METAMATERIALS´2008

Pamplona 21-26 September

upna Universidad Pública de Navarra
Nafarroako Unibertsitate Publikoa

Proceedings

ISBN 978-84-9769-229-8

METAMATERIALS´2008
Pamplona 21-26 September

Contents

METAMATERIALS´2008

Pamplona 21-26 September

Organized by

Virtual Institute for Artificial Electromagnetic Materials and Metamaterials

Universidad Pública de Navarra

In cooperation with the following organizations:

IET

Journal of Optics A: Pure and Applied Optics

Journal of Physics D: Applied Physics

EPS

AIS

SPIE Europe

U.R.S.I.

Sponsored by:

Gobierno de Navarra

upna Universidad Pública de Navarra Nafarroako Unibertsitate Publikoa

Plan Tecnológico de Navarra

anain AGENCIA NAVARRA DE INNOVACIÓN

ELSEVIER

Foreword

Sergei Tretyakov,
General Chair

Filiberto Bilotti, Chair of
the Steering Committee

Ramón Gonzalo,
Chair of the Local
Organization
Committee

It is our great pleasure to welcome you to the Second International Congress on Advanced Electromagnetic Materials in Microwaves and Optics (*Metamaterials 2008*), initiated by the European Network of Excellence *Metamorphose* and organized by the Virtual Institute for Artificial Electromagnetic Materials and Metamaterials (*Metamorphose VI*).

This series of events brings together and continues the traditions of the highly successful series of International Conferences on Complex Media and Metamaterials (*Bianisotropics*) and *Rome International Workshops on Metamaterials and Special Materials for Electromagnetic Applications and Telecommunications*. International Conferences on Complex Media and Metamaterials had eleven editions, with the names "Chiral", "Bi-isotropics", or "Bianisotropics", reflecting the developments in the field of artificial electromagnetic materials, while the Workshop *on Metamaterials and Special Materials for Electromagnetic Applications and Telecommunications* had three editions with an ever increasing attendance. The first edition of the Congress, held in Rome in October 2007, has established good traditions which we are happy to follow and develop.

The Congress programme covers a wide area of research, related to artificial electromagnetic materials and surfaces for microwave and optical ranges, and encompasses various aspects of their general theory, modelling, design, applications, fabrication and measurements. It is formed as a balanced set of plenary talks, keynote talks, invited and contributed presentations, all subjected to rigorous peer review. Special sessions address key topical problems.

We would like to thank all colleagues who have helped with the organization of this event and offered their scientific and technical contributions, as well as our sponsoring agencies. The papers in the Congress program are of the highest standard and address the most challenging problems in this exciting area of Advanced Electromagnetic Materials.

Furthermore, from the Local Organization Committee, we would like to welcome you to Pamplona, we hope you enjoy your stay in this city and come back in a near future.

Sergei Tretyakov, General Chair
Filiberto Bilotti, Chair of the Steering Committee
Ramón Gonzalo, Chair of the Local Organization Committee

Preface

Rick Ziolkowski,
TPC Chair

It is the great pleasure of the Technical Program Committee (TPC) to thank all of you for contributing your exciting research, your efforts, and your time to make the Second International Congress on Advanced Electromagnetic Materials in Microwaves and Optics, Metamaterials 2008, a very memorable event. Your TPC focused the technical program around a Plenary Session and fourteen Special Sessions, which highlight a variety of significant advances in metamaterials and their applications in the microwave; millimeter and terahertz; and optical frequency regimes. The Plenary Session emphasizes three talks, given by recognized experts in each of those regimes; each Special Session was organized with a Keynote Speaker and three Invited Speakers. The oral and poster sessions were created to complement all of these special sessions and to fill a variety of technical gaps, including more details and other interesting topics.

In an attempt to respond to comments from the MTM2007 participants, we have restricted the program in any given time period to only three parallel oral sessions, including only one of the special sessions. We have also tried to minimize overlaps between the topical coverage of those sessions. The poster sessions are highlighted in a time slot and an appealing location that are available to all participants. An evening open discussion forum will provide an opportunity to discuss general issues of interest to the metamaterials community.

We hope that you will be technically and culturally stimulated by this wonderful, very cross-disciplinary meeting which is set in the very welcoming and world famous Pamplona, Spain. MTM2008 uniquely blends together many science and engineering disciplines across many frequency regimes. We hope that you will enjoy sharing your new ideas and results with your old friends and the many new ones which we hope you will make during MTM2008.

Your TPC Committee:

Rick Ziolkowski, TPC Chair
Ferran Martin and Harald Giessen, TPC Co-Chairs
Gennady Shvets, Special Sessions Chair

Metamaterials 2008 Committees

General Chair

Sergei Tretyakov,
Helsinki University of Technology
Finland

Steering Committee Chair

Filiberto Bilotti,
Roma Tre University,
Italy

TPC Chair

Richard Ziolkowski,
University of Arizona,
USA

Local Committee Chair

Ramón Gonzalo,
Universidad Pública de Navarra,
Spain

Steering Committee

F. Bilotti (Chair), Italy

A. Schuchinsky (Past Chair), UK

V. Podlozny, Finland

V. Shalaev, USA

Y. Vardaxoglou, UK

Technicar Program Committee

R. Ziolkowski (Chair), USA

H. Giessen (Co-Chair, optics), Germany

F. Martin (Co-Chair, microwaves), Spain

G. Shvets (Co-Chair, Special Sessions), USA

Local Organization Committee

R. Gonzalo (Chair)

I. Ederra (General Secretary)

E. Saenz

J.C. Iriarte

I. Khromova

Metamaterials 2008 Committees

Web design and technical support

V. Kanevska, Finland

Scientific Advisory Board

P. de Maagt, The Netherlands
G. Eleftheriades, Canada
N. Engheta, USA
S. He, Sweden/China
T. Itoh, USA
K. Kivshar, Australia
A.N. Lagarkov, Russia
L.W. Li, Singapore
D. Lippens, France
R. Marquès, Spain
R. McPhedran, Australia
J. Mosig, Switzerland
R. Mittra, USA
H. Nakano, Japan
S. Noda, Japan
A. Oliner, USA
E. Ozbay, Turkey
J. Pendry, UK
A. Priou, France
A. Sihvola, Finland
C. Soukoulis, Greece/USA
M. Stockman, USA
V.V. Varadan, USA
L. Vegni, Italy
I.B. Vendik, Russia
V.G. Veselago, Russia
N. Zheludev, UK
S. Zouhdi, France

Reviewers

Andrea Alù
Hiroyuki Arai
Pavel Belov
Steven Best
Filiberto Bilotti
Alexandra Boltasseva
Filippo Capolino
George Eleftheriades
Nader Engheta
Javier Garcia de Abajo
Harald Giessen
Ramón Gonzalo
Anthony Grbic
Yang Hao
Silvio Hrabar
Ismo Lindell
Stefan Linden
Didier Lippens
Vitaliy Lomakin
Peter de Maagt
Stefan Maier
Ferran Martín
Willie Padilla
Ross McPhedran
Michael Scalora
Alexander Schuchinsky
Gennady Shvets
Ari Sihvola
Constantin Simovski
Mario Sorolla
Sergei Tretyakov
Ricardo Marqués
Ekaterina Shamonina
Vasundara Varadan
Martin Wegener
Keith Whites
Michael Wiltshire
Richard Ziolkowski

Exhibition

CST - Computer Simulation Technology

CST - Computer Simulation Technology develops and markets high performance software for the simulation of electromagnetic fields in all frequency bands.

