical properties in self-assembled lamellar plasmonic nanocomposites. The nanocomposites are produced by the assembly of plasmonic nanoparticles templated by ordered matrices of block copolymers and have a periodic lamellar structure of period between 50 and 100 nm. Their structure is studied by X-ray scattering and electron microscopy. Their optical properties are determined by spectroscopic ellipsometry and analyzed by appropriately developed effective medium models. The possible application in the production of hyperbolic materials is discussed.

14:45 – 15:00 Microfluidic-Assisted Growth of Densely-Packed Arrays of Nanoparticles Oral

Antonio Iazzolino, Université de Bordeaux, LOF, France
Julie Angly, Université de Bordeaux, LOF, France
Jean-Baptiste Salmon, Université de Bordeaux, LOF, France
Jacques Leng, Université de Bordeaux, LOF, France
Aurélie Le Beulze, Université de Bordeaux, ICMCB, France
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Virginie Ponsinet, Université de Bordeaux, CRPP, France
Miguel Correa-Duarte, Departamento de Quimica Fisica, Universidade de Vigo, Spain

We use evaporation within a microfluidic device to extract the solvent of a dispersion of metal-based nanoparticles and to concentrate them until a solid made of densely-packed nanoparticles grows and totally invades the microfluidic geometry. It permits us to grow and shape-up solids, including superlattices and extended and thick arrays of nanoparticles, made of unary and binary dispersions, composites, and hetero-junctions between distinct types of nanoparticles. In all cases, the geometry of the final solids is imparted by that of the microfluidic device and their surfaces are flat within optical quality.
15:00 – 15:15 Tunable Magnetic Dipole Response of Core-Shell Clusters

**Oral**

**Martin Fruhnert**, Friedrich-Schiller-Universität Jena, Germany  
**Stefan Mühlig**, Friedrich-Schiller-Universität Jena, Germany  
**Carsten Rockstuhl**, Friedrich-Schiller-Universität Jena, Germany  
**Falk Lederer**, Friedrich-Schiller-Universität Jena, Germany

We investigate the magnetic response of meta-atoms amenable for a fabrication with bottom-up techniques. The meta-atoms consist of a dielectric core surrounded by a huge number of plasmonic nanoparticles. Contrary to the meta-atoms considered thus far, we study here for the first time hollow plasmonic nanoparticles instead of solid. With such building blocks we solve two of the most pertinent problems of nowadays self-assembled metamaterials. The first is the requirement to encounter a resonance at deep-subwavelength structures; necessary to consider the metamaterial as effectively homogenous. The second is the requirement of a huge resonance strength at sufficiently small absorption; necessary to observe negative material parameters. Having solved these problems, self-assembled negative index materials come in reach, as will be also shown in our contribution.

15:15 – 15:30 Optical Properties of Strongly Coupled 2D Trimer and 3D Tetramer Plasmonic Structures

**Oral**

**Xingzhan Wei**, School of Chemistry and Bio21 Institute, University of Melbourne, Australia  
**Steven Barrow**, School of Chemistry and Bio21 Institute, University of Melbourne, Australia  
**Alison Funston**, School of Chemistry, Monash University, Australia  
**Paul Mulvaney**, School of Chemistry and Bio21 Institute, University of Melbourne, Australia

We present DNA-directed self assembly of 2D trimer, and unique 3D clusters. We conclude that drastically enhanced local fields are produced within the interparticle gaps. Even interestingly, the symmetric clusters can exhibit polarization-independent characteristics, and Fano resonances are generated when the symmetry is broken.

14:00 - 15:30 Oral session I.3: Nanoantennas

Session chairperson: Martin Wegener

14:00 – 14:30 Metamaterial Scatterers, Antennas and Gratings: Polarizability, Radiation Damping and Emission Control with a Magnetic Twist

**Invited oral**

**Femius Koenderink**, Center for Nanophotonics, FOM Institute AMOLF, Netherlands  
**Ivana Sersic**, Center for Nanophotonics, FOM Institute AMOLF, Netherlands  
**Felipe Bernal Arango**, Center for Nanophotonics, FOM Institute AMOLF, Netherlands  
**Andrej Kwadrin**, Center for Nanophotonics, FOM Institute AMOLF, Netherlands

The subwavelength building blocks that metamaterials are composed of are like very strong plasmonic scatterers, but with in addition a strong magnetic response. An essential questions we deal with is how to retrieve this polarizability from experiment and simulations. Furthermore, we design new nanoantennas that probe and manipulate electric dipole LDOS, magnetic LDOS and magneto-electric LDOS.
14:30 – 15:00  Superdirective Magnetic Nanoantennas with Effect of Light Steering: Theory and Experiment  
Extended oral
Alexandr Krasnok, ITMO, St Petersburg, Russia
Dmitry Filonov, ITMO, St Petersburg, Russia
Alex Slobzhanyuk, ITMO, St Petersburg, Russia
Constantin Simovski, Radio Science and Engineering Dept., Aalto University, Finland
Pavel Belov, ITMO, St Petersburg, Russia
Yuri Kivshar, Nonlinear Physics Center, Australian National University, Australia

We introduce a novel concept of superdirective nanoantennas based on the generation of higher-order optically-induced magnetic multipoles. Such an all-dielectric nanoantenna can be realized as an optically small spherical dielectric nanoparticle with a notch excited by a point source located in the notch. Proposed superdirectivity effect is not associated with high dissipative losses, because of the magnetic nature of the nanoantenna operation. For these dielectric nanoantennas we predict the effect of the beam steering at the nanoscale characterized by a subwavelength sensitivity of the beam radiation direction to the source position. We confirm the predicted effects experimentally through scaling to the microwave frequency range.

15:00 – 15:15  Tailoring the Electric and Magnetic Response of All-Dielectric Nanodiscs  
Oral
Dragomir Neshev, Australian National University, Australia
Isabelle Staude, Australian National University, Australia
Manuel Decker, Australian National University, Australia
Andrey Miroshnichenko, Australian National University, Australia
Tumasang Fofang, Sandia National Laboratories, USA
Sheng Liu, Sandia National Laboratories, USA
Edward Gonzales, Sandia National Laboratories, USA
Ting Luk, Sandia National Laboratories, USA
Igal Brener, Sandia National Laboratories, USA
Yuri Kivshar, Australian National University, Australia

We demonstrate numerically and experimentally that high-dielectric nano-disks made of silicon can exhibit simultaneously magnetic and electric resonances. We show that the spectral position of the resonances can be tailored by varying the disk height to radius aspect ratio. Furthermore, there exist a critical aspect ratio where both resonances can fully overlap. This overlap offers new opportunities for functional metasurfaces as well as for conceptually new all-dielectric metamaterials and unidirectional nanoantennas.

15:15 – 15:30  Modeling Large Metasurfaces Comprised of Nonuniform Plasmonic Nanorods Arrays  
Oral
Tianyu Dong, State Key Lab of Electrical Insulation and Power Equipment, School of Electrical Engineering, Xi'an Jiaotong University, China
Raj Mittra, Electromagnetic Communication Laboratory, Department of Electrical Engineering, The Pennsylvania State University, USA
Xikui Ma, State Key Lab of Electrical Insulation and Power Equipment, School of Electrical Engineering, Xi'an Jiaotong University, China

In this work, we present a numerically efficient technique, called the Characteristics Basis Function Method (CBFM), to model large non-uniform plasmonic arrays of...
nanorods. The use of the CBFM dramatically reduces the number of unknowns without sacrificing the computational accuracy and enables us to handle large, truncated and non-uniform arrays. The method is rigorous and includes the mutual coupling effects to obtain accurate results. Furthermore, the method is readily parallelizable and is capable of handling arrays comprised of nanoantennas with complex shapes, without any difficulty.

14:00 - 15:30 **Oral session I.4: Microwave & RF Metamaterials II**

Session chairperson: Ferran Martin

14:00 – 14:15 **Enhanced Transmission of Electromagnetic Radiation Through Two Subwavelength Slits**

*Oral*

Steve Young, *University of Michigan Physics, USA*
Carl Pfeiffer, *University of Michigan Electrical Engineering, USA*
Anthony Grbic, *University of Michigan Electrical Engineering, USA*
Roberto Merlin, *University of Michigan Physics, USA*

We demonstrate strong resonant enhancement of transmission through two parallel slotted conducting plates, where the slits are small relative to the wavelength (~wavelength/10), using finite element calculations and experimental characterization at 10 GHz. The enhancement occurs when the incident electric field is parallel to the slits and the plates are separated by approximately half the wavelength. Because the resonance is sharp, conduction losses in the plates limit the transmission. Nevertheless, at 10 GHz we observe greater than $10^4$ enhancement compared to off-resonant transmission through the slits.

14:15 – 14:30 **Tailoring Lattice Parameters for Broadband Artificial Diamagnetism**

*Oral*

Anastasia Krylova, *NRU ITMO, St. Petersburg, Russia*
Mikhail Lapine, *The University of Sydney, Australia*
Chris Poulton, *University of Technology Sydney, Australia*
Ross McPhedran, *The University of Sydney, Australia*
Yuri Kivshar, *Australian National University, Australia*
Pavel Belov, *NRU ITMO, St. Petersburg, Russia*

We report a strategy to achieve the values of the effective magnetic permeability close to zero by using anisotropic metamaterial made of dense arrays of conductive loops. We present an extensive parametric analysis of the role of lattice parameters and symmetry, and also of the geometry of the loops. The magnitudes of the real part of the permeability reach 0.05 and are observed in a very broad frequency span, accompanied with negligible dissipation. Importantly, our analysis is applicable in a wide range of absolute sizes, being appropriate up to the THz range. Finally, we assess the dielectric properties of the optimal diamagnetic metamaterials, providing a complete picture of its interaction with the electromagnetic waves.

14:30 – 14:45 **Experimental Demonstration of μ-Near-Zero Metamaterials**

*Oral*

Ilya Yagupov, *Metamaterials Laboratory, NRU ITMO, St.Petersburg, Russia*
Alexey Slobozhanyuk, *Photonic and Optical Informatics Dept., NRU ITMO, St.Petersburg, Russia*
Dmitry Filonov, *Photonic and Optical Informatics Dept., NRU ITMO, St.Petersburg, Russia*
Polina Kapitanova, *Photonic and Optical Informatics Dept., NRU ITMO,*
We manufacture and analyse a metamaterial composed as a square lattice of nonmagnetic metallic cubes. We present numerical simulations of this metamaterial and confirm a possibility to obtain extremely low permeability values. We show that the practical assembly is quite sensitive to fabrication tolerances, and demonstrate that permeability of about $\mu = 0.15$ can be achieved experimentally.

14:45 – 15:00 Experimental Evidence for Super-Resolution in the Spherical Geodesic Waveguide Oral

Dejan Grabovičkić, Cedint, Universidad Politécnica de Madrid, Spain
Juan Carlos González, Cedint, Universidad Politécnica de Madrid, Spain
Hamed Ahmadpanahi, Cedint, Universidad Politécnica de Madrid, Spain
Jorge Carbonell, Departamento de Ingeniería Electronica, Universitat Politècnica de Valencia, Spain
Juan Carlos Miñano, Cedint, Universidad Politécnica de Madrid, Spain
Pablo Benítez, Cedint, Universidad Politécnica de Madrid, Spain
José Sánchez-Dehesa, Departamento de Ingeniería Electronica, Universitat Politècnica de Valencia, Spain

In the paper we present the experimental results for a manufactured Spherical Geodesic Waveguide, showing the super-resolution up to $\lambda/25$. The results obtained by the experiment and COMSOL simulation are similar, which confirms the precision of the measurements.

15:00 – 15:15 Towards High-Impedance Surfaces Realization Using Single-Layer Arrays of Electrically Small Particles Oral

Younes Ra’di, Department of Radio Science and Engineering/SMARAD Center of Excellence, Aalto University, Finland
Viktar Asadchy, Department of Physics, Gomel State University, Belarus
Sergei Tretyakov, Department of Radio Science and Engineering/SMARAD Center of Excellence, Aalto University, Finland

We consider possible realizations of artificial magnetic conductors (high-impedance surfaces) as single-layer arrays of electrically small resonant particles. In contrast to the conventional designs (like “mushroom” layers), this approach does not require a ground plane and needs only one layer of electrically small particles.

15:15 – 15:30 Lenters - The Evolution from Filter to Lens and Beyond. Oral

Paul Moseley, University College London, United Kingdom
Giorgio Savini, University College London, uk
Elena Saenz, ESTEC, Netherland
Jin Zhang, Cardiff University, UK
Peter Ade, Cardiff University, UK
A prototype gradient index lens has recently been produced by using a stack of frequency selective surfaces, based on a square patch unit cell. The lens was modelled using a transmission line method (TLM) and HFSS. Additional measurements have been taken using a VNA which allows for detailed magnitude and phase information at precise frequencies. The lens has a broadband performance due to non resonating metamaterial structure used. A proposed solution is given to increase the performance of the GRIN lens by the use of antireflection coating built into the design of the lens.

15:30 - 16:00 Coffee break (Monday afternoon)

Oral sessions (Monday afternoon 2)

16:00 - 17:45 Smart, Hybrid, Multifunctional Metamaterials  
Auditorium

16:00 - 17:45 Light Concentrators & Nanoantennas  
Badiane Hall

16:00 - 17:45 Microwave & RF Metamaterials III  
Patio Hall

16:00 - 17:45 Special session I.3: Smart, hybrid, multifunctional metamaterials  
Organizer: Yaroslav Urzhumov  
Session chairperson: Yaroslav Urzhumov  
Auditorium

16:00 – 16:30 Driving Reconfigurable Photonic Metamaterials with Light and Electrical Signals: Exploiting Forces and Fields at the Nanoscale  
Keynote

Nikolay Zheludev, University of Southampton, United Kingdom
Eric Plum, University of Southampton, United Kingdom
Kevin F. MackDonald, University of Southampton, United Kingdom
J. Ou, University of Southampton, United Kingdom
Jianfa Zhang, University of Southampton, United Kingdom
Joao Valente, University of Southampton, United Kingdom
W.M. Zhu, Nanyang Technological University, Singapore
A.Q. Liu, Nanyang Technological University, Singapore

Metamaterials, artificial electromagnetic media achieved by structuring on the sub-wavelength scale, were initially suggested as negative index media for the “superlens” and for transforming electromagnetic space to control the propagation of waves. The research agenda is now shifting to achieving tuneable, switchable, nonlinear and sensing functionalities using metamaterials. We show how engaging the changing balance of forces and plasmonic light confinement at the nanoscale opens up the burgeoning field of reconfigurable photonic metadevices - structures that can be controlled by external electric and magnetic signals and by light by engaging Coulomb, Ampere and Lorentz forces.

16:30 – 17:00 Elastically Self-Adjustable Electromagnetic Cloaking Using Smart Metamaterials  
Invited oral

Kyoungsik Kim, Yonsei university, Korea (South)
Dongheok Shin, Yonsei university, Korea (South)
Yaroslav Urzhumov, Duke university, USA
Youngjean Jung, Yonsei university, Korea (South)
David Smith, Duke university, USA

We propose a smart metamaterial whose electromagnetic properties can be effectively changed by mechanical deformation. With this concept, we experimentally test self-adjustable carpet cloak whose functionality derives from quasi-conformal coordinate transformations.

17:00 – 17:15 Quantum Opto-Mechanical Phenomena in Hyperbolic Metamaterials

Pavel Ginzburg, King’s College London, United Kingdom
Alexey Krasavin, King’s College London, United Kingdom
Alexander N. Poddubny, ITMO, St. Petersburg, Russia
Alexander S. Shalin, ITMO, St. Petersburg, Russia
Mazhar Nasir, King’s College London, United Kingdom
James Levitt, King’s College London, United Kingdom
Klaus Suhling, King’s College London, United Kingdom
Pavel A. Belov, ITMO, St. Petersburg, Russia
Yuri S. Kivshar, Australian National University, Canberra, Australia
Anatoly V. Zayats, King’s College London, United Kingdom

Optical forces are the fundamental phenomena important in various fields of science, from astronomy to biology. Generally, intense external radiation sources are required to achieve measurable effects, vital for applications. Metamaterials could provide a promising endeavor to this problem. Here we demonstrate that quantum emitters placed in a homogeneous anisotropic medium induce self-torques, aligning themselves in the well-defined direction, determined by the anisotropy, in order to maximize their radiation efficiency. We developed a universal quantum-mechanical theory of self-induced torques acting on the emitter placed in material environment. We show more than 2 orders of magnitude self-torque enhancement by an anisotropic metamaterial with hyperbolic dispersion, having negative ratio of permittivity tensor components, in comparison to conventional anisotropic crystal with the highest naturally available anisotropy. Estimated torques hold a promise for various applications, such as studies of molecular dynamics and quantum information processing. Preliminary experimental data show the evidence of the proposed effects.

17:15 – 17:30 Optical Bistable Element Using Phase Transition Materials

Uday Chettiar, University of Pennsylvania, USA
Nader Engheta, University of Pennsylvania, USA

Optical bistability in the presence of optical nonlinearity is widely understood and used in numerous applications. In this work we are exploring the possibility of using phase transition materials to achieve an optical bistable element. Phase transition materials like vanadium dioxide can give rise to significant change in optical properties while undergoing a phase change. Consequently we can get a nanoscale bistable element where the intensity requirements to achieve bistability may be less than that using conventional bistable elements.

17:30 – 17:45 Semiconductor-Based Non-Reciprocal Gyrotropic Metamaterials Requiring No External Magnetic Field

Christophe Caloz, École Polytechnique de Montréal, Canada
Toshiro Kodera, Yamaguchi University, Japan
Dimitrios L. Sounas, The University of Texas at Austin, U.S.A.

The paper presents an overview of the novel paradigm of semiconductor-based nonreciprocal gyrotropic metamaterials. These metamaterials achieve non-reciprocity via an external electric current, in contrast to ferromagnetic, magneto-
optic and plasma materials, which require an external magnetic field. They subsequently exhibit major advantages for applications.

16:00 - 17:45 Oral session I.5: Light concentrators & Nanoantennas
Session chairperson: Richard W. Ziolkowski
Badiane Hall

16:00 – 16:30 Solitonic Metamaterial-Driven Magnetooptic Structures, Vortex Creation and Energy Concentrators Invited oral
Allan Boardman, University of Salford, United Kingdom
Peter Egan, University of Salford, United Kingdom
Yuriy Rapoport, Kyiv Taras Shevchenko National University, Ukraine

Nonlinear metamaterial-driven waveguide geometries are discussed with an emphasis upon solitonic behaviour and the critical role of magnetooptics as a controlling influence that will drive not only applications but some future directions of metamaterial creation. The exotic family of excitations that emerge will include highly structured light in the form of optical vortices, which can be shaped to take advantage of a new, nonlinear, diffraction that dominates over nonparaxiality. Finally, a brief introduction to novel nonlinear energy concentrators is developed.

16:30 – 17:00 Ultrahigh-Efficiency Solar Cells based on Metamaterial Design Invited oral
Albert Polman, Center for Nanophotonics, FOM Institute AMOLF, Netherlands

For decades solar-cell efficiencies have remained far below the thermodynamic limits. New approaches to light management using resonant plasmonic and dielectric nanostructures and metamaterials enable ultrahigh efficiencies previously considered impossible.

17:00 – 17:15 Stopped Light Lasing in Plasmonic Waveguides Oral
Tim Pickering, Imperial College London, United Kingdom
Adam Page, Imperial College London, United Kingdom
Sebastian Wuestner, Imperial College London, United Kingdom
Joachim Hamm, Imperial College London, United Kingdom
Ortwin Hess, Imperial College London, United Kingdom

We investigate the coupling of an active gain medium to the stopped-light point in a 1D plasmonic Metal-Insulator-Metal (MIM) waveguide. By considering a gain region of finite lateral extent in the core of the waveguide we show how a highly localised lasing state can be formed. By varying the width of this gain section we test the limits of this new type of light localisation and investigate the physical mechanisms behind the stopped-light lasing state.

17:15 – 17:30 Ultralow-Loss, Isotropic 2D Optical Negative-Index Metamaterials based on Metal-Semiconductor Core-Shell Nanowires Oral
Jose A. Sanchez-Gil, Instituto de Estructura de la Materia (CSIC), Spain
Ramon Paniagua-Dominguez, Instituto de Estructura de la Materia (CSIC), Spain
Diego R. Abujetas, Instituto de Estructura de la Materia (CSIC), Spain
Fernando Lopez-Tejeira, University of Zaragoza, Spain
Luis Froufe-Perez, Instituto de Estructura de la Materia (CSIC), Spain
Ricardo Marques, University of Seville, Spain

Here we propose a 2D isotropic metamaterial with negative electric and magnetic responses in the optical regime, based on hybrid metallo-dielectric core-shell
nanowires. The magnetic response stems from the lowest magnetic resonance of the dielectric shell with high refractive index (i.e., lossless semiconductor), and can be tuned to coincide with the plasmon resonance of the metal core, responsible for the electric response. Also, their scattering properties are investigated in connection with directionality and invisibility.

17:30 – 17:45 Enhanced Light Trapping with Optical Nanoantennas for Thin-Film Solar Cells Oral

Constantin Simovski, Aalto University, School of Electrical Engineering, Department of Radio Science and Engineering, Finland
Dmitry Morits, Aalto University, School of Electrical Engineering, Department of Radio Science and Engineering, Finland
Pavel Voroshilov, Saint Petersburg National Research University of Information Technologies, Mechanics and Optics, Russia
Michael Guzhva, Saint Petersburg National Research University of Information Technologies, Mechanics and Optics, Russia
Pavel Belov, Saint Petersburg National Research University of Information Technologies, Mechanics and Optics, Russia
Yuri Kivshar, Nonlinear Physics Center, Research School of Physics and Engineering, Australian National University, Australia

We propose a new type of efficient light-trapping structures for thin-film solar cells based on arrays of planar nanoantennas whose operational band doesn’t match with plasmonic resonances. The operation of our light-harvesting structures is based on the excitation of collective modes of the nanoantenna arrays whose electric field is localized between the adjacent metal elements.

16:00 - 17:45 Oral session 1.6: Microwave & RF Metamaterials III Session chairperson: Silvio Hrabar

16:00 – 16:30 Differential Dual-Band Impedance Inverter with Common Mode Suppression based on Composite Right/Left Handed (CRLH) Transmission Lines Invited oral

Paris Velez, CIMITEC - Universitat Autonoma de Barcelona, Spain
Miguel Duran-Sindreu, CIMITEC - Universitat Autonoma de Barcelona, Spain
Jordi Bonache, CIMITEC - Universitat Autonoma de Barcelona, Spain
Ferran Martin, CIMITEC - Universitat Autonoma de Barcelona, Spain

In this work, a differential dual-band impedance inverter with common mode rejection operating at f1=1.8GHz (GSM band) and f2=2.4GHz (ISM band) is presented. The designed impedance inverter is based on a TI-type differential composite right/left handed (CRLH) transmission line implemented in microstrip technology through semi-lumped resonators; that is, stepped impedance resonators (SIRs) for the shunt branch, and interdigital capacitors series connected to inductive strips for the series branch. The device exhibits its functionality at the design frequencies, with a common mode rejection ratio (CMRR) better than 35dB. The total occupied area of the common mode suppressed differential dual-band impedance inverter is 0.37λx0.27λ (where λ is the guided wavelength at f1).

16:30 – 17:00 New Results on Extraordinary Optical Transmission and Fishnet Metamaterials Invited oral

Vicente Jesús Delgado Pozo, University of Seville, Spain
Ricardo Marqués Sillero, University of Seville, Spain
Lukas Jelinek, Czech Technical University in Prague, Czech Republic

A generalized transverse waveguide analysis for Extraordinary Transmission (ET) and Fishnet Metamaterials (FMs) in realistic metallic screens has recently been published by the authors. The model is valid for lossy metallic screens thanks to the Surface Impedance (SI) approximation. A standard scattering matrix formalism makes the model applicable to stacked screens with possible dielectric boards. A number of reported phenomena related to screens with a periodic array of slits or holes are reproduced efficiently with the presented analysis. New interesting results are presented now.

17:00 – 17:15 Design and Operation of a Negative-Index Parallel-Plate Metamaterial Oral

Nicholas Estep, The University of Texas at Austin, USA
AmirNader Askarpour, The University of Texas at Austin, USA
Andrea Alu, The University of Texas at Austin, USA

We discuss the design and modeling challenges for a negative index (NI) metamaterial realized with patterned parallel-plate technology containing etched-out complementary split ring resonators. We present an optimized unit cell design and discuss the anisotropic nature of this configuration and ways to reduce it within the NI band.

17:15 – 17:30 Accurate Analytical Model of Coupled Omega Particles for Metamaterial Design Oral

Davide Ramaccia, "RomaTre" University, Italy
Filiberto Bilotti, "RomaTre" University, Italy
Alessandro Toscano, "RomaTre" University, Italy

We propose an analytical model of the bi-omega particle consisting of two opposite-oriented and spaced omega resonators. Properly placing the two omega particles very close to each other, the coupling effect between them contributes to shift down the resonant frequency, achieving a simple and deeply electrically small inclusion for the design of metamaterials with negative permeability working in the microwave frequency range. The proposed model, based on the small antenna theory, takes into account all the coupling effects that comes into play when the distance between the two omegas is very small. The results of the analytical model are compared to the numerical ones, showing a very good agreement.

17:30 – 17:45 Spoof Surface Plasmons on Ultrathin Corrugated Metal Structures in Microwave and Terahertz Frequencies Oral

Tie Jun Cui, Southeast University, China
Xiaopeng Shen, Southeast University, China

Structured metal surfaces can support spoof surface plasmons (SPs) in the microwave and terahertz frequencies, opening up a new road to manipulate the surface electromagnetic waves in subwavelength scales. The strong field confinements and fantastic plasmonic effects have motivated a vast range of studies and applications. However, the existing spoof SP structures are difficult to be integrated due to the nonplanar features. In this presentation we will review our recent work on the spoof SPs on ultrathin textured metallic surfaces, including the printed planar surface plasmon polaritons (SPPs) and conformal SPPs propagating on ultrathin corrugated metallic strips, and the spoof multipolar localized SPs on ultrathin textured metallic disks. We show that the proposed designs are versatile and flexible to route and localize SPs by numerical simulations and experiments. Hence the proposed ultrathin textured metallic structures have potential applications in building plasmonic components and sensors in the microwave and terahertz frequencies.
18:00 - 19:15  **Evening special session**

**20th Anniversary of the Metamaterials Conference and its Impact on the Field**

Organizers: Nader Engheta; Ari Sihvola
Session chairpersons: Nader Engheta; Ari Sihvola

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18:00 - 18:15

**From Complex Media to Metamaterials: Early History of the Congress Series**

Ari Sihvola,  *Aalto University, Finland*

The series of Metamaterials Congresses is running healthy and expanding its impact and importance for the scientific community. This presentation traces the history of the congress series into its origins from the end of 20th century.

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18:15 - 18:30

**What’s New in the Electrodynamics of Metamaterials Made?**

Victor Veselago,  *A.M.Prokhorov Institute of General Physics, Russia*

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18:30 - 18:45

**From Artificial Engineered Materials to Metamaterials: 10th Anniversary of the Rome Workshops on “Metamaterials and Special Materials for Electromagnetic Applications and TLC”**

Filiberto Bilotti,  *"Roma Tre" University, Italy*
Giuseppe Pelosi,  *University of Florence, Italy*
Alessandro Toscano,  *"Roma Tre" University, Italy*
Lucio Vegni,  *"Roma Tre" University, Italy*

Metamaterials Congress was initiated in 2007 by the FP6 Network of Excellence Metamorphose as the fusion between the series of conferences Bianisotropics and the series of the international workshops Metamaterials and Special Materials for Electromagnetic Applications and TLC. This year we celebrate the 20th anniversary of the Bianisotropics (previously called Bi-isotropics) conference and the 10th anniversary of the meta-workshops. In this contribution, we present a brief history of the meta-workshops and how they merged with Bianisotropics to originate the Metamaterials Congress. In particular, by using the paradigmatic example of the artificial chiral materials, we would also like to reflect the status of the research on complex media in the late 90s and in the beginning of the new century, in order to highlight the reasons behind the contemporary origin of the meta-workshops and of the network Metamorphose.

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18:45 - 19:00

**Metamaterials: New Phenomena, Challenges and Opportunities**

George Eleftheriades,  *U. Toronto/ECE, Canada*

The field of metamaterials in now over thirteen years old (excluding work in artificial dielectrics and other related work that preceded metamaterials). Over these years, new and exciting physical phenomena have been established such as negative refraction, the resonant "amplification" of evanescent waves, forward and backward radiation from single leaky-wave antennas, controlled optical magnetic effects, controlled spatial distribution of the electromagnetic fields by bulk metamaterials and "metasurfaces", and many more. The challenge now is how to exploit these
new physical phenomena for real-world applications. We will review some of these new physical phenomena and critically discuss their potential applications in areas such as imaging, wireless communications and defence.

19:00 – 19:15  **Metamaterials: Where Do We Go From Here?** Oral

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

Celebrating the 20th anniversary of our metamaterials conference, we discuss how much impact this series of conferences, which dates back to Chiral’93 in Espoo, Finland in 1993, has had on the development of the field of metamaterials. Then looking to the future, we provide a personal forecast, perspective and prediction of where our field may go from here.

19:15 – 21:30  **Welcome Reception / Buffet dinner**

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**Tuesday, 17th September**

**Oral sessions (Tuesday morning)**

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<td>09:00 – 10:30</td>
<td><strong>Metamaterials for Emission and Radiative Heat Control I</strong></td>
<td>Auditorium</td>
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<td>09:00 – 10:30</td>
<td><strong>Hyperbolic Metamaterials</strong></td>
<td>Badiane Hall</td>
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<td>09:00 – 10:30</td>
<td><strong>Metamaterials for Antennas I</strong></td>
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<td>09:00 – 10:30</td>
<td><strong>Special session II.1: Metamaterials for Emission and Radiative Heat Control I</strong></td>
<td>Auditorium</td>
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<td>09:00 – 09:30</td>
<td><strong>Optimization of Radiative Heat Transfer in Hyperbolic Metamaterials for Thermophotovoltaic Applications</strong> Keynote</td>
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<td><strong>Constantin Simovski, Aalto University, Finland</strong></td>
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<td><strong>Sergei Tretyakov, Aalto University, Finland</strong></td>
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<td>We analyze the radiative heat transfer in micron-thick multilayer stacks of metamaterials with hyperbolic dispersion. We show that the huge transfer of near-infrared thermal radiation across micron layers of metamaterials is achievable and can be optimized at high temperatures and, moreover, is compatible with the frequency selectivity. The double functionality makes hyperbolic multilayer stacks promising for micron-gap thermophotovoltaics.</td>
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<td>09:30 – 10:00</td>
<td><strong>Semiconductor Metamaterial Thermal Emitters</strong> Invited oral</td>
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<td><strong>Jon Schuller, UC Santa Barbara, USA</strong></td>
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<td>In this talk, we will experimentally and theoretically characterize the resonant modes of subwavelength rod-shaped dielectric particles and demonstrate their use in</td>
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negative index metamaterials and novel infrared light emitters. We will conclude the talk by discussing our ongoing efforts to make silicon-based metamaterial thermal emitters.

10:00 – 10:30 **Equivalent Circuit Approach for Radiative Heat Transfer Problems**  
Extended oral

*Stanislav Maslovski, Universidade de Coimbra, Portugal*
*Constantin Simovski, Aalto University, Finland*
*Sergei Tretyakov, Aalto University, Finland*

Here, we consider radiative thermal transfer in multilayered structures with arbitrary distribution of temperatures and electromagnetic properties among the layers. We show that an equivalent circuit model can be formulated for such problems, which has proven to be very handy in studies of radiative heat transfer effects in metamaterial structures.

09:00 - 10:30 **Oral session II.1: Hyperbolic Metamaterials**  
Session chairperson: C.T. Chan

09:00 – 09:30 **Optical Hyperspace: Light Propagation and Related Phenomena in Metamaterials with Hyperbolic Dispersion**  
Invited oral

*Evgenii Narimanov, Purdue University, USA*

Metamaterials with hyperbolic dispersion (where two eigenvalues of the dielectric permittivity tensor have opposite signs) exhibit a broad bandwidth singularity in the photonic density of states, with resulting manifestations in a variety of phenomena, from spontaneous emission to light propagation and scattering. In this presentation, I will review some of the recent developments in this field.

09:30 – 10:00 **A Titanium Nitride-based Hyperbolic Metamaterial in the Visible and Infrared**  
Invited oral

*Gururaj Naik, Purdue University, USA*
*Bivas Saha, Purdue University, USA*
*Sammy Saber, Purdue University, USA*
*Eric Stach, Purdue University, USA*
*Timothy Sands, Purdue University, USA*
*Vladimir Shalaev, Purdue University, USA*
*Alexandra Boltasseva, Purdue University, USA*

Epitaxially grown TiN/(Al,Sc)N superlattices behave as hyperbolic metamaterials in the visible range. The individual superlattice layers are found to be ultrathin (down to 2 nm), ultrasmooth (rms < 0.2 nm), and have sharp interfaces. The epitaxial-quality hyperbolic metamaterial shows much higher transmission than its metal-based counterparts and is useful in applications such as a hyperlens where light transmission through the metamaterial is important.