CST's success is based on the implementation of unique, leading edge technology in a user-friendly interface. It's customers operate in industries as diverse as Telecommunications, Defense, Automotive, Electronics, and Medical Equipment, and include market leaders such as IBM®, Intel®, Mitsubishi, Samsung, and Siemens.

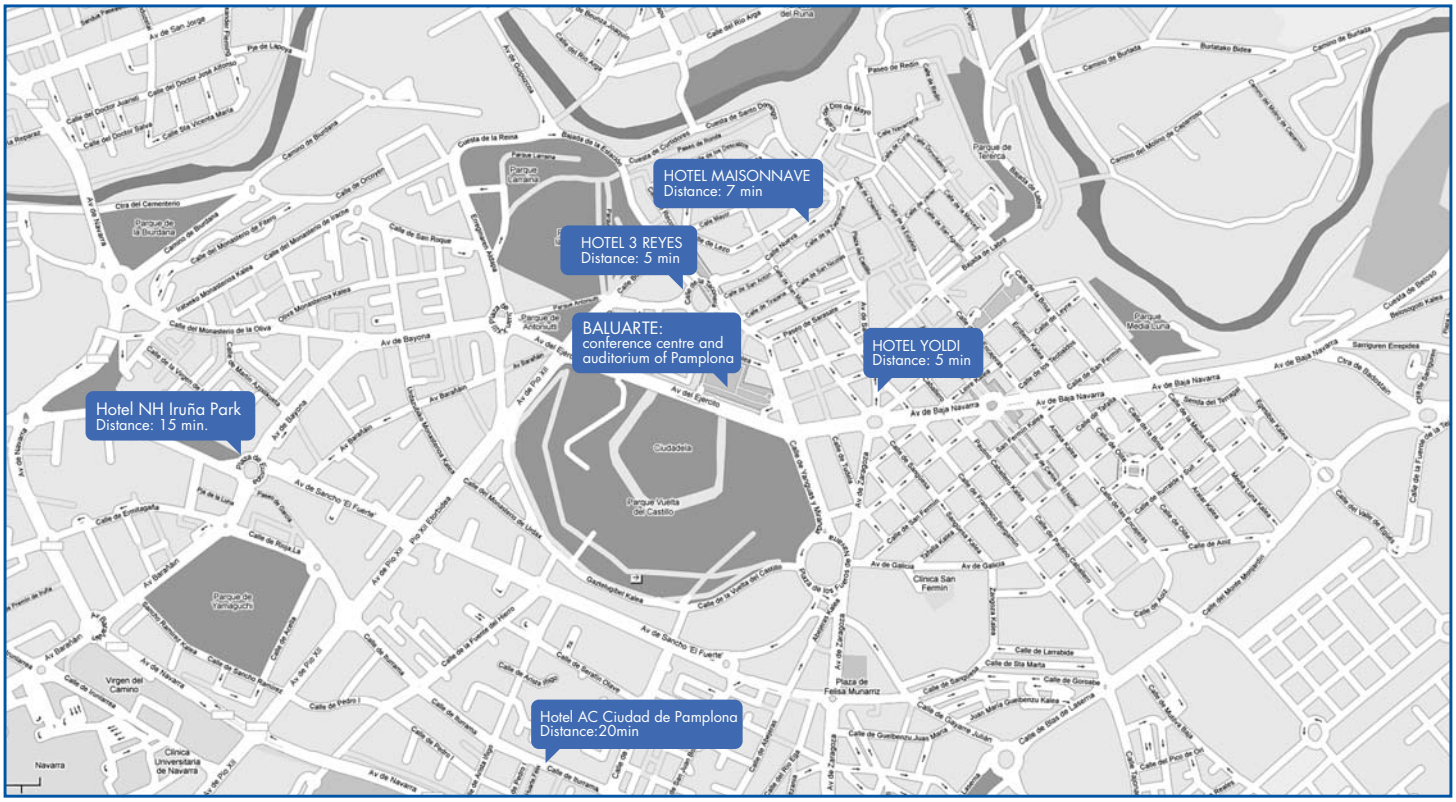
CST markets its products worldwide through a network of distribution and support centers which also provide comprehensive customer support and training.

Ansoft

Ansoft is a leading developer of high-performance electronic design automation (EDA) software.

Engineers use Ansoft software to design state-of-the-art electronic products, such as cellular phones, Internet-access devices, broadband networking components and systems, integrated circuits (ICs), printed circuit boards (PCBs), automotive electronic systems and power electronics. Ansoft markets its products worldwide through its own direct sales force and has comprehensive customer-support and training offices throughout North America, Asia and Europe.

Location



In the centre of the Autonomous Community of Navarre, on a plain surrounded by mountains, lies Pamplona, the capital of the Ancient Kingdom of Navarre.

Founded in 75 B.C. by the Roman general Pompey on the ancient Vascon settlement of Iruña, it has been crossed by several cultures throughout the centuries and has always been an important stopping point on the Pilgrim's Way to Santiago de Compostela. Nowadays, with a population of almost 200,000, it is a welcoming, modern city with many large parks that is full of corners with charm and history.

The Old Quarter, surrounded by walls and watched over by towers and belfries, is a medieval city of narrow streets, small squares, churches and noble houses.

Go deeper into the city and its stones will tell you its history. Feel the hospitality of the people of Pamplona, first take a stroll around the city walls and then taste its pinchos (tapas) and its rich cuisine. Ignore tourist clichés; let yourself be enchanted by a historic city that has turned its main festivity, the Sanfermines, into a synonym for the word 'fiesta' all over the world.

With good communications and excellent services, Pamplona is an essential stopover for visitors to the region and a good place to start any excursion through Navarre. The city's layout and size mean that the best way to discover it is on foot.

Well known thanks to the prestige of its universities and hospitals, Pamplona is one of the Spanish cities with the highest proportion of green spaces per inhabitant, with large parks such as La Ciudadela, La Taconera, Media Luna and Yamaguchi.

Congress Palace

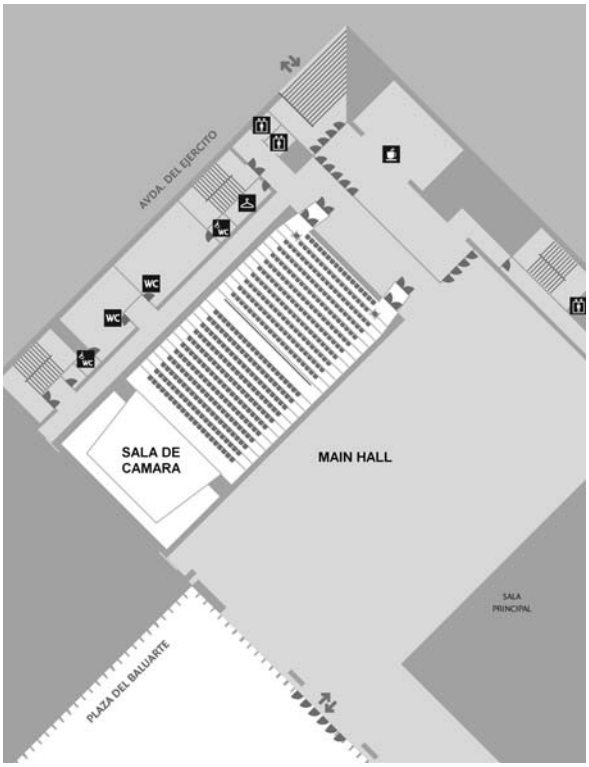
Venue

Conference Centre and Auditorium of Pamplona, BALUARTE, constructed by the Navarre Government is a large space able to accommodate all types of cultural and commercial events. BALUARTE boasts a privileged position in the centre of the city. The building has one main auditorium with a capacity of 1,560, a Chamber hall for some 450 delegates and several different sized conference rooms. The third floor of the building offers specific rooms for meetings, with its modular design able to adapt to any size of congress. The building also offers around 5,000 m2 of exhibition and commercial fair space. The versatility of its space enables it to hold any type of congress or show irrespective of its characteristics, size or number of participants.

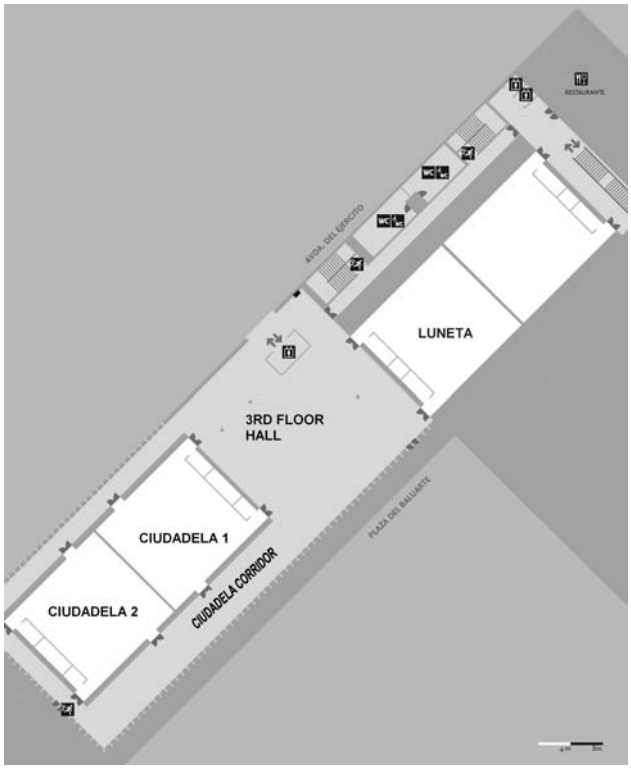
Baluarte, Palacio de Congresos y Auditorio de Pamplona
Plaza del Baluarte. 31002 Pamplona
Tel: 948 066 066
Fax: 948 066 077
baluarte@baluarte.com

Venue

The next maps describe the situation of the rooms within the Congress Palace where the sessions will be held.



Ground Floor



Third Floor

- **Opening Ceremony and Plenary Session** (Tuesday morning):
  SALA DE CAMARA
- **Regular Sessions:**
  CIUDADELA 1 and CIUDADELA 2
- **Special Sessions:**
  LUNETA
- **Poster Sessions:**
  CIUDADELA CORRIDOR
- **Panel Session** (Wednesday afternoon):
  LUNETA
- **Closing Ceremony** (Friday evening):
  LUNETA

Congress dinner and visit to Castillo-Palacio Real de OLITE

Visit to Olite

The Castle-Palace of Kings of Navarra is one of the most important castles of its kind. Jewel of the European Gothic castles, Olite castle-palace was the former residence of the Kings of Navarra until the union of the kingdom with Castile in the 13th century.

It was declared a National Monument in 1925. During the 13th-14th centuries underwent alterations, but the most important development came during the times of King Carlos III "the Noble".

This visit is free for Congress attendees. If you have not registered yet you can do it at the Conference Desk. You are welcome to reserve up to two places for you and your partner in the bus.

The plan for the tour is as follows:

17:00 Departure of buses from Baluarte (Conference Venue)
17:45 Guided visit of the Royal Palace of Olite (45 min approx)
18:30 Guided visit of the Santa María church (30 min approx)
19:00 Wine tasting at the Morera Yard of the Palace
20:00 Come back to Pamplona for the Conference Banquet

Conference Banquet

The Conference Banquet will be in the Restaurant Castillo de Gorraiz (4 Km away from Pamplona) on Thursday the 25th. Dinner tickets (the cost is 50 euros) can be purchased at the Conference Desk on Tuesday.

The buses will depart from Baluarte (Conference Venue) at 20:30.