10:00 - 10:15 **Highly Directional Spontaneous Emission Enhancement in Hypergrating-Based Optical Hyperbolic Metamaterials**  
Oral

*Antonio De Luca, University of Calabria, Italy*
*Sreekanth Kandammathe Valiyaveedu, Department of Physics, Case Western Reserve University, USA*
*Giuseppe Strangi, Department of Physics, Case Western Reserve University, USA*
We report the fabrication of a hyperbolic metamaterial (HMM) based on Au/TiO2 multilayers and demonstrate the modification of spontaneous emission using a hypergrating-based configuration. The proposed HMM shows a hyperbolic dispersion at optical frequencies, above 548 nm wavelength. The proposed has potential applications such as single photon sources, fluorescence imaging and single molecule detection.

10:15 – 10:30 Absorption of Near Fields Generated by a Two-Dimensional Array of Dipoles Above a Hyperbolic Metamaterial Oral

Caner Guclu, University of California, Irvine, USA
Salvatore Campione, University of California, Irvine, USA
Filippo Capolino, University of California, Irvine, USA

We investigate the power emitted by a two-dimensional array of impressed dipoles above a hyperbolic metamaterial (HM). Transmission line formalism of TM/TE spectral plane waves is used to model the scattering from the HM substrate. We show that the HM enhances the amount of emitted power which is mostly absorbed by the HM.

09:00 - 10:30 Oral session II.2: Metamaterials for Antennas I
Session chairperson: Douglas H. Werner

09:00 - 09:30 EBG Superstrate Based Antennas for Space Applications Invited oral

Ramon Gonzalo, Universidad Publica de Navarra, Spain
Inigo Ederra, Universidad Publica de Navarra, Spain
Juan Carlos Iriarte, Universidad Publica de Navarra, Spain
Amagoia Tellechea, Universidad Publica de Navarra, Spain

In this paper the use of Electromagnetic Band Gap (EBG) superstrate array configurations for Space applications are presented. Two space applications are covered, the first one is the Wide Area Augmentation System (WAAS) and the second one the C-Band geostationary TT&C telecommunication system. Both designs use as feeding configuration a 2x2 sequentially rotated patch array. In the first case, the EBG superstrate was formed by a square pattern of circular holes in a metallic sheet. In the second one, a metallic sheet with holes and equally distanced ring and jerusalem cross shaped metallic elements composes the EBG superstrate. The proposed EBG technology designs introduce simplifications to conventional antennas, as cost reduction, Beam Forming Network simplification, height reduction and low mass while offering similar RF performances.

09:30 – 10:00 Quasi-Conformal Transformations for Antenna Applications Invited oral

Rhiannon Mitchell-Thomas, Queen Mary University of London, UK
Oscar Quevedo-Teruel, Queen Mary University of London, UK
Yang Hao, Queen Mary University of London, UK

In this presentation, an overview of three distinct variations of the method of transformation optics, and example devices resulting from each of the techniques are described. It is emphasised that the quasi-conformal transformation method has a strong role to play for the purpose of antenna engineering due to the possibility of operating over a broad band of frequencies, and the ease with which such devices can be fabricated.

10:00 - 10:15 Band Structures of Mono- and Diatomic Metamaterials with Inter-Element Coupling Oral

Anna Radkovskaya, M. V. Lomonosov Moscow State University, Russia
Ekaterina Shamonina, Imperial College London, United Kingdom

Band structures of electro- and magnetoinductive waves propagating by virtue of inter-element coupling on mono- and diatomic metamaterials are compared in a wide frequency range from MHz to THz. When the elements are scaled down to infrared frequencies, electrons’ inertia results in dramatic reduction of magnetic coupling leaving the electric coupling unchanged. Narrowing of the passbands of slow waves of coupling can be prevented by employing metamaterial structures with electric coupling. Experimental and numerical studies confirm our analytical predictions.

10:15 – 10:30 Designing Slot Arrays by Using Gap Waveguide Technology Oral

Lucia Caballero-Moron, University Carlos III of Madrid, Spain
Luis Inclan-Sanchez, University Carlos III of Madrid, Spain
Eva Rajo-Iglesias, University Carlos III of Madrid, Spain

The use of gap waveguide technology is proposed in the design of slot arrays to enhance the performance of the feeding networks and at the same time reducing coupling and back radiation. Some initial ideas are proposed and these solutions provide simultaneously the packaging of all the circuitry related to the feeding network. The real advantages of this technology are exhibited in high frequency designs.

10:30 – 11:00 Coffee break (Tuesday)

11:00 -12:00 Plenary Session II

11:00 Plenary Session II
Session chairperson: Andrea Alù

11:00 – 12:00 Metamaterial Apertures for Computational Imaging

David Smith, Duke University, USA
David Brady, Duke University, USA
John Hunt, Duke University, USA
Matt Reynolds, Duke University, USA
Alex Mrozack, Duke University, USA
Guy Lipworth, Duke University, USA

Computational imaging uses prior knowledge about a scene to enable novel approaches to collecting and processing scene information for image recovery. Computational imaging schemes benefit from electromagnetically complex apertures, which facilitate varying degrees of image processing on the physical layer.

12:00 – 13:30 Lunch
### Oral sessions (Tuesday afternoon 1)

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<th>Time</th>
<th>Session</th>
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<td>13:30 - 15:00</td>
<td><strong>Graphene and Quantum Effects in Metamaterials I</strong></td>
<td>Auditorium</td>
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<td>13:30 - 15:00</td>
<td><strong>Metasurfaces I</strong></td>
<td>Badiane Hall</td>
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<td>13:30 - 15:00</td>
<td><strong>Metamaterials for Antennas II</strong></td>
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<tr>
<td>13:30 - 15:00</td>
<td><strong>Special Session II.2: Graphene and Quantum Effects in Metamaterials I</strong></td>
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<td>Session chairperson: Nader Engheta</td>
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<td>13:30 – 14:00</td>
<td><strong>Graphene Plasmonics and Graphene-Based Metamaterials</strong> Keynote</td>
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<td><strong>Javier Garcia de Abajo, CSIC, Spain</strong></td>
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<td>We discuss recent advances in the study of plasmons in graphene and graphene-related metamaterials, which lead to exciting new physics and a wealth of potential applications, including a new paradigm for the design of molecular metamaterials.</td>
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<td>14:00 – 14:30</td>
<td><strong>Transparent Graphene-Based Non-reciprocal Devices Magnetically Biased with Ferromagnetic Nanowire Metamaterials and Electrically Biased with Frequency Selective Surfaces</strong> Invited oral</td>
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<td><strong>Christophe Caloz, École Polytechnique de Montréal, Canada</strong></td>
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<td><strong>Dimitrios L. Sounas, The University of Texas at Austin, U.S.A.</strong></td>
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<td><strong>Louis-Philippe Carignan, Apollo Microwaves Ltd., Canada</strong></td>
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<td><strong>Hualin Zhan, École Polytechnique de Montréal, Canada</strong></td>
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<td><strong>Nima Chamanara, École Polytechnique de Montréal, Canada</strong></td>
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<td>A stacked multi-scale and multi-substance structure, where a graphene sheet is magnetically biased by a transparent ferromagnetic nanowire (FMNW) metamaterial and electrically biased by a frequency selective surface (FSS), is proposed for Faraday rotators and magnetoplasmonic devices.</td>
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<td>14:30 – 14:45</td>
<td><strong>Nano-Plasmonic Phenomena in Graphene: Toward Tunable Metamaterials</strong> Oral</td>
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<td><strong>Dmitri Basov, University of California San Diego, USA</strong></td>
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<td>Unique electromagnetic properties of graphene may enable a number of appealing applications in plasmonic metamaterials. In my group at UCSD we have systematically investigated surface plasmons in graphene by direct infrared nano-imaging. We demonstrated tunability of plasmons using the gate voltage and also ultra-fast optical excitation. We discovered that regions in graphene layer with dissimilar carrier density in the vicinity of grain boundaries act as efficient plasmonic reflectors. The major obstacle towards implementing metamaterials are losses that we investigated using a novel technique of scanning plasmon interferometry</td>
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<td>14:45 – 15:00</td>
<td><strong>A Perfect Lens for Ballistic Electrons</strong> Oral</td>
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<td><strong>Ivana Hrebikova, Czech Technical University in Prague, Dept. of Electromagnetic Field, Czech Republic</strong></td>
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<td><strong>Lukas Jelinek, Czech Technical University in Prague, Dept. of</strong></td>
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The analogy between plane electromagnetic waves and electron waves is presented and subsequently applied to the description of a quantum perfect lens. The natural constraints resulting from available semiconductor compounds are discussed. The final lens design relies on the inverted bandstructure of the HgTe compound, and uses a voltage gate to created the lens structure.

13:30 - 15:00 Oral session II.3: Metasurfaces I
Session chairperson: Stefano Maci

13:30 – 14:00 Manipulating Wavefronts with Metamaterial Huygens’ Surfaces
Invited oral
Carl Pfeiffer, University of Michigan, USA
Anthony Grbic, University of Michigan, USA

By utilizing nonuniform distributions of collocated electric and magnetic dipoles, a reflectionless, metamaterial Huygens’ surface is demonstrated. This surface is so-named because its design is based upon a rigorous formulation of Huygens’ principle. When illuminated by an incident field, the electric and magnetic dipole moments can be designed to render the surface reflectionless, with complete control of the transmitted phase. An efficient beam-refracting surface is experimentally demonstrated at 10 GHz.

14:00 – 14:30 A Surface Cloak Using Active Huygens Sources
Invited oral
Michael Selvanayagam, University of Toronto, Canada
George Eleftheriades, University of Toronto, Canada

Generating discontinuities in the electromagnetic field can be accomplished by impressing electric and magnetic currents along the boundary of the discontinuity. Here we demonstrate how this idea can be used to develop cloaks and refract plane-waves in an arbitrary fashion. The discontinuity in the field is satisfied by using a surface of discrete orthogonal electric and magnetic dipoles which can be thought of as a Huygens source. We also demonstrate initial results towards implementing these sources for cloaking by showing a planar loop antenna acting as a magnetic dipole.

14:30 – 14:45 Single-Layer Dipole Arrays for General Transformations of Plane Waves
Oral
Sergei Tretyakov, Aalto University, Finland
Teemu Niemi, Aalto University, Finland
Antti Karilainen, Nokia Corporation, Finland
Victor Asadchy, Aalto University, Finland
Younes Ra’di, Aalto University, Finland

In this presentation we review our recent studies of arrays of electrically small particles designed to perform general transformations of normally incident plane waves. We show that single-layer dipole arrays can, for example, act as matched polarization transformers, perfect absorbers, high-impedance surfaces, ideal isolators and other devices. The analysis reveals what physical mechanisms can be used to realize a desired functionality, and the developed synthesis methodology gives a way to design inclusions to realize the devices.
14:45 – 15:00  **Metasurfaces Nanoantennas for Light Manipulation**  
**Oral**  
**Hossein Mosallaei**, Northeastern University, USA  
Metasurfaces nanoantennas will be presented to control amplitude and phase of an incoming wave and engineer desired mathematical transfer functions for optics processing. Material, size, and shape will all be tailored in a building block to enhance design flexibility.

13:30 - 15:00  **Oral session II.4: Metamaterials for Antennas II**  
Session chairperson: Yang Hao

13:30 – 14:00  **Broadband Low-Loss Metamaterial-enabled Antennas**  
**Invited oral**  
**Douglas H. Werner**, Pennsylvania State University, USA  
**Z. H. Jiang**, Pennsylvania State University, USA  
**J. P. Turpin**, Pennsylvania State University, USA  
**C. P. Scarborough**, Pennsylvania State University, USA  
**M. D. Gregory**, Pennsylvania State University, USA  
**Q. Wu**, Pennsylvania State University, USA  
**P. L. Werner**, Pennsylvania State University, USA  
In this paper, we present some recent progress on the development of broadband low-loss metamaterial-enabled antennas. Specifically, metamaterials with tailored electromagnetic properties were designed to enhance the radiation and/or impedance performance for various types of antennas, including single- and dual-polarized horn antennas, quarter-wave wire monopoles, half-wave slots, and circular-polarized dipoles. Several antenna prototypes were fabricated and characterized, demonstrating strong agreement between measurements and simulations.

14:00 – 14:15  **Millimeter-Waves Extraordinary Transmission Corrugated Antennas**  
**Oral**  
**Unai Beaskoetxea**, Universidad Pública de Navarra / Public University of Navarre, Spain  
**Francisco José Aliste**, Universidad Pública de Navarra / Public University of Navarre, Spain  
**Miguel Beruete**, Universidad Pública de Navarra / Public University of Navarre, Spain  
**Tahsin Akalin**, Lille University, France  
**Miguel Navarro-Cia**, Imperial College London, United Kingdom  
**Mario Sorolla**, Universidad Pública de Navarra / Public University of Navarre, Spain  
Several antennas are described in this work, based all of them on the extraordinary transmission resonance displayed by flat metallic planes with a subwavelength aperture surrounded by periodic structures. Sinusoidal as well as triangular corrugation profiles are tested, working at millimeter and submillimeter waves. Good radiation characteristics have been obtained from simulations.

14:15 – 14:30  **Design of a Circular Polarized Horn Filtenna Using Complementary Electrically Small Resonators**  
**Oral**  
**Mirko Barbuto**, Roma Tre University, Italy  
**Filiberto Bilotti**, Roma Tre University, Italy  
**Alessandro Toscano**, Roma Tre University, Italy  
We present a circular polarized (CP) filtering antenna (filtenna) consisting of a
regular conical horn and a novel polarization transformer. The proposed linear-to-circular polarization transformer is obtained by using complementary electrically small resonators etched on a metallic sheet. This structure behaves both as a polarization transformer and a filter allowing to reduce the impedance bandwidth of the conical horn to avoid additional noise in satellite receiving systems. The proposed antenna, operating at X-band, exhibits a CP realized gain of 17.5 dBi.

**14:30 – 14:45**

**Precision Orbital Angular Momentum (OAM) Multiplexing Communication Using a Metasurface**

*Mohamed Salem, Ecole Polytechnique de Montreal, Canada*

*Christophe Caloz, Ecole Polytechnique de Montreal, Canada*

A novel approach for orbital angular momentum (OAM) multiplexing based communication systems is proposed. This approach utilizes a metasurface to precisely manipulate the phase fronts of the transmitted information-carrying electromagnetic field to form a vortex beam at the receiver location. In contrast to vortex beams generated by other techniques, this beam has not been altered by phase dispersion effects associated with propagation and other factors, such as atmospheric turbulence, which can be compensated for. Since OAM separation takes place only in the spectral domain, the system is not of the multiple-in-multiple-out (MIMO) type.

**14:45 – 15:00**

**Superdirectivity by Virtue of Coupling between Meta-atoms**

*Ekaterina Shamonina, Imperial College London, United Kingdom*

*Laszlo Solymar, Imperial College London, United Kingdom*

We explore the possibility of achieving superdirectivity in metamaterials by relying on magnetoinductive waves, short-wavelength slow waves capable of providing rapidly varying current distribution. Using a dimer of magnetically coupled split rings we identify conditions for achieving superdirectivity in terms of the dimer size, the coupling strength and the quality factor. Predictions of the analytical model are verified numerically. Our results might lead to the first realization of genuine superdirective antenna arrays.

**15:00 -16:30**

**Poster Session I**

*and coffee break*

**15:00**

**Poster session I**

Session chairperson: Jon Schuller

1 - **Quantum Properties of Nanocomposite Globular Photonic Crystals**

*Vladimir Gorelik, P.N.Lebedev Physical Institute of RAS, Russia*

Electromagnetic waves dispersion curves in nanocomposite globular photonic crystals, filled by semiconductors, ferroelectrics, magnetic or metals have been calculated at one-dimensional approximation. Bose-Einstein condensation of polariton and massive photons at high enough temperature due to small effective rest mass is predicted. The opportunity of unitary polariton (massive photon) - paraphoton conversion process observation are discussed.

2 - **Enhancing Light Absorption in Graphene-based Photonic Crystals**

*Redouane Miloua, LECM, Algeria*

*Zoubir Kebbab, LECM, Algeria*

*Fafa Chiker, LECM, Algeria*
Mohamed Khadraoui, LECM, Algeria
Kamel Sahraoui, LECM, Algeria
Noureddine Benramdane, LECM, Algeria

We theoretically investigate the possibility of enhancing light absorption in graphene-based one dimensional photonic crystals. We demonstrate that it is possible to achieve total light absorption at technologically important wavelengths using multilayered structures of the form (A/graphene/B)^N(C/D)^M. By means of the transfer matrix method, we investigate the effect of refractive indices and layer numbers on the optical response of the structures.

3 - Design and Experimental Evidence of a Flat Graded-Index Photonic Crystal Lens Poster

Eric Akmansoy, IEF, Université Paris Sud, France
Fabian Gaufillet, IEF, Université Paris Sud, France

We report on the design and the experimental evidence of a flat graded index photonic crystal lens. The gradient has been designed so that the flat slab focuses a plane wave and so that it converts the wave issued from a punctual source into a plane wave. Thus, this graded-index photonic crystal lens operates as a convex lens. The gradient of index results from varying the filling factor of the photonic crystal in the direction perpendicular to that of the propagation of the electromagnetic field. As only a few layers were necessary, this shows the ability of graded photonic crystals to efficiently apply for various photonic devices, from microwave range to the optical domain.

4 - Spectral Selectivity of Subwavelength Gold-based Photonic Crystals on GaAs Substrate Poster

Reyhaneh Soltanmoradi, School of Information and Communication Technology, Royal Institute of Technology (KTH), Sweden
Qin Wang, Department of Nanoelectronics, Swedish ICT Acreo AB, Sweden
Min Qiu, School of Information and Communication Technology, Royal Institute of Technology (KTH), Sweden
Jan Y. Andersson, Department of Nanoelectronics, Swedish ICT Acreo AB, Sweden

Au-based subwavelength photonic crystal structures on GaAs substrate were fabricated on a wafer scale targeting high volume production. They then were characterized and compared with related simulation results. Integrating these structures onto III-V semiconductor infrared photodetectors through a top-down approach has promising potential to enhance detector’s performance.

5 - The Near-Field Microwave Microscope with Photonic Crystal as Resonator and Adjustable Coupling Element Poster

Dmitry Usanov, Saratov State University, Russia
Sergey Nikitov, Saratov State University, Russia
Alexander Skripal, Saratov State University, Russia
Alexander Frolov, Saratov State University, Russia

The new type of probe for near-field microwave microscope based on the one-dimensional photonic crystal with resonator and controllable coupling element has been proposed. The high sensitivity of this type of probe to the change of parameters of dielectric plates and to the change of thickness of nanometer metal layers applied to dielectric substrates has been shown.
6 - **Topological Transitions in Two-Dimensional Hyperbolic Metamaterials** Poster

**Alyona Chshelokova**, NRU ITMO, St Petersburg, Russia  
**Polina Kapitanova**, NRU ITMO, St Petersburg, Russia  
**Alexander Poddubny**, NRU ITMO, St Petersburg, Ioffe Physical-Technical Institute of the Russian Academy of Sciences, Russia  
**Dmitry Filonov**, NRU ITMO, St Petersburg, Russia  
**Yuri Kivshar**, NRU ITMO, St Petersburg, Russia and Australian National University, Australia  
**Pavel Belov**, NRU ITMO, St Petersburg, Russia

We demonstrate a novel two-dimensional transmission-line metamaterial with topological transitions. We observe the hyperbolic isofrequency contour above the resonance frequency of the transmission line, and the elliptic isofrequency contour-- below the resonance frequency. Our results are supported by a direct solution of the Kirchhoff equations for the structure. We also study the emission of a current source and reveal the effect of metamaterial discreteness on the cross-like emission pattern in the hyperbolic regime.

7 - **Optimizing the Directional Radiation of Metamaterial Antenna** Poster

**Ruixin Wu**, Nanjing University, China  
**Yan Gu**, Nanjing University, China  
**Lirong Tan**, Nanjing University, China

Metamaterial antenna involving a shell of left-handed materials (LHM) and a line source could be a directional antenna with lower RCS. To optimize the performance of the antenna, we studied the effects of the line source position and the properties of LHM shell on the directional radiation. The results show that these factors can greatly change the directional emission of the antenna. To maximize directive emission, one needs to optimize the source position and the size of LHM shell, and to balance the directivity and side-lobe peak levels of the antenna.

8 - **Electronically Tunable Composite Right / Left Handed Transmission Line for the Slotted Waveguide Antenna Stiffened Structure** Poster

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

The Slotted Waveguide Antenna Stiffened Structure utilizes hat-stiffeners in aircraft structures as microwave waveguides. This work extends the SWASS concept by demonstrating electronic phase shifting along the waveguide axis. This is achieved with a varactor loaded coaxial CRLH-TL for approximate matched tuning about the design frequency.

9 - **Non-reciprocity in Doubly Periodic Strip Arrays on Ferrite-Dielectric Substrate** Poster

**Gwendal Cochet**, Lab-STICC, University of Brest, France  
**Patrick Queffelec**, Lab-STICC, University of Brest, France  
**Alexander Schuchinsky**, ECIT, Queen’s University Of Belfast, UK  
**Vincent Laur**, Lab-STICC, University of Brest, France  
**Robert Cahill**, ECIT, Queen’s University Of Belfast, UK

A doubly periodic conductor strip arrays printed on a composite ferrite-dielectric substrate have been investigated at oblique incidence of linear polarized plane
waves. The simulation results revealed strong nonreciprocity of wave reflectance and transmittance at positive and negative angle of incidence. It is also shown that the nonreciprocity is further enhanced by the strip conductor pattern.

10 - Metamaterial Based Near-Field Loop Antenna Periodically Loaded with Split-Ring Resonators **Poster**

Dmitry Kozlov, St.-Petersburg Electrotechnical University, Russia
Vesna Crnojevic-Bengin, University of Novi Sad, Serbia
Vasa V. Radonic, University of Novi Sad, Serbia
Irina Vendik, St.-Petersburg Electrotechnical University, Russia

The transmission line periodically loaded with split-ring resonators (SRR) has been investigated. The phase delay of the wave in the considered transmission line is equal to zero at the frequency slightly above the SRR resonance. This effect was used for designing the near-field loop antenna providing the uniform current distribution along the loop. A comparison of the proposed design and the conventional loop antenna was made.

11 - Printed Scanning Antenna Array with SRR Phase Shifters **Poster**

Nikola Boskovic, Institute of Physics, Belgrade, Serbia
Branka Jokanovic, Institute of Physics, Belgrade, Serbia
Aleksandar Nesic, Institute IMTEL Communication A.D., Belgrade, Serbia

We present a new design of frequency-scanning array antenna which consists of eight antiresonant dipoles fed by symmetrical microstrip line. Feeding network between dipoles is designed using left-handed unit cell that increases the frequency dependant phase difference between antenna elements. Left-handed unit cell consists of four split-ring resonators (SRRs) coupled with balanced microstrip line and via which short-circuits the feeding line. The beam scanning is found to be Δθ=34 degrees with frequency variation in the range from 5.85GHz to 6.05GHz (±1.5% of the central frequency) and gain of 12dBi.

12 - Steerable Ka-Band Leaky Wave Antenna based on Liquid Crystal Material **Poster**

Maria Roig, Institute for Microwave Engineering and Photonics, Technische Universität Darmstadt, Germany
Matthias Maasch, Institute for Microwave Engineering and Photonics, Technische Universität Darmstadt, Germany
Christian Damm, Institute for Microwave Engineering and Photonics, Technische Universität Darmstadt, Germany
Rolf Jakoby, Institute for Microwave Engineering and Photonics, Technische Universität Darmstadt, Germany

A steerable Ka-Band leaky wave antenna (LWA) based on liquid crystal is presented. Beam steering is achieved by tuning a dielectric layer of liquid crystal by means of a static magnetic field which is confirmed by the measured dispersion characteristics and far field patterns. The LWA shows a beam steering range larger than 8 degrees for the frequencies between 26~GHz and 28 GHz.

13 - Superdirective Antenna with Artificial Dielectric Substrate **Poster**

Maciej Smierzchalski, University of Rennes 1, IETR, France
Kouroch Mahdjoubi, University of Rennes 1, IETR, France
Ala Sharaiha, University of Rennes 1, IETR, France

A summation of orthogonal modes allows to determine maximum directivity in desired direction. The higher spherical and azimuthal/cylindrical modes leads to
increase of the sizes of the radiator of a given mode. The simpler case for combination of modes is introduction of azimuthal one, represented with annular rings. The size of the radiators representing given mode is reduced by application of artificial dielectric. This technique provides the freedom in realization of modes, as well allows to reduce the size of the system, i.e. superdirective antenna.

14 - Metamaterial Split-Ring Resonators for Retrieval of Soil Electromagnetic Properties Poster

Davide Ramaccia, University Roma Tre, Italy
Maria Claudia Guattari, University Roma Tre, Italy
Filiberto Bilotti, University Roma Tre, Italy
Alessandro Toscano, University Roma Tre, Italy

A new application of a metamaterial-inspired inclusion, i.e. the Split-Ring Resonator (SRR), combined with a commercial Ground Penetrating Radar (GPR) is presented. An SRR is embedded within a soil sample and excited by the GPR antenna. Exploiting the resonant properties of the inclusion, the dielectric permittivity of a typical soil is estimated by observing the GPR data. The proposed method turns out to be very quick and the results are in agreement with many findings in the open technical literature. The point of strength of this approach is the combination of GPR technology and metamaterial concepts that leads to a quick and accurate in-situ estimation, i.e. not-destructive, of the dielectric properties of the underground.

15 - Gray and Dark Spatial Solitary Waves in Left-Handed Waveguide Structure Poster

Hana Mousa, Al-azher university, Palestine
Mohammed Shabat, Islamic University, Palestine

The propagation characteristics of both TE gray and dark solitary waves in a waveguide structure consisting of left handed material LH film sandwiched in a nonlinear defocusing medium is investigated. In (LH) film both permittivity and magnetic permeability are negative in definite frequency range. We study dispersion and grayness properties of the solitary waves. We found that the implementation of the left handed material stimulate the backward traveling of the waves with high intensity at the film boundaries. We also found that higher values of wave’s grayness are obtained for relatively small magnetic permeability of LH film.

16 - A Study on The Application of A Periodic Structure on a Compact Fully Anechoic Chamber Poster

Dong-Uk Sim, Electronics and Telecommunications Research Institute, Korea (South)
Jong-Myun Kim, Electronics and Telecommunications Research Institute, Korea (South)
Young-Jun Chong, Electronics and Telecommunications Research Institute, Korea (South)
Seong-Ook Park, Korea Advanced Institute of Science and Technology, Korea (South)

In this paper, a new approach to implement a compact fully anechoic using a periodic structure is presented.

17 - Metamaterials-Based Gradient Index Broadband Lens Antennas Poster

Abdallah Dhouibi, LEME, EA 4416, Univ. Paris-Ouest, France
Shah Nawaz Burokur, IEF, Univ. Paris-Sud, CNRS, UMR 8622, France
André de Lustrac, IEF, Univ. Paris-Sud, CNRS, UMR 8622, France
Gradient index lenses are proposed to transform a cylindrical wave into a plane one. The lenses are designed from metamaterials engineering in a wide frequency band. A primary source operating in the whole X-band is used to feed the lenses. The lens-antenna systems are low profile and exhibit a directive emission in the H-plane. A very good agreement is observed between measurements performed on the fabricated lens-antennas and numerical simulations.

18 - Planar Photonic Crystals for Microwave Region. Poster

Evgeny Vionogradov, Prokhorov General Physics Institute, Russian Academy of Sciences, Russia
Galina Vinogradova, Prokhorov General Physics Institute, Russian Academy of Sciences, Russia
Vladimir Golovanov, Prokhorov General Physics Institute, Russian Academy of Sciences, Russia

This paper presents the results of experimental studies of the dispersion characteristics of photonic crystals with negative refractive index in the microwave region of electromagnetic waves. The possibility of good agreement dispersion wavelength phonon 2D-photonic crystal and simultaneously in a single implementation of conductive metal cylinders in the air. On its basis, reviewed and consistently implemented the transition to a planar photonic crystal structure of 2D and 3D dimensions. Are design features, a comparison of the dispersion characteristics of the major benefits of their use.ut your abstract here

19 - Metamaterial Shells Based on Radial Photonic Crystals: Theory and Applications Poster

Jorge Carbonell, Universitat Politècnica de Valencia, Spain
Ana Diaz-Rubio, Universitat Politècnica de Valencia, Spain
Daniel Torrent, Universitat Politècnica de Valencia, Spain
Jose Sanchez-Dehesa, Universitat Politècnica de Valencia, Spain

Metamaterial shells based on radially dependent anisotropic parameters are analyzed in view of achieving different types of applications. The theoretical proposal is reviewed together with some possible applications of these resonant structures. Position sensors, energy harvesters or wireless energy transfer systems are briefly presented.

20 - Using Subwavelength Diffraction Gratings to Design Open Microwave Cavities Poster

Matthieu Dupre, Institut Langevin, ESPCI ParisTech-UMR 7587, France
Mathias Fink, Institut Langevin, ESPCI ParisTech-UMR 7587, France
Geoffroy Lerosey, Institut Langevin, ESPCI ParisTech-UMR 7587, France

We introduce an open microwave cavity that has a wall replaced by a sub-wavelength grating. Usually, sub-wavelength gratings show very low transmission. In our experiment, this phenomenon is compensated by the microwave cavity that finally allows all the energy to be transmitted. We study the far field emission of this system and show that coupling the cavity with a sub-wavelength grating gives rise to a zero order emission only at discrete angles and frequencies. We study the relations between angles of emissions and frequencies, the influence of geometric parameters such as the grating fill factor and the behavior of a chaotic cavity. We show that it allows us to make a configurable system that may have many applications in the fields of communications, detection and imaging, and may allow the study of open microwave cavities on a fundamental point of view.
21 - Forward Magneto-inductive Wave Propagation in Planar Magnetically Coupled Capacitor Grids

Christopher Stevens, Oxford University, United Kingdom
Christopher Chan, Oxford University, UK

One, two and Three dimensional arrays of magnetically coupled resonant circuits have recently been shown to support propagating waves. Here we consider a similar structure in which the individual resonators have coalesced forming 1d ladder. Whilst most planar magneto-inductive waveguides are expected to be negatively magnetically coupled resulting in backward wave propagation these structures are found to support forward waves despite their planar structure.

22 - Electric Tuning of Spin-Electromagnetic Waves in Thin Film Ferrite-Ferroelectric Structures

Andrey Nikitin, Saint Petersburg Electrotechnical University LETI, Russia
Vitaly Vitko, Saint Petersburg Electrotechnical University LETI, Russia
Alexey Nikitin, Saint Petersburg Electrotechnical University LETI, Russia
Alexander Semenov, Saint Petersburg Electrotechnical University LETI, Russia
Alexey Ustinov, Saint Petersburg Electrotechnical University LETI, Russia

Multilayered ferrite-ferroelectric structures are considered as metamaterials that could be used for increasing functionality of the microwave devices. It is shown that using a thin ferroelectric film between the two different ferrites films gives possibility to tune the interaction strength of the spin-electromagnetic waves in the different ferrite layers therefore electrically tune the spin-electromagnetic wave spectrum. An influence of the different ferrite-ferroelectric structure parameters on the tuning range is analyzed.

23 - A Novel Dual-Bandpass Microwave Filter Using Epsilon-Near-Zero Metamaterials

Viacheslav Turgaliev, St. Petersburg Electrotechnical University 'LETI', Russia
Dmitry Kholodnyak, St. Petersburg Electrotechnical University 'LETI', Russia
Irina Vendik, St. Petersburg Electrotechnical University 'LETI', Russia
Vasa Radonić, University of Novi Sad, Serbia
Vesna Crnojević-Bengin, University of Novi Sad, Serbia

A dual-band filter design based on the resonators using the epsilon-near-zero (ENZ) metamaterials (MTMs) is considered. A novel dual-mode resonator on a combination of a substrate integrated waveguide (SIW) capacitively loaded cavity and a complimentary split-ring resonator (CSRR) etched on the SIW structure top cover is proposed. At the both resonant frequencies such a resonator behaves as an ENZ MTM. The resonator has a small size and is well suited for the design of compact dual-bandpass filters with a low loss. Design of a dual-band filter for WLAN application is presented.

24 - Design of 0-dB Reconfigurable Directional Coupler Using Metamaterial Structure

Irina Munina, St.Petrsburg Electrotechnical University, Russia
Irina Vendik, St.Petrsburg Electrotechnical University, Russia
Vesna Crnojević-Bengin, University of Novi Sad, Serbia

0-dB coupled-line directional coupler exhibiting forward and backward coupling
characteristics is designed on a combination of split-ring and mushroom-shaped resonators embedded in coupled line structure. Adding tunable varactors in the gap of split-ring resonator can change type of coupling of the directional coupler at the same frequency and design the 0-dB reconfigurable directional coupler on the proposed metamaterial structure.

25 - Ultra-Compact Superconductive Resonator with Double-Spiral Structure Poster

Alexander Averkin, National University of Science and Technology (MISIS), Moscow, Russia
Alexander Zhuravel, Verkin Institute for Low Temperature Physics and Engineering, NAS of Ukraine, Kharkov, Ukraine
Alexander Karpov, National University of Science and Technology (MISIS), Russia
Steven Anlage, CNAM, Physics Department, University of Maryland, USA
Alexey Ustinov, Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

We discuss the characteristics of an ultra-compact double-spiral superconductive Nb micro-resonator as a potential magnetic metamaterial element. This resonator consists of two superconducting Nb spirals, sandwiched face to face, with a small gap. We study the resonator spectral response by using numerical simulation. The resonator modal structure has been also examined with a laser scanning microscope. The achieved resonator size with respect to the wavelength in our experiment is about $\lambda/4200$.

26 - Wave-Vector Analyses for Bloch Waves in Two-Dimensional Metamaterial Sample Using Electrooptically Derived Complex Phasor Images Poster

Masahiro Tsuchiya, National Institute of Information and Communications Technology, Japan
Takahiro Shiozawa, Kagawa National College of Technology, Japan

Wave vectors have been experimentally analyzed for microwaves in a two-dimensional metamaterial sample. This novel approach is based on Fourier transforms of electrooptically derived complex phasor images and has successfully made the sample’s Bloch waves dissected into wave vectors of periodic Bloch functions and plane backward-wave envelope functions.

27 - Electric Coupling in Strongly-Coupled Magneto-Inductive Cable Poster

Richard Syms, Imperial College London, United Kingdom
Timmy Floume, Imperial College London, UK

Magneto-inductive (MI) waveguides are linear arrangements of magnetically coupled L-C resonators that can propagate RF energy. At resonance, propagation loss is inversely proportional to the coupling coefficients between elements and to their quality factors. To achieve strong magnetic coupling, the current-carrying sections of adjacent elements must close together, resulting in parasitic capacitance. Electric coupling is demonstrated theoretically and experimentally in magneto-inductive cable, and it is shown that its effect is to introduce multiple propagation bands above the MI band.

28 - Terahertz Nanoantenna Based on Spin Torque Oscillator and Polaritonic Metamaterials Poster

Kirill Petrov, MPEI, Russia
The structure and EM-fields of spin torque nano-oscillator have been considered. It is shown that the fields of the STNO can be approximated by the fields of two crossed magnetic dipoles with a phase shift between them π/2. The method of the nanoantenna theory has used to enhance of radiated power and improve STNO directivity by the employment in their design the polaritonic subwavelength cylinders in the THz regime.

29 - Circularly Polarized Dual-Band Crossed Dipole Antenna on an Artificial Magnetic Conductor Reflector

Ikmo Park, Ajou University, Korea (South)
Son Xuat Ta, Ajou University, Korea (South)

This paper presents a circularly polarized (CP) dual-band crossed dipole antenna incorporated with an artificial magnetic conductor (AMC) surface that serves as a reflector. Here, two crossed asymmetric dipoles are utilized as the primary radiation elements for a CP dual-band operation. Further, a novel AMC is designed with four T-shaped slits in a unit-cell patch to significantly reduce its second resonant frequency. Consequently, the first and second resonant frequencies of the proposed AMC structure are easily adjusted for the desired dual-band antenna operation.

30 - Refractive Index of 3D-Nanocomposites with Transition-Metal Nanoparticles

Anatoly Rinkevich, Institute of Metal Physics, Russia
Dmitry Perov, Institute of Metal Physics, Russia
Mikhail Samoylovich, Central Research Technological Institute “TECHNOMASH”, Russia
Svetlana Klescheva, Central Research Technological Institute “TECHNOMASH”, Russia
Evgeny Kuznetsov, Niznij Tagil State Social Pedagogical Academy, Russia

Investigation and application of extraordinary electromagnetic properties of metamaterials and nanocomposites becomes one of the most promising topics in last years. The problem of interaction between electromagnetic wave and magnetic nanoparticles is of essential interest. Resonance phenomena in 3D opal-based nanocomposites are studied here through frequency and magnetic field dependences of the transmission and reflection coefficients measured in millimeter waveband. Observation of magnetic antiresonance phenomenon is reported in a 3D-nanocomposite based on opal packages with embedded metallic magnetic particles. The antiresonance is seen at microwave frequencies of the millimeter waveband and it results in distinct maximum of the reflection or transmission coefficients.

31 - Impedance Space Stability Analysis of Engineered Metamaterials of Active Loops

Yifeng Fan, Queen Mary University of London, United Kingdom
Khalid Rajab, Queen Mary University of London, United Kingdom
Yang Hao, Queen Mary University of London, United Kingdom

In this paper we demonstrate the stability analysis of an effective medium consisting of loop arrays in a form of impedance space based on the Energy Source Analysis Consortium (ESAC) criterion which is an extension of Nyquist theory.

32 - Negative Refraction and Perfect Tunneling of Electron Waves in Graphene Superlattices

David Fernandes, Instituto de Telecomunicações - Universidade de
In this work, we study the transmission of an electron wave propagating in a graphene-based nanomaterial when it impinges on a slab of another graphene nanomaterial. Using effective-medium techniques, we computed the reflectivity and transmissivity of the structure, proving that analogous to electromagnetic metamaterials, the considered structure provides some form of spatial localization and negative refraction of electrons for all the stationary states associated with a specific value of energy.

33 - Equivalent Circuit Extraction of the Double-fishnet Metamaterial based on its Electrodynamics Poster

Víctor Torres, Universidad Pública de Navarra, Spain
Pablo Rodríguez-Ulibarri, Universidad Pública de Navarra, Spain
Miguel Navarro-Cía, Imperial College London, UK
Miguel Beruete, Universidad Pública de Navarra, Spain

In this work, an equivalent circuit for the double-fishnet metamaterial is proposed. The extraordinary transmission (ET) through each of the two layers of subwavelenth holes is modeled as two LC parallel tanks. Another LC parallel tank put in series with the previous two, models the mutual inductance and capacitance between the layers, also associated with the ET and the higher order modes. All lumped elements are extracted from a full inspection of the electromagnetic fields at the most relevant frequencies. The effective index of refraction and the scattering parameters obtained with the equivalent circuit matches remarkably the one obtained from full-wave numerical calculations.

34 - Plasmons and Magnetoplasmons in Single and Multilayer Graphene Structures. Poster

Ivan Iorsh, NRU ITMO, Russia
Pavel Buslaev, NRU ITMO, Russia
Ilya Shadrivov, Nonlinear Physics Centre, Australian National University, Canberra, Australia
Pavel Belov, NRU ITMO, Russia
Yuri Kivshar, Nonlinear Physics Centre, Australian National University, Canberra, Australia

We show that in the presence of external magnetic field TE and TM plasmons that may propagate along the graphene sheet become coupled forming the hybridized surface waves which can exhibit circular polarization and can be controlled with magnetic field. Moreover, we demonstrate that the multilayer graphene structure can be described as a hyperbolic media for a THz range is characterized by extremely large density of states in a wide frequency range. Finally we show that the coupled surface plasmon polaritons in multilayer graphene structures can be effectively controlled with external magnetic field.

35 - Experimental Demonstration of Negative Group Delay on the Coupled Regime of Extraordinary Transmission Hole Arrays Poster

Miguel Navarro-Cía, Imperial College London, United Kingdom
Miguel Beruete, Universidad Pública de Navarra, Spain
Francisco Falcone, Universidad Pública de Navarra, Spain
Mario Sorolla, Universidad Pública de Navarra, Spain
Vitaliy Lomakin, University of California in San Diego, USA
Negative group delay (i.e. superluminal transmission) through perforated subwavelength hole arrays under TE (or s) polarization has been analyzed theoretically, numerically and experimentally at millimetre-waves. The underlying physics relies on the coupling of resonant anomalies and Rayleigh-Wood’s anomalies. The former resonances manifest themselves because of the grounded dielectric slab TE modes as a result of the dielectric sandwiched of the array, whereas the latter anomalies are intrinsic features of periodic gratings. The conclusions reached in this work apply to general periodic gratings within the couple regime and envisions applications in, for instance, pulse shaping.

36 - General Theory of Magnetic Metamaterials Poster

Natalia Grigoryeva, Saint-Petersburg Electrotechnical University, Russia
Boris Kalinikos, Saint-Petersburg Electrotechnical University, Russia

A general theory of the magnetic metamaterials is presented. Magnetic metamaterial is assumed to be a thin-film ferromagnetic medium with periodic variation of the magnetic parameters along the wave propagation direction. The exact dispersion relation is obtained in the form of an infinite determinant, which can be reduced to the finite one for each particular problem.

37 - Collective Response of Metamaterial Arrays and Applications of Cooperative Resonances Poster

Janne Ruostekoski, School of Mathematics and the Centre for Photonic Metamaterials, United Kingdom
Stewart Jenkins, School of Mathematics and the Centre for Photonic Metamaterials, United Kingdom

We theoretically analyze the experimental observations of a spectral line collapse in a metamaterial array of asymmetric split rings. We show that the system exhibits a cooperative response, explaining the observed system-size dependent narrowing of the transmission resonance. Significantly stronger narrowing could be achieved in media with suppressed non-radiative losses.

38 - Scalar Potential Depolarizing Dyad Artifact for a Uniaxial Bipanisotropic Medium Poster

Michael Havrilla, Air Force Institute of Technology, USA

A scalar potential formulation for a homogeneous uniaxial bianisotropic medium is derived through the use of Helmholtz’s theorem and operator orthogonality and compared with prior findings. It is shown that an expected and unexpected depolarizing dyad appears in the development. Using a spectral domain analysis and Leibnitz’s rule in the field recovery process, it is shown the unexpected depolarizing dyad is canceled. Thus, a mathematically and physically consistent scalar potential theory is confirmed.

39 - Broadband Flat-base Luneburg Lens Antenna for Wide Angle Scan Poster

Sidharath Jain, Department of Electrical Engineering, The Pennsylvania State University, USA
Raj Mittra, Department of Electrical Engineering, The Pennsylvania State University, USA
Mohamed Abdel-Mageed, Department of Electrical Engineering, The Pennsylvania State University, USA

In this paper we present the design of a Luneburg type of lens antenna, with a flat base, designed for wide angle scan. The antenna consists of a 11-layer lens, fed at its base by a 6x6 array of waveguides. The lens is broadband and has a very high
aperture efficiency, only 1 dB below that of a reference aperture antenna with a uniform amplitude and phase. Its sidelobe level is good, only -21 dB at boresight and -13 dB for a scan angle of 64 degrees. Its performance is shown to be considerably superior to that of a flat Luneburg lens previously reported in the literature, both in terms of the gain and scan capability, as well as the ease of fabrication.

40 - Reducing and Increasing the Apparent Size of Electromagnetic Sources Through Transformation Optics

Paul-Henri Tichit, IEF, Univ. Paris-Sud, CNRS, UMR 8622, France
Shah Nawaz Burokur, IEF, Univ. Paris-Sud, CNRS, UMR 8622, France
André de Lustrac, IEF, Univ. Paris-Sud, CNRS, UMR 8622, France

Transformation optics concept is used to change the physical size of radiating sources. By choosing transformations that either compress or expand space, and then match it to the surrounding radiation environment, we are able to either increase or reduce the aperture size of the embedded source. We show that a small aperture antenna can then behave as one with a large aperture and vice-versa. A study of the two transformations of the space metric is presented. Simulations are performed to validate the proposed approach at microwave frequencies. This study paves the way to interesting applications in telecommunications and aeronautical domains.

41 - Novel Active CRLH Transmission Lines Incorporating FETs

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Keito Ota, Salesian Polytechnic, Japan
Ryo Ishikawa, University of Electro-Communications, Japan
Kazuhiro Honjo, University of Electro-Communications, Japan

In this paper, the novel active composite right/left-handed transmission lines (CRLH-TLs) are presented incorporating FETs as the active devices. The demonstrated CRLH-TL with three FETs has four states with respect to the bias combination of the FETs. The measured characteristics of the developed active CRLH-TL indicate two states of the radiation and the reflection with the bias combination. In the case of the radiation state, the backward radiations are observed from the EM simulation in the left-handed (LH) region. It is found that the proposed active CRLH-TLs incorporating FETs provide the multifunction of the switch and the leaky wave antenna, simultaneously.

42 - Duality Constrained Meta Atoms

Ivan Fernandez-Corbaton, Macquarie University, Australia
Gabriel Molina-Terriza, Macquarie University, Australia

Maxwell’s equations in curved space-time are invariant under electromagnetic duality transformations. We exploit this property to constraint the polarisability tensor of the constituent meta atoms for metamaterials used for transformation optics: A general transformation can be implemented using only dual symmetric meta atoms. We obtain the explicit expression for the constraints.

43 - Microwave Power Influence on Insertion Loss and Frequency Position Bragg Zones of Nonlinear Magnonic Crystals

Andrey Drozdovskii, Saint Petersburg Electrotechnical University LETI, Russian Federation
Boris Kalinikos, Saint Petersburg Electrotechnical University LETI, Russian Federation

Results of the theoretical and experimental investigation of a magnonic crystal, which is periodic magnetic film structure, are presented. In doing so, the
fundamental peculiarities of metamaterials fabricated from nonlinear media having the dispersion characteristics depended on the amplitude of the microwave spin-wave signal are investigated. It is shown that an effect of linear and nonlinear spin-wave dissipation destroys an effective Bragg resonance condition. For example, in the nonlinear regime an increasing of the signal spin-wave amplitude leads to the frequency shift and frequency broadening of the magnonic crystals stop-bands.

44 - Broadband Chaotic Microwave Ring Generators Based on Metalized Ferrite Films Poster

**Alexandr Kondrashov,** *St Petersburg Electrotechnical University, Russia*

**Alexey Ustinov,** *St Petersburg Electrotechnical University, Russia*

**Boris Kalinikos,** *St Petersburg Electrotechnical University, Russia*

Investigation of a broadband microwave signal self-generation in a metalized ferrite film being a waveguiding nonlinear element in an active feedback loop is reported. Utilization of the metalized ferrite film allowed to obtain chaotic signal with a bandwidth of more than 1 GHz. Self-generation of microwave solitonic short pulses (on the order of unity of nanoseconds) was observed during a transition from the stationary to the chaotic self-generation regime. Control of the self-generation regimes was realized by varying the ring gain coefficient. Influence of the magnetic field on the dynamic regimes was studied.

45 - A Remote Optical Switch for the Third Optical Communication Window by Illusion Optics Poster

**Hamed Reza Shoorian,** *K. N. Toosi University of technology, Iran*

In this paper transformation and illusion optics is employed to design an optical switch for third optical communication window. Using an illusion device in a distance, effective refraction index of a dielectric waveguide is modified remotely in order to project an illusion of a Distributed Bragg Reflector within the waveguide. When the illusion device comes close to a certain distance to the waveguide, light with the wavelength within the stop band of DBR are forbidden to propagate in the waveguide. The waves can propagate through the waveguide again, when illusion device is removed. The constitutive parameters, need to realize the illusion device, are homogeneous and anisotropic which can be implemented with layered structure. The most important advantages of this method are avoiding physical changes or damages of the original device and the ability of tuning the device optical behavior.

46 - RCS Computations of Targets with Plasmonic Coatings Poster

**F. Duverger,** *CEA, France*

**C. Saint-Flour,** *CEA, France*

**Olivier Vacus,** *CEA, France*

RCS issues lead to problems of hundreds of thousands of unknowns as soon as the target gets greater than the wavelength. For computational limiting reasons, equivalent boundary conditions or effective medium approximation are then necessary. In this paper we consider spheres with plasmonic coatings.

47 - Superconducting Split-Ring Resonators with Embedded Tunable Inductors Poster

**Alexander Vidiborskiy,** *National University of Science and Technology MISIS, Russia*

**Valery Koshelets,** *Kotel’nikov Institute of Radio Engineering and Electronics, Russia*

**Lyudmila Filippenko,** *Kotel’nikov Institute of Radio Engineering and Electronics, Russia*

**Sergey Shitov,** *National University of Science and Technology MISIS, Kotel’nikov Institute of Radio Engineering and Electronics, Russia*
Alexey Ustinov, National University of Science and Technology MISIS, Russia, Karlsruhe Institute of Technology, Germany

We propose tunable superconducting split-ring resonators (SRRs) employing nonlinear inductance. A fraction of SRR is replaced by Nb-AlOx-Nb Josephson tunnel junctions connected in parallel and forming a superconducting quantum interference device (SQUID), which inductance is sensitive to the external magnetic field. Due to this modification, the SRR can be made smaller and its resonance frequency can be tuned via application of magnetic field.

48 - Design and Experimental Study of Superconducting Left-Handed Transmission Lines with Tunable Dispersion Poster

Evgeniya Ovchinnikova, National University of Science and Technology (MISIS), Russia

Susanne Butz, Physikalisches Institut, Karlsruhe Institute of Technology, Germany

Philipp Jung, Physikalisches Institut, Karlsruhe Institute of Technology, Germany

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Alexey Ustinov, Physikalisches Institut, Karlsruhe Institute of Technology, Germany, National University of Science and Technology (MISIS), Russia

We study properties of a superconducting left-handed transmission line (LHTL) with Josephson junctions. Pairs of Josephson junctions connected in parallel form superconducting quantum interference devices (SQUIDs) serving as magnetic field-tunable inductors are used to modify the microwave dispersion in the line. Left- and right-handed transmission bands are divided by a rejection band, which can be tuned by applying a magnetic field. The dependence of the rejection band frequency on the dc magnetic field is evaluated experimentally and compared with numerical simulations.

49 - A Coupling Tunable THz Chiral Metamaterial Poster

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Qinghua Song, Xi'an Jiao Tong University, China

Hong Cai, Institute of Microelectronics, Agency for Science Technology & Research, Singapore

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Jinghua Teng, Institute of Materials Research and Engineering, Agency for Science Technology & Research, Singapore

Xinhai Zhang, Institute of Materials Research and Engineering, Agency for Science Technology & Research, Singapore
Dimlee Kwong, Institute of Microelectronics, Agency for Science Technology & Research, Singapore
Aiqun Liu, Nanyang Technological University, Singapore

This paper reports a coupling tunable chiral metamaterial consisting of double-layered gammadion elements with different orientations. The alignments between two faced gammadion elements on the top and bottom layer can be changed through transactional movement. The chirality tuning in THz is realized through the alignment change. The tunable chirality can be applied to manipulate THz polarization and realize negative refractive indexed functions such as super-lens.

50 - Cloak Based on Non-Resonant Straight Wires

Ihar Faniayeu, Gomel State University, Belarus
Victor Asadchy, Gomel State University, Belarus
Igor Semchenko, Gomel State University, Belarus
Andrey Samofalov, Gomel State University, Belarus
Sergey Khahomov, Gomel State University, Belarus

In this article we study scattering of plane electromagnetic waves by a metal cylinder surrounded by straight copper wires. Possibility to achieve partial recovery of the wave front behind the cylinder is demonstrated with certain parameters of the wires and their location in the structure. Reconstruction of the wave front is observed in frequency range from 3 to 3.25 GHz.

51 - Electric Concentrator and Cloak Made of DC Metamaterials

Wei Xiang Jiang, Southeast University, China
Chen Yang Luo, Southeast University, China
Di Bao, Southeast University, China
Wen Xuan Tang, Southeast University, China

Metamaterials have drawn a great deal of attention due to their many novel properties in wave dynamics. In this paper, we present two kinds of transformation electrostatic devices based on recent-developing dc metamaterials. One is dc electric concentrator for steady current fields, which will focus electric currents in to the central concentrated region and enhance the electric field and current density; the other is ultrathin but nearly perfect dc invisibility cloak, which is composed of one-unit-cell-thick anisotropic dc metamaterials.

52 - Liquid Crystal Tunable Metamaterial Absorber for THz Frequency Range

Bartłomiej Grześkiewicz, Poznan University of Technology, Faculty of Technical Physics, Poland
Eryk Wolarz, Poznan University of Technology, Faculty of Technical Physics, Poland
Andrzej Sierakowski, Institute of Electron Technology, Department of Micro- and Nanotechnology of Wide Bandgap Semiconductors, Poland
Jacek Marczewski, Institute of Electron Technology, Department of Micro- and Nanotechnology of Wide Bandgap Semiconductors, Poland
Norbert Pałka, Military University of Technology, Institute of Optoelectronics, Poland

We present a numerical study of the electromagnetic properties of liquid crystal tunable metamaterial absorber (LCTMA). LCTMA is characterized by absorption of terahertz radiation in narrow frequency range. Selective absorption of LCTMA can by tuned by reorientation of molecules in liquid crystal thin film as a results of applied electric field.
53 - Metamaterial Description of Magnonic Modes along Gamma M Direction in a 2D Antidot Lattice

**Poster**

**Roberto Zivieri**, Dipartimento di Fisica e Scienze della Terra, Università di Ferrara and CNISM, Unità di Ferrara, Italy

The metamaterial properties of a two-dimensional array of circular holes embedded into a continuous film of permalloy are studied along the Gamma M direction. Bragg's law for magnonic modes is derived by means of the effective wavelength and the scattering of collective modes from holes is described as a metamaterial effect.

54 - Circular Dichroism Effects in Nonlinear-Optical Response of Planar Chiral Metamaterials

**Poster**

**Evgeniy Mamonov**, Moscow State University, Department of Physics, Moscow, Russia  
**Irina Kolmychek**, Moscow State University, Department of Physics, Moscow, Russia  
**Stefaan Vandendriessche**, Molecular Electronics and Photonics, INPAC, Katholieke Universiteit Leuven, Leuven, Belgium  
**Mohamad Hojeij**, Laboratory for Micro and Nanotechnology, Paul Scherrer Institute, Villigen-PS, Switzerland  
**Yasin Ekinici**, Laboratory of Metal Physics and Technology, Department of Materials, ETH Zurich, Switzerland  
**Ventsislav Valev**, University of Cambridge, Department of Physics, Cavendish Laboratory, Cambridge, United Kingdom  
**Thierry Verbiest**, Molecular Electronics and Photonics, INPAC, Katholieke Universiteit Leuven, Leuven, Belgium  
**Tatiana Murzina**, Moscow State University, Department of Physics, Moscow, Russia

Circularly polarized optical second harmonic generation (SHG) is studied experimentally in regular arrays of planar G-shaped nanostructures. Circular dichroism in SHG is observed and the sign of the effect reverses with the handedness of the nanostructures, which is a signature of chirality in the nonlinear optical response.

55 - Tunable Infrared Resonance Spectra of Split Ring Resonators Embedded in a Liquid Crystal

**Poster**

**Heinz Kitzerow**, University of Paderborn, Germany  
**Bernhard Atorf**, University of Paderborn, Germany  
**Holger Mühlenbernd**, University of Paderborn, Germany  
**Thomas Zentgraf**, University of Paderborn, Germany

Two-dimensional arrays of sub-μm size split ring resonators are embedded in a liquid crystal and the infrared resonance spectra are measured. The results indicate that the wave number of the resonances can be shifted by 30 – 80 cm⁻¹ owing to realignment of the liquid crystal. The spectral shift depends on the mode, the polarization and the spectral region considered.

56 - Light Coupling in Microwave Metamaterials

**Poster**

**Alexey Slobozhanyuk**, NRU ITMO, St Petersburg, Russia  
**Polina Kapitanova**, NRU ITMO, St Petersburg, Russia  
**Ilya Shadrivov**, Nonlinear Physics Centre, Australian National University, Australia  
**Dmitry Filonov**, NRU ITMO, St Petersburg, Russia  
**David Powell**, Nonlinear Physics Centre, Australian National University, Australia  
**Pavel Belov**, NRU ITMO, St Petersburg, Russia
Mikhail Lapine, CUDOS, School of Physics, University of Sydney, Australia
Yuri Kivshar, Nonlinear Physics Centre, Australian National University, Australia

We report our achievements in tuning metamaterials with light. We introduce a novel approach to design metamaterials with sign-varying nonlinear response. For this purpose, we use split-ring resonators loaded by photodiodes and varactor diodes. We show how the nonlinear response of photosensitive metamaterials can be directly controlled by light coupling.

57 - Voltage Tunable Nonreciprocity of Microwaves Transmission with Varactor-Loaded Planar Meta-Structures Poster

Galina Kraftmakher, Kotelnikov V.A. Institute of Radioengineering & Electronics RAS, Russia
Valery Butylkin, Kotelnikov V.A. Institute of Radioengineering & Electronics RAS, Russia
Yuri Kazantsev, Kotelnikov V.A. Institute of Radioengineering & Electronics RAS, Russia

We suggest new planar meta-structures “ferrite plate – varactor-loaded resonant element” that provide voltage tunable nonreciprocity of microwaves transmission in contrast to traditional magnetic control. The effect is observed by tuning varactor capacitance with changing reverse-bias voltages under the ferromagnetic resonance excitation near the varactor-loaded element resonance frequency. Wide tuning range has been obtained with nonreciprocity 19 dB between 5.4 and 5.9 GHz. Presented meta-structures are useful for development of quick-tunable nonreciprocal systems.

58 - The Implementability of Electromagnetic Wave Expander Based on Metamaterials Poster

Xudong Pang, East China Normal University, China
Shouzheng Zhu, East China Normal University, China

In this paper, the effect of loss on the performance of the two-dimensional cylindrical wave expander is studied. The variations of the normalized distributions of the constitutive parameters are analyzed in detail with the minification factor and the relative thickness respectively. The work above can provide some guidance and suggestions for the practical implementations.

Oral Sessions (Tuesday afternoon 2)

16:30 - 18:15 Graphene and Quantum Effects in Metamaterials II
16:30 - 18:15 Metasurfaces II
16:30 - 18:15 Low-Loss and Active Metamaterials

16:30 - 18:15 Special Session II.3: Graphene and Quantum Effects in Metamaterials II
Organizer: Nader Engheta
Session chairperson: Nader Engheta

16:30 – 17:00 Zero-Gap Semiconductor Superlattices Invited oral
Mario Silveirinha, University of Coimbra - Instituto de Telecomunicacoes,
Based on an effective-medium approach, we describe how by combining mercury-cadmium-telluride semiconductor alloys with band gap energies of opposite signs it may be possible to design a superlattice where the electrons have zero-effective mass and a single valley linear energy dispersion.

17:00 – 17:30  Quantum Metamaterials and Magnetic Metafluids  
**Invited oral**

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

We explore optical-frequency quantum and magnetic plasmon modes. Our results demonstrate the quantum-to-classical transition in individual nanoparticles and in coupled nanoparticle and metamaterial systems, as well as the emergence of optical-frequency magnetism in a metamaterial fluid.

17:30 – 17:45  Dynamic Inductive Tuning of Fano-Resonant Meta-Surfaces Using Plasmonic Response of Graphene in Mid-Infrared  
**Oral**

**Gennady Shvets, UT, USA**

We demonstrate theoretically and experimentally that electrically gated single-layer graphene can be used to inductively tune the infrared optical response of Fano-resonant meta-surfaces. Several implementations will be introduced: graphene of the meta-surface, graphene directly under the meta-surface, and graphene separated by a thin spacer from the meta-surface. Both electrostatic and chemical doping of graphene will be discussed and supporting experimental results presented. Finally, we will demonstrate how the spectral shifts of metamaterials resonances introduced by the graphene can be utilized to extract graphene’s electronic properties such as the complex-valued resistivity.

17:45 – 18:00  Design, Fabrication and Testing of Superconducting Quantum Interference Device (SQUID) Metamaterials  
**Oral**

**Steven Anlage, University of Maryland, USA**

We have designed, fabricated, and tested a new class of metamaterials based on the Superconducting Quantum Interference Device (SQUID). Our motivation is to create new metamaterials with extreme degrees of tunability (> 100%) on very short time scales (< micro-seconds). The design philosophy, fabrication, and initial testing results under cryogenic conditions are discussed.

18:00 – 18:15  Nonhermitian Concepts in Classical and Quantum Plasmonics and Metamaterials  
**Oral**

**Pavel Ginzburg, King’s College London, United Kingdom**

**Francisco J. Rodríguez-Fortuño, Universidad Politécnica de Valencia, Spain**

**Alejandro Martínez, Universidad Politécnica de Valencia, Spain**

**Anatoly V. Zayats, King’s College London, United Kingdom**

We will present rigorous theoretical treatment of dissipation, commonly used in quantum optics, to describe optical properties of plasmonic systems in their non-Markovian dynamics. In particular, it will be shown that the decay of weakly coupled to radiation (dark) modes of subwavelength plasmonic nanostructures may be strongly nonexponential. Their lifetime is overestimated by conventional exponential relaxation time obtained in the standard Markovian approximation. We will then discuss plasmonic analogues of quantum effects and some of their applications in photonics. We will concentrate on quantum Hanle effect and show the impact of
quantum concepts on the engineering of metamaterial assembly. In particular, artificial plasmonic "atoms" will be shown to exhibit strong circular birefringence and circular dichroism as the manifestation of the dissipation.

**16:30 - 18:15**  **Oral session II.5: Metasurfaces II**
Session chairperson: Anthony Grbic

**16:30 – 17:00**  **Planar Meta-Optics**  **Keynote**

**Xingjie Ni**, School of Electrical and Computer Engineering and Birck Nanotechnology Center, Purdue University, USA  
**Alexander V. Kildishev**, School of Electrical and Computer Engineering and Birck Nanotechnology Center, Purdue University, USA  
**Satoshi Ishii**, School of Electrical and Computer Engineering and Birck Nanotechnology Center, Purdue University, USA  
**Vladimir M. Shalaev**, School of Electrical and Computer Engineering and Birck Nanotechnology Center, Purdue University, USA

The control of phase plays a fundamental role in wave propagation. Metasurfaces (thin metamaterial layers) can introduce an additional spatially non-uniform phase in the incoming wave, thereby affecting its propagating characteristics. A metasurface consisting a plasmonic nano-antenna array can introduce an abrupt phase discontinuity at the interface and therefore have unparalleled wave-front control over the incident light. We experimentally demonstrate a computer generated hologram operating at a visible wavelength by a metasurface consisting of Babinet-inverted nano-antennas perforated on a 30-nm-thick gold film. Micrometer-sized metasurface lenses (metalenses) are made with the same technique.

**17:00 – 17:30**  **Metasurface Transformation Optics**  **Invited oral**

**Enrica Martini**, University of Siena, Italy  
**Stefano Maci**, University of Siena, Italy

This work presents an extension of Transformation Optics (TO) to control the wavefront of surface waves through the use of modulated metasurfaces. This methodology can be applied to design a large number of planar devices including lenses, beam splitters and invisibility cloaks.

**17:30 – 17:45**  **Symmetry Properties of Metamaterials at Oblique Incidence**  **Oral**

**Sergey Kruk**, Australian National University, Australia  
**Christian Heigert**, Friedrich-Schiller University Jena, Germany  
**Manuel Decker**, Australian National University, Australia  
**Isabelle Staude**, Australian National University, Australia  
**Christoph Menzel**, Friedrich-Schiller University Jena, Germany  
**David Powell**, Australian National University, Australia  
**Christoph Etrich**, Friedrich-Schiller University Jena, Germany  
**Carsten Rockstuhl**, Friedrich-Schiller University Jena, Germany  
**Thomas Pertsch**, Friedrich-Schiller University Jena, Germany  
**Dragomir Neshev**, Australian National University, Australia  
**Yuri Kivshar**, Australian National University, Australia

We compare, both experimentally and theoretically, metamaterials with three different symmetries: square, hexagonal, and quasicrystalline for different angles of excitation. By relying on an advanced Jones calculus, we link the symmetry properties to the optical response. We show that in contrast to periodic
arrangements, quasicrystalline symmetry inhibits anisotropy in metamaterials.

17:45 – 18:00 Polarization-Resolved SHG Microscopy of Chiral G-shaped Nanostructures

Evgeniy Mamonov, Moscow State University, Department of Physics, Moscow, Russia
Irina Kolmychek, Moscow State University, Department of Physics, Moscow, Russia
Anton Maydykovsky, Moscow State University, Department of Physics, Moscow, Russia
Ventsislav Valev, Department of Physics, Cavendish Laboratory, University of Cambridge, UK
Alejandro Silhanek, Département de Physique, Université de Liège, Belgium

Polarization-resolved second harmonic generation (SHG) microscopy was performed for chiral G-shaped nanostructures. SHG polarization hotspots were observed. Stokes parameters of SHG radiation were determined.

18:00 – 18:15 A Mechanically Flexible Free Standing Optical Filter

Peter Reader-Harris, University of St Andrews, United Kingdom
Armando Ricciardi, University of Sannio, Italy
Thomas Krauss, University of St Andrews, United Kingdom
Andrea Di Falco, University of St Andrews, United Kingdom

A flexible filter based on the principle of guided mode resonances is demonstrated, operating in the visible. We are able to produce different kinds of filter by changing the geometrical parameters. We exploit the unique properties of our filter by wrapping it round the end of a collimated fibre output.

16:30 - 18:15 Oral session II.6: Low-Loss and Active Metamaterials
Session chairperson: Mikhail Lapine

16:30 – 17:00 Realization of High-Quality Metamaterials Resonators Adding Metallic Structures to Dielectric Slabs

Costas Soukoulis, Ames Lab/Iowa State Univ & IESL-FORTH, Crete, USA

We combine experimental methods with computer simulations to develop a set of novel metamaterials exhibiting resonances that store energy mainly in a dielectric material. This avoids resonant loss in the metals and we indeed demonstrate electric and magnetic metamaterial resonators with very large quality factors.

17:00 – 17:15 Lossless Light Propagation in Plasmonic Metamaterial: Spasers vs Uncoupled Quantum Emitters

Arkadi Chipouline, FSU Jena, Germany
Mikhail Dobynde, MSU, Russia
Andrey Fedyanin, MSU, Russia
Vassili Fedotov, ORC, UK
J. Ruostekoski, School of Mathematics, University of Southampton, UK
Stewart Jenkins, *School of Mathematics, University of Southampton, UK*

It is shown theoretically, that the optical properties of metamaterials with loss compensation depends significantly on the coupling strength between the plasmonic metaatoms and quantum emitters. The question about compatibility of the loss compensation and negative refraction is resolved using combination of multipole approach and semiclassical system of equations for spaser dynamics.