Session Matrix

Tuesday, Sept 23

8:20	Registration *Main Hall*		
9:00	**Opening Ceremony** *Sala de Camara*		
9:30	**Plenary Session** *Sala de Camara*		
14:35	**Special session on 3D and bulk MTMs** (R. Marques) *Luneta*	MTM based Antennas (F. Bilotti) *Ciudadela 1*	Novel Structures and Applications (I) (R. Ziolkowski) *Ciudadela 2*
16:35	**Special session on optical structures** (G. Shvets) *Luneta*	Directive MTM Antennas (A. Yakovlev) *Ciudadela 1*	Photonic EBG structures (E. Ozbay) *Ciudadela 2*
19:30	Welcome Cocktail *Sala de Armas (Ciudadela)*		

Wednesday, Sept 24

8:20	**Special session on millimeter waves** (D. Lippens) *Luneta*	Nano-antennas and applications (N. Van Hulst) *Ciudadela 1*	Negative Refraction (A. Zayats) *Ciudadela 2*
10:20	**Special session on THz waves** (W. Padilla) *Luneta*	Active and Nonlinear MTM (A. Schuchinsky) *Ciudadela 1*	Transmission-line, waveguide, and planar MTMs and applications (A. Grbic) *Ciudadela 2*
12:00	Poster session *Ciudadela Corridor*		
14:50	**Special session on plasmonics** (G. Shvets) *Luneta*	Miniaturisation with MTMs (I. Vendik) *Ciudadela 1*	Optical MTMs (I) (H. Giessen) *Ciudadela 2*
16:50	**Special session on extraordinary transmission** (J. Garcia Abajo) *Luneta*	Homogenization and effective medium modelling (M. Silveirinha) *Ciudadela 1*	Perfect lenses and Imaging (C. Simovski) *Ciudadela 2*
18:45	**Panel Session** *Luneta*		

Session Matrix

Thursday, Sept 25

8:20	**Special session on planar MTMs (I)** (F. Martin) *Luneta*	Chriral and bianisotropic MTMs (A. Sihvola) *Ciudadela 1*	Optical MTMs (II) (S. Maier) *Ciudadela 2*
10:20	**Special session on planar MTMs (II)** (S. Hrabar) *Luneta*	Cloaking (A. Alu) *Ciudadela 1*	Novel Structures and Applications (II) (V. Varadan) *Ciudadela 2*
12:00	Poster session *Ciudadela Corridor*		
14:50	**Special session on tunable/ reconfig./ active MTMs** (S. Gevorgian) *Luneta*	EOT (I) (M. Sorolla) *Ciudadela 1*	Fabrication and Measurements (S. Linden) *Ciudadela 2*
16:50	**Special session on superlenses, hyperlenses, other near-field imaging devices** (R. Merlin) *Luneta*	EBG based structures (B. Jecko) *Ciudadela 1*	Plasmonics (I) (M. Stockman) *Ciudadela 2*
21:00	Conference banquet		

Friday, Sept 26

8:20	**Special session on electrically small antennas and arrays** (R. Ziolkowski) *Luneta*	Transformation electromagnetics (R. McPhedran) *Ciudadela 1*	Plasmonics (II) (M. Scalora) *Ciudadela 2*
10:20	**Special session on nano-antennas** (B. Hecht) *Luneta*	SSRs: Theory and experiment (M. Wiltshire) *Ciudadela 1*	EOT (II) (V. Lomakin) *Ciudadela 2*
12:00	Poster session and student paper competition *Ciudadela Corridor*		
14:50	**Special session on cloaking and Transformation electromagnetics** (N. Engheta) *Luneta*	Metasurfaces and Metafilms (A. Feresidis) *Ciudadela 1*	THz metamaterials (R. Gonzalo) *Ciudadela 2*
16:50	**Special session on extreme MTMs** (V. Shalaev) *Luneta*	Fundamental Theory (I. Lindell) *Ciudadela 1*	Optical Metamaterials (III) (A. Zayats) *Ciudadela 2*
18:30	**Closing Ceremony** *Luneta*		

09:00 **Opening ceremony**

Chair: Ramón Gonzalo, *Public University of Navarra, Spain*

Plenary session, part I

Chair: Filiberto Bilotti, *University Roma Tre, Italy*

09:30 **Some recent topics in bulk split-ring metamaterials**

Ricardo Marqués, Facultad de Física, Universidad de Sevilla, Spain

Ricardo Marqués

Along this contribution some recent topics in bulk split ring metamaterials, which includes capacitively loaded rings and split ring resonators metamaterials, are reviewed. Among these topicas are isotropy, relation between electromagnetic and magnetoinductive waves, spatial dispersion and chirality.

10:30 **Coffee break**

Plenary session, part II

Chair: Alexander Schuchinsky, *Queens University, Belfast, UK*

11:00 **Hardware implementation of EBG and AMC structures for space applications**

Jean-Marc Baracco , Mardel, France
Yan Brand, MDA, Canada
Ramón Gonzalo, Public University of Navarra, Spain
Andrea Neto, TNO Defence, Security and Safety, the Netherlands
Peter de Maagt, ESTEC, the Netherlands

Peter de Maagt

This paper focuses on existing (sub)systems that are predominantly based on EBG and AMC technology. The applications are introduced, design challenges indicated and the results achieved presented. This gives a reasonable showcase of some successful implementations.

12:00 **Photonic metamaterials: Optics starts walking on two feet**

Martin Wegener, Institut für Angewandte Physik, Universität Karlsruhe (TH), Germany
Stefan Linden, Institut für Angewandte Physik, Universität Karlsruhe (TH), Germany

Martin Wegener

We review recent progress in the field of metamaterials for photonics. Examples are artificial magnetism at optical frequencies, negative phase and group velocities, and enhanced nonlinear phenomena.

13:00 **Lunch**

Special Session Room Luneta

3D and bulk metamaterials

Special session organized by Ricardo Marqués, *Facultad de Física, Universidad de Sevilla, Spain*
Chair: Ricardo Marqués, *Facultad de Física, Universidad de Sevilla, Spain*

14:35 **Extreme-parameter metamaterials. Keynote talk**
Nader Engheta, University of Pennsylvania, USA

Metamaterials whose parameters may attain high or low relative values exhibit unconventional properties in their interaction with electromagnetic and optical waves. In this talk, we give an overview of electromagnetic characteristics of metamaterials with relative permittivities near zero or very high values.

15:15 **Design equations for broadband, volumetric NRI media. Invited talk**
Scott Rudolph, Dept. of EECS, University of Michigan , USA
Anthony Grbic, Dept. of EECS, University of Michigan, USA

In this paper, a simplied form of multiconductor transmission-line analysis is used to model a volumetric negative-refractive-index medium. This simplied model still takes into account the spatial dispersion of the medium, allowing the low-frequency cutoff to be accurately predicted. Design equations for the cutoff frequency and the electric and magnetic plasma frequencies are given in terms of the capacitance and inductance parameters of the multiconductor system and the loading elements.

15:35 **Swiss Rolls: a versatile RF metamaterial. Invited talk**
Michael Wiltshire, Imperial College London, United Kingdom

The Swiss Roll structure is a very effective magnetic metamaterial at radiofrequency, and may be made in both conventional and chiral forms. In this presentation I will review the performance of the conventional material with particular emphasis on its imaging capability, and then describe the production and preliminary characterisation of chiral Swiss Rolls.