17:15 – 17:30  **Control of Quantum-Dot Emission in Magnetic Metamaterials**  
*Oral*

Dragomir Neshev, *Australian National University, Australia*  
Manuel Decker, *Australian National University, Australia*  
Sergey Kruk, *Australian National University, Australia*  
Isabelle Staude, *Australian National University, Australia*  
Ivan Shishkin, *National Research University for Information Technology, Mechanics and Optics, Russia*  
Kirill Samusev, *National Research University for Information Technology, Mechanics and Optics, Russia*  
Patrick Parkinson, *Australian National University, Australia*  
Varun Sreenivasan, *Macquarie University, Australia*  
Alexander Minovich, *Australian National University, Australia*  
Andrey Miroshnichenko, *Australian National University, Australia*  
Andrey Zvyagin, *Macquarie University, Australia*  
Chennupati Jagadish, *Australian National University, Australia*  
Yuri Kivshar, *Australian National University, Australia*

We overview our studies on emission of quantum dots coupled to photonic metamaterials. We reveal how the interactions of the quantum dots simultaneously with the magnetic and the electric resonances of the metamaterials affect their spontaneous emission and result in eliptically polarized light emission at off-normal directions.

17:30 – 17:45  **Dynamical Model for Gain-assisted Localized Surface Plasmons**  
*Oral*

Alessandro Veltri, *LICRYL - Liquid Crystal Research Center; Dept. of Physics, University of Calabria, Italy*  
Ashod Aradian, *Centre de Recherche Paul Pascal - CNRS - University of Bordeaux, France*  
Arkadi Chipouline, *Institute of Applied Physics, Jena, Germany*

We present a dynamical model for a classically treated metal spherical inclusion in a gain assisted medium described using quantum formalism. The model integrates geometry via a proper set of boundary conditions and it is shown to be consistent with the statical formula for polarizability, which can be obtained in the low amplitude linear approximation. This dynamical approach is able to describe transient regimes, to study instabilities and to account the effects of a pulsed pump.

17:45 – 18:00  **Gain-Plasmon Dynamics: Loss Compensation Routes in Meta-Structures**  
*Oral*

Giuseppe Strangi, *Dept. of Physics, Case Western Reserve Univ., USA*  
Antonio de Luca, *Univ. of Calabria, Italy*  
Melissa Infusino, *Univ. of Calabria, Italy*  
Rakesh Dhama, *Univ. of Calabria, Italy*  
Alireza Rahmi-Rashed, *Univ. of Calabria, Italy*  
Marinella Striccoli, *IPCF CNR Bari, Italy*  
Lucia Curri, *IPCF CNR Bari, Italy*  
Roberto Bartolino, *Univ. of Calabria, ITALY*
In this work, we experimentally demonstrate that the incorporation of gain material (fluorophores) in the high-local-field areas of metamaterial nanostructures makes it possible to induce resonant energy transfer processes from gain units to plasmonic nanostructures. The multipronged routes used to compensate losses in these metastructures permits one to obtain important advances in materials science and paves the way toward further promising scientific research aimed to enable the wide range of electromagnetic properties of optical metamaterials.

18:00 – 18:15 Loss Compensation in RF Metamaterials by Single Transistor Circuits
Oral

Lukas Jelinek, CTU Prague, Faculty of Electrical Engineering, Dept. of Electromagnetic Field, Czech Republic
Jan Machac, CTU Prague, Faculty of Electrical Engineering, Dept. of Electromagnetic Field, Czech Republic

This paper shows that reduction of losses, or even addition of gain, in RF metamaterials can be achieved by a single transistor circuit that exploits its conditional stability. The presented solution offers not only extreme simplicity, but also absolute control over stability and achieved gain values.

18:15 – 18:30 Evening break (Tuesday)

18:30 – 20:00 Special Event: Metamaterials in High-Impact Journals and Funding Agencies

18:30 – 20:00 Special Event: Metamaterials in High-Impact Journals and Funding Agencies
Session chairperson: Andrea Alù

18:40 – 19:00 US Navy Perspective on Metamaterials
Invited oral
Mark Spector, Office of Naval Research

19:00 – 19:20 Stay Highly Relevant to Metamaterials Research: The Strengths and Challenges of the Physical Review Journals
Invited oral
Ling Miao, Physical Review X

19:20 – 19:40 Nature Photonics and You
Invited oral
Rachel Won, Nature Photonics

19:40 – 20:00 Uncloaking the Editorial Processes at Nature Communications
Invited oral
Nicky Dean, Nature Communications
### Oral Sessions (Wednesday morning 1)

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<td>Metamaterials for Emission and Radiative Heat Control II</td>
<td>Auditorium</td>
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<td>09:00 - 10:30</td>
<td>Exotic Effects in Metamaterials I</td>
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<td>09:00 - 10:30</td>
<td>Fano Resonances in Metamaterials</td>
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<tr>
<td>09:00 - 10:30</td>
<td>Special Session III.1: Metamaterials for Emission and Radiative Heat Control II</td>
<td>Auditorium</td>
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<tr>
<td>09:00 – 09:30</td>
<td>Novel Nanophotonic Phenomena in Systems of Macroscopic Size</td>
<td>Invited Oral</td>
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<td><strong>Marin Soljacic, MIT, USA</strong></td>
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<td>Nanophotonics provides superb opportunities for tailoring of the photonic density of states. In this talk, I will present some of our recent theoretical and experimental progress in exploring these opportunities in systems of macroscopic size.</td>
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<td>09:30 – 10:00</td>
<td>Applications of Infrared Meta-Surfaces to Thermal Emission: from Thermo-Photovoltaics to Polarization State Manipulation</td>
<td>Invited Oral</td>
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<td><strong>Gennady Shvets, The University of Texas at Austin, USA</strong></td>
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<td>We will present a concept of an integrated frequency selective absorber/emitter based on an ultra-thin plasmonic metamaterial for Solar Thermo-Photovoltaics (STPV) applications. By employing non-shiny metals (such as tungsten or molybdenum), the absorption spectrum of the metamaterial can be designed to be broad-band in the visible range and narrow-band in the infrared range. A detailed balance calculation demonstrates the total STPV system efficiency exceeding the Shockley-Queisser limit for emitter temperatures above Te = 1200K, and an efficiency as high as 41% for Te = 2300K. Such emitter temperature is shown to be achievable under modest Sun concentration (less than 1000 Suns) because of the thermal insulation provided by the metamaterial. Experimental demonstration of the wide-angle frequency selective absorptivity will be presented, and its implications for developing broadband infrared absorbers/emitters will be discussed. Another novel concept that will be discussed in this talk is that of an all-dielectric metamaterial exhibiting extraordinary spectral sharpness. First experimental results of Si-based Fano resonant metamaterials with the quality factor exceeding 100 will be discussed, and its applications to ultra-thin polarization converters and thermal emitters of circularly polarized infrared radiation will be discussed. Finally, the experimental realization of SiC-based arrays of thermally emitting antennas will be demonstrated, and its implications for developing non-metallic antenna emitters across entire infrared spectrum will be discussed.</td>
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<td>10:00 - 10:15</td>
<td>Super-Planckian Near-Field Heat Transfer</td>
<td>Oral</td>
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<td><strong>Svend-Age Biehs, Institut für Physik, Carl von Ossietzky Universität, Oldenburg, Germany</strong></td>
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It is well known that the radiative heat flux exchanged between two hot bodies separated by a distance larger than their thermal wavelengths cannot be larger than the flux exchanged between two blackbodies at the same temperature. However at subwavelength distances, the heat flux can surpass the blackbody limit by several orders of magnitude due to the contribution of the evanescent electromagnetic field. In this case one can speak of super-Planckian thermal radiation. In this work we discuss in detail the origin of super-Planckian exchanges between multilayer materials and we propose different strategies to enhance them by tailoring the evanescent modes supported by these media.

10:15 – 10:30 Coherent Thermal Emission from Graphene-based Asymmetric Hyperbolic Metamaterial Oral

Igor Nefedov, Aalto University, Finland
Leonid Melnikov, Saratov State Technical University, Saratov, Russia

Using Green's function method, fluctuating-dissipation theorem, and the Kubo model of graphene, we analyze thermal emission from an asymmetric hyperbolic metamaterial formed of graphene multilayers with graphene sheets, tilted with respect to medium interfaces. Asymmetry appears in a strong difference in normal components of wave vectors for waves, propagating downward and upward to hyperbolic medium interfaces. Due to asymmetry, under certain conditions photons, belonging to states with a very high density, do not undergo a total internal reflection and can be radiated from the asymmetric hyperbolic medium into far zone. We demonstrate that the graphene asymmetric hyperbolic metamaterial can produce high-directive and quite strongly coherent thermal emission.

09:00 - 10:30 Oral session III.1: Exotic Effects in Metamaterials I
Session chairperson: Jensen Li

09:00 - 09:30 Dispersion Manipulation of Isotropic Media through Indefinite Route Invited oral

Ari Sihvola, Aalto University, Finland
Henrik Wallén, Aalto University, Finland
Henrik Kettunen, University of Helsinki, Finland

In this presentation, we study the possibilities of enhancing losses in plasmonic--dielectric layered structures and tailoring their frequency dependence towards elimination of the dispersion variation. This is done by building the material inclusions as radially anisotropic (RA) spheres which are externally isotropic.

09:30 – 10:00 Robust Interface States in Two Dimensional Photonic Crystals with Dirac Cone Dispersions Invited oral

C T Chan, Physics Department, Hong Kong University of Science and Technology, Hong Kong
Xueqin Huang, Physics Department, Hong Kong University of Science and Technology, Hong Kong
Meng Xiao, Physics Department, Hong Kong University of Science and Technology, Hong Kong

We have previously shown that two dimensional (2D) photonic crystals (PCs) with Dirac-like cone dispersion at $\Gamma$ point ($k=0$) can in some cases be described as a
Recently, we found that if we create an interface by putting together two semi-infinite PCs with the parameters slightly perturbed from the Dirac-like cone condition, there are always localized states in the interface. The robustness of such interface states can be explained by angle dependent effective parameters derived from a layer-by-layer multiple scattering theory.

10:00 - 10:15  **Unidirectional Excitation of Guided Light Using a Circularly Polarized Emitter**  
*Oral*

**Francisco Rodríguez-Fortuño**, Universidad Politécnica de Valencia, Spain  
**Giuseppe Marino**, King’s College London, United Kingdom  
**Pavel Ginzburg**, King’s College London, United Kingdom  
**Daniel O’Connor**, King’s College London, United Kingdom  
**Alejandro Martínez**, Universidad Politécnica de Valencia, Spain  
**Gregory Wurtz**, King’s College London, United Kingdom  
**Anatoly Zayats**, King’s College London, United Kingdom

We show that the vectorial near field interference of a single emitter can be tailored to achieve unidirectional excitation of electromagnetic modes in a nearby waveguide. A near field sub-wavelength source, usually modeled by a point linear dipole, is known to excite electromagnetic modes uniformly in all directions when brought close to a waveguide. We show theoretically and experimentally that if the dipole is elliptically polarized, the interference that occurs in its near fields can result in a unidirectional excitation of the guided modes determined by the direction of dipole rotation.

10:15 – 10:30  **Mathematical Manipulation with Metamaterials**  
*Oral*

**Alexandre Silva**, University of Pennsylvania, USA  
**Francesco Monticone**, University of Texas at Austin, USA  
**Giuseppe Castaldi**, University of Sannio, Italy  
**Vincenzo Galdi**, University of Sannio, Italy  
**Andrea Alu**, University of Texas at Austin, USA  
**Nader Engheta**, University of Pennsylvania, USA

Here, we present our ideas of using metamaterials as tools to manipulate mathematical functions. We discuss several approaches to designing metamaterials that can perform mathematical operations on functions presented at their inputs. We explore properly designed metastructures that facilitate several operations.

09:00 - 10:30  **Oral session III.2: Fano Resonances in Metamaterials**  
*Session chairperson: Albert Polman*

09:00 – 09:30  **Fano Resonances of Organic Films on Asymmetric Split-Ring Resonators (A-SRRs)**  
*Invited oral*

**Nigel Johnson**, University of Glasgow, United Kingdom  
**Basudev Lahiri**, NIST, Center for Nanoscale Science and Technology, USA  
**Graham Sharp**, University of Glasgow, UK  
**Richard De La Rue**, University of Glasgow, UK  
**Scott McMeekin**, Glasgow Caledonian University, UK

Thin organic films on arrays of asymmetric split-ring resonators (A-SRRs) produces a shift in their resonance spectra that can be utilised for sensitive analyte detection. Localization of blocks of PMMA at different positions on the A-SRR array also shows their relative sensitivity. Other organic materials such as progesterone show...
similar Fano resonances.

09:30 – 10:00  **Fano Resonances in All-Dielectric Metamaterials**  
*Extended oral*

*Mikhail Limonov*, NRU ITMO, St Petersburg, Russia  
*Mikhail Rybin*, NRU ITMO, St Petersburg, Russia  
*Kirill Samusev*, NRU ITMO, St Petersburg, Russia  
*Alexander Poddubny*, NRU ITMO, St Petersburg, Russia  
*Arash Hosseinzadeh*, Michigan Technological University, USA  
*Elena Semouchkina*, Michigan Technological University, USA  
*George Semouchkin*, Michigan Technological University, USA  
*Yuri Kivshar*, Australian National University, Australia

We study the fundamental properties of all-dielectric metamaterials composed of high-index dielectric rods. We vary the value of rod permittivity from low to high, and analyze a crossover between photonic crystals and metamaterials observed in the scattering features associated with the Bragg and Mie resonances. We reveal new features of the collective response in the scattering which can be explained by the physics of Fano resonances.

10:00 - 10:15  **Unconventional Fano Resonances in Plasmonic Coated Spheres**  
*Oral*

*Tiago Arruda*, Universidade de São Paulo, Brazil  
*Alexandre Martinez*, Universidade de São Paulo, Brazil  
*Felipe Pinheiro*, Universidade Federal do Rio de Janeiro, Brazil

We show that unconventional Fano resonances exist for metallic spheres coated with single dielectric layers even in the Rayleigh limit. We find that unconventional and conventional Fano resonances can occur at the same input frequency provided the core has negative refractive indices, leading to optimal field enhancements inside the particle.

10:15 – 10:30  **Multi-Bi- and Tri-Stability Using Nonlinear Plasmonic Fano Resonators**  
*Oral*

*Muhammad Amin*, King Abdullah University of Science and Technology, Saudi Arabia  
*Mohamed Farhat*, King Abdullah University of Science and Technology, Saudi Arabia  
*Hakan Bagci*, King Abdullah University of Science and Technology, Saudi Arabia

A plasmonic Fano resonator embedding Kerr nonlinearity is used to achieve multi-bi- and tri-stability. Fano resonance is obtained by inducing higher-order plasmon modes on metallic surfaces via geometrical symmetry breaking. The presence of the multiple higher order plasmon modes provides the means for producing multi-bi- or tri-stability in the response of the resonator when it is loaded with a material with Kerr nonlinearity. The multi-stability in the response of the proposed resonator enables its use in three-state all optical memory and switching applications.

10:30 – 11:00  **Coffee break (Wednesday morning)**
Plenary Session III

11:00 – 12:00

Photonic Structures: Advanced Thermal Control, and Effective Gauge Field for Light

Shanhui Fan, Stanford University, USA
Zongfu Yu, Stanford University, USA
Kejie Fang, Stanford University, USA
Eden Rephaeli, Stanford University, USA
Aaswath Raman, Stanford University, USA

Novel mechanisms to control electromagnetic interaction, as evidenced by the recent developments of a wide variety of nanophotonic structures, have broad implications for both fundamental and applied research. In this talk, we will present two separate classes of examples of some of our recent works in seeking to create novel electromagnetic interactions, and to exploit these interactions for new applications. We will show that one can achieve an effective gauge field for photons, which leads to a rich set of new non-reciprocal physics effects, as well as a very promising avenue towards on-chip non-magnetic linear optical isolator. We will also discuss some of our recent works in using nanophotonic structures to control heat flow, which results in the possibility for overcoming the apparent blackbody radiation limit to the far field for a given emitter size, and daytime radiative cooling.

12:00 - 13:30

Lunch (Wednesday)

Oral Sessions (Wednesday afternoon 1)

13:30 - 15:00

Acoustic, Mechanical and Elastic Metamaterials I

13:30 - 15:00

Exotic Effects in Metamaterials II

13:30 - 15:00

Fabrication of Metamaterials

13:30 - 15:00

Special session III.2: Acoustic, Mechanical and Elastic Metamaterials I

Organizer: Jose Sanchez-Dehesa
Session chairperson: Jose Sanchez-Dehesa

13:30 – 14:00

Applied Acoustic Metamaterials Keynote

Steven Cummer, Duke University, USA

After reviewing the short history of acoustic metamaterials and describing some of the foundational research in the field, we will report some recent experimental work from our group focusing on the development of new approaches to create acoustic metamaterials with effective material properties that are useful for a range of
Using the idea of analogue spacetimes, we derive an "analogue transformation acoustics" formalism that naturally allows the use of transformations mixing space and time or involving moving fluids, both of which were impossible with the standard approach. We illustrate the use of the method by designing acoustic versions of a dynamic compressor and a spacetime cloak. The proposed method can be generalized to transform other kinds of physical fields beyond the constraint of form-invariance, finding potential applications in other branches such as quantum fluids and graphene electronics.

Direct Observation of Ultra Slow and Negative Group Velocities of Sound Wave

We present the first experimental observation of ultra slow and negative group velocities using an acoustic analog of EIT consisting of coupled radiant (interacting) and dark (not interacting with acoustic waves) resonators. We observed highly transparent and remarkably sharp 5.6 Hz transmission window in the middle of the band near 482 Hz with a significant slowdown of the sound speed by a factor of 125.7. Strong dispersion of the transparent window will lead to applications such as compression of sound and high sensitivity sensors.

Advances in Acoustic Cloaks and Acoustic Metamaterials with Double Negative Parameters and Density Near Zero Density

The recent results in the design and characterization of acoustic cloaks for airborne sound will be reviewed. Two-dimensional (2D) and three-dimensional cloaks based on the scattering cancellation will be reported. In addition, quasi-2D acoustic metamaterials with double negative parameters or density near zero will be described and characterized.
demonstrated a double-negative microwave metamaterial by guiding through the cutoff-free TEM mode between two curled conducting wires. Field mappings and effective medium extraction confirm our studies.

**14:00 – 14:15** Flat Lens for Bending Waves Focusing in Time Domain Oral

Marc Dubois, Institut Langevin, France  
Mohammed Farhat, Institute of Condensed Matter Theory and Solid State Optics, Germany  
Emmanuel Bossy, Institut Langevin, France  
Stefan Enoch, Institut Fresnel, France  
Sébastien Guenneau, Institut Fresnel, France  
Patrick Sebbah, Institut Langevin, France

Flat lens concept proposed in 1968 by V.G. Veselago is extended to elastic waves on a thin plate. A 45°-tilted square lattice of circular holes drilled in a Duraluminium plate has been chosen to experimentally demonstrate focusing of flexural waves. Lamb wave pulse focusing is achieved below the first stop band. If most investigations have been performed in the monochromatic regime, it was recognized that understanding the time development of the superlensing effect is crucial.

**14:15 – 14:30** Non-Radiating Excitations, Vector Potential Waves and Toroidal Metamaterials Oral

Vassili Fedotov, Optoelectronics Research Centre, University of Southampton, United Kingdom  
Vassili Savinov, Optoelectronics Research Centre, University of Southampton, United Kingdom  
Alexandra Rogacheva, Optoelectronics Research Centre, University of Southampton, United Kingdom  
Din Ping Tsai, Department of Physics, National Taiwan University and Research Center for Applied Sciences, Academia Sinica, Taiwan  
Nikolay Zheludev, Optoelectronics Research Centre, University of Southampton, United Kingdom

We demonstrate theoretically and confirm experimentally a new mechanism of resonant electromagnetic transparency, which yields narrow isolated symmetric Lorentzian transmission lines in metamaterials. It exploits the long sought non-trivial non-radiating charge-current excitation based on interfering electric and toroidal dipole moments. Such interference is also expected to result in gauge-irreducible vector potential waves generated in the complete absence of scattered electromagnetic fields.

**14:30 – 14:45** Coupled-Mode Theory for Nonlinear Plasmonic Structures and Metamaterials Oral

Andrey Sukhorukov, Australian National University, Australia  
Alexander Solntsev, Australian National University, Australia  
Sergey Kruk, Australian National University, Australia  
Dragomir Neshev, Australian National University, Australia  
Yuri Kivshar, Australian National University, Australia

We develop a systematic procedure for deriving the coupled-mode equations based on the Lorentz reciprocity theorem. The equations describe the spatial evolution of the slowly-varying amplitudes of electromagnetic modes in nonlinear periodic lossy media. Our approach is applicable to a broad range of structures, including plasmonic waveguides and metamaterials.
14:45 – 15:00 **Optimal Arrangement of Smooth Helices in Uniaxial 2D-Arrays**

*Viktar Asadchy, Gomel State University, Belarus*
*Ihar Faniayeu, Gomel State University, Belarus*
*Younes Ra‘di, Aalto University, Finland*
*Igor Semchenko, Gomel State University, Belarus*
*Sergei Khakhomov, Gomel State University, Belarus*

Uniaxial electrically thin layers formed by arrays of smooth helices are under study. Simple and smooth shape of the helices makes them more preferable from experimental point of view in comparison to other chiral particles. Here we optimize by simulation mutual orientation and density of the helices in the array so that it acts as a twist-polarizer or a perfect absorber.

13:30 - 15:00 **Oral session III.4: Fabrication of Metamaterials**

Session chairperson: Alexandra Boltasseva

13:30 – 14:00 **Fabricating Arrays of 3D Micro and Nanostructures Using Metal-assisted Chemical Etching**

*Owen Hildreth, National Institute of Standards and Technology, USA*
*C. P. Wong, The Chinese University of Hong Kong Shitan, China*

This work summarizes recent advances in the field of Metal-assisted Chemical Etching (MaCE) enabling the fabrication of 3D micron and nano-sized structures in silicon in a single lithography/etch cycle. How to fabricate both vertically aligned thin films and spiraling 3D structures with controlled chirality are discussed.

14:00 – 14:15 **Experimental Realization of an Epsilon-Near-Zero Metamaterial at Visible Wavelengths**

*Ruben Maas, FOM-institute AMOLF, the Netherlands*
*James Parsons, FOM-institute AMOLF, the Netherlands*
*Nader Engheta, University of Pennsylvania, U.S.A.*
*Albert Polman, FOM-Institute AMOLF, the Netherlands*

We fabricate an optical metamaterial consisting of a multilayer array of Ag and SiN with unit cell size 85-280 nm and Ag filling fraction 30-80%. Using interferometry we demonstrate epsilon-near-zero behavior tunable over the entire visible spectral range for TE modes. Variation of the metamaterial unit cell size shows a clear transition from an effective-medium model to coupled waveguide-based metamaterial dispersion.

14:15 – 14:30 **Optical Properties of Raspberry-Like SiO2@Mn Nanoclusters**

*Aurélie Le Beulze, ICMCB, France*
*Hélène Géhan, ICMCB, France*
*Anthony Désert, ICMCB, France*
*Stéphane Mornet, ICMCB, France*
*Serge Ravaine, CRPP, France*
*Etienne Duguet, ICMCB, France*
*Mona Tréguer-Delapierre, ICMCB, France*

Coupling of localized surface plasmon resonances results in singular effects at the void space between noble metal nanoparticles. Here, we present an approach that allows to produce raspberry-like nanoclusters in which metal nanoparticles are in close interaction. Two types of architectures based on isotropic or anisotropic metallic nanoparticles have been explored. Their production, in high yield and high
amount, is based on colloidal chemistry methods. First optical characterization yields novel and intriguing plasmonic effects.

14:30 – 14:45  **Electrohydrodynamics Jet Printing: Alternative Fabrication Method for Terahertz Metamaterial with High Refractive Index**  Oral

**Hadi Teguh Yudistira**, Sungkyunkwan University, Korea (South)
**Ayodya Pradhipta Tenggara**, Sungkyunkwan University, Korea (South)
**Vu Dat Nguyen**, Enjet Co., Korea (South)
**Teun Teun Kim**, Korea Advanced Institute of Science and Technology, Korea (South)
**Muhan Choi**, Kyungpook National University (KNU), Korea (South)
**Doyoung Byun**, Sungkyunkwan University, Korea (South)

Metamaterial is an artificial material in which the electromagnetic properties, such as permittivity and permeability, can be controlled. By engineering its unit structure, metamaterial is able to develop special optical properties which are rarely or maybe impossible to be found in nature, like negative refractive index, high refractive index, absorber. Here we have shown the direct fabrication of the metamaterial using the electrohydrodynamic jet printing under atmospheric condition. which is studied by us is EHD jet printing. Controlling the electrical pulse Using DC signal into make drop-on-demand drop on in EHD printing, we success to could fabricate the metamaterial’s structure until microscale pattern for developing with high refractive index properties in tera-THz application frequency. The peak refractive index was 11.12 at around 0.5 tera-THz with 5 µm gap size pattern.

14:45 – 15:00  **Enhanced Cross-Section of Gold Nanoparticles in The Vicinity of a Silicon Substrate**  Oral

**Kevin Ehrhardt**, CNRS & Univ. Bordeaux, France
**Zhiqiang Zheng**, CNRS & Univ. Bordeaux, France
**Julien Vieaud**, CNRS & Univ. Bordeaux, France
**Olivier Merchiers**, CNRS & Univ. Bordeaux, France
**Yves Borensztein**, CNRS & Univ. Paris 6, France
**Ashod Aradian**, CNRS & Univ. Bordeaux, France
**Virginie Ponsinet**, CNRS & Univ. Bordeaux, France

Monolayers of gold nanoparticles deposited on top of a polymer layer (spacer) above a silicon wafer were prepared by electrostatically-controlled layer-by-layer assembly. Their structure was studied by atomic force microscopy and X-ray reflectivity. Spectroscopic ellipsometry was used to extract the individual absorption cross-section of the nanoparticles in the visible spectrum. We show that this cross-section varies with the substrate proximity, in a way which cannot be fully described by the classically described image dipole effect.
15:00 - 16:30  Poster Session II - Student Competition and coffee break

15:00  Poster Session II
Session chairperson: Jennifer Dionne

1 - Substrate-Mediated Sub-Diffraction Guiding of Optical Signals Through a Linear Chain of Metal Nanoparticles: Polarization Dependence and The Role of the Dispersion Relation  

P.J. Compaïjen, University of Groningen and Zernike Institute for Advanced Materials, Netherlands  
Jasper Knoester, University of Groningen and Zernike Institute for Advanced Materials, Netherlands  
Victor Malyshev, University of Groningen and Zernike Institute for Advanced Materials, Netherlands

We theoretically investigate the efficiency of transmitting optical signals through a linear chain consisting of identical and equidistantly spaced silver nanoparticles in the presence of a reflecting substrate. The energy exchange between surface plasmon polaritons of the chain and the substrate can give rise to an increased transmission. We focus on the effects of the polarization of the excitation and the role of the dispersion relation of the collective chain-substrate modes.

2 - Optical Response of a Nanohybrid: Molecular Dimer + Metal Nanoparticle  

Bintoro Siswo Nugroho, Zernike Institute for Advanced Materials, Netherlands  
Alexander A. Iskandar, Institut Teknologi Bandung, Indonesia  
Victor A. Malyshev, Zernike Institute for Advanced Materials, Netherlands  
Jasper Knoester, Zernike Institute for Advanced Materials, Netherlands

We study theoretically the optical response of a hybrid system comprise of a dimer coupled to a metal nanoparticle. The intermolecular coupling between molecules J and the dimer-MNP coupling G drive the optical response of the hybrid. We found that, for certain combinations of these couplings, optical bistability can occur.

3 - Mode Analysis of a Large Number of Mutually Coupled Ferromagnetic Metamaterial Based on Spin Torque Oscillators  

Ansar Safin, National Technical University Moscow, Power Engineering Institute, Russia

The results of an investigation of the structure of oscillatory modes of a coupled ladder line and ring of ferromagnetic metamaterial based on spin torque oscillators are presented. Method of mode calculation in this type of ensemble geometry is investigated. It has been demonstrated that only single modes could be stable. Simultaneous two, three and more modes are not stable.

4 - Dielectric Electromagnetically Induced Transparency Metamaterial  

Fuli Zhang, Northwestern Polytechnical University, China  
Xu Zhou, Northwestern Polytechnical University, China  
Yaling Zhou, Northwestern Polytechnical University, China  
Sha An, Northwestern Polytechnical University, China
Gengyao Yu, Northwestern Polytechnical University, China

We report a windmill type electromagnetically induced transparency (EIT) metamaterial composed of two identical orthogonal dumbbell dielectric resonators with relatively high permittivity at terahertz. With proper external excitation, dielectric dumbbell resonator can operate as EIT bright and dark element via electric and magnetic Mie resonances, respectively. Rigorous numerical analysis demonstrates that resulting windmill type metamaterial exhibits electromagnetic induced transparency (EIT) transmission line shape featured by large group index at terahertz frequency.

5 - Dynamics of Nanolaser Coupled with High-Q Microresonator as an Analog of Superconducting Structure Poster

Arkadi Chipouline, FSU Jena, Germany
E. Khaidarov, IAP, Jena, Germany
A. Zagoskin, Department of Physics, Loughborough University, UK
E. Ilichev, IPHT, Jena, Germany

Dynamics of a nanolaser-type structure (plasmonic nanoresonator coupled with quantum dots - QD) optically coupled with a high-Q microresonator is considered theoretically using simple model. Main peculiarities of the classical dynamics of the plasmonic nanoresonator and dielectric microresonator, and quantum dynamics of the QD are obtained. Analogy with the quantum dynamics of a superconducting structure is found and perspectives for the experimental realization are given.

6 - A Dynamically-Tunable Graphene-Based Fano Metasurface Poster

Muhammad Amin, King Abdullah University of Science and Technology, Saudi Arabia
Mohamed Farhat, King Abdullah University of Science and Technology, Saudi Arabia
Hakan Bagci, King Abdullah University of Science and Technology, Saudi Arabia

A planar graphene metasurface with rectangular holes, which is capable of supporting a dynamically tunable Fano resonance at Terahertz (THz) frequencies, is proposed. The rectangular hole is patterned asymmetrically within the metasurface’s unit cell to “brighten” an originally-dark quadrupolar surface plasmon mode. Fano resonance is achieved via the destructive interference of this mode with a dipolar surface plasmon. The spectral location and line shape of the Fano resonance can be dynamically tuned via a gate voltage applied to the metasurface to change graphene’s optical properties. The dynamic tunability of the Fano resonance suggests the applicability of the proposed metasurface in designing THz wave modulators and band-pass filters.

7 - Substrate Controllable Transverse Magnetic Surface Waves onto a Graphene Layer at Far-Infrared Frequencies Poster

Stamatios Amanatidis, Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Greece
Nikolaos Kantartzis, Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Greece

The propagation properties of transverse magnetic surface waves onto a graphene layer and the influence of the surrounding media are thoroughly examined. After developing a realistic model of graphene, in a homogeneous medium, its conductivity of the resulting surface waves are extracted in terms of the medium’s dielectric permittivity.
8 - Perfect Plasmonic Absorber for Visible Frequency

Mehdi Keshavarz Hedayati, Nanochemistry and Nanoengineering, Institute for Materials Science, Faculty of Engineering, University of Kiel, Germany
Mady Elbahri, Nanochemistry and Nanoengineering, Institute for Materials Science, Faculty of Engineering, University of Kiel, Germany

Here, we show design and fabrication of a nanocomposite with a routine method of MEMS/NEMS industry as a tunable metamaterial spanning broad range of spectrum from UV to NIR. It provides the opportunity to realize a perfect plasmonic absorber with a wide-band peak which is polarization insensitive and angle-invariant.

9 - Experimentally Feasible Green-Light Negative Index Metamaterial

M. Mahfuz Rahman, Michigan Tech, USA
M. Imran Aslam, NED University of Engineering and Technology, Pakistan
Durdu Guney, Michigan Tech, USA
Philip Evans, Oak Ridge National Laboratory, USA

We propose a novel green-light plasmonic negative index metamaterial (NIM). Underlying experimental data for the metal layers and the fabrication feasibility based on electron-beam lithography render the structure arguably the most promising in the literature to further scale the operating frequency of the NIMs to new record low visible wavelengths.

10 - Anisotropic Effective Medium Approach for Metamaterials Made of Arrays of Metallic Nanopillars

Alexandre Baron, CRPP, France
Kévin Ehrhardt, CRPP, France
Vasyl Kravets, University of Manchester, UK
A. N. Grigorenko, University of Manchester, UK
Ashod Aradian, CRPP, France
Marc Warenghem, Unité de Catalyse et de Chimie du Solide, France

The optical response of a surface covered with an array of gold nanopillars is studied both experimentally, using spectroscopic ellipsometry, and numerically. When treating the gold pillars as an effective layer, we find that it is possible to extract anisotropic effective optical indices that fit the experimental data. However, a detailed numerical study of the behavior of the metamaterial under illumination shows the presence of localized, specific coupling effects with the underlying layer, suggesting that homogenization, and effective indices should be considered with caution and have only limited applicability.

11 - Radiation of Chiral Molecules in Chiral MetaEnviroment

Vasily Klimov, Lebedev Physical Institute, Russia

Within Classical and Quantum Electrodynamics we have considered spontaneous emission of chiral (optically active) molecule placed in different chiral environments: half-space, sphere and antenna made of 2 chiral nanoparticles. For all these geometries we have found analytical description of the problem for arbitrary parameters of environment, including chiral double negative (DNG, "left-handed") metamaterials. It turns out to be that one can effectively control radiation of “right” and “left” molecules separately by tuning parameters of chiral nano-meta particles indeed.
12 - T-matrix Analysis of Dipole Waves on Chains of Dielectric Particles

Oleksandr Zhuromskyy, Institute of Optics, Information and Photonics, University Erlangen-Nürnberg, Germany
Ulf Peschel, Institute of Optics, Information and Photonics, University Erlangen, Germany

Loss less propagation of longitudinal magnetic-dipole waves is predicted for regular chains of rutile particles. Rigorous T-matrix simulation techniques are applied to deduce the dispersion characteristics of the dipole waves and to optimize the properties of the closing elements in the waveguide for maximum power transmission. The proposed technique can be used to optimize the interaction between light and particle ensembles.

13 - Guided Wave Metamaterial Configurations for Application in the Near IR Domain

Natalia Dubrovina, IEF, University Paris Sud, France
Rafael Salas-Montiel, LNIO, Université de Technologie de Troyes, France
Sylvain Blaize, LNIO, Université de Technologie de Troyes, France
André de Lustrac, IEF, University Paris Sud, France
Gilles Lerondel, LNIO, Université de Technologie de Troyes, France
Anatole Lupu, IEF, University Paris Sud, France

We address the potential of a metamaterials in a guided wave configuration for applications in the near IR domain. We consider a hybrid type structure made of 2D metamaterial array over a high index slab waveguide, as for instance silicon our case. The experimental and modeling results show that effective index and loss level in such hybrid waveguides can be carefully controlled by the engineering of metamaterial resonances. The investigated approach may constitute a promising alternative to the bulk multi-layers metamaterial structures.

14 - Flexible Metamaterial Using Subwavelength Holes Arrays for Absorption at THz Frequencies

Eric Lheurette, IEMN, Université de Lille 1, France
Nadia Soltani, IEMN, Université de Lille 1, France
Guillaume Ducournau, IEMN, Université de Lille 1, France
Didier Lippens, IEMN, Université de Lille 1, France

This study deals with metamaterial design for THz electromagnetic wave absorption. The structure is based on subwavelength holes arrays separated by a Polyethylene-Naphtalate (PEN) soft substrate whose complex permittivity has been experimentally determined by means of Vectorial Network Analysis in the 325-500 GHz frequency band. The principle of this absorbing layer is related to an asymmetry between the elliptical aspect ratio (EAR) of the top and the bottom metallic layer apertures which leads to an efficient absorption by reducing both transmission and reflection coefficients values.

15 - Terahertz Negative Index Metamaterials by means of Stacked Subwavelength Hole Arrays

Didier Lippens, IEMN, France
Nadia Soltani, Université de Lille, France
Guillaume Ducournau, Université de Lille, France
Eric Lheurette, Université de Lille, France
Jean François Lampin, Université de Lille, France
We report on the experimental assessment of stacked Au/BCB bilayers structured with sub-wavelength hole arrays. On the basis of a full wave analysis, it shown that these structures exhibit a composite left- and right-handed dispersion characteristic. The experimental characterization is carried by means of a CW vector network analysis of the complex reflection and transmission characteristics from which the complex effective index is experimentally deduced.

16 - Magnetic Response of Planar Dielectric Rings of Arbitraty Width
Poster

Michael Bakunov, University of Nizhny Novgorod, Russia
Alexey Maslov, University of Nizhny Novgorod, Russia
Svetlana Kuznetsova, University of Nizhny Novgorod, Russia

We analyze the response of a planar dielectric ring to an applied time-harmonic magnetic field. The distribution of the polarization current is calculated self-consistently. It is shown that the magnetic moment of the ring exhibits multiple resonances. The results are compared with that from an equivalent LCR circuit model.

17 - Demonstration of Dielectric Optical Magnetic Mirrors Using Phase-locked Infrared Time-domain Spectroscopy
Poster

Sheng Liu, Sandia National Lab, USA
Young Chul Jun, Sandia National Lab, USA
Thomas Mahony, Sandia National Labs, USA
James Ginn, Sandia National Labs, USA
Daniel Bender, Sandia National Labs, USA
Joel Wendt, Sandia National Labs, USA
Jon Ihlefeld, Sandia National Labs, USA
Paul Clem, Sandia National Labs, USA
Jeremy Wright, Sandia National Labs, USA
Michael Sinclair, Sandia National Labs, USA
Igal Brener, Sandia National Labs, USA

We directly demonstrate a dielectric optical magnetic mirror using phase-locked mid-infrared time-domain spectroscopy. Our theoretical studies further confirm that an electric dipole emitter placed close to the dielectric magnetic mirror can radiate efficiently in contrast to quenched emission near normal mirrors. This magnetic mirror is formed by micron-sized cubes of tellurium fabricated on a dielectric substrate.

18 - Effect of Disorder in U-Shaped Metamaterials
Poster

Geraldine Guida, LEME France, France
Habiba Ouslimani, LEME France, France
Bruno Gallas, INSP, France

We present a study of a very perturbed U-shaped metamaterial in order to understand the disorder in such a structure. Figures of absorbance reveal large modifications in the case of perturbed metamaterials that can be explained considering individual U perturbed. Absorbance spectra observed reveal numerous peaks that appear for arrays of individual U of same perturbation.

19 - Near Infrared Metamaterial Containing a Metal
Poster

Slawa Lang, Hamburg University of Technology, Institute of Optical and Electronic Materials, Germany
Alexander Petrov, Hamburg University of Technology, Institute of Optical
A layered hyperbolic metamaterial with 7 nm of gold and 42 nm of silicon is demonstrated with hyperbolic transition in near infrared. The collision frequency of gold in thin layers increases by an order of magnitude. The obtained metamaterial is not inferior to ones with infrared plasmonic materials.

20 - Domain Nonreciprocity of Electromagnetic Waves in Centrosymmetric TbMnO3

Irina Chupis, Institute for Low Temperature, Ukraine

Polariton spectrum of centrosymmetric TbMnO3 in the commensurate antiferromagnetic (AF) state at low temperature after spin-flop has been analyzed. Different velocities of electromagnetic waves, opposite directions of the rotations of electric field and polarization plane in the terbium domains with reversed direction of AF vector were revealed. The velocities of electromagnetic waves in AF terbium domains and the rotation angle of polarization plane are of the same order.

21 - Plasmonic and Dielectric Nano-Cylinders: Lumped Nano-Capacitors and Nano-Inductors from Plane Waves with Arbitrary Orientation and Polarization

Leonardo Ambrosio, University of Campinas, Brazil
Hugo Hernández-Figueroa, University of Campinas, Brazil

We present the nano-impedances associated with dielectric and plasmonic nano-cylinders with radii much smaller than the operating wavelength. The capacitive or inductive behavior is shown to be dependent upon both the polarization of the incident wave and the angle between the wave vector and the principal axis of the cylinder.

22 - Influence of Plasmonic Particle on Resonance Fluorescence of a Quantum Emitter

Evgeny Andrianov, Moscow Institute of Physics and Technology, Institute for Theoretical and Applied Electromagnetics RAS, Russia
Alexander Pukhov, Moscow Institute of Physics and Technology, Russia
Alexey Vinogradov, Institute for Theoretical and Applied Electromagnetics RAS, Russia

We consider the resonance fluorescence spectrum of an two-level atom located in the near field of plasmonic particle. It is shown that when the atom approaches to the plasmonic particle the high-frequency peak of Mollow triplet disappears, and the spectrum takes the form of the Fano resonance. Next, the low-frequency peak disappears too. At short distances, where the interaction of the atom with the particle is much larger than with the external field, the spectrum takes the form of Lorentz line, which width is proportional to the square of the interaction between the particle and the atom.

23 - Imaging The Electromagnetic Response Of Superconducting Metasurfaces

Philipp Jung, Physikalisches Institut, Karlsruhe Institute of Technology, Germany
Roman Kosarev, National University of Science and Technology MISIS, Russia
We present a method to analyze the electromagnetic behavior of superconducting planar microwave metamaterials. Using a laser scanning microscope (LSM), we image the microwave response of two-dimensional arrays of magnetic meta-atoms. This method allows us to investigate contributions of individual meta-atoms to the macroscopic response and thus provides a useful tool for characterization and optimization. The meta-atoms in the present experiment are frequency tunable superconducting quantum interference devices (SQUIDs).

**24 - A Tunable SQUID-Loaded Transmission Line Metamaterial**

**Poster**

**Susanne Butz**, Karlsruhe Institute of Technology, Physikalisches Institut, Germany

**Philipp Jung**, Karlsruhe Institute of Technology, Physikalisches Institut, Germany

**Valery P. Koshelets**, Kotel'nikov Institute of Radio Engineering and Electronics, Moscow, Russia

**Lyudmilla V. Filippenko**, Kotel'nikov Institute of Radio Engineering and Electronics, Moscow, Russia

**Alexey V. Ustinov**, Karlsruhe Institute of Technology, Physikalisches Institut, Germany

Metamaterials consisting of superconducting quantum interference devices (SQUIDs) as magnetic meta-atoms have a number of advantages over conventional metamaterials at microwave frequencies. In addition to the low-loss nature of the superconductor, their resonance frequency is tunable by magnetic field. In this work, we demonstrate how a one-dimensional array of SQUIDs can be used to modify the properties of a coplanar waveguide. Furthermore, we show how transmission spectroscopy data from such an experiment can be used to extract the effective magnetic permeability. This effective parameter can deviate strongly from unity over a wide band of frequencies and even becomes negative.

**25 - Generalized Fresnel Coefficients for Arbitrary Periodic Metafilms**

**Poster**

**Alexandros Dimitriadis**, Department of Electrical & Computer Engineering, Aristotle University of Thessaloniki, Greece

**Theodoros Tsiboukis**, Department of Electrical & Computer Engineering, Aristotle University of Thessaloniki, Greece

In this paper, analytical expressions for the co- and cross-polar scattering coefficients of periodic metafilms comprising arbitrary meta-atoms are systematically derived. These formulas are obtained under the assumption that the metafilm is characterized via a suitable surface susceptibility model. The novel results are successfully employed for three existing surface susceptibility models,
showing very good agreement with numerical simulation outcomes.

26 - Polarized Light Transmission in Distorted 2-Dimensional Slab Colloidal Plasmonic-Photonic Crystals

Sergei Romanov, Institute of Optics, Information and Photonics University of Erlangen-Nuremberg, Germany

Polarization rotation was induced in 2-dimensional plasmonic-photonic crystal by uniformly distorting the shape of silver semishells. Physical mechanism of this phenomenon was analyzed using co- and cross-polarized transmission spectra.

27 - Plasmonic Analogy of a Phased-Array Antenna

Nadezda Lapshina, NRU ITMO, St.Petersburg, Russia, Max Planck Institute for the Science of Light, Germany
Roman Noskov, NRU ITMO, St.Petersburg, Russia, Max Planck Institute for the Science of Light, Germany
Yuri Kivshar, NRU ITMO, St.Petersburg, Russia and Australian National University, Canberra, Australia

We introduce the novel concept of a nanoantenna with self-tunable scattering pattern composed of two nonlinear subwavelength silver nanoparticles. This nonlinear nanoantenna action originates from modulational instability occurred in a plasmonic nanodimer. Modulational instability stipulates a dynamical energy exchange between the nanoantenna eigenmodes resulting in periodic scanning of the nanoantenna scattering pattern. Such nanoantenna demonstrates a wide scanning sector, low operation threshold, and ultrafast time response being potentially useful for many applications in nanophotonics circuitry.

28 - Tailoring Plasmonic Resonances of Nanowires by Corrugation and Corners

Maxim Gorkunov, Institute of Crystallography, RAS, Russia
Boris Sturman, Institute of Automation and Electrometry, Russian Academy of Sciences, Russia
Evgeniy Podivilov, Institute of Automation and Electrometry, Russian Academy of Sciences, Russia

We analyze the effect of crosssection corrugation of metal nanowires on their plasmonic resonances. For weak periodic corrugations, the problem admits a full-scale analytical treatment revealing nontrivial plasmonic properties. Numerical study shows nonlinear growth of the red shift of the main resonance with increasing modulation periodicity and amplitude. For nanowires with sharp corners of variable curvature, we predict the simultaneous occurrence of several fundamental phenomena: the main dipolar plasmonic mode experiences strong red shift with increasing corner curvature; for large curvature, the resonance is controlled by the apex angle of the corner; the split-off dipolar plasmonic mode experiences strong localization at the corners. Altogether, the results pave the way for tailoring metal nanostructures for wavelength-selective excitation of localized plasmons with strong near-field enhancement.

29 - Comparison of Two Metamaterial Methods in Earthquake Engineering

Sang-Hoon Kim, Mokpo National Maritime University, Korea (South)

There are two methods for earthquake engineering as an application of acoustic metamaterials. One is the traditional cloaking method that it makes the seismic wave deflect and rotate the building to be protected. The other is the shadow zone method. It makes the seismic wave disappear. We explain the fundamental principles of the two methods and compare the advantages and disadvantages of
30 - Superconducting Active Metamaterials: Conceptual Development

Stanislav Eismont, National University of Science and Technology MISIS, Moscow, Russia
Sergey Shitov, National University of Science and Technology MISIS, Moscow, Russia; Institute of Radioengineering and Electronics, Russian Academy of Sciences (IREE RAS), Moscow, Russia
Alexey Ustinov, National University of Science and Technology MISIS, Moscow, Russia; Physikalisches Institut, Karlsruhe Institute of Technology, Karlsruhe, Germany

We present two concepts for development of active superconducting metamaterials, which can generate and amplify the GHz-range signals. We analyzed two electromagnetic models based on 2-D circuits with Josephson junctions: (i) superconducting oscillator employing ac Josephson effect is formed from a network of underdamped junctions tuned by applied magnetic field; (ii) overdamped junctions arranged in two distributed 2-D amplifying media. To increase the saturation level and optimize the impedance of such media, the series-in-parallel connections are suggested. It is estimated that the high-efficiency oscillator can perform at least up to 0.7 THz with tunability of about 2%; the distributed rf SQUID-amplifier anticipated to operate over the band 8-12 GHz.

31 - Microwave Cloaking Using Resonant and Non-Resonant Dielectric Materials

Elena Semouchkina, Michigan Tech University, USA
Xiaohui Wang, Michigan Tech University, USA

The efficiency of two approaches to cloaking cylindrical objects by using dielectric materials, one based on transformation optics and employing resonant metamaterials and another one based on scattering cancellation and employing ordinary dielectrics, is quantitatively compared. The extension of the cloaking approach using ordinary dielectric materials to designing spherical cloaks is proposed.

32 - Experimental Realization of a Coaxial Plasmonic Metamaterial at Visible/UV Frequencies

Marie Anne van de Haar, FOM institute AMOLF, Netherlands
Ruben Maas, FOM institute AMOLF, the Netherlands
Hinke Schokker, FOM institute AMOLF, the Netherlands
James Parsons, FOM institute AMOLF, the Netherlands
Albert Polman, FOM institute AMOLF, the Netherlands

We demonstrate the experimental realization of a coaxial, polarization-independent negative index metamaterial in the blue/UV spectral range, using a combination of electron-beam lithography, reactive ion etching, metal infiltration, and focused ion beam polishing. UV interferometry is used to optically characterize the metamaterial. The experimental results are compared with numerical simulations and analytical calculations.

33 - Spoof Planar Surface Plasmons on Corrugated Metallic Strip and a Plasmonic Ring Resonator

Xiaopeng Shen, State Key Laboratory of Millimeter Waves, Southeast University, China
Tie Jun Cui, State Key Laboratory of Millimeter Waves, Southeast University, China
We propose a spoof planar surface plasmons (SPPs) on thin corrugated metallic strips in the microwave and terahertz frequencies. From theoretical simulations and experiments, we show that spoof SPPs can propagate along a thin metallic film by corrugating its edge with periodic array of grooves. We demonstrate that such a planar plasmonic metamaterial can sustain highly localized SPPs along two orthogonal directions. Based on such features, we design and simulate a planar ring resonator in terahertz frequency, and made experiments in microwave frequency, both of which exhibit excellent performance. The proposed planar plasmonic metamaterials will play important roles in integrated plasmonic circuits and systems.

34 - Generalized Image Method for Radiation Problems Involving the Minkowskian Isotropic Medium Poster

Filipa Prudêncio, Instituto Superior Técnico - Instituto de Telecomunicações, Portugal
Sérgio Matos, ISCTE – University Institute of Lisbon, Instituto de Telecomunicações, Portugal
Carlos Paiva, Instituto Superior Técnico - Instituto de Telecomunicações, Portugal

We formulate a generalized image theory for the radiation of electromagnetic sources in the vicinity of a vacuum - Minkowskian isotropic medium (MIM) interface, proving that the secondary scattered fields can be expressed in terms of virtual sources. This theory extends classical results to a broad class of electromagnetic media.

35 - Acoustic Extraordinary Transmission Using Zero-Mass Metamaterials Poster

Jong Jin Park, Institute of Physics and Applied Physics, Yonsei University, Korea (South)
K. J. B. Lee, Department of Physics, Ewha Womans University, Korea (South)
Oliver B. Wright, Division of Applied Physics, Faculty of Engineering, Hokkaido University, Japan
Myoung Ki Jung, Institute of Physics and Applied Physics, Yonsei University, Korea (South)
Sam H. Lee, Institute of Physics and Applied Physics, Yonsei University, Korea (South)

We experimentally demonstrate about 80% transmission of sound through a rigid wall perforated with subwavelength holes of 3% areal coverage. This remarkable transmission efficiency was obtained by making the mass of the air column in the hole to vanish effectively. The effective mass of the hole was made zero by installing tight thin membranes. Energy flux density of the incident wave was concentrated into the holes by the factor of 30. Potential applications include high sensitivity acoustic sensors.

36 - Macroscopic Optical Tuning: Highly Organized Plasmonic Structures, a Step Towards Metamaterials Poster

Moritz Tebbe, University of Bayreuth, Germany

In this work we report novel methods to produce large scale bottom-up organized structures of plasmonic nanoparticles. These organizations can be done either at the macroscopic or at the nanoscale using completely lithography-free approaches based on self-assembly.
37 - Highly Tuneable Kerr Effect in Magneto-Optical Metamaterials

Brian Toal, Queens University Belfast, United Kingdom
Robert Pollard, Queens University Belfast, United Kingdom

We investigate tuneability of the magneto-optic response of a metamaterial consisting of an array of low aspect ratio nickel nanowires in an anodised aluminium oxide template. The bilayer structure acts as a Fabry-Perot resonator with enhanced magneto-optical effects at reflectivity minima which can be spectrally shifted by altering the dimensions of the nickel nanowires. The results are also accurately modelled using Effective Medium Theory.

38 - New Plasmonic Material Based Split Ring Resonators for High Frequency Applications

Emmy Sharples, The Cockcroft Institute and Lancaster University, UK
Rosa Letizia, The Cockcroft Institute and Lancaster University, UK

The resonant frequencies of split ring resonator metamaterials based on new plasmonic materials are investigated, to identify alternatives to gold and silver for high-frequency applications. We show how these resonances can be tuned by changing the substrate permittivity and identify which setup for each plasmonic material maximises the resonant response.

39 - Self-Assembled Nanocomposite Made of Gel and Gold Nanoparticles for Metamaterial Applications

Julien Vieaud, National Institute of Materials Science, Japan

This work is focusing on the establishment of a dielectric matrix fabrication allowing a homogenous dispersion of metaatom. We use the tridimensional network of a gel to surround the particles and then to avoid any physical aggregation of the metaatoms.

40 - Revisit of Fishnet Metamaterials: From Viewpoint of Dimensionality, Symmetry, and Designs of Unit Cell

Masanobu Iwanaga, National Institute for Materials Science, Japan

Physical insight for fishnet metamaterials (MMs) has been advanced further for a few years. The resonances are systematically described by a first-principles approach, that is, eigenmode analysis for perforated metal-insulator-metal structures. We provide more general understandings and underlying physics of fishnet MMs.

41 - Bottom-up Fabrication of Ordered 2D and 3D Gold Nanoparticle Assemblies Showing Collective or Individual Plasmon Resonances

Claudia Pacholski, Max Planck Institute for Intelligent Systems, Germany
Sebastian Scheeler, Max Planck Institute for Intelligent Systems, Germany
Simon Ullrich, Max Planck Institute for Intelligent Systems, Germany
Stefan Kudera, Max Planck Institute for Intelligent Systems, Germany

The fabrication of plasmonic metamaterials mainly relies on top-down methods which allow for a precise control of their geometrical dimensions and consequently their optical properties. Chemical routes to plasmonic nanostructures are challenged by the required accurateness for well-resolved optical responses but allow for the generation of extended nanostructured areas. We report on a self-assembly approach for the fabrication of plasmonic metamaterials whose optical properties can be dictated either by individual or collective plasmon resonance of their building blocks. For this purpose wet-chemically synthesized gold nanoparticles are equipped with a polymer shell and self-assembled into ordered
2D or 3D structures using alternating spin-coating and plasma treatment cycles.

42 - Synthesis and Optical Characterization of Gain Assisted Plasmonic Material Poster

Christophe Coutant, Bordeaux University, CNRS CRPP, France
Alexandre Baron, Bordeaux University, CNRS CRPP, France
Ashod Aradian, Bordeaux University, CNRS CRPP, France
Philippe Barois, Bordeaux University, CNRS CRPP, France
Serge Ravaine, Bordeaux University, CNRS CRPP, France

We elaborate and characterize gain assisted plasmonic material out of gold-silica nanoparticles. The chemistry part will cover the synthesis of core-shell, the incorporation of active fluorescent molecules into silica, and the auto-assembling techniques. The physical part will display the predicted theoretical behavior of the systems and the first experimental results.

43 - Plasmon-Enhanced Photoluminescence from Metal Nano-Structures Poster

Tigran Shahbazyan, Jackson State University, USA

A microscopic theory of plasmon-enhanced metal photoluminescence is developed. New mechanism of luminescence suppression in small nanostructures is identified: excitation of Auger plasmons by core holes. Our numerical calculations are in excellent agreement with experiment.

44 - Respon Bandwidth of Plasmonic Nanoresonators Coupled with Quantum Emitters Poster

Arkadi Chipouline, FSU Jena, Germany
M. Saygin, MSU, Russia
M. Dobynde, MSU, Russia
A. Chirkin, MSU, Russia

The plasmonic resonators of different configurations coupled with quantum emitters (like quantum dots – QD) are expected to exhibit laser-like behavior provided the internal ohmic and radiative losses are fully compensated. The energy transferred from the pumped QD to the plasmonic resonators, depends on the multiple factors, but in most experimental cases is insufficient to reach the generation threshold. The observable bandwidth of the spasers at the overcompensation (full loss compensation or generation mode) and below compensation (partial loss compensation mode) is investigated. Principal difference between these modes is underlined.

45 - Slow-Light in a Cage Poster

Jianji Yang, Institut d’Optique, France
Weiming Zhou, U.S. Army Research Laboratory Adelphi, USA
Connie Chang-Hasnain, Department of Electrical Engineering and Computer Sciences, University of California at Berkeley, USA
Philippe Lalanne, Institut d’Optique, France

Slow-light effect has potential for applications ranging from optical information processing to optical switching. It is well-known that material dispersion can induce slow-light near some resonances, such as electromagnetically induced transparency. Additionally, structural dispersion can also be applied to realize slow-light, e.g. photonic crystal waveguides (PhCWs). Here we study the Bloch modes of a silicon periodic waveguide with an ultra-large hollow-core. With three-dimensional fully-vectorial calculations, we successively find that the proposed periodic waveguide can support lossless guided Bloch modes. Moreover, this cage
waveguide is quite flexible for geometric tailoring of dispersion relation.

46 - Strong Localization In Unintentional Disordered Photonics Crystal Waveguides

Xiaorun Zang, Lab. Photonique Numérique et Nanosciences, France
Philippe Lalanne, Lab. Photonique Numérique et Nanosciences, France

Photonics crystal waveguide (PhCW), as a promising tool for realizing photonic integrated chip, can provide remarkable confinements of light field. In this report, we show that real PhCWs (i.e. PhCWs with fabrication imperfections left by state of the art fabrication facilities) without any intentional disorder support highly-confined localization states with a spatial extent comparable to that achieved with engineered micro-cavities.

47 - Spontaneous Emission in the Presence of a Spherical Plasmonic Cloak

Wilton J.M. Kort-Kamp, Instituto de Física/Universidade Federal do Rio de Janeiro, Brazil
Felipe S.S. Rosa, Instituto de Física/Universidade Federal do Rio de Janeiro, Brazil
Felipe A. Pinheiro, Instituto de Física/Universidade Federal do Rio de Janeiro, Brazil
Carlos Farina, Instituto de Física/Universidade Federal do Rio de Janeiro, Brazil

We investigate the spontaneous emission (SE) of a two-level atom placed in the vicinity of a plasmonic cloak composed of a coated sphere. We demonstrate that the SE rate is strongly modified, suggesting that atoms could be used as quantum, local probes of the effectiveness of plasmonic cloaks.

48 - Omnidirectional Broadband Flexural Focusing Structure

Alfonso Climente Alarcon, Universitat Politècnica de València, Spain
Daniel Torrent Marti, Universitat Politècnica de València, Spain
Jose Sanchez-Dehesa Moreno-Cid, Universitat Politècnica de València, Spain

We present the proposal and the theoretical characterization of the elastic analog of the so-called photonic black-hole. The structure has a cylindrical symmetry and consists of two parts, a shell that bends the flexural waves and a core where the energy concentrates. The shell behaves like a gradient index lens and the variation of the refractive index has been obtained by changing the thickness of the plate. The simulations based on a multiple scattering algorithm demonstrate the broadband and omnidirectional properties of the structure.

49 - Achieving Invisibility with a Tunable Cloaking Device

Wilton Kort-Kamp, Universidade Federal do Rio de Janeiro, Brazil
Felipe Pinheiro, Universidade Federal do Rio de Janeiro, Brazil
Felipe Rosa, Universidade Federal do Rio de Janeiro, Brazil
Carlos Farina, Universidade Federal do Rio de Janeiro, Brazil

We investigate the electromagnetic plane wave scattering by a cylinder coated by a magneto optical shell. In the long wavelength limit we show that an external static magnetic field can be used to tune the electric response of the system and then reduce the cylinder scattering cross section making it nearly transparent to electromagnetic radiation. This result suggests the construction of a tunable cloaking device.
50 - Hyperbolic Metamaterials for Terahertz Applications

Alexander Atrashchenko, Ioffe Physical-Technical Institute, Russian Academy of Sciences, St. Petersburg, NRU ITMO, St. Petersburg, Russia
Ilya Shadrivov, NRI ITMO, St. Petersburg, Russia; Nonlinear Physics Center, Australian National University, Canberra, Australia
Vladimir Ulin, Ioffe Physical-Technical Institute, Russian Academy of Sciences, St. Petersburg, Russia
Galina Li, Ioffe Physical-Technical Institute, Russian Academy of Sciences, St. Petersburg, Russia
Pavel Belov, NRU ITMO, St. Petersburg, Russia
Yuri Kivshar, NRU ITMO, St. Petersburg, Russia; Nonlinear Physics Center, Australian National University, Canberra, Australia

We develop a method for fabricating hyperbolic metamaterials for terahertz (THz) applications. We prepare a porous silicon matrix with a triangular lattice of holes, which we fill with copper by means of electrochemical deposition. We study transmission properties of this wire medium using THz time-domain spectroscopy, and demonstrate hyperbolic media properties.

51 - Metamaterial-Based Gradient Index Beam Steerer Operating in the THz-Regime

Jens Neu, University of Kaiserslautern, Germany
Marco Rahm, University of Kaiserslautern, Germany

We demonstrate the design, fabrication and characterization of a metamaterial-based gradient index beam steerer fabricated as 100 µm thick membrane. The fabricated sample is designed for 1.3THz with an operating bandwidth of 300GHz. We measured via 3D THz-TDS raster scanning a maximum beam deflection angle of 1.9° (single-layer deflector) and 5.5° (double-layer device).

52 - Polarization Transformations by a Biaxial Metamaterial on a Metal Substrate

Illia Fedorin, National Technical University Kharkiv Polytechnic Institute, Ukraine
Aleksey Bulgakov, Institute for Radiophysics and Electronics of NAS of Ukraine, Ukraine

Polarization properties of a subwavelength metamaterial, which located on a metal substrate are investigated. We compared polarization characteristics of reflected electromagnetic waves for different thicknesses of the layers, magnetic fields and dissipation factors of semiconductor layer and metal substrate in terms of the functionality of linear to elliptic polarization transformation.

53 - Loss Compensated and Lasing Terahertz Metamaterials Based on Optically Pumped Graphene: A Numerical Study

Peter Weis, University of Kaiserslautern, Germany
Juan Luis Garcia-Pomar, Instituto de Óptica, Spain
Marco Rahm, University of Kaiserslautern, Germany

We investigate optically pumped graphene in a hybridized system with metamaterials. After elucidating the conditions of THz-amplification in graphene its interaction with metamaterials is examined. We find that optically pumped graphene can be used to compensate the inherent loss of metamaterials and beyond that acts as a lasing source when asymmetric split-ring resonators are utilized.
54 - Finite Element Analysis for Laser Action in Random Porous Media
Poster

Garuda Fujii, Faculty of Systems Science and Technology, Akita Prefectural University, Japan
Tsuyoshi Ueta, Physics Laboratory, The Jikei University School of Medicine, Japan
Mamoru Mizuno, Faculty of Systems Science and Technology, Akita Prefectural University, Japan

We present the properties of laser action in random porous media by means of a finite element method. Porous media composed of a dielectric material and randomly arranged pores are assumed. Laser action in random porous media occurs from not only modes of random laser but also whispering gallery modes.

55 - Dispersion Characteristics of Two-dimensional Capacitor-connected Grids
Poster

Yue Li, Communication Research Group, Department of Engineering, University of Oxford, United Kingdom
Christopher W.T. Chan, Communication Research Group, Department of Engineering, University of Oxford, United Kingdom
Christopher J. Stevens, Communication Research Group, Department of Engineering, University of Oxford, United Kingdom

This study expands previous work on 1-D CCGs to 2-D CCG surface waveguides, offering great potential for UWB contactless multi-terminal data transfer channels. 2-D CCG waveguides have two propagation modes: one supports forward waves while the other supports backward waves. Theoretical dispersion characteristics of different wave propagation modes around 100MHz are studied with the aid of four 2-D CCG examples with different electric coupling strengths.

56 - Magneto-Inductive Wave Power Transfer Structures
Poster

Christopher Stevens, Oxford University, United Kingdom

Metamaterials offer new propagation modes for electromagnetic signals which have been explored as media for data exchange. They also offer a good prospect for efficient power transfer. This paper considers the limits on transferable power and their consequences in relation to magneto inductive waves in 1D magnetic metamaterial structures. The upper limit is found to be directly related to the voltage tolerance of capacitances used in the metamaterial's construction. Higher resonant frequencies offer better efficiency and higher maximum powers. For a proposed device operating in the Qi band (100-200kHz) power transfer limits of 500W are derived.
**Oral sessions (Wednesday afternoon 2)**

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<td>Acoustic, Mechanical and Elastic Metamaterials II</td>
<td>Auditorium</td>
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<td>16:30 - 18:00</td>
<td>Tunable Metamaterials</td>
<td>Badiane Hall</td>
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<tr>
<td>16:30 - 18:00</td>
<td>Hybrid &amp; Multifunctional Metamaterials</td>
<td>Patio Hall</td>
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<td>16:30 - 18:00</td>
<td>Special Session III.3: Acoustic, Mechanical and Elastic Metamaterials II</td>
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<td>16:30 – 17:00</td>
<td>Metallic Structures for Transformation Acoustics and Negative Index Phononic Crystals</td>
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<td><strong>Invited oral</strong></td>
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<td><strong>Andrew Norris, Rutgers University, USA</strong></td>
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<td><strong>Adam Nagy, Rutgers University, USA</strong></td>
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<td><strong>Jeffrey Cipolla, Weidlinger Associates Inc, USA</strong></td>
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<td><strong>Nachiket Gokhale, Weidlinger Associates Inc, USA</strong></td>
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<td><strong>Anne-Christine Hladky-Hennion, IEMN, France</strong></td>
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<td><strong>Charles Croënne, City University of Hong Kong, China</strong></td>
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<td><strong>Jerome Vasseur, IEMN, France</strong></td>
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<td><strong>B Dubus, IEMN, France</strong></td>
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<td>17:00 – 17:15</td>
<td>Tunable Locally Resonant Granular Crystal</td>
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<td><strong>Luca Bonanomi, Department of Mechanical and Process Engineering, ETH Zurich, Switzerland</strong></td>
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<td><strong>Georgios Theocharis, Laboratoire d'Acoustique de l'Université du Maine UMR-CNRS 6613, France</strong></td>
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<td><strong>Duc Ngo, School of Engineering, Eastern International University, Vietnam</strong></td>
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<td><strong>Chiara Daraio, Department of Mechanical and Process Engineering, ETH Zurich, Switzerland</strong></td>
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<td>17:15 – 17:30</td>
<td>Toward Ultrasonic Ultra-Damping Metamaterials</td>
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<td><strong>Benoit Mascaro, University of Bordeaux, France</strong></td>
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<td><strong>Thomas Brunet, University of Bordeaux, France</strong></td>
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<td><strong>Olivier Poncelet, CNRS, France</strong></td>
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We report the achievement of highly monodisperse emulsions exhibiting about ten acoustic Mie resonances. Thanks to robotics, the effective acoustic properties of such strongly scattering media can be precisely targeted by means of the production of calibrated (random) liquid-droplets. Ultrasonic experiments are compared, with an excellent quantitative agreement, to theoretical predictions derived within the framework of the independent scattering approximation. The dependence of the sound speed and of the acoustic attenuation on both the size, the polydispersity and the volume fraction of droplets is quantitatively examined. These results are briefly discussed into the context of metamaterials for which scattering resonances are central to their effective properties.