15:55 **3D isotropic DNG material based on a set of coupled dielectric spheres with Mie resonance. Invited talk**
Irina Vendik, St. Petersburg Electrotechnical University, Russia
Mikhail Odit, St. Petersburg Electrotechnical University, Russia

Different ways to create the 3-D isotropic and 2-D DNG medium based on a regular lattice of resonant inclu-sions are known: i) 2D array of dielectric cylindrical resonators; ii) 3D regular lattice of magnetodielectric spherical resonators; iii) 3D regular array of dielectric spherical resonant inclusions. In this paper we consider characteristics of a regular array of strongly coupled dielectric resonant spheres. The coupling between resona-tors leads to splitting resonance modes. The first Mie resonance in the dielectric sphere gives rise to the magnetic dipole. The electric dipole arises from the sphere interaction. Electric and magnetic dipole existence provides the DNG response of the media. The structure based on randomly distributed spherical resonators is considered.

16:15 **Coffee break**

Regular Session Room Ciudadela 1

Metamaterial-based antennas

Chair: Filiberto Bilotti, University Roma Tre - Dept. of Applied Electronics, Italy

14:35 **Multi-functional antennas with artificial magnetic materials: theoretical aspects and numerical simulations. Invited talk**
Filiberto Bilotti, University Roma Tre - Dept. of Applied Electronics, Italy
Simone Tricarico, University Roma Tre - Dept. of Applied Electronics, Italy
Lucio Vegni, University Roma Tre - Dept. of Applied Electronics, Italy

In this paper, we present the theoretical aspects and the full-wave simulations of multi-functional dipole antennas in presence of artificial magnetic material slabs. At first, the artificial magnetic material is assumed as an isotropic and homogenous material, whose permeability function follows the Lorentz dispersion. The operating frequency regions of interest are those ones in which the real permeability is positive and high-valued and those ones in which it is close to zero. In these two regions the slab behaves in substantially different ways, enabling two different operation modes for the dipole antenna. The physical operation of the antenna in the two frequency regions is deeply discussed and verified through a series of numerical examples. Then, the analysis is repeated replacing the ideal metamaterials with real materials made of given arrangements of artificial magnetic inclusions and the features of the corresponding antennas are pointed out. Finally, a few antenna layouts are proposed and the implementation of such radiators in real-life applications is also discussed.

14:55 **An electrically small monopole-like antenna with embedded metamaterial high-μ matching network**
Titos Kokkinos, Dept. of Electronic and Electrical Engineering, Loughborough University, United Kingdom
Alexandros P. Feresidis, Dept. of Electronic and Electrical Engineering, Loughborough University, United Kingdom

A novel electrically small, self-resonant, monopole-like antenna is reported in this paper. The proposed antenna is composed of two low-profile, closely spaced, vertical posts, that are connected through a planar, fully-printed, metamaterial matching network. The effective high-μ property of the employed metamaterial network enable the proposed structure to operate as a folded monopole that becomes self-resonant irrespectively of its profile and achieves an operating bandwidth of up to 5 % and a radiation efficiency of up to 80 %.

15:15 **Design of high-power metamaterial-based scanning leaky-wave antenna**
Silvio Hrabar, University of Zagreb, Croatia
Helga Kumric, University of Stuttgart, Germany
Davor Zaluski, University of Zagreb, Croatia

One of interesting applications of backward-wave propagation deals with leaky-wave radiating structures with back-fire to end-fire scanning capabilities. However, majority of published designs are in planar technology, thus they are unsuitable for high-power applications. In this report, the main problems in design of high-power leakywave antenna are highlighted and the waveguide antenna based on a chain of the resonant-slot coupled cavity chain is proposed. Preliminary numerical and experimental results revealed scanning angle greater than ± 20 degrees from the broadside for the seventeen unit cells long waveguide with a longitudinal slot.

15:35 **Bandwidth and size behaviour study for patch antennas using metamaterial fillings with positive permittivity and permeability**
Pere J Ferrer, AntennaLab - UPC, Spain
Irena Calafell, AntennaLab - UPC, Spain
José M. González-Arbesú, AntennaLab - UPC, Spain
Jordi Romeu, AntennaLab - UPC, Spain

The bandwidth and size behaviours of patch antennas are studied for the case of lossless and nondispersive material substrates loaded with positive values of permittivity and permeability. High bandwidths can be achieved for high permeability ($\mu_r >> 1$) and low permittivity ($\varepsilon_r << 1$) substrates.

16:15 **Coffee break**

Regular Session Room Ciudadela 2

Novel structures and applications I

Chair: Richard W. Ziolkowski, *ECE Dept, University of Arizona, USA*

14:35 **High-index meta-materials and Tungsten structures for broad-band solar absorption. Invited talk**
Shanhui Fan, Stanford University, USA

In this presentation we will discuss our recent works on designing three-dimensional isotropic metamaterials that exhibit large refractive index. We will also discuss Tungsten solar absorber that operates over the entire solar bandwidth, and over wide ranges of angles.

14:55 **Transition from diffusive to localized in 2D random lasers**
Patrick Sebbah, CNRS, France
Christian Vanneste, CNRS, France

We present a numerical study of light scattering in active random media. A two dimensional random struc-ture of dielectric scatterers embedded in a gain medium is systematically explored at threshold when the refrac-tive index of the scatterers is varied from 1.05 to 2. This allows us to explore the nature of the quasimodes in regimes of light propagation ranging from diffusive to localized.

15:15 **Design of nanofilters at optical frequencies**
Alessandro Toscano, Università Roma Tre, Italy
Sebastian Emanuel Lauro, Università Roma Tre, Italy
Lucio Vegni, Università Roma Tre, Italy

Starting from the lumped-element approach recently presented in Alù *et al.* (published on line at http://arxiv.org/abs/0710.0616v1), we present here a new schema to design a filtering module at optical frequen-cies, using collections of nanoparticles acting as "lumped" nanocircuit elements. We, first, demonstrate, using numerical simulations of a fully 3D geometry of lumped nanocircuit elements at optical frequencies, that the behavior of these nanoelements may strongly reproduce that of their lower frequency counterparts. A complete analysis through design formulas of nanoscale filtering 3D modules at optical frequencies is then presented and discussed.

15:35 **Scattering analysis of graded porous metamaterials using effective permittivity functions**
Matthew Mishrikey, ETH Zurich, Switzerland
Arya Fallahi, ETH Zurich, Switzerland
Christian Hafner, ETH Zurich, Switzerland
Ruediger Vahldieck, ETH Zurich, Switzerland
Leonid Braginsky, ETH Zurich, Switzerland
Valery Shklover, ETH Zurich, Switzerland

Graded thermal barrier coatings can be simulated and optimized using numerical field solvers. We apply an effective material approximation to reduce the computation time for these metamaterials, and show that the approximation provides a suitable lower bound on their performance.