17:30 – 17:45  **Elastic Analogue of Graphene: Dirac Cones and Edge States in the Propagation of Flexural Waves in Thin Plates**  
Daniel Torrent, Universitat Politècnica de València, Spain  
Didier Mayou, Institut Néel, CNRS – Université Joseph Fourier, France  
José Sánchez-Dehesa, Universitat Politècnica de València, Spain

An elastic analogue of graphene is presented. It consists of a honeycomb arrangement of spring-mass resonators attached to a thin elastic plate. It is shown that the band structure for the propagation of flexural waves of the resulting system presents Dirac points. Also, it is shown that finite “slabs” of this honeycomb arrangement can be used as waveguides due to the presence of “edge states”, a special type of guided states that does not appear in the dispersion relation of the infinite system. Finally, multiple scattering simulations of finite clusters of resonators are shown supporting the theory.

17:45 – 18:00  **Steering Electromagnetic and Acoustic Waves at Deep Sub-wavelength Scales in Ordered and Disordered Metamaterials**  
Nadège Kaina, Institut Langevin, ESPCI ParisTech, France  
Mathias Fink, Institut Langevin, ESPCI ParisTech, France  
Geoffroy Lerosey, Institut Langevin, ESPCI ParisTech, France

Using a microscopic approach, we prove that the hybridization bandgap of some resonant metamaterials only results from the local resonance. Hence, we experimentally demonstrate that we can mold the flow of waves at very subwavelength scales in ordered and disordered metamaterials by locally tailoring the unit cells.
Oral session III.5: Tunable Metamaterials
Session chairperson: Christophe Caloz

16:30 – 17:00
Tunable Metamaterials for Microwave and Terahertz Frequencies

Ilya Shadrivov, Australian National University, Australia

In this talk we will overview our recent studies of nonlinear and tunable metamaterials. We will focus on experimental results with terahertz and microwave metamaterials.

17:00 – 17:30
Active and Tunable Metamaterials based on Strong and Ultra-strong Coupling to Semiconductor Excitations

Igal Brener, Sandia National Labs, USA

We use strong coupling between planar metamaterial resonators and optical excitations in semiconductors as a means for tuning their optical response. Two cases will be presented: i) strong coupling to intersubband transitions in semiconductor quantum wells; ii) strong coupling to epsilon near zero waves in thin highly doped semiconductor layers.

17:30 – 17:45
Storing and Retrieving Electromagnetic Waves in a Metamaterial by Dynamic Control of Structural Symmetry

Toshihiro Nakanishi, Kyoto University, Japan
Takehiro Otani, Kyoto University, Japan
Yasuhiro Tamayama, Kyoto University, Japan
Masao Kitano, Kyoto University, Japan

We introduce a tunable metamaterial based on an analogy of electromagnetically induced transparency (EIT). The structural symmetry of the metamaterial can be dynamically controlled by an external control voltage. We report first demonstration of storage and retrieval of electromagnetic waves using the tunable EIT metamaterial.

17:45 – 18:00
Planar Metamaterial with Separately Voltage Tunable Electric and Magnetic Dispersion based on Liquid Crystal

Matthias Maasch, Institute for Microwave Engineering and Photonics, Technische Universität Darmstadt, Germany
Maria Roig, Institute for Microwave Engineering and Photonics, Technische Universität Darmstadt, Germany
Christian Damm, Institute for Microwave Engineering and Photonics, Technische Universität Darmstadt, Germany
Rolf Jakoby, Institute for Microwave Engineering and Photonics, Technische Universität Darmstadt, Germany

In this work a planar metamaterial unit cell in coplanar waveguide (CPW) technology with separately tunable magnetic and electric dispersion is presented. The tunability is realized by a dielectric layer of liquid crystal (LC). Alignment of the LC molecules is achieved by applying static electric or magnetic fields. The independent tuning of the effective permeability and permittivity is demonstrated analytically and by simulations and measurements of a prototype designed for an operation frequency of 30 GHz.
16:30 - 18:00  Oral session III.6: Hybrid & Multifunctional Metamaterials
Session chairperson: Mario Silveirinha

16:30 – 16:45  Optical Properties of Hybrid Atomic and Plasmonic Systems in the Weak and Strong Coupling Regime
Karolina Sadowik, Institute of Condensed Matter Theory and Solid State Optics, Germany
Robert Filter, Institute of Condensed Matter Theory and Solid State Optics, Germany
Jakob Straubel, Institute of Condensed Matter Theory and Solid State Optics, Germany
Carsten Rockstuhl, Institute of Condensed Matter Theory and Solid State Optics, Germany
Falk Lederer, Institute of Condensed Matter Theory and Solid State Optics, Germany

Atomic systems placed in close vicinity to metallic nanoparticles can significantly modify the optical properties of the latter when the hybrid system is weakly driven, i.e. at the single quantum excitation level. Here, by combining rigorous electromagnetic simulations and quantum optical considerations we develop a theory to investigate the dynamics of these systems in the weak and strong coupling regime. Moreover, we study the extinction spectra to find that the response of the hybrid system sensitively depends on the number of atoms involved. This promises novel applications for sensing devices at the single-molecule level.

16:45 – 17:00  Graphene-Ferroelectric Hybrid Metamaterials for Bistable Terahertz Wave Switching
Woo Young Kim, Korea Advanced Institute of Science and Technology, Republic of Korea
Hyeon-Don Kim, Korea Advanced Institute of Science and Technology, Republic of Korea
Teun-Teun Kim, Korea Advanced Institute of Science and Technology, Republic of Korea
Seung Hoon Lee, Korea Advanced Institute of Science and Technology, Republic of Korea
Hyun Joo Choi, Korea Advanced Institute of Science and Technology, Republic of Korea
Bumki Min, Korea Advanced Institute of Science and Technology, Republic of Korea

We demonstrate bistable switching of transmitted terahertz waves in a graphene-ferroelectric hybrid metamaterial. When being poled by electric gating, the ferroelectric layer provides long-lasting polarization states by which charge carriers in graphene layer can be controlled. Thus, two polarization states in the ferroelectric result in two distinct doping levels of graphene and lead to bistable states of terahertz wave transmission through the hybrid metamaterial.

17:00 – 17:15  Giant Nonlinear Response via Twists and Turns of Metamaterials
Mingkai Liu, Nonlinear Physics Centre, Australian National University, Australia
Yue Sun, Nonlinear Physics Centre, Australian National University, Australia
David Powell, Nonlinear Physics Centre, Australian National University, Australia
Australia

Ilya Shadrivov, Nonlinear Physics Centre, Australian National University, Australia

Mikhail Lapine, CUDOS, School of Physics, University of Sydney, Australia

Ross McPhedran, CUDOS, School of Physics, University of Sydney, Australia

Yuri Kivshar, Nonlinear Physics Centre, Australian National University, Australia

We propose the concept of torsional metamaterials by exploiting the internal twisting within a dimer meta-atom. We demonstrate that this approach provides strong coupling between electromagnetic and elastic properties, which leads to giant nonlinear response such as bistability. We also perform a microwave experiment to confirm our predictions, showing the tunable nonlinear response in such system.

17:15 – 17:30 Switching Near-IR Metamaterial Response with Electrically-Controlled Liquid Crystals Oral

Oleksandr Buchnev, Optoelectronics Research Centre, University of Southampton; EPSRC Centre for Photonic Metamaterials, University of Southampton, UK

Jun-Yu Ou, Optoelectronics Research Centre, University of Southampton, EPSRC Centre for Photonic Metamaterials, University of Southampton, UK

Malgosia Kaczmarek, School of Physics and Astronomy, University of Southampton, UK

Nikolay I. Zheludev, Optoelectronics Research Centre, University of Southampton, EPSRC Centre for Photonic Metamaterials, UK; Centre for Disruptive Photonic Technologies, Nanyang Technological University, Singapore

Vassili A. Fedotov, Optoelectronics Research Centre, University of Southampton, EPSRC Centre for Photonic Metamaterials, University of Southampton, UK

We experimentally demonstrate efficient electrical modulation and switching of the near-IR response of plasmonic metamaterials loaded with liquid crystals. That has been achieved by controlling micro-scale volume and (for the first time) nano-scale in-plane ordering of liquid crystals in the resulting hybrid metamaterial systems.

17:30 – 17:45 Optomechanical “Nonlinear” Light Modulation on Nano-Scale Oral

Alexander Shalin, Kotel'nikov's Institution of Radio Engineering and Electronics of RAS, Russia

Interaction between light beams at different frequencies requires an object, mediating the process. Most commonly, nonlinear materials are used for this purpose, but having naturally small nonlinear susceptibilities, they demand high light intensities which put certain limitations on devices performances. Here we investigate an approach for nonlinear optical interactions, mediated by nanoelectromechanical systems. Nanoparticle, controllably moved by a driving beam in and out the focus of a signal, modulates the intensity of the later. We investigated the system which contains of a deep-subwavelength plasmonic v-groove waveguide and resonant nanoparticle. The particle is driven by the pump into controllable oscillatory motion inside the v-groove and scatters the waveguided (signal) mode, modulating its intensity. The visibility of 10% per single particle was demonstrated. Moderate intensities, efficient interactions and deep subwavelength devices dimensions make nanoelectromechanical systems to be of a primary...
17:45 – 18:00 **Multifunctional Metamaterial Absorber Based on Honeycomb Filled with Epoxy-Carbon Nanotube Nanocomposite and Split Ring Resonator**

**Pierre Bollen**, Université catholique de Louvain, Belgium  
**Thomas Pardoen**, Université catholique de Louvain, Belgium  
**Christian Bailly**, Université catholique de Louvain, Belgium  
**Isabelle Huynen**, Université catholique de Louvain, Belgium

In order to absorb below the cutoff, a single split ring resonator is inserted in each honeycomb cell to generate simultaneously negative values of the real parts of effective parameters.

18:00 – 23:30 **Tasting tour and Gala dinner at Château Smith-Haut-Lafitte**

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**Thursday, 19th September**

**Oral Sessions (Thursday morning 1)**

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<td>09:00 - 10:30</td>
<td><strong>Cloaking I</strong></td>
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<td>09:00 - 10:30</td>
<td><strong>Theoretical Advances in Metamaterials</strong></td>
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<td>09:00 - 10:30</td>
<td><strong>Special Session IV.1: Nonlinearity and Nonreciprocity in Metamaterials I</strong></td>
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<td>Organizer(s): Ilya Shadrivov</td>
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<td>Session chairperson(s): Ilya Shadrivov</td>
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<td>09:00 – 09:30</td>
<td><strong>Mixing Metamaterials with Nonreciprocity</strong> Keynote</td>
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<td><strong>Nader Engheta</strong>, University of Pennsylvania, USA</td>
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<td><strong>Uday Chettiar</strong>, University of Pennsylvania, USA</td>
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<td><strong>Arthur Davoyan</strong>, University of Pennsylvania, USA</td>
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<td><strong>Ahmed Mahmoud</strong>, University of Pennsylvania, USA</td>
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<td><strong>Fereshteh Abbasi</strong>, University of Pennsylvania, USA</td>
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In this talk, we present an overview of some of our ongoing works in the areas of metamaterials-based electromagnetic nonreciprocity and the various methods by which the concept of metamaterials may influence the phenomenon of nonreciprocity. We show some of the unique outcomes of such hybridization of metamaterials with nonreciprocity, which can be achieved by proper designs of magnetically biased or nonlinear structures.
We review our recent achievements in the development of metamaterials with mechanical nonlinearity. The novel nonlinearity types are achieved by enabling new degrees of freedom in metamaterial design, which allow a dynamic changes in the geometry of “meta-atoms” or in the lattice structure. We present the outcomes of magnetoeelastic, conformational, rotational and optical nonlinear feedback, and predict unusual phenomena to be observed in such metamaterials.

Quasi-Periodic Stacks of Semiconductor Layers: Combinatorial Frequency Generation

Oksana Shramkova, ECIT, Queen’s University Belfast, UK
Alexander Schuchinsky, ECIT, Queen’s University Belfast, UK

The nonlinear scattering and combinatorial frequency generation by the quasi-periodic Fibonacci and Thue–Morse stacks of semiconductor layers have been investigated taking into account the nonlinear charge dynamics. It has been shown that the mixing processes in passive semiconductor structures are driven by the competitive effects of the collision of charges and resonance interactions of carriers with pump waves. The effects of the stack arrangements and constituent layer parameters on the efficiency of the combinatorial frequency generation are discussed.

Dynamic Optical Activity and Self-oscillation in Torsional Metamaterials

Mingkai Liu, Nonlinear Physics Centre, Australian National University, Australia
David Powell, Nonlinear Physics Centre, Australian National University, Australia
Ilya Shadrivov, Nonlinear Physics Centre, Australian National University, Australia
Mikhail Lapine, CUDOS, School of Physics, University of Sydney, Australia
Yuri Kivshar, Nonlinear Physics Centre, Australian National University, Australia

We study the nonlinear dynamic properties of coupled torsional meta-molecules. We find that this structure may exhibit self-oscillation behaviour, and we analyse two different mechanisms leading to this effect. Contrary to many previously studied optomechanical systems, self-oscillations of torsional meta-molecules can be extremely robust against mechanical damping and they can be manipulated by the polarisation of electromagnetic waves. We also study the dynamic nonlinear optical activity arising in the system and its active control.
USA
David Smith, Duke University, Center for Metamaterials and Integrated Plasmonics, USA

The rapid evolution of additive manufacturing techniques has the potential to revolutionize a wide range of fabrication-limited fields. In this article, we apply plastic additive manufacturing to the creation of radio-frequency electromagnetic devices, demonstrating a metamaterial-like unidirectional cloak.

09:30 – 10:00 Efficient Analysis of 2D Cloaking with 3D Devices and of Related Bandwidth Limitation
Christophe Craeye, universite catholique de Louvain, Belgium
Arnab Batthacharya, Universite catholique de Louvain, Belgium
David Gonzalez-Ovejero, University of Siena, Italy

2D structures made of 3D metamaterial inclusions often exhibit a sectoral symmetry. This enables a vastly accelerated Method-of-Moment analysis of such structures. Further acceleration is offered by the multipole decomposition of the linear infinite-array Green’s function. Such methods allow the fast frequency-domain response of cloaking metamaterials and in particular of their maximum bandwidth, which is shrinking for larger objects in terms of wavelengths, due to causality limitations.

10:00 - 10:15 On the Physical Bounds of Cloaking and Invisibility
Francesco Monticone, The University of Texas at Austin, USA
Andrea Alu, The University of Texas at Austin, USA

We discuss fundamental physical bounds on the possibility of achieving electromagnetic invisibility, based on the passivity, causality and linearity of the scattering system. By applying Bode-Fano theory to an equivalent circuit for the scattering coefficients, we derive limitations on bandwidth and scattering reduction valid for any passive cloaking scheme.

10:15 – 10:30 From Planar Transmission-Line-Based Cloak to Volumetric Cloak
Iva Malcic, University of Zagreb, Croatia
Silvio Hrabar, University of Zagreb, Croatia

A simple volumetric cylindrical cloak, based on a pile of stacked transmission-line-based layers, is presented. Each layer comprises a web-like network designed by homogenization of constitutive tensors in cylindrical systems. The layers are sandwiched between two parallel metallic plates without any matching layer. Full-wave simulations confirmed the existence of a cloaking effect.

09:00 - 10:30 Oral session IV.2: Theoretical Advances in Metamaterials I
Session chairperson: Stanislas Maslovski

09:00 – 09:30 Resolving Some Fundamental Issues in the Representations of EM materials Using a Rigorous Spatially Dispersive Formulation of Electric and Magnetic Polarizations
Arthur Yaghjian, Electromagnetics Research Consultant, USA

It is shown how four fundamental problems encountered in applying the classical Maxwell equations to materials and metamaterials can be resolved with a recently formulated rigorous anisotropic theory of spatially dispersive metamaterial arrays.
First-Principles Parameter Retrieval of Complex Single-Negative Bulk Metamaterials

Theodosios Karamanos, Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Greece
Stylianos Assimonis, Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Greece
Alexandros Dimitriadis, Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Greece
Nikolaos Kantartzis, Department of Electrical and Computer Engineering, Aristotle University of Thessaloniki, Greece

The retrieval of effective parameters for complicated single-negative structures is presented in this paper through a first-principles homogenization method. The technique considers each metamaterial unit-cell as an electrically-small scatterer and evaluates its polarizabilities. These outcomes and the extracted wavenumbers are inserted in the homogenization relations to obtain the medium parameters.

Nonlinear Optimization Technique for the Homogenization of Metamaterials from Scattering Parameters

Efthymios Kallos, University of Patras, Greece
Georgios Kallos, British Telecom Technologies, United Kingdom
Vassilios Yannopapas, University of Patras, Greece

We propose a novel numerical method for extracting the effective medium parameters of metamaterial structures. The reference scattering parameters of a metamaterial structure are provided as the target goal of a nonlinear optimization algorithm. The algorithm internally executes electromagnetic simulations of a homogeneous medium for identical excitations, and varies the relative permittivity and permeability values until the scattering parameters of that medium match the reference scattering values. A specific example for homogenizing a row of silver nanorods in visible wavelengths is presented, which highlights the limitations of relying solely on the scattering parameters.

Enhanced Casimir Interaction Torque in Nanowire Systems

Tiago Morgado, Instituto de Telecomunicações, University of Coimbra, Portugal
Stanislav Maslovski, Instituto de Telecomunicações, University of Coimbra, Portugal
Mário Silveirinha, Instituto de Telecomunicações, University of Coimbra, Portugal

The Casimir torque induced in systems formed by dense arrays of metallic nanorods embedded in dielectric fluids is studied. It is demonstrated that the magnitude of the torque generated in this kind of systems is several orders of magnitude larger than the torque induced in other known structures (e.g., birefringent plates). This anomalously strong Casimir interaction stems from the ultra-large density of photonic states that boost the interaction energy associated with quantum fluctuations of the electromagnetic field in nanowire materials.

Waveguide Metamaterials

Cristian Della Giovampaola, University of Pennsylvania, USA
Nader Engheta, University of Pennsylvania, USA

Here, we explore the geometrical and structural dispersion of certain structures such as waveguides to “create” effectively epsilon-negative and effective epsilon-
zero media by using only conventional positive-epsilon dielectrics, providing a road map to achieving various plasmonic phenomena, e.g., local surface plasmon resonance, surface plasmon polariton (SPP) surface wave, and waveguiding along chains of plasmonic elements, at microwave frequencies.

10:30 – 11:00 Coffee break (Thursday morning)

**Oral Sessions (Thursday morning 2)**

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<td>11:00 - 12:30</td>
<td>Nonlinearity and Nonreciprocity in Metamaterials II</td>
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<td>11:00 - 12:30</td>
<td>Theoretical Advances in Metamaterials II</td>
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<td>11:00 - 12:30</td>
<td>Special Session IV.2: Nonlinearity and Nonreciprocity in Metamaterials II</td>
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<td>11:00 – 11:30</td>
<td>Nonreciprocal Metal-Dielectric Photonic Structures with Extreme Directionality</td>
<td>invited oral</td>
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- **Kyle Smith,** *University of Texas at San Antonio, USA*
- **Turhan Carroll,** *Air Force Research Laboratory, Wright Patterson AFB, USA*
- **Joshua Bodyfelt,** *Ohio State University, USA*
- **Ilya Vitebskiy,** *Air Force Research Laboratory, Wright Patterson AFB, USA*
- **Andrey Chabanov,** *University of Texas at San Antonio, USA*

We show using numerical simulations that a stack of ferromagnetic metallic nanolayers interlaced between dielectric layers can become highly transmissive, display large Faraday rotation, and extreme directionality/collimation. It can be used for wide-aperture isolation.

| 11:30 – 12:00 | Metamaterials based on Intersubband Polaritons | invited oral    |

- **Jongwon Lee,** *The University of Texas at Austin, USA*
- **Pai-Yen Chen,** *The University of Texas at Austin, USA*
- **Christos Argyropoulos,** *The University of Texas at Austin, USA*
- **Andrea Alu,** *The University of Texas at Austin, USA*
- **Mikhail Belkin,** *The University of Texas at Austin, USA*

We will discuss metasurfaces based on strong coupling of quantum-engineered electron states in multi-quantum-well semiconductor structures and electromagnetic modes in plasmonic nanostructures. This concept allows for creating active, reconfigurable, and highly nonlinear polaritonic metamaterials. Experimental results on voltage-tunable spectral response and nonlinear optical response in these structures will be presented.
**12:00 – 12:15** Enhancement of Four-wave Mixing in a Multi-layered EIT Metamaterial
Oral

**Kosuke Wada**, Kyoto University, Department of Electronic Science and Engineering, Japan  
**Toshihiro Nakanishi**, Kyoto University, Department of Electronic Science and Engineering, Japan  
**Yasuhiro Tamayama**, Kyoto University, Department of Electronic Science and Engineering, Japan  
**Masao Kitano**, Kyoto University, Department of Electronic Science and Engineering, Japan

We propose a metamaterial mimicking electromagnetically induced transparency (EIT), loaded with varactors as nonlinear elements. We demonstrate the enhancement of four-wave mixing (FWM) in the varactor-loaded EIT metamaterial, and observe coherent build-up of the side-band signals generated by FWM in the multi-layered metamaterial.

**12:15 – 12:30** Non-Reciprocal One-Way Transparent Sheets
Oral

**Viktar Asadchy**, Gomel State University, Belarus  
**Younes Ra’di**, Aalto University, School of Electrical Engineering, Finland  
**Sergei Tretyakov**, Aalto University, School of Electrical Engineering, Finland

Electrically thin layers formed by infinite periodical arrays of uniaxial lossless particles are under study. The layers are illuminated by normally incident plane waves. Here we derive the required polarizabilities of the particles such that the layers composed of them are totally transparent for illumination from one side but show different electromagnetic properties from the other side. We show that non-reciprocal electromagnetic coupling is necessary to realize one-way transparent sheets.

**11:00 - 12:30** Oral session IV.3: Cloaking II
Session chairperson: Christophe Craeye

**11:00 – 11:30** Measuring the Cloak
Invited oral

**Ross McPhedran**, University of Liverpool/University of Sydney, UK  
**Daniel Colquitt**, University of Liverpool, UK  
**Ian Jones**, John Moores University, UK  
**Nataliya Movchan**, University of Liverpool, UK  
**Alexander Movchan**, University of Liverpool, UK  
**Michele Brun**, Università di Cagliari/University of Liverpool, Italy/UK

Despite the large number of papers which have investigated various aspects of wave cloaking, relatively few have discussed ways of measuring or accurately demonstrating in simulations the quality of the cloaking which has been achieved. We give examples of notable papers which have investigated effectiveness criteria for cloaking. We then go on to discuss in detail the cloaking of a square object from waves obeying the Helmholtz equation. We illustrate numerically the effectiveness of the cloaking delivered by a continuous cloak, and secondly by a discrete or lattice cloak. We employ a novel way of using Young’s classical interference experiment to illustrate the excellence of the continuous cloak, in a way which raises interesting questions concerning the overlap between metamaterials and quantum mechanics.
11:30 – 11:45  **Spacetime Transformations: Cloaking and Other Applications**  
**Oral**  
**Paul Kinsler**, Imperial College London, United Kingdom  
**Martin McCall**, Imperial College London, United Kingdom

We show that spacetime cloaking is achievable in any wave theory, and always admits a simple “speed-cloak” approximation. We discuss the possibilities of any technology of spacetime transformations from the re-expression of existing ideas to the more exotic concepts of the spacetime modeling of bubble universes, and causal "shell-game" illusions.

11:45 – 12:00  **Transformation Optics and 3D Metamaterials for Infrared Applications**  
**Oral**  
**Andre de Lustrac**, IEF - University of Paris Sud, France  
**Rasta Ghasemi**, IEF - University of Paris Sud, France  
**Natalya Dubrovina**, IEF - University of Paris Sud, France  
**Paul-Henri Tichit**, IEF - University of Paris Sud, France  
**Aloyse Degiron**, IEF - University of Paris Sud, France  
**Anatole Lupu**, IEF - University of Paris Sud, France

In this study transformation optics is applied to the design of a mode adapter between two low index SU8 waveguides in the near infrared. The control of the electromagnetic mode in the adapter is made by using a thin layer of metamaterial inserted between a layer of 2μm SU8 resin and a SOI substrate. We demonstrate by simulation that this thin layer of metamaterial calculated by space transformation allows a precise control of the wave propagation in the adapter. Then we propose a multilayer metamaterial to realize this control. Numerical simulations and experimental realizations are conducted to validate the material design and its feasibility.

12:00 – 12:15  **Graphene Metasurface Makes the Thinnest Possible Cloak in the Terahertz Spectrum**  
**Oral**  
**Yashwanth R. Padooru**, University of Mississippi, Department of Electrical Engineering, USA  
**Pai-Yen Chen**, The University of Texas at Austin, Department of Electrical and Computer Engineering, USA  
**Alexander B. Yakovlev**, University of Mississippi, Department of Electrical Engineering, USA  
**Andrea Alù**, The University of Texas at Austin, Department of Electrical and Computer Engineering, USA

We propose metasurface cloak designs composed of subwavelength graphene nanopatches to realize wideband-tunable scattering cancellation in the terahertz (THz) spectrum. By adjusting the parameters and Fermi energy of graphene nanopatches, an inductive or capacitive surface reactance can be tailored at will, thereby enabling the scattering suppression of different dielectric and conductive micro-scale objects.

12:15 – 12:30  **Design and Simulations of Dual-Polarized Mantle Cloaking Devices**  
**Oral**  
**Alessio Monti**, University of Roma Tre, Italy  
**Andrea Alù**, The University of Texas at Austin, Texas  
**Alessandro Toscano**, University of Roma Tre, Italy  
**Filiberto Bilotti**, University of Roma Tre, Italy

We propose a general procedure to design mantle cloaks able to reduce the scattering of an object for both polarizations at the same frequency. In particular, we analyze the applicability of closed-form formulas available in the literature for the
design of planar metasurfaces consisting of rectangular meshes, and validate their applicability in conformal mantle cloaks for cylindrical objects. Furthermore, we propose an easy retrieval procedure useful to refine the initial analytical design and quickly obtain the required surface impedance of the metasurface for both polarizations. Practical examples of dual-polarization mantle cloaks are presented and discussed.

11:00 - 12:30  
**Oral session IV.4: Theoretical Advances in Metamaterials II**  
Session chairperson: Sergei Tretyakov

11:00 - 11:30  
**Analytical Circuit Modeling of 1D and 2D Planar Metal Gratings Embedded in Stratified Dielectric Structures**  
*Invited oral*

Francisco Medina, University of Sevilla, Dept. of Electronics and Electromagnetism, Spain  
Francisco Mesa, University of Sevilla, Dept. of Applied Physics 1, Spain  
Raul Rodriguez-Berral, University of Sevilla, Dept. of Applied Physics 1, Spain  
Maria Garcia-Vigueras, EPFL, Lab. of Electromagnetisme et Acoustique (LEMA), Switzerland

The development of circuit-like models for the study of periodic 1D and 2D distributions of planar metallic scatterers has a long tradition in the microwaves and antenna literature, specially in the frame of the characterization of frequency-selective surfaces. In recent years, there have been developed improved models that account for extraordinary transmission/reflection phenomena and incorporate the presence of finite thickness dielectric slabs in a very accurate manner. The topology and parameters of these models are systematically derived from simplified integral equation formulations, which give rise to equivalent circuits that overcome some drawbacks of commonly used circuit analogues. In particular, dynamic effects related to the presence of the finite thickness slabs and higher-order mode interactions are accounted for.

11:30 – 11:45  
**Quality Factor Of 3D Metal-Insulator-Metal Nanoresonators**  
*Oral*

Jianji Yang, Institut d'Optique, France  
Christophe Sauvan, Institut d'Optique, France  
Anthony Jouanin, Institut d'Optique, France  
Stéphane Collin, Laboratoire de Photonique et Nanostructures, France  
Jean-Luc Pelouard, Laboratoire de Photonique et Nanostructures, France  
Philippe Lalanne, Institut d'Optique, France

We study the quality factor variation of three-dimensional Metal-Insulator-Metal nanoresonators when their volume is shrunk from the diffraction limit down to the quasi-static limit. In addition to rigorous fully-vectorial calculations, we provide a comprehensive study of the cavity mode and a closed-form expression of the quality factor Q obtained with a semi-analytical Fabry-Perot model. The latter quantitatively predicts the absorption and radiation losses of the nanoresonator over the whole length scale, and it also provides an in-depth understanding of the mode lifetime that cannot be obtained with brute-force computations. In particular, it highlights the impact of slow-wave effects on the Q-factor as the size of the resonator is decreased. The Fabry-Perot model also evidences that, unexpectedly, wave retardation effects are present in metallic nanoparticles, even for deep subwavelength dimensions in the quasi-static regime.
Metamaterial Characterization Using Boltzmann’s Kinetic Equation for Electrons

Andrei Novitsky, Belarusian State University, Belarus
Sergei Zhukovsky, DTU Fotonik, Technical University of Denmark, Denmark
Denis Novitsky, B.I. Stepanov Institute of Physics, Belarus
Andrei Lavrinenko, DTU Fotonik, Technical University of Denmark, Denmark

Statistical properties of electrons in metals are taken into consideration to describe the microscopic motion of electrons. Assuming degenerate electron gas in metal, we introduce the Boltzmann kinetic equation to supplement Maxwell’s equations. The solution of these equations clearly shows the resonant behavior of electronic response to an external electromagnetic field. We demonstrate the approach for planar and circular geometries of the metamolecules.

Light Pressure on Right-Handed and Left-Handed Continuous Media

Maxim Gorkunov, Institute of Crystallography, RAS, Russia
Alexey Kondratov, Institute of Crystallography, RAS, Russia

The ambiguity of macroscopic description of light pressure on continuous medium originates from the uncertainty of dividing the energy-momentum tensor of electromagnetically excited matter into material and field parts or, equivalently, the total acting force into pressure and deformation terms. We show that from the continuum of formally correct formulations, one can adopt the appropriate form of the macroscopic field stress tensor that allows unified description of pressure during elementary light-matter interactions in right-handed and left-handed frequency dispersive media. The proposed expressions for the pressure force are simple, convenient and compatible with the polariton momentum $\hbar \mathbf{k}$. The corresponding electromagnetic momentum density generalizes Rytov’s definition.

Classical Analogue of Quantum Friction

Stanislav Maslovski, Instituto de Telecomunicações, Universidade de Coimbra, Portugal
Mário Silveirinha, Instituto de Telecomunicações, Universidade de Coimbra, Portugal

We study the classical analogue of the quantum friction force resulting from interaction of electromagnetic surface states in a pair of monoatomic layers (e.g., graphene sheets) sliding one with respect to another with a nonrelativistic velocity $v \ll c$. The layers are modeled as two-dimensional arrays of dipolar oscillators. Using a Hamiltonian formalism we demonstrate that the effect of quantum friction can be explained quasi-classically by a process of parametric amplification of surface waves in such arrays.

Lunch (Thursday)
Oral Sessions (Thursday afternoon 1)

14:00 - 15:30 THz Metamaterials I

14:00 - 15:30 Optical Metamaterials I

14:00 - 15:30 Absorption in Metamaterials

14:00 - 15:30 Special Session IV.3: THz Metamaterials
Organizer: Tahsin Akalin
Session chairperson: Tahsin Akalin

14:00 – 14:30 Metamaterials for Novel THz and Infrared Applications
Willie Padilla, Boston College, USA

We demonstrate metamaterials that enable full control of the fundamental light matter interactions at surfaces. These high technology composites may be used for numerous unique applications ranging from energy harvesting and emission control, to sensing and imaging. An overview of recent progress in this area is provided.

14:30 – 15:00 High-Performance Terahertz Spatial Light Modulators Based on Reconfigurable Diamagnetic Meta-surfaces
Mona Jarrahi, University of Michigan, USA
Mehmet Unlu, University of Michigan, USA
Mohammad Reza Hashemi, University of Michigan, USA
Christopher W. Berry, University of Michigan, USA
Shenglin Li, University of Michigan, USA
Shang-Hua Yang, University of Michigan, USA

We present high-performance spatial light modulators based on a new class of reconfigurable meta-surfaces that offer extreme diamagnetic switching capability over a broad frequency band. We experimentally demonstrate record high modulation depths (> 70%) and modulation bandwidths (> 1.5 THz) through a fully integrated device solution at room temperature.