15:55 **Flexible magneto-inductive resonators and waveguides**
Richard Syms, Imperial College London, United Kingdom
Ian Young, Imperial College London, United Kingdom
Laszlo Solymar, Imperial College London, United Kingdom

A flexible metamaterial RF detector for magnetic resonance imaging is described. The circuit consists of a polygonal arrangement of magnetically coupled L-C resonators with rectangular inductors, which supports magneto-inductive waves. The elements are mechanically linked to allow adjacent elements to rotate as the ring is flexed. The pivot is optimised to hold the nearest neighbour coupling coefficient κ_1 invariant to small changes in angle so resonances are unaffected. Theory is developed to find the optimum pivot and verified using PCB elements. The method is also applicable to flexible waveguides.

16:15 **Coffee break**

Special Session Room Luneta

Optical metamaterials

Special session organized by Gennady Shvets, *The University of Texas at Austin, USA*
Chair: Gennady Shvets, *The University of Texas at Austin, USA*

16:35 **Ferromagnetic and antiferromagnetic ordering in optical metamterials. Keynote talk**
Harald Giessen, Universität Stuttgart, Germany

In this paper, we demonstrate magnetic ordering in three-dimensional magnetic metamaterials at optical frequencies. We present a detailed study on the coupling effects in 3D magnetic metamaterials. We further show that the interaction between magnetic moments carried by individual magnetic constituents in metamaterials can give rise to ferromagnetic and antiferromagnetic ordering in 3D twisted split-ring resonator and 3D fishnet metamaterials, respectively. We explain the complex optical spectra, symmetries as well as selection rules of these 3D metamaterials by the hybridization of the magnetic response.

17:15 **Photoluminescence modification by high-order photonic band with abnormal dispersion in an ZnO inverse opal. Invited talk**
Hui Cao, Department of Applied Physics, Yale University, USA
Heeso Noh, Materials Research Institute, Northwestern University, USA
Michael Scharrer, Materials Research Institute, Northwestern University, USA
Mark A. Anderson, Materials Research Institute, Northwestern University, USA
Robert P. H. Chang, Materials Research Institute, Northwestern University, USA

We measured the angle- and polarization-resolved reflection and photoluminescence spectra of ZnO inverse opals. Significant enhancement of spontaneous emission is observed. The enhanced emission not only has good directionality but also can be linearly polarized. A detailed theoretical analysis and numerical simulation reveal that such enhancement is caused by the abnormal dispersion of a high-order photonic band. The frozen mode at a stationary inflection point of a dispersion curve can strongly modify the intensity, directionality and polarization of spontaneous emission.

17:35 **Photonic metamaterials with a twist. Invited talk**
Stefan Linden, Forschungszentrum Karlsruhe, Germany
M. Decker, Universität Karlsruhe, Germany
M. Ruther, Forschungszentrum Karlsruhe, Germany
M. Wegener, Universität Karlsruhe, Germany

We present some of our recent experimental results and numerical calculations on “2D-chiral” and 3D-chiral metamaterials operating at optical frequencies.

17:55 **Metamaterials enter the physics playground: from EIT to lasing spaser. Invited talk**
Vassili Fedotov, Optoelectronics Research Centre, University of Southampton, United Kingdom
N. Papasimakis, Optoelectronics Research Centre, University of Southampton, United Kingdom
E. Plum, Optoelectronics Research Centre, University of Southampton, United Kingdom
S. L. Prosvirnin, Institute of Radio Astronomy, National Academy of Sciences, Kharkov, Ukraine
N. I. Zheludev, Optoelectronics Research Centre, University of Southampton, United Kingdom

We will overview our recent and ongoing research of a novel class of metamaterials exhibiting narrow high-Q transmission and reflection resonances linked to so-called “trapped-modes” excitations, and will introduce a concept of a “coherent” metamaterial, where narrow resonance is formed by a collective response of the entire metamaterial structure rather than by that of individual meta-molecules.
Some remarkable parallels between the well established quantum effects and classical electromagnetic response of metamaterials will be explored. Cornerstone quantum phenomena such as the Mossbauer Effect, Einstein-Bose condensation and Electromagnetically Induced Transparency (EIT) are among those that can be mimicked through electromagnetic response of coherent “trapped-mode” metamaterials. Several intriguing applications of this new class of artificial media will be discussed, in particular achieving considerable delays in propagation of electromagnetic pulses, enhancing asymmetric transmission and building a coherent source of electromagnetic radiation fuelled by plasmonic oscillations - the lasing spaser.

19:30 **Welcome cocktail**

Regular Session Room Ciudadela 1

Directive metamaterial antennas

Chair: Alexander B. Yakovlev, *University of Mississippi, USA*

16:35 **Reduction of undesired lobes in composite right/left-handed transmission line (CRLH-TL) based leaky-wave antenna**
Atiqur Rahman, Electronic Engineering Dept., Queen Mary Univ of London, United Kingdom
Yang Hao, Electronic Engineering Dept., Queen Mary Univ of London, United Kingdom
Clive Parini, Electronic Engineering Dept., Queen Mary Univ of London, United Kingdom

In this paper we offer a solution to the reduction of the undesired lobes of interdigital capacitor and stub inductor based leaky-wave antenna fabricated on a finite size ground plane while keeping antenna compactness intact. This technique can be applied for the CRLH-TL based leaky-wave antenna reported in [1] and [2].

16:55 **Investigation on ferromagnetic nanowired substrates for leaky-wave antennas**
Judith Spiegel, Université Catholique de Louvain, Belgium
Stéphanie Eggermont, Université Catholique de Louvain, Belgium
Isabelle Huynen, Université Catholique de Louvain, Belgium

Ferromagnetic nanowiredmembranes are good candidates forminiaturized tunable and non-reciprocal devices. We propose a novel topology of leaky-wave antenna, where broadside scanning is obtained by a left-handed behavior induced by negative permeability of the substrate. The ferromagnetic nature of wires allows beam scanning at fixed frequency by applying an external magnetic DC field.

17:15 **A novel high gain 60 GHz antenna using a suspended frequency selective surface (FSS)**
Sumanth Kumar Pavuluri, School of Engineering & Physical Sciences, Heriot-watt University, United Kingdom
Feresidis Alexandros, Department of Electronic and Electrical Engineering, Loughborough University, United Kingdom
George Goussetis, School of Engineering & Physical Sciences, Heriot-watt University, United Kingdom
Changhai Wang, School of Engineering & Physical Sciences, Heriot-watt University,United Kingdom

A novel high gain planar antenna for operating at 60 GHz using a suspended frequency selective surface (FSS) has been investigated. The antenna device is based on the concept of a FSS based Fabry- Perot cavity for high directivity. The FSS structure is on a thin film polymer film to reduce loss and to produce a low profile device. The thin polymer film is suspended above the ground plane using a micromachined polymer ring spacer. The excitation of the cavity is provided using a waveguide-fed aperture in the ground plane. For device fabrication, the polymer spacer will be fabricated on the thin film substrate after the FSS structure has been produced and will then be assembled onto the substrate with the ground plane using a low temperature polymer bonding process. The design of the FSS was carried out using method of moment code by analysing the reflectivity of the structure. The FSS is then incorporated into the antenna structure for device design and modelling using MicrostripesTM, a time domain based electromagnetic (EM) simulation package. The results show that the novel antenna device has substantial directivity of around 25 dBi required for WLAN communications at 60 GHz frequency band.

17:35 **Dual-band cavity antenna using a PRS superstrate and an AMC ground plane**
Dongho Kim, Electronics and Telecommunications Research Institute, South Korea
Junho Yeo, Daegu University, South Korea

This paper presents a Fabry-Pérot type resonator antenna whose superstrate and substrate are composed of an array of conductive strips and an artificial magnetic conductor (AMC), respectively. The main purpose of this antenna is to introduce more than -20dB rejection band in-between two adjacent service bands (up- and downlink bands) of Korean personal communication service (PCS). Additionally, with the help of metallic walls enclosing all the opening between the super- and substrate, more than 10dB realized gain in two operation bands is obtained and the back radiation is reduced remarkably.

17:55 **Electrically small superdirective endfire arrays of low-profile folded monopoles**
Titos Kokkinos, Dept. of Electronic and Electrical Engineering, Loughborough University, United Kingdom
Tomas Rufete-Martinez, Dept. of Electronic and Electrical Engineering, Loughborough University, United Kingdom
Alexandros P. Feresidis, Dept. of Electronic and Electrical Engineering, Loughborough University, United Kingdom

An electrically small, superdirective, two-element, microstrip-based, single port, endfire array is reported in this paper. The proposed endfire array is composed of two low-profile folded monopoles that attribute their operation to an embedded metamaterial high-μ matching network. Given the selfresonant characteristics of the employed radiating elements and the extremely low coupling between any pair of them, the array feeding network, that properly sets the array superdirective mode, is composed exclusively of a 180º ring hybrid and conventional microstip lines. The resulting twoelement array is compact, easily fabricated, low-cost and can deliver directivities up to 3 dB larger than those of the single element.

19:30 **Welcome cocktail**

Regular Session Room Ciudadela 2

Photonic EBG structures

Chair: Ekmel Ozbay, *Bilkent University, Turkey*

16:35 **Parallel fabrication of atom nanostructures with arbitrary shape**
Victor Balykin, Institute of Spectroscopy, Russia
Pavel Melentiev, Institute of Spectroscopy, Russia
Dmitry Lapshin, Institute of Spectroscopy, Russia

In this presentation we report on a new approach in atom lithography that is based on the use the atom pinhole camera. Owing to the use of this approach, an array of 10^7 identical nanostructures of arbitrary shapes and characteristic size of 30 nm of In, Cr and Ag atoms has been created on a silicon surface.

16:55 **Fabrication of photonic crystals and negative index materials by Nanoimprint Lithography**
Iris Bergmair, Profactor GmbH, Austria
Michael Muehlberger, Profactor GmbH, Austria
Rainer Schoeftner, Profactor GmbH, Austria
Michael Bergmair, CD Laboratory for Surface Optics, Austria
Ulrich Dobramysl, CD Laboratory for Surface Optics, Austria
Thomas Glinsner, EV Group Schärding, Austria
Kurt Hingerl, CD Laboratory for Surface Optics, Austria

Nanoimprint lithography (NIL) is a fast and cost efficient technique for the mass production of nanostructures. We briefly show our NIL work regarding the realization of a 3D woodpile photonic crystal and negative index materials using this technology and its suitability as a fabrication method for such structures. In both materials negative refraction can occur but its origin is quite different and is discussed in short in this work.

17:15 **Research of magnetophotonic crystals and surface states in microwave band**
Sergey Tarapov, Institute of Radiophysics and Electronics Nat.Ac.Sci of Ukraine, Ukraine
D. Belozorov, NSC "Kharkov Institute of Physics & Technology", Nat.Ac.Sci of Ukraine, Ukraine
S. Chernovtsev, Institute of Radiophysics and Electronics Nat.Ac.Sci of Ukraine, Ukraine
M. Khodzitskiy, Institute of Radiophysics and Electronics Nat.Ac.Sci of Ukraine, Ukraine

The paper is devoted to modeling and experimental research of surface states of electromagnetic waves in a bounded magnetophotonic crystal (MPC). The experimental specimen is a 1D periodical structure. The elementary Bloch cell of the structure consists of three successive plates of ferrite-quartz-vacuum. In experiment the crystal is placed between two electromagnetic horns, or embedded inside the one-mode waveguide. The wavelength of electromagnetic wave is in the 8-mm wavelength band. The spatial localization of the electromagnetic field in 1D structure was studied for various boundary conditions. The mathematical simulation of the field distribution in the system revealed the field concentration near the crystal boundary depending on the properties of adjacent media. The experimental studies of the 1D specimen also revealed the concentration of the electromagnetic field near the specimen boundary provided that the frequency of electromagnetic wave was in the forbidden gap of the MPC. The last is the condition for existence of Tamm states. Analogy between the observed surface states and Tamm states is discussed.

17:35 **Nano-scaled onion like carbon: prospective material for microwave coatings**
Polina Kuzhir, Institute for Nuclear Problems of Belarusian State University, Belarus
Sergey Maksimenko, Institute for Nuclear Problems of Belarusian State University, Belarus
Dmitry Bychanok, Institute for Nuclear Problems of Belarusian State University, Belarus
Sergey Moseenkov, Boreskov Institute of Catalysis SB RAS, Russia
Vladimir Kuznetsov, Boreskov Institute of Catalysis SB RAS, Russia
Olga Shenderova, International Technology Center, USA
Philippe Lambin, FUNDP –University of Namur, Belgium

The experimental study of a novel technological material –'96 onion like carbon (OLC) –'96 in microwaves demonstrates its high potentiality for the design of electromagnetic coatings in the form of OLC-based composites.