15:00 – 15:15 Photoinduced Structural Transition in a Checkerboard-like Meta-surface
Yoshiro Urade, Kyoto University, Department of Electronic Science and Engineering, Japan
Yosuke Nakata, Kyoto University, Department of Electronic Science and Engineering, Japan
Toshihiro Nakanishi, Kyoto University, Department of Electronic Science and Engineering, Japan
Masao Kitano, Kyoto University, Department of Electronic Science and Engineering, Japan

We propose a checkerboard-like metasurface including photoconductive semiconductor sheets. We numerically demonstrate that the nature of the metasurface can be inverted with photoexcitation and that the metasurface exhibits a flat transmission spectrum on a specific condition. We also present a circuit model illustrating the property of the metasurface.
Critical Behavior of Terahertz Transmission Property in Metallic Checkerboard Patterns with Randomness

Keisuke Takano, Osaka University, Japan
Fumiaki Miyamaru, Shinshu University, Japan
Yasunori Tokuda, Okayama Prefectural University, Japan
Masanori Hangyo, Osaka University, Japan

Metallic checkerboard patterns have been fabricated with changing nominal metal square size keeping the period constant. The terahertz transmission spectra have transmission-invariant frequencies, which indicate that the spectra are sum of two types of spectra with different composition ratio depending on the nominal square size.

Oral session IV.5: Optical Metamaterials I

Session chairperson: Carsten Rockstuhl

Metamaterials for THz and Optical Applications

Irina Vendik, St. Petersburg Electrotechnical university, Russia
Carolina Mateo-Segura, Heriot Watt University, Institute of Sensors, Signals and Systems, United Kingdom
Mikhail Odit, St. Petersburg Electrotechnical university, Russia
Irina Munina, St. Petersburg Electrotechnical university, Russia
Dmitry Kozlov, St. Petersburg Electrotechnical university, Russia
Viacheslav Turaliev, St. Petersburg Electrotechnical university, Russia

Tunable THz metamaterials have been designed and modeled. Three different structures are under investigations: array of U-shaped planar resonators and metal-dielectric-metal patch array with voltage controlled cantilevers and dielectric resonators based structure with disturbed Mie resonance. All structures exhibit efficient control of electromagnetic response. An optical superlens based on a coupled pair of 2-D arrays of plasmonic nano-ellipsoids is presented and analyzed. The superlens is capable of restoring sub-wavelength features of an object for s- and p-polarization of light. Simulations revealed sub-wavelength resolution at a distance of nearly 1.4λeff between the source and the image plane.

All-Angle Negative Refraction in the Ultraviolet

Henri Lezec, NIST, USA
Ting Xu, NIST, USA
Amit Agrawal, Syracuse University, USA
Maxim Abashin, NIST, USA
Kenneth Chau, University of British Columbia, Canada

Here, we report the first experimental implementation of a bulk metamaterial with a LH response in the ultraviolet (UV). The structure, based on stacked plasmonic waveguides, yields an omni-directional LH response for transverse-magnetic (TM) polarization, characterized by a quasi-isotropic, negative refractive index for both phase and power.

Purcell Factor of Plasmonic Nanoresonators

Christophe Sauvan, Institut d’Optique, France
Jean-Paul Hugonin, Institut d’Optique, France
Philippe Lalanne, Institut d’Optique, France

We provide a self-consistent electromagnetic theory of the coupling between dipole
emitters and dissipative nanoresonators. The theory that relies on the concept of quasi-normal modes with complex frequencies is capable of accurately handling any photonic or plasmonic resonator with strong radiation leakage, absorption and material dispersion. We use the formalism to revisit Purcell's factor. The new formula substantially differs from the usual one; in particular, it predicts that a spectral detuning between the emitter and the resonance does not necessarily result in a Lorentzian response in the presence of dissipation. Fully-vectorial numerical calculations for plasmonic nanoresonators made of coupled gold nanorods provide a strong support to our theoretical analysis.

15:15 – 15:30 Control of Airy Plasmon Trajectories in Linear Gradient Systems Oral
Alexander Minovich, The Australian National University, Australia
Felix Bleckmann, Physikalisches Institut, Universität Bonn, Germany
Jakob Frohnhaus, Physikalisches Institut, Universität Bonn, Germany
Dragomir Neshev, The Australian National University, Australia
Stefan Linden, Physikalisches Institut, Universität Bonn, Germany

In this work we demonstrate experimentally the manipulation of Airy surface plasmon beams in a linear potential system. We used a negative-tone grey-scale electron beam lithography to fabricate plasmonic structures with a dielectric ramp which provides a graded refractive index. Using such carefully engineered structures we show that the bending of an Airy surface plasmon beam can be fully reversed and controlled by the potential.

14:00 - 15:30 Oral session IV.6: Absorption in Metamaterials
Session chairperson: Filiberto Bilotti

14:00 – 14:15 RCS Study of Impedance-Matched Scatterers Constructed with Magnetodielectric Cubes Oral
Olivier Vacus, CEA, France
Richard W. Ziolkowski, University of Arizona, Tucson, USA

The theorem of Weston states that a null RCS is observed for matched objects with rotational symmetry. In this work we study a generalization of this result applied to heterogeneous magnetodielectric scatterers (divided into a set of small cubical unit cells that are alternatively either purely dielectric or purely magnetic). Numerical computations are presented to compare the RCS levels of the original perfectly and the lego-based roughly impedance-matched scatterers.

14:15 – 14:30 Ferroelectric Metamaterial Perfect Absorber Oral
Didier Lippens, IEMN, France
Jianping Hao, Université de Lille, France
Véronique Sadaune, Université de Valenciennes, France
Ludovic Burgnies, Université de Lille, France
Eric Lheurette, Université de Lille, France

We propose a new approach for designing absorbing metasurfaces based on high permittivity ferroelectric films which are structured in sub-wavelength cube array. Dual absorption peaks close to 100% are found which are experimentally assessed in a hollow waveguide configuration. It is also found that the periodicity plays a key role in the achievement of high absorbance levels which involve the coupling of surface and trapped waves.

14:30 – 14:45 Plasmonic Absorber based on Gold Nanoparticles Oral
Jin Dai, KTH-Royal Institute of Technology, Sweden
Fei Ye, KTH-Royal Institute of Technology, Sweden
We both numerically and experimentally demonstrate a type of plasmonic absorber based on a monolayer of gold nanoparticles deposited on top of a continuous gold reflector, which can be easily adapted for devising efficient light absorbers of large areas.

14:45 – 15:00 Loss Enhancement and Cloaking Properties of Cylinders with Polar Anisotropy

Henrik Kettunen, University of Helsinki, Finland
Henrik Wallén, Aalto University School of Electrical Engineering, Finland
Ari Sihvola, Aalto University School of Electrical Engineering, Finland

This presentation studies the response of a polarly anisotropic cylinder in a quasistatic electric field. With permittivity components of opposite signs, the structure is shown to enhance material losses. We also consider using an anisotropic cylindrical shell as a cloak.

15:00 – 15:15 Trapping Light by Mimicking Gravitational Lensing

Chong Sheng, National Laboratory of Solid State Microstructures & Department of Physics, Nanjing University, China
Hui Liu, National Laboratory of Solid State Microstructures & Department of Physics, Nanjing University, China
Yi Wang, National Laboratory of Solid State Microstructures & Department of Physics, Nanjing University, China
Shining Zhu, National Laboratory of Solid State Microstructures & Department of Physics, Nanjing University, China
Dentcho Genov, College of Engineering and Science, Louisiana Tech University, United States

We propose a distorted optical waveguide around a microsphere to mimic curved spacetimes caused by the “gravitational fields”. Gravitational lensing effects analogues are experimentally demonstrated and this can be used to prospective light harvesting.

15:15 – 15:30 Passivity Limitations on Absorption Properties of Low-Scattering Objects

Nasim Mohammadi Estakhri, The University of Texas at Austin, USA
Romain Fleury, The University of Texas at Austin, USA
Jason Soric, The University of Texas at Austin, USA
Andrea Alù, The University of Texas at Austin, USA

We analyze the constraints governing absorption and scattering of arbitrary sensors or receiving antennas. Our findings bring forward interesting physical limitations on the amount of accessible absorption in a low-scattering sensor and suggest practical ways to achieve efficient designs for noninvasive sensors, based on the application needs.
15:30 - 17:00

**Poster Session III**

and coffee break

**15:30**

**Poster Session III**

Session chairperson: Hatice Altug

1 - **Necessary Symmetry Conditions for Optical Activity**

*Ivan Fernandez-Corbaton, Macquarie University, Australia*

*Xavier Vidal, Macquarie University, Australia*

*Nora Tischler, Macquarie University, Australia*

*Gabriel Molina-Terriza, Macquarie University, Australia*

Two conditions on symmetries are identified as necessary for a linear scattering system to be able to rotate the linear polarisation of light: Lack of at least one mirror plane of symmetry and electromagnetic duality symmetry. Duality symmetry is equivalent to the conservation of electromagnetic helicity.

2 - **Effective Bianisotropic Parameters of Metamaterial Transmission Line**

*Vojislav Milosevic, Institute of Physics, Serbia*

In this paper we present the bianisotropic parameter retrieval procedure for the case of transmission line metamaterials. After reviewing the formulas, we apply the proposed method on unit cell with asymmetric edge-coupled split-ring resonators. Results are compared with standard Nicolson-Ross-Weir extraction procedure.

3 - **Two-Dimensionally Isotropic Optical Metamaterial Feasible for Stimulated Emission Depletion Microscopy Inspired Direct Laser Writing**

*Sanjoy Debnath, Michigan Tech, USA*

*Xu Zhang, Michigan Tech, USA*

*Durdu Guney, Michigan Tech, USA*

*Costas Soukoulis, Iowa State University, USA*

Stimulated emission depletion microscopy inspired direct laser writing (STED-DLW) processes incorporated with electroplating can offer diffraction-unlimited fabrication of complex metallic structures in three dimensions, not possible with traditional electron-beam or optical lithography. We propose a two-dimensionally isotropic optical metamaterial with negative permeability for fabrication with STED-DLW and electroplating of gold.

4 - **Asymmetric Bloch Impedance for Characterization Bianisotropic Metamaterials**

*Maciej Smierzchalski, University of Rennes 1, IETR, France*

*Kouroch Mahdjoubi, University of Rennes 1, IETR, France*

A novel method is presented for characterization of constitutive parameters of bianisotropic metamaterials. In the proposed method is considered the size of the unit metamaterial cell which leads to operate out of long wave regime. The bianisotropic media can introduce the asymmetric in the medium and can lead to dependence of impedance from propagation direction. The influence of spatial dispersion of bianisotropic medium is consideration by the application of Bloch impedance related with the electric and magnetic dipoles ratio and distinguished for forward and backward direction. The method is applied and validated for the split
ring resonator, and the retrieved parameters of permittivity, permeability and electromagnetic coupling are presented and discussed.

5 - Spatially Isotropic SRR-based Unit Cell for Conformable Metamaterials Poster

Alireza Ajami, IHF, Germany
Abdullah Al-Najjar, GUC, Egypt
Andreas Bülow, IHF, Germany
Hammam Shakhtour, IHF, Germany

The patterned metamaterials (MTMs) working in microwave region contain basically split ring resonators (SRRs). Both metallic and complementary SRRs (CSRRs) are mostly designed on a planar surface oriented perpendicularly or parallel to the incoming wave, i.e. the functionality of these unit cells depends on the incident angle of the incoming wave and the designed MTM is mostly spatially anisotropic. Using a spherically formed substrate coated with some bent SRRs on its surfaces can solve the spatial anisotropy evidently. In this work we present a spatially isotropic unit cell (SIUC) using the bent SRRs mounted on a sphere. Based on the geometrical isotropy of a sphere and occurred magnetic and electric resonances in bent SRRs the optimal design is achieved. The spatial isotropy is compared between the proposed SIUC and the conventional planar unit cell by considering the stability of the retrieved electromagnetic parameters for incoming wave from different directions. The SIUC leads to a three-dimensional metamaterial with macroscopic spatial isotropy, which initiates new applications for MTM in the microwave region, where deforming and conforming of metamaterials are asked.

6 - Kapitza Dielectric Metamaterials Poster

Carlo Rizza, Dipartimento di Scienza e Alta Tecnologia, Università dell'Insubria, Italy
Alessandro Ciattoni, Consiglio Nazionale delle Ricerche, CNR-SPIN, L'Aquila, Italy

We theoretically investigate the homogenization of the dielectric response of Kapitza dielectric metamaterials, i.e. materials hosting a subwavelength periodic grating whose depth scales as the large wavelength to modulation period ratio. We show that the standard effective medium theory is inadequate to describe the propagation in the considered metamaterials and, most importantly, a novel regime of diffractionless propagation occurs for transverse magnetic waves.

7 - Dynamic Polarizability Tensor for Cylindrical Rods and their Application to the Homogenization of Uniaxial Metamaterials Poster

Diana Strickland, Southwest Research Institute, USA
Andrea Alu, The University of Texas at Austin, USA
Arturo Ayon, The University of Texas at San Antonio, USA

We develop fully dynamic expressions for components of the polarizability tensor characterizing cylinders of arbitrary electrical size and material properties. The spatially dispersive results extend validity to arbitrary incidence angle and moderately large sizes, and satisfy newly derived passivity conditions. We study the effects of size and materials on polarizabilities and use our formalism to explore effective uniaxial metamaterial parameters.

8 - Effective Medium Theory based on Dressed Polarizability for Systems of Resonant Plasmonic Nanoparticles Poster

SeokJae Yoo, Korea University, Department of Physics, Korea (South)
Q-Han Park, Korea University, Department of Physics, Korea (South)

Plasmonic interaction between nanoparticles has played a pivotal role in plasmonic
devices and metamaterials. Here we provide a simple analytic model, so-called “dressed polarizability,” to describe plasmonic interaction between resonant plasmonic nanoparticles. To utilize the effective medium theory based on the dressed polarizability, we also show that optical properties of dense resonant plasmonic nanoparticle systems can be accurately predicted. Our results open new possibility of designing plasmonic devices and metamaterials.

9 - Hybridization of Spin Waves and Josephson Plasmons in a Layered Antiferromagnetic Superconductor

Anton Bespalov, Université Bordeaux 1, France
Alexandre Buzdin, Université Bordeaux 1, France

We calculate the spectrum of spin and plasma waves propagating in a layered structure consisting of alternating monoatomic superconducting and antiferromagnetic layers. We show that for a given wave-vector three modes exist: one magnetic mode with no Josephson current and two hybridized magnon-like and plasmon-like modes.

10 - Metamaterial Properties of a 3D Permalloy/Cobalt Magnonic Crystal

Roberto Zivieri, Dipartimento di Fisica e Scienze della Terra, Università di Ferrara, and CNISM, Unità di Ferrara, Italy
Perla Malagò, Dipartimento di Fisica e Scienze della Terra, Università di Ferrara, and CNISM, Unità di Ferrara, Italy

A theoretical investigation of the metamaterial properties of a three-dimensional cobalt/permalloy magnonic crystal is performed. Dispersion of the collective mode mainly confined in the permalloy film is calculated. The collective mode dynamics is studied within an effective medium approximation in the propagative regime and the metamaterial wave dispersion is discussed.

11 - Spectroscopy of Optical Modes with High Spatial, Temporal and Energy Resolution Using Electron-Photon Interference Effects: A Numerical Study

Nahid Talebi, Max-Planck Institute for Intelligent Systems, Germany
Wilfried Sigle, Max-Planck Institute for Intelligent Systems, Stuttgart, Germany
Ralf Vogelgesang, University of Oldenburg, Oldenburg, Germany
Peter van Aken, Max-Planck Institute for Intelligent Systems, Stuttgart, Germany

By considering the electron’s self-radiation and the optical pulses, a numerical investigation of the effect of the optical intensities on the spectroscopy of plasmonic modes at the context of the photon-assisted electron-energy-loss spectroscopy is demonstrated. It will be shown that by a deliberate tuning of the optical intensities, an interference pattern becomes visible, which can be used for the spectroscopy of plasmon modes with high temporal, energy and spatial resolution.

12 - Arbitrary Control of Flux and Wave Guiding in Inhomogeneous Anisotropic Zero-Index Media

Yun Lai, Soochow University, China
Jie Luo, Soochow University, China

Zero-index materials is an unique and important class of metamaterials. In this work, we show that inhomogeneous anisotropic zero-index media with one permittivity component being almost zero can be utilized to control energy flux freely, and thus achieve wave guiding in an unprecedented manner. Based on this
mechanism, an efficient bending waveguide has been proposed by us and experimentally verified by other groups.

13 - Left-Handed Material Composed of Dielectric Spheres Put between Metal Cylinders Poster

Hiroshi Kubo, Yamaguchi University, Japan
Ryuji Mashino, Yamaguchi University, Japan
Atsushi Sanada, Yamaguchi University, Japan
Tsunayuki Yamamoto, Yamaguchi University, Japan

A two-dimensional LH material composed of dielectric spheres put between metal cylinders is proposed. In the material a TEM-like LH wave propagates, so that a plane wave is incident in the material with low reflection. It is confirmed by simulation that the wave going out of the flat lens made of the material gathers.

14 - “Digitally” Addressable and Localized on a Nanometer-Sized Scale Laser Light Spot Poster

Pavel Melentiev, Institute for Spectroscopy, Russian Academy of Sciences, Russia
Anton Afanasiev, Institute for Spectroscopy, Russian Academy of Sciences, Russia
Victor Balykin, Institute for Spectroscopy, Russian Academy of Sciences, Russia

We propose and experimentally realize a sub-wavelength light localization on a nanometer-sized hot spot based on optical nonlinearity of an individual element in nanoplasmonics - a split hole resonator (SHR). Here, we demonstrate the use of the SHR as a highly efficient nonlinear optical element for: (1) the generation of the third harmonic from a single SHR; (2) the excitation of intense multiphoton luminescence from a single SHR; (3) the realization of a polarization-ultrasensitive nanoelement; and finally, as a practical application, (4) the building up of an all-optical display.

15 - Near-field Imaging with Metamaterial: Deconvolution of an Image Using SVD Poster

Denis Tihon, Université catholique de Louvain, Belgium
Nilufer A. Ozdemir, Université catholique de Louvain, Belgium
Christophe Craeye, Université catholique de Louvain, Belgium

A deconvolution procedure based on the Array Scanning Method and the Singular Value Decomposition is presented to capture a source distribution from an image affected by white noise. The image is obtained using a collimating metamaterial made of infinite, doubly periodic array of silver nanorods with the help of the Array Scanning Method. The numerical results show that the source distribution can be captured from the image by tuning the threshold in SVD used for inversion, hence by selecting a proper source subspace.

16 - Dynamic Director Grating and Two Beam Energy Exchange in Photorefractive Hybrid Cholesteric Cell Poster

Igor Pinkevych, Physics Faculty, Taras Shevchenko National University of Kyiv, Ukraine
Victor Reshetnyak, Physics Faculty, Taras Shevchenko National University of Kyiv, Ukraine
Tim Sluckin, School of Mathematics, University of Southampton, UK
Gary Cook, Air Force Research Laboratory, Wright-Patterson AFB, USA
Dean Evans, Air Force Research Laboratory, Wright-Patterson AFB, USA
We develop a theoretical model to describe two-beam energy exchange in a hybrid photorefractive inorganic-cholesteric cell. Weak and strong light beams are incident on the cell and induce a periodic space-charge field in the photorefractive windows. This field penetrates into the LC, inducing a diffraction grating written on the LC director. Flexoelectricity is the principal physical mechanism governing the magnitude of the director grating. We calculated the energy gain of the weak beam as a result of its interaction with the pump beam within the diffraction grating. The calculation includes rotation of the light beam polarization in the cholesteric LC and the spectral position of its gap. Theoretical results for the exponential gain coefficient have been compared with experiment for hybrid cells filled with cholesteric LC BL038/CB15 in the single photorefractive window geometry. A good fit between experiment and theory can be achieved, providing good evidence that the key physics of the system has been correctly identified.

17 - Finite-element Simulations of a Volumetric Scanning Microwave Probe for Imaging at

Abiola Oladipo, Bio-Nano Consulting, United Kingdom
Manuel Kasper, Johannes Kepler University, Austria
Sypros Lavdas, University College London, United Kingdom
Georg Gramse, Johannes Kepler University, Austria
Ferry Kienberger, Agilient Technologies, Austria
Nicolae C. Panoiu, University College London, United Kingdom

Many electrical scanning probe microscopy (SPM) techniques suffer from parasitic stray EM field contributions, which give rise to low signal to noise ratio and make the image retrieval process more difficult. Here, we validate via computational modeling a calibration procedure that employs three calibration standards and three complex coefficients to obtain a black-box transfer function between the systemic reflection coefficient and the reflection coefficient at the tip of the probe, from which the impedance, capacitance and dielectric constant of nano-sized structures can be determined. We find that a 10° variation in the inclination angle of the cantilever can cause a 10% variation in the bulk systemic impedance. Experimental scanning microwave microscope measurements agree with our simulation results.

18 - Interface Electromagnetic Waves of Isotropic and Uniaxially Bianisotropic Metamaterials

Hiroshi Miyazaki, Applied Physics, Tohoku University, Japan

Effect of chirality on the phase diagrams of interface electromagnetic waves (IEMWs) for isotropic and uniaxially bianisotropic metamaterials are studied. Numerical results show that isotropic chirality significantly modifies the phase diagrams and even create new IEMWs. Bianisotropic chirality is found to have a variety of intriguing influence on the phase diagrams of IEMWs.

19 - Sub-Diffraction Imaging in The THz Range Using Wire Array Metamaterial Fibers and Stacked Layers of Inkjet Printed Wire Grids

Korbinian J. Kaltenecker, University of Freiburg / French-German Research Institute of Saint Louis, Germany
Alessandro Tuniz, University of Sydney, Australia
Patrick Bollgruen, University of Freiburg, Germany
Dario Mager, University of Freiburg, Germany
Jan G. Korvink, University of Freiburg, Germany
Simon C. Fleming, University of Sydney, Australia
Alex Argyros, University of Sydney, Australia
Boris T. Kuhlme, University of Sydney, Australia
A wire medium is a device which is capable of transmitting an electric field distribution with subwavelength resolution. We investigate the transport mechanism and imaging capability through different wire media in the THz regime using THz near-field microscopy.

20 - Crossover from Spoof-SPP Mode to Dielectric-Slab Waveguide-Like Mode in 1D Metal Gratings

Masanori Hangyo, Osaka University, Japan
Dazhi Li, Institute for Laser Technology, Japan
Keisuke Takano, Osaka University, Japan
Hiroshi Miyazaki, Tohoku University, Japan
Michael I. Bakunov, University of Nizhny Novgorod, Russia

One-dimensional metal gratings support so-called spoof SPPs. On the other hand, periodic cut-through metal slit arrays behave like dielectric slabs. For metal gratings, we show that the crossover from the spoof SPP mode to dielectric-slab waveguide-like mode occurs with increasing the groove depth by the modal expansion method.

21 - Effective Conductivity and Magnetic Permeability of Nano-Structured Media in Magnetic Field

Anatoly Rinkevich, Institute of Metal Physics, Russia
Dmitry Perov, Institute of Metal Physics, Russia

The problem of homogenization of the nanostructured materials placed in DC magnetic field has been discussed. The experimental data are obtained for the several classes of nanostructured materials: metallic superlattices, metal-dielectric thin films and 3D-nanostructured metamaterials. All these materials contain ferro- or ferrimagnetic component. The transmission and reflection coefficients were measured on the waves of millimeter waveband. It has been shown that the experimental frequency spectra of the coefficients in zero magnetic field can be described by the effective conductivity and dielectric permittivity. The spectra of ferromagnetic resonance, however, cannot be calculated correctly with the averaged magnetization.

22 - Optical Second Harmonic Generation in Vortex Magnetic Structures

Tatiana Murzina, Department of Physics, Moscow State university, Russia
Victor Krutyanskiy, Department of Physics, Moscow State university, Russia
Irina Kolmychek, Department of Physics, Moscow State university, Russia
Boris Gribkov, Institute for Physics of Microstructures RAS, Russia
Evgeniy Skorohodov, Institute for Physics of Microstructures RAS, Russia

Optical second harmonic generation (SHG) is studied in a regular array of magnetic nanodots that can reveal a uniform vortex magnetic state. We demonstrate that the SHG excited by a circularly polarized fundamental radiation can be used to visualize the vortex state of the magnetization.

23 – Optical Information Storage with Lattice Polariton Solitons in Nanocavity-QED Arrays

Alexander Alodjants, Vladimir State University, Russia
Eugene Sedov, Vladimir State University, Russia
Sergey Arakelian, Vladimir State University, Russia
You-Lin Chuang, National Tsing-Hua University, Taiwan
Y. Y. Lin Lin, National Tsing-Hua University, Taiwan
Ray-Kuang Lee, National Tsing-Hua University, Taiwan

By considering qubits in an array of weakly coupled nano-cavities, we reveal a variety of dynamical regimes, such as diffusion, self-trapping, soliton, and breathers for the wavepackets in the presence of photon tunneling processes between the next-nearest cavities. By manipulating detuning frequency adiabatically, the low-branch lattice polariton solitons evolve between photon-like and matter-like states, based on which we propose a scheme for spatially distributed storage and retrieving of optical information.

24 - Study of the Coupling Properties of Plasmonic Vortex Lenses with Nanoantenna Resonators Poster
Marta Carli, University of Padova, Italy
Pierfrancesco Zilio, LaNN-Lab. for Nanofabrication of Nanodevices, Italy
Denis Garoli, LaNN-Laboratory for Nanofabrication of Nanodevices, Italy
Michele Massari, LaNN-Lab. for Nanofabrication of Nanodevices, Italy
Filippo Romanato, University of Padova, Italy

We investigate the coupling between a holey plasmonic vortex lens and nanoantennae. Depending on spiral chirality and polarization of the impinging wave, different resonant patterns can be obtained. Results for two relevant cases are shown, together with the fabrication of the designed structures.

25 - High Q-factor Resonances of the Surface Waves in Thin Metamaterial’s Cylinder Poster
Alexander Anyutin, Russian New University, Russia
Igor Korshunov, Institute of Radio Engineering and Electronics, Russian Academy of Science, Russia
Alexander Shatrov, Institute of Radio Engineering and Electronics, Russian Academy of Science, Russia

The 2D problem of cylindrical wave scattering by metamaterial’s cylinder is investigated. It is determined that metamaterial’s cylinder of small radius has high quality resonances if its permittivity and permeability are closed to -1. It was detected that the resonance is occurred, the scattering pattern has many lobes as it is characteristic of super direction antennas. The influence of losses on resonance characteristics was investigated.

26 - Substrate Effects onto Complex Modes and Optical Properties of 2D Arrays of Linear Trimers of Plasmonic Nanospheres Poster
Salvatore Campione, University of California, Irvine, USA
Caner Guclu, University of California, Irvine, USA
Regina Ragan, University of California, Irvine, USA
Filippo Capolini, University of California, Irvine, USA

We analyze substrate effects onto complex modes and optical properties of 2D arrays of linear trimers of plasmonic nanospheres and show that Fano resonant features appear for oblique TM-polarized plane wave incidence illumination. These features are attributed to the forced excitation of free modes supported by the array, here computed via modal analysis. We observe strengthened Fano features due to the presence of the multilayered environment.
27 - Nonlinear s-Polarized Quasisurface Waves in Symmetric Three-Layer Structure with Metamaterial Film

Olesya V. Korovai, T.G. Shevchenko State university, Tiraspol, Moldova  
Piotr Khadzhi, IAP, AS RM, Moldova

Put your abstract here. We study the theory of the nonlinear s–polarized quasisurface waves, propagating along the plane interface of symmetric three–layer structure with linear left-handed film, embedded in infinite nonlinear semiconductor. The dispersion laws are obtained and investigated.

28 - Analysis of Photonic Crystals using FDTD technique

Hanna Sliusarenko, Usikov Institute of Radiophysics and Electronics, Ukraine  
Ludmyla Velychko, Usikov Institute of Radiophysics and Electronics, Ukraine

The spatial-temporal computational scheme for analysis of 3-D photonic crystals is presented. The model boundary value problems are formulated rigorously. Basic analytical results that define general properties of the scattered fields in frequency and time domains are obtained. These results are illustrated by examples of numerical analysis of 3-D photonic crystals.

29 - Spectral Analysis of High-Contrast Metamaterial Strings

Kirill Cherednichenko, Cardiff University, United Kingdom  
Shane Cooper, Fresnel Institute, France  
Sebastien Guenneau, Fresnel Institute, France

We study the behaviour of the spectrum of a family of one-dimensional operators with periodic high-contrast coefficients as the period goes to zero, which may represent (e.g.) the elastic response of a two-component composite medium such as a heterogeneous string. Formal asymptotic analysis and numerical tests with finite elements suggest the existence of localised eigenfunctions (“defect modes”), whose eigenvalues are situated in the gaps of the limit spectrum for the unperturbed problem.

30 - Non-Local Surface Susceptibility Model for Periodic Biaxialotropic Metafilms

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

A novel surface susceptibility model for periodic metafilms of electrically-small biaxialotropic meta-atoms is analytically derived in this paper. The featured algorithm results in a matrix of non-local surface effective parameters, unlike most of the existing characterization techniques. The accuracy of the proposed methodology is verified by the accurate prediction of the scattering properties of a challenging metafilm comprising non-planar, chiral helix particles.

31 - New Metamaterial with Strong Magneto-Electric Effect

Pavel Pyshkin, B. Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, Ukraine  
Andrey Yanovsky, B. Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, Ukraine

It is shown that the magnetization of microscopic isolated magnetic/non-magnetic hybrid structures induces the electric polarization due to the spin-dependent
32 - Directional Surface Plasmon Polariton Excitation Using Metasurface with Helicity Dependent Interfacial Phase Discontinuity
Poster

Lingling Huang, Tsinghua University, China
Xianzhong Chen, University of Birmingham, UK
Benfeng Bai, Tsinghua University, China
Qiaofeng Tan, Tsinghua University, China
Guofan Jin, Tsinghua University, China
Thomas Zentgraf, University of Paderborn, Germany
Shuang Zhang, University of Birmingham, UK

We report helicity dependent Surface Plasmon Polariton (SPP) unidirectional excitation for circularly polarized incident light on a metasurface composed of nano-aperture array by using interfacial phase discontinuity. Such phase discontinuity is geometric in nature and does not rely on the incident wavelength. Asymmetry momentum matching conditions are achieved for opposite helicity of the incident light, and selective unidirectional excitation of SPPs as well as ellipticity tunability is experimentally demonstrated at optical frequencies.

33 - Parametric Analysis of a Broadband Tooth Bow-Tie-Like Plasmonic Antenna and its Potential for Non-linear Optics
Poster

Victor Torres, Universidad Pública de Navarra, Spain
Miguel Navarro-Cia, Imperial College London, UK
Heykel Aouani, Imperial College London, UK
Miguel Beruete, Universidad Pública de Navarra, Spain
Stefan A. Maier, Imperial College London, UK

Inspired by microwaves antennas, a broadband log-periodic-based plasmonic antenna is analyzed. The dependence of the extinction/scattering/absorption cross-sections and the electric field enhancement at different positions of the gap with respect to the geometrical parameters is shown. We also demonstrate that this broadband plasmonic antenna boost the efficiency of non-linear processes given its large extinction cross section and lightning rod effect at the fundamental and harmonic frequencies.

34 - Perfect Narrow-Band Absorber based on a Colloidal Monolayer of Core-Shell Microspheres
Poster

Pavel Dyachenko, Hamburg University of Technology, Germany
Alexander Petrov, Hamburg University of Technology, Germany
Manfred Eich, Hamburg University of Technology, Germany

We have studied how two-dimensional arrays of metallodielectric core-shell microspheres on a gold substrate can efficiently absorb infrared electromagnetic radiation. Our simulations indicate perfect absorption efficiencies can be achieved for resonance frequencies. Influence of core-shell microspheres geometry is studied on absorption properties.

35 - Superconducting Metamaterial for Electronic Imaging: Conceptual Development
Poster

Eugeny Erhan, National University of Science and Technology MISIS, Moscow, Russia
Sergey Shitov, National University of Science and Technology MISIS, Moscow, Russia; Kotel’nikov Institute of Radioengineering and Electronics,
Russian Academy of Sciences, Moscow, Russia
Alexey Ustinov, Physikalisches Institut, Karlsruhe Institute of Technology, Karlsruhe, Germany; National University of Science and Technology MISIS, Moscow, Russia

We present conceptual design of a superconducting 2-D metasurface suitable for sensitive detection and imaging of small signals in frequency range 600-700 GHz. This 2-D medium contains compact planar antennas densely distributed over hexagonal spot and coupled to individual resonators, providing a possibility for simultaneous readout of the pixel-antennas using FDM technique. The layout and EM-simulations are presented; the numerical result demonstrates the feasibility of study of such devices aiming for application at THz-range frequencies.

36 - Numerical Investigation of Wave Propagation in Metal-Wire Dielectric Periodic Structure: New Hyperbolic Eigenwaves
Olga Kozina, Kotel’nikov Institute of Radio-Engineering and Electronics of Russian Academy of Science, Russia
Leonid Melnikov, Saratov State Technical University, Russia
Igor Nefedov, Aalto University, School of Electrical Engineering, Finland
Anna Zotkina, Saratov State Technical University, Russia

We are carefully analyse the properties of the eigenwaves of 2D-structure with regular hexagonal ordered ideal metal nanorods in lossless dielectric. Plane-wave-decomposition was used in numerical calculations. New ‘hyperbolic” solutions were found.