17:55 **The influence of a surface roughness on the transmission properties of 1D photonic crystals**
Oleksandr Glushko, University of Leoben, Austria
Ronald Meisels, University of Leoben, Austria
Friedemar Kuchar, University of Leoben, Austria

In this contribution we present numerical simulations as well as experimental investigations of 1D photonic crystal with intentionally introduced surface roughness. Transmission experiments were performed in the microwave region on a mm-sized structure with roughness of the order of 10 percent. The simulations show the general effect of band edges smearing and reducing of the depths of the gaps. However, the effect becomes significant only for wavelengths which are of the same order with the surface roughness features. Besides, we have shown that if increasing roughness cause decreasing of air filling fraction of a photonic crystal this lead to "shrinking" of the entire band structure resulting in redshift of the gaps edges

19:30 **Welcome cocktail**

Special Session Room Luneta

Millimeter Waves

Special session organized by Didier Lippens, University of Lille 1 /IEMN, France
Chair: Didier Lippens, University of Lille 1 /IEMN, France

08:20 **Fabrication of millimeter wave scale metamaterials. Keynote talk**
Ekmel Ozbay, Bilkent University, Turkey

In this talk, we will review our research on millimeter wave scale metamaterials. We have obtained metamaterials with true left handed metamaterials operating at 100 GHz. Besides microfabrication methods, we have also developed standard PCB based millimeter wave split ring based metamaterial structure. A negative pass-band with a peak value of -2.7 dB was obtained experimentally. We numerically and experimentally investigated a fishnet metamaterial operating at around 100 GHz. Applications of these metamaterials will also be reported.

09:00 **A metamaterial approach towards high gain antenna. Invited talk**
Steven Franson, Motorola, USA
Richard Ziolkowski, University of Arizona, USA

As wireless trends dictate that ever increasing data rates will be demanded by consumers, it is imperative that technology capable of delivering multi-gigabit per second speeds be developed. The data rates for lower GHz communication links are quickly saturating as spectral efficiency is being pushed to its limits. To address this issue, several start-up companies have begun deploying millimeter-wave point-to-point links near 60, 70, 80, and 90 GHz, where there is plenty of available spectrum. This article addresses the design of one of the most critical and expensive components in these systems: the antenna. We examine a grid superstrate, which has been described previously as a `zero-n' metamaterial structure, integrated with a patch antenna and demonstrate that one can achieve gigabit per second data rate transmissions with this high directivity antenna system.

09:20 **Negative refraction route by stacked subwavelength hole arrays at millimeter wave and THz frequencies. Invited talk**
Mario Sorolla, Universidad Pública de Navarra, Spain
Miguel Beruete, Universidad Pública de Navarra, Spain
Miguel Navarro-Cia, Universidad Pública de Navarra, Spain
Igor Campillo, CIC nanoGUNE, Spain
Mariam Aznabet, Universidad Pública de Navarra, Spain
Otman El Mrabet, Universidad Pública de Navarra, Spain
Francisco Falcone, Universidad Pública de Navarra, Spain
Sergei A. Kuznetsov, Budker Institute of Nuclear Physics SB RAS, Russia
A. V. Gelfand, Institute of Semiconductor Physics SB RAS, Russia
N. I. Fedorinina, Institute of Semiconductor Physics SB RAS, Russia

The possibilities to design novel lefth handed metamaterials operating at millimeter and THz wavelengths by stacking subwavelength hole arrays will be considered. Moreover, negative refraction by means of prisms and by oblique incidence measurements will be discussed. These facts open the way to the design of a planoconcave parabolic negative index lens operating at millimeter wavelengths. The possibility to design similar planoconcave devices in the terahertz and optical wavelengths could be open.

09:40 **Tunable negative permeability metamaterials based on ceramic dielectric materials. Invited talk**
Qian Zhao, Tsinghua University, China
Lei Kang, Tsinghua University, China
Hongjie Zhao, Tsinghua University, China
Ji Zhou, Tsinghua University, China
Fuli Zhang, Université de Lille, France
Didier Lippens, Université de Lille, France

Two approaches for metameterials with negative permeability based on ceramic dielectric materials, instead of metallic structure, are introduced. One of them is derived from Mie resonance of dielectric particles, and the other from magnetic resonance in the ferrites. The tuning of the negative permeability is realized in these two systems by temperature and external magnetic field.

10:00 **Coffee break**

Regular Session Room Ciudadela 1

Nano-antennas and Applications

Chair: Niek van Hulst, ICFO - Institute of Photonic Sciences, Spain

08:20 **Manipulating optical nanoantennas with optical nanocircuits**
Nader Engheta, University of Pennsylvania, USA
Andrea Alu, University of Pennsylvania, USA

Here we give an overview of our recent efforts in developing techniques for manipulating the functionalities of optical nanoantennas using the concepts of optical nanocircuit elements. We have shown, through extensive analytical and numerical studies, that optical nanoantennas may be tuned at different wavelengths at will, loaded with nanoelements for filtering signals, and matched to optical waveguides for efficient energy coupling using optical nanostructures that behave as lumped optical nanoelements. This can provide useful and versatile design methodologies in structuring and engineering optical nanoantennas within the context of plasmonic nano-optics, and manipulation of optical fields and optical signal processing at the nanoscale.

08:40 **Near-field imaging and opto-mechanical tuning of plasmonic nanoantennas**
Aitzol Garcia-Etxarri, Donostia International Physics Center and Centro Mixto de Fisica de Materiales (CSIC-UPV/EHU), Donostia, Spain
Isabel Romero, Donostia International Physics Center, Donostia, Spain
F. Javier García de Abajo, Insituto de Óptica, Madrid, Spain
Rainer Hillenbrand, CIC nanoGUNE Consolider, Donostia, Spain
Javier Aizpurua, Donostia international Physics Center and Centro Mixto de Física de Materiales (CSIC-UPV/EHU), Donostia, Spain

We present a study of the role of a probing tip in the imaging and control of the plasmon patterns of a metallic nanoparticle with use of scattering-type scanning near-field optical microscopy (s-SNOM). We identify two regimes depending on the dielectric response of the tip: a weakly coupling regime where the tip does not distort the near fields and thus the plasmon patterns of a metallic nanoantenna, and a strongly interacting regime where the fields and thus the plasmon patterns of the optical antenna are completely modified. Our model calculations explain the modification of the plasmon response based on full electrodynamical calculations and are consistent with a simple dipolar-coupling scheme. Experimental realisation of both interacting and non-interacting regimes are also presented with use a carbon nanotube for the weakly-interacting regime, and with Pt and Si tips for the strongly-interacting regime, showing the expected modification of the plasmon patterns of the nanoantenna.

09:00 **Plasmonic nanoantennas for field-enhanced infrared spectroscopy and microscopy**
Javier Aizpurua, Donostia International Physics center and Centro Mixto de Fisica de Materiales (CSIC-UPV/EHU), Donostia, Spain
Aitzol Garcia-Etxarri, Donostia International Physics Center and Centro Mixto de Fisica de Materiales (CSIC-UPV/EHU), Donostia, Spain
Thomas