37 - Controlling Extraordinary Transmission by means of Hedgehog Subwavelength Hole Arrays
Pablo Rodríguez-Ulibarri, Universidad Pública de Navarra, Spain
Bakhtiyar Orazbayev, Universidad Pública de Navarra, Spain
Victor Torres, Universidad Pública de Navarra, Spain
Miguel Beruete, Universidad Pública de Navarra, Spain
Miguel Navarro-Cía, Imperial College London, United Kingdom

Additional transmission peaks arise on a metal holey screen when it is backed or sandwiched by dielectric slabs. Grounded slab modes (both TM and TE) are responsible of those extra transmission peaks. In the same manner, control over extraordinary transmission (ET) peaks by means of anisotropic slabs in the form of a Fakir’s bed is presented here. This configuration allows red-shifting ET peaks related to TM modes while TE modes are suppressed because of the inherent dispersion features of the free-standing grounded pins. This control over ET brings us mechanisms for designing THz devices useful in future applications.

38 - Anti-Symmetric Transmission of Circularly Polarized Light through Chiral Meta-Interface
Satoshi Tomita, Nara Institute of Science and Technology, Japan
Yuuka Kosaka, Nara Institute of Science and Technology, Japan
Hisao Yanagi, Nara Institute of Science and Technology, Japan
Kei Sawada, RIKEN SPring-8 center, Japan

We have studied circular dichroism (CD) in the visible region of double-layer films consisting of transparent chiral molecule and absorptive achiral dye. We discuss the origin of the anti-symmetric transmission of circularly polarized light, which is very similar to the magneto-optical effect, at the chiral meta-interface.
39 - Realization of Powered Transistor-based Active Metamaterials

**John Barrett, Duke University, USA**

**Steven Cummer, Duke University, USA**

We present an active metamaterial unit cell that exhibits frequencies of zero loss and gain. The active circuit provides a negative differential resistance which stably cancels the parasitic resistance. Measurements demonstrate simultaneous signal gain and an increase in radiation efficiency caused by the presence of the active unit cell near an electrically small antenna.

40 - Stability of Embedded Non-Foster Metamaterials with Potentially Unstable Circuit Parameters

**Thomas Weldon, Univ. of N. Carolina at Charlotte, USA**

**Ryan Adams, Univ. of N. Carolina at Charlotte, USA**

**Joshua Shehan, Univ. of N. Carolina at Charlotte, USA**

Stability conditions are given for a slab of active non-Foster metamaterial embedded in a surrounding medium. The approach combines lumped-element line-section models of unit cells with reflection and transmission models of the embedded active metamaterial slab.

41 - Broadband Loss Compensation in Gain Assisted Mesoporous Plasmonic Capsules

**Melissa Infusino, CNR-IPCF UOS Cosenza, Italy**

**Antonio De Luca, University of Calabria, Italy**

**Rakesh Dhama, University of Calabria, Italy**

**Carmen Vázquez Vázquez, Universidad de Vigo, Spain**

**Miguel A. Correa Duarte, Universidad de Vigo, Spain**

**Giuseppe Strangi, Case Western Reserve University, United States**

Porous silica mesocapsules have been used as nanostructured scaffolds for anisotropic growth of gold nano-nuggets (NNs). The gold nano-objects growth is determined by the characteristics of nano-pores, that work as a mold during their formation process. Variety of sizes and shapes of the nano-pores is reflected in the gold NNs distribution; this lead to a wide plasmonic resonance band over a spectral range of about 200 nm (500-700nm). We demonstrated that by bringing gain (fluorophore molecules) to close proximity of the nano-nuggets embedded in the mesoporous scaffold, a broadband optical loss compensation can be achieved. This hierarchical approach opens a new route towards mesoscale systems where plasmon-gain dynamics play a relevant role towards applications of optical metamaterials.

42 - Landau-Lifshitz Theory of Single Susceptibility Maxwell Equations

**Kikuo Cho, Institute of Laser Engineering, Osaka University, Japan**

The conflicting arguments in the discussion forum of Barcelona conference are lead to convergence. Four forms of Maxwell equations, "Casimir, Landau-Lifshitz, Anapole, and natural" forms are compared and shown interchangeable. The natural form by the author is shown to be most informative among the four.

43 - The Effect of Tarnish on Extraordinary Optical Transmission of Silver Subwavelength Slit Gratings

**Maxim Gorkunov, Institute of Crystallography, RAS, Russia**

**Vladimir Artemov, Institute of Crystallography, RAS, Russia**

**Sergey Yudin, Institute of Crystallography, RAS, Russia**
Sergei Palto, Institute of Crystallography, RAS, Russia

Tarnishing of silver nanostructures strongly affects their optical performance. We report that in the course of months under regular laboratory conditions, subwavelength silver gratings undergo tarnishing differently from plain silver films: instead of thin layer of evenly distributed silver sulfide, a random pattern of rare larger crystals is formed across the grating area. The observable changes in the optical transmittance are specific: the Wood diffraction anomaly degrades totally while the extraordinary transmission peak noticeably attenuates. The high sensitivity of silver gratings to atmospheric sulfur is prospective for sensor applications.

44 - Influence of Dispersion Law on Field Excitation in Metamaterials with Periodic Boundary. Poster

P. Melezhik, Institute of Radiophysics and Electronics of National Academy of Sciences of Ukraine, Ukraine
A. Poyedinchuk, Institute of Radiophysics and Electronics of National Academy of Sciences of Ukraine, Ukraine
Nataliya Yashina, Institute of Radiophysics and Electronics of National Academy of Sciences of Ukraine, Ukraine
G. Granet, Université BLaise Pascal, Clermont-Ferrand, France.

The decisive influence of dispersion character of constitutive parameters on the interaction of electromagnetic field with metamaterials is discussed here. The conjunction of metamaterials with certain periodicity of the scale of electromagnetic wave length makes the characteristic features of the metamaterial more pronounced. The choice of the inhomogeneous electromagnetic wave as an incident one helps us to exploit more properties of periodic boundary for our investigation. The rigorous solution to the boundary value problem of inhomogeneous wave diffraction by periodic boundary of metamaterial is used as a base for numerical simulation.

45 - A general Method to Retrieve Electromagnetic Polarizability Tensors of Metamaterial Resonators Poster

Javier L. Araque, Universidad Nacional de Colombia, Colombia
Juan D. Baena, Universidad Nacional de Colombia, Colombia

A general method to characterize the electromagnetic polarizability tensor of electrically small particles through numerical simulations is proposed. Polarizability tensors of several resonators previously used for designing metamaterials have been retrieved. The Method of Moments has been used in order to calculate the dipoles excited by different plane waves.

46 - Electromagnetic Metamaterial Illusion Devices Poster

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

We extended the concept of electromagnetic illusion, which can make the electromagnetic image of a target gathered by radar look like a different target as desired. We have realized three kinds of radar illusion device experimentally. The first one is to change the radar image of a metallic target into a dielectric target with predesigned size and material parameters, and the second one is to transform an arbitrary object to a virtual smaller object with the desired size and material parameters, and the third one is to make the an object invisible and generate the scattering signature of multiple isolated ghost objects.
47 - Finite Element Method Modelling of Polarisation Conversion from Rectangular Microcavity Arrays

Ben Tremain, University of Exeter, United Kingdom
Alastair Hibbins, University of Exeter, United Kingdom
Roy Sambles, University of Exeter, United Kingdom

Spectral conversion is observed on resonance of a rectangular microcavity array formed of a metallic bgratin above a ground plane. By carefully selecting the cavity dimensions and illuminating the surface at an azimuth of 45° to both mirror planes, 100% conversion can be maintained across a 2GHz frequency band.

48 - Extensions to the Contour Integral Method for Efficient Modeling of TM Scattering in Two-Dimensional Photonic Crystals

Jan Birger Preibisch, Technische Universität Hamburg-Harburg, Germany
Xiaomin Duan, Technische Universität Hamburg-Harburg, Germany
Christian Schuster, Technische Universität Hamburg-Harburg, Germany

We present an extension to the contour integral method (CIM) for the treatment of two-dimensional scattering problems from circular inclusions with plane wave excitation. CIM is an integral equation approach to planar problems whose efficiency can be greatly enhanced by semi-analytical treatment of circular scatterers. It is related to the boundary element method (BEM) and shows promising domain decomposition capabilities. The performance and accuracy is compared to the full-wave finite integral technique (FIT) by studying the scattering of an array of dielectric rods.

49 - Interpretation Of The Electric Resonance In Z-Shaped Meta-Atom

Abdallah Dhouibi, LEME, EA 4416, Univ. Paris-Ouest, France
Shah Nawaz Burokur, IEF, Univ. Paris-Sud, CNRS, UMR 8622, France
Anatole Lupu, IEF, Univ. Paris-Sud, CNRS, UMR 8622, France
André de Lustrac, IEF, Univ. Paris-Sud, CNRS, UMR 8622, France
Alain Priou, LEME, EA 4416, Univ. Paris-Ouest, France

A planar Z-shaped meta-atom has been recently proposed as an alternative design to the conventional electric-LC (ELC) resonator for achieving negative permittivity. Transforming the LC topology of the resonator helps to facilitate transposition of geometrical parameters for the optical regime and also to improve the metamaterial homogeneity. In this work, we discuss about the interpretation of the resonance in such Z-shaped meta-atom.

50 - Effects of Incident Light Polarization on Bound to Continuum Light Absorption in Self-Assembled Quantum Dots

Yasser El-Batawy, Cairo University - Faculty of Engineering, Eng. Physics Dept., Egypt
Tarek Ameen, Cairo University - Faculty of Engineering, Eng. Physics Dept., Egypt

The effects of the incident light polarization on the bound to continuum absorption coefficient of self-assembled quantum dots are presented. Generally, decreasing the dot's dimensions results in an increase of the in-plane polarized light absorption, a decrease of the perpendicularly polarized light absorption, and moving the absorption coefficient peaks towards longer wavelengths.
51 - Equivalent Circuit Model with External Coupling for Metamaterials Composed of Wired Metallic Spheres

Takashi Hisakado, Dept. of Electrical Engineering, Kyoto University, Japan
Keisuke Yoshida, Dept. of Electrical Engineering, Kyoto University, Japan
Osami Wada, Dept. of Electrical Engineering, Kyoto University, Japan

This paper describes circuit modeling of external coupling which consists of excitation by external field and radiation. Using the structure of wired metallic spheres, we show a theoretical method for modeling the external coupling with excitation source and radiation resistance. We confirm the validity of the model by the comparison with electromagnetic analysis.

52 - Electrodynamics of a Spiral Resonator as a Suitable Magnetic Component of Metamaterials

Nataliya Maleeva, National University of Science and Technology MISIS, Russia
Mikhail Fistul, National University of Science and Technology MISIS, Russia
Alexandr Averkin, National University of Science and Technology MISIS, Russia
Alexendre Karpov, National University of Science and Technology MISIS, Russia
Alexey Ustinov, National University of Science and Technology MISIS, Russia

We consider spiral resonators as promising ultra-compact magnetic components for negative index metamaterials. In order to explore such a possibility, we study the electrodynamics of a planar monofilar Archimedean superconducting spiral resonator. The frequencies of microwave resonances that can be excited in such a system are calculated taking into account an inhomogeneous current distribution across the spiral. It is shown that the resonance frequencies are equidistant, and the current distribution inside of the spiral can be presented in a simple analytical form. The obtained values of resonance frequencies are in a good agreement with experiment.

53 - Polarization Effects in Stretchable Metasurfaces for THz Frequency Range

Dmitry Morits, Aalto University, Finland
Sergei Tretyakov, Aalto University, Finland
Constantin Simovski, Aalto University, Finland

In this paper we study unusual optical properties of a metasurface composed of orthogonal metal strips located on both sides of a thin polymer film. Combination of strong electric and magnetic dipolar resonances leads to resonance for both co- and cross-polarizations in the range of 150-250 GHz. Strong dependence of the polarization of the reflected field on the applied mechanical strain opens the door toward prospective optical strain gauges.

54 - Dependence of THz Metamaterial Resonance on Doping Carrier Density and Pattern Line Width

Y. U. Lee, Ewha Womans University, Korea (South)
E. Y. Choi, Ewha Womans University, Korea (South)
E. S. Kim, Ewha Womans University, Korea (South)
J. H. Woo, Ewha Womans University, Korea (South)
A series of THz metamaterials were fabricated, which have different pattern line widths of Au and different doping carrier densities of p-type silicon substrate. Transmission spectra of the metamaterials were obtained by a terahertz time domain spectroscopic measurement. Upon increasing the doping carrier density and narrowing the pattern line width, the transmission spectra showed a blue shift in resonance frequency and a broadening of resonance spectral shape, i.e., a decrease in quality factor.

55 - Observation of the Enhancement of the Electric Field Normal to the Surface of Mid-Infrared Slot Antennas
Kouichi Tsushima, Ritsumeikan University, Japan
Suguru Mori, Ritsumeikan University, Japan
Yuuki Nishimura, Ritsumeikan University, Japan
Kazuki Hishii, Ritsumeikan University, Japan
Kenichi Kasahara, Ritsumeikan University, Japan
Toyonari Yaji, Ritsumeikan University, Japan
Hideki Miyazaki, National Institute for Materials Science, Japan
Naoki Ikeda, National Institute for Materials Science, Japan
Masayuki Ochiai, National Institute for Materials Science, Japan
Hirotaka Osato, National Institute for Materials Science, Japan
Yoshimasa Sugimoto, National Institute for Materials Science, Japan

After growing a thin Al2O3 layer by atomic layer deposition on a Si substrate, slot antenna arrays were formed on it. When the Al2O3 layer thickness was 6 nm, characteristic aspects appearing in the reflectivity spectra, presumably caused by the surface phonon polariton of a natural SiO2 layer, disappeared.

56 - A Novel Approach of Metamaterials Characterization with Application of Oblique Incident Excitations
Maciej Smierzchalski, University of Rennes 1, IETR, France
Kouroch Mahdjoubi, University of Rennes 1, IETR, France

A novel method is proposed to characterize bi-anisotropic metamaterials. The oblique excitation incident is introduced to determinate all components of the constitutive parameters of the medium. The proposed method is applied on split ring resonator type medium and the different angles are launched for the validation.
## Oral Sessions (Thursday afternoon 2)

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<td>Optical Metamaterials II</td>
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<td>17:00 - 18:45</td>
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<td>17:00 – 17:30</td>
<td>Reconfigurable Plasmonic Devices Using Liquid Metals</td>
<td>Invited oral</td>
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<td>J Wang, University of Utah, USA</td>
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<td>S Liu, University of Utah, USA</td>
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<td>Ajay Nahata, University of Utah, USA</td>
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<td>Organizer: Tahsin Akalin</td>
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<td>Session chairperson: Tahsin Akalin</td>
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<tr>
<td>17:30 – 17:45</td>
<td>Fabrication and Experimental Evaluation of MEMS Spiral Metamaterial for Tunable THz Optical Activity</td>
<td>Oral</td>
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<td>Tetsuo Kan, The University of Tokyo, Japan</td>
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<td>Akihiro Isozaki, The University of Tokyo, Japan</td>
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<td>Natsuki Kanda, RIKEN, Japan</td>
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<td>Natsuki Nemoto, The University of Tokyo, Japan</td>
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<td>Kuniaki Kanda, The University of Tokyo, Japan</td>
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<td>Makoto Kuwata-Gonokami, The University of Tokyo, Japan</td>
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<td>Kiyoshi Matsumoto, The University of Tokyo, Japan</td>
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<td>Isao Shimyama, The University of Tokyo, Japan</td>
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<td>We present a fabrication and an experimental evaluation of an electrostatically actuated spiral structure as a metamaterial for circularly polarized light in the terahertz (THz) frequency range. An array of planar spiral structures was fabricated with micro electro mechanical system (MEMS) technology, and the geometry of the structures can be changed by electrostatic actuation. The effect of the fabrication design change was experimentally verified.</td>
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<td>17:45 – 18:00</td>
<td>A Semi-3D based THz Chiral Metamaterial</td>
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<td>Wu Zhang, Nanyang Technological University, Singapore</td>
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<td>Weiming Zhu, Nanyang Technological University, Singapore</td>
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<td>Qinghua Song, Xi'an Jiao Tong University, China</td>
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<td>Hong Cai, Institute of Microelectronics, Agency for Science Technology &amp; Research, Singapore</td>
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<td>Piotr Kropelnicki, Institute of Microelectronics, Agency for Science Technology &amp; Research, Singapore</td>
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<td>Andrew Randles, Institute of Microelectronics, Agency for Science Technology &amp; Research, Singapore</td>
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</table>
Min Tang, Institute of Microelectronics, Agency for Science Technology & Research, Singapore
Hendrix Tanoto, Institute of Materials Research and Engineering, Agency for Science Technology & Research, Singapore
Qingyang Wu, Institute of Materials Research and Engineering, Agency for Science Technology & Research, Singapore
Jinghua Teng, Institute of Materials Research and Engineering, Agency for Science Technology & Research, Singapore
Xinhai Zhang, Institute of Materials Research and Engineering, Agency for Science Technology & Research, Singapore
Dimlee Kwong, Institute of Microelectronics, Agency for Science Technology & Research, Singapore
Aiqun Liu, Nanyang Technological University, Singapore

This paper reports a semi-3D metamaterial consisting of a single layered metal pattern on a trenched surface. The metamaterial design possesses a chiral property and induces strong activity in THz spectrum. The strong chirality can be applied to manipulate THz polarization and realize negative refractive indexed functions such as super-lens.

18:00 – 18:15 Toroidal Response in Dielectric Metamaterials
Alexey A. Basharin, Institute of Electronic Structure and Laser, Foundation for Research and Technology Hellas, Heraklion, Greece; National Research University "Moscow Power Engineering Institute", Russia
Maria Kafesaki, Institute of Electronic Structure and Laser, Foundation for Research and Technology Hellas, Heraklion, Greece; Department of Materials Science and Technology, University of Crete, Greece
Eleftherios N. Economou, Institute of Electronic Structure and Laser, Foundation for Research and Technology Hellas, Heraklion, Greece; Department of Physics, University of Crete, Greece
Costas M. Soukoulis, Institute of Electronic Structure and Laser, Foundation for Research and Technology Hellas, Heraklion, Greece; Department of Materials Science and Technology, Ames Laboratory-USDOE, Department of Physics and Astronomy, Iowa State University, USA

We present and analyze a dielectric cluster based on subwavelength LiTaO3 polaritonic cylinders for demonstrating toroidal response in THz regime due to mutual coupling of Mie- resonance modes of the cylinders. Based on this cluster, we demonstrate a low-loss metamaterial with the dominant toroidal response, which plays a key role in achieving resonant total transmission.

18:15 – 18:30 Design and Characterization of Active THz Metamaterials based on Metal-Insulator Transition of VO2 Patterns
J. Leroy, XLIM, CNRS/University of Limoges, France
A. Crunteanu, XLIM, CNRS/University of Limoges, France
G. Humbert, XLIM, CNRS/University of Limoges, France
J.-C. Orlianges, SPCTS, CNRS/University of Limoges, France
C. Champeaux, SPCTS, CNRS/University of Limoges, France
P. Blondy, XLIM, CNRS/University of Limoges, France

We designed and characterized a tunable metamaterial in the terahertz frequency domain (0.1- 1 THz) based on an hybrid topology composed of metallic cut-wires separated by vanadium dioxide (VO2) patterns. The THz frequency response of the
hybrid metamaterial is significantly changing as the VO₂ material is performing a reversible thermally or electrically-driven metal-insulator transition which drastically modifies its electrical and optical properties.

18:30 – 18:45  **Slot-Dimer Babinet Metamaterials as Polarization Shapers for Terahertz Waves**  
*Oral*

S. V. Zhukovsky, Technical University of Denmark, Lyngby, Denmark  
D. N. Chigrin, RWTH Aachen University, Aachen, Germany  
A. V. Lavrikenko, Technical University of Denmark, Lyngby, Denmark

We theoretically study optical properties of free-standing metallic membranes patterned with an array of two-slot elements (dimers) comprising two rectangular slots of different dimensions and orientation. It is shown that these structures feature extraordinary optical transmission with strong and spectrally selective polarization conversion capabilities. The output polarization is highly dependent on the dimer geometry, which can be used in the design of compact polarization shapers for terahertz waves.

17:00 - 18:45  **Oral session IV.7: Optical Metamaterials II**  
Session chairperson: Henri Lezec

17:00 – 17:15  **High Resolution Optical Holograms based on Carbon Nanostructures**  
*Oral*

Haider Butt, University of Cambridge, United Kingdom  
Yunuen Montelongo, University of Cambridge, United Kingdom  
Tim Butler, University of Cambridge, United Kingdom  
Gehan A. J. Amaratunga, University of Cambridge, United Kingdom  
Timothy D. Wilkinson, University of Cambridge, United Kingdom

We have demonstrated the utilization of carbon nanotubes (nanostructures) as the smallest possible scattering element for diffracting light in a highly controlled manner to produce a two dimensional image of the word "CAMBRIDGE". An array of carbon nanotubes was elegantly patterned to produce a high resolution hologram. In response to the incident light on the hologram a high contrast image was produced.

17:15 – 17:30  **Purcell Effect and the Role of Coupling with Nano-Resonators in Active Plasmonic Systems**  
*Oral*

Arkadi Chipouline, FSU Jena, Germany  
A Rogach, Department of Physics and Materials Science, City University of Hong Kong, Hong Kong  
A. Susha, Department of Physics and Materials Science, City University of Hong Kong, Hong Kong  
A. Csáki, IPHT, Jena, Germany  
J. Jatschka, IPHT, Jena, Germany  
A. Steinbrück, IAP, Jena, Germany  
N. Janunts, IAP, Jena, Germany  
M. Dobynde, MSU, Russia  
W. X.-Wang, IAP, Jena, Germany  
V. Fedotov, ORC Southampton, Germany  
W. Fritzsche, IPHT, Jena, Germany  
T. Pertsch, IAP, Jena, Germany

We show theoretically and experimentally the enhancement of spontaneous
emission rate (Parcell effect) in a system of coupled quantum emitter and plasmonic nano-resonator (e.g. gain metamaterial, spaser). Peculiarities of the relaxation dynamics is analyzed using simple analytical model.

**17:30 – 17:45**

**Arrays of Plasmonic Nanocavities for Non-Linear Light Interactions**

*Oral*

Antony Murphy, *Queen’s University Belfast, United Kingdom*

Yannick Sonnefraud, *Imperial College London, United Kingdom*

Pavel Ginzburg, *King’s College London, United Kingdom*

Alexey Krasavin, *King’s College London, United Kingdom*

Stefan Maier, *Imperial College London, United Kingdom*

Anatoly Zayats, *King’s College London, United Kingdom*

Robert Pollard, *Queen’s University Belfast, United Kingdom*

Here we present a plasmonic metamaterial consisting of a large-scale array of gold coaxial rod-tube (CRT) nanocavities. The fabrication process can create 5nm cavities, smaller than conventional top-down techniques. The large electric-field enhancements associated with nanometer-sized gaps show potential for applications in non-linear optics.

**17:45 – 18:00**

**Spatial Solitons in a Nanowire Array Embedded in a Self-Defocusing Medium**

*Oral*

David Fernandes, *Instituto de Telecomunicações - Universidade de Coimbra, Portugal*

Mário Silveirinha, *Instituto de Telecomunicações - Universidade de Coimbra, Portugal*

We investigate the propagation of spatial solitons in a nonlinear metamaterial formed by metallic nanowires embedded in a Kerr-type material. We show that within an effective medium description, the formation of spatial optical solitons is only possible when the wires are embedded in a self-defocusing medium, and demonstrate that for comparable nonlinear perturbations the confinement of spatial-solitons depends on the degree of hyperbolicity of the dispersion of the photonic states.

**18:00 – 18:15**

**Subwavelength Solitons and Pattern Formation in Two-Dimensional Lattices of Nonlinear Metal Nanoparticles**

*Oral*

Roman Noskov, *NRU ITMO St Petersburg, Russia*

Daria Smirnova, *Nonlinear Physics Center, Australian National University, Australia*

Yuri Kivshar, *Nonlinear Physics Center, Australian National University, Australia*

We report on our recent findings in exploration of nonlinear discrete modes in two-dimensional arrays of nonlinear metal nanoparticles. We analyze numerically nonlinear scenarios of the modulation instability development leading to spontaneous pattern formation. We also study bistability-induced oscillons, solitons, and kinks.

**18:15 – 18:30**

**Nonreciprocal Nonlinear Scattering by Stacked Magnetoactive Semiconductor Layers**

*Oral*

Oksana Shramkova, *ECIT, Queen’s University Belfast, UK*

Alexander Schuchinsky, *ECIT, Queen’s University Belfast, UK*

The combinatorial frequency generation by the periodic stacks of magneto-biased semiconductor layers has been modelled in the self-consistent problem formulation, taking into account the nonlinear dynamics of carriers. It has been
shown that the nonlinear response of the magnetoactive semiconductor periodic structure is strongly enhanced by the magnetic bias and the combinations of layer physical and geometrical parameters. The effects of the pump wave nonreciprocal reflectance and field displacement on the efficiency of the three-wave mixing process is illustrated by the simulation results.

18:30 – 18:45 Efficient Optical Modulation of Terahertz Metamaterial Based on Charge Transfer at Organic/Inorganic Semiconductor Interface

Tatsunosuke Matsui, Mie University, Japan
Ryosuke Takagi, Mie University, Japan
Keisuke Takano, Osaka University, Japan
Masanori Hangyo, Osaka University, Japan

Terahertz transmission modulation through split-ring resonator array metamaterial fabricated on copper phthalocyanine (CuPc)-coated Si under various laser light irradiation conditions. Transmission can be efficiently modulated by laser light irradiation. Photo-induced metallization due to charge carrier transfer from Si to CuPc plays crucial role for the terahertz transmission modulation.

17:00 - 18:45 Oral session IV.8: Metamaterials for sensing
Session chairperson: Willie Padilla

17:00 – 17:30 A First-Principles Study of Surface Enhanced Raman Spectra of Molecules Adsorbed to Optical Nanoantennas

Carsten Rockstuhl, Friedrich-Schiller-Universität Jena, Germany
Martin Thomas, Friedrich-Schiller-Universität Jena, Germany, University of Vienna, Austria
Stefan Mühlig, Friedrich-Schiller-Universität Jena, Germany
Erik Hebestreit, Friedrich-Schiller-Universität Jena, Germany
Tanja Deckert-Gaudig, Friedrich-Schiller-Universität Jena, Institute of Photonic Technology e.V. Jena, Germany
Volker Deckert, Friedrich-Schiller-Universität Jena, Institute of Photonic Technology e.V. Jena, Germany
Philipp Marquetand, University of Vienna, Germany

Surface enhanced Raman scattering is a well-established analytical tool. However, the interplay between various enhancement mechanisms is not fully understood yet. Here, we use real time time-dependent density functional theory combined with rigorous electromagnetic simulations to unravel how the chemical and the electromagnetic mechanisms enhance the measurement signal.

17:30 – 18:00 Plasmonics for High Throughput Diagnostics and Biosensing Technologies

Hatice Altug, Ecole Polytechnique Federale de Lausanne, Switzerland

We present a high-throughput label-free protein microarray technology using large-area plasmonic nanohole arrays. Our detection principle is based on multi-spectral on-chip imaging and enables accurate and quantitative bio-detection. We use low-cost and large area nanofabrication methods for manufacturing of plasmonic nanostructures with high optical quality.

18:00 – 18:15 Fabrication and Characterisation of Arrays of Freestanding Palladium Nanotubes for Optical Hydrogen Sensing

Matthew McAuley, Queen's University Belfast, United Kingdom
Robert Pollard, Queen's University Belfast, United Kingdom

Arrays of freestanding upright palladium nanotubes have been fabricated. Optical transmission tests using a range of post-fabrication treatments suggest that hydrogen diffuses into both inner and outer surfaces, displaying potential as a hydrogen sensor.

Alexey Slobozhanyuk, NRU ITMO, St Petersburg, Russia
Alexander Kozachenko, NRU ITMO, St Petersburg, Russia
Constantin Simovski, Aalto University, Aalto, Finland
Pavel Belov, NRU ITMO, St Petersburg, Russia

We report about the first experimental verification of evanescent waves enhancement inside wire metamaterial. An excellent agreement between the experimental and numerical results is found. Furthermore the applicability of this concept for improvement of magnetic resonance imaging is demonstrated.

18:30 – 18:45 Reduction of Noise Correlation in Magnetic Resonance Imaging Coil Arrays with Metamaterials Oral
Manuel Freire, University of Seville, Spain
Jose Algarin, University of Seville, Spain
Ricardo Marques, University of Seville, Spain

This work presents a method to calculate the noise correlation between magnetic resonance imaging coils loaded with metamaterial lenses and in the presence of a conducting phantom resembling human tissue. The method is validated by the comparison with experimental results. With this method it is studied the ability of magnetoinductive lenses to decrease the noise correlation between coils in the array and thus to increase the signal-to-noise ratio.

18:45 – 19:15 Closing Ceremony
# Session Matrix

**Monday, 16\textsuperscript{th} September**

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<td>09:15 – 09:30</td>
<td>Opening Ceremony</td>
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<tr>
<td>09:30 – 10:00</td>
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<td>Plenary session 1</td>
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<td>10:30 – 11:00</td>
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<td><strong>Coffee break</strong></td>
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<td>11:00 – 12:30</td>
<td>SS I.1 Active, non Foster, PT-symmetry metamaterials</td>
<td>OS I.1 Chiral metamaterials</td>
<td>OS I.2 Microwave &amp; RF metamaterials I</td>
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<td>12:30 – 14:00</td>
<td><strong>Lunch</strong></td>
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<td>14:00 – 15:30</td>
<td>SS I.2 Bottom-up and self-assembled metamaterials</td>
<td>OS I.3 Nanoantennas</td>
<td>OS I.4 Microwave &amp; RF metamaterials II</td>
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<td>16:00 – 17:45</td>
<td>SS I.3 Smart, Hybrid, Multifunctional Metamaterials</td>
<td>OS I.5 Light Concentrators &amp; Nanoantennas</td>
<td>OS I.6 Microwave &amp; RF metamaterials III</td>
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<td>17:45 – 18:00</td>
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<td>19:15 – 21:30</td>
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<tr>
<td>09:00 – 10:30</td>
<td>SS II.1 Metamaterials for Emission and Radiative Heat Control I</td>
<td>OS II.1 Hyperbolic Metamaterials</td>
<td>OS II.2 Metamaterials for Antennas I</td>
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<tr>
<td>10:30 – 11:00</td>
<td>Coffee break</td>
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<tr>
<td>11:00 – 12:00</td>
<td>Plenary session II</td>
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<tr>
<td>12:00 – 13:30</td>
<td>Lunch</td>
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<tr>
<td>13:30 – 15:00</td>
<td>SS II.2 Graphene and Quantum Effects in Metamaterials I</td>
<td>OS II.3 Metasurfaces I</td>
<td>OS II.4 Metamaterials for Antennas II</td>
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<tr>
<td>15:30 – 16:30</td>
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<tr>
<td>16:30 – 18:15</td>
<td>SS II.3 Graphene and Quantum Effects in Metamaterials II</td>
<td>OS II.5 Metasurfaces I</td>
<td>OS II.6 Low-loss and Active Metamaterials</td>
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<td>18:15 – 18:30</td>
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<tr>
<td>18:30 – 20:00</td>
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**Wednesday, 18th September**

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<tr>
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<td>OS III.1 Exotic effects in Metamaterials I</td>
<td>OS III.2 Fano Resonances in Metamaterials</td>
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<td>11:00 – 12:00</td>
<td>Plenary session III</td>
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<td>12:00 – 13:30</td>
<td>Lunch</td>
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<tr>
<td>13:30 – 15:00</td>
<td>SS III.2 Acoustic, Mechanical and Elastic Metamaterials I</td>
<td>OS III.3 Exotic effects in Metamaterials II</td>
<td>OS III.4 Fabrication of Metamaterials</td>
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<tr>
<td>15:00 – 16:30</td>
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<tr>
<td>16:30 – 18:00</td>
<td>SS III.3 Acoustic, Mechanical and Elastic Metamaterials II</td>
<td>OS III.5 Tunable Metamaterials</td>
<td>OS III.6 Hybrid &amp; Multifunctional Metamaterials</td>
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<tr>
<td>18:00 – 23:30</td>
<td>Tasting tour and gala dinner at Château Smith-Haut-Lafitte</td>
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<td>09:00 – 10:30</td>
<td>SS IV.1 Nonlinearity and Nonreciprocity in Metamaterials I</td>
<td>OS IV.1 Cloaking I</td>
<td>OS IV.2 Theoretical Advances in Metamaterials I</td>
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<tr>
<td>14:00 – 15:30</td>
<td>SS IV.3 THz Metamaterials I</td>
<td>OS IV.5 Optical Metamaterials I</td>
<td>OS IV.6 Absorption in Metamaterials</td>
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<tr>
<td>17:00 – 18:45</td>
<td>SS IV.4 THz Metamaterials II</td>
<td>OS IV.7 Optical Metamaterials II</td>
<td>OS IV.8 Metamaterials for Sensing</td>
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<tr>
<td>18:45 – 19:15</td>
<td>Closing Ceremony</td>
<td></td>
<td></td>
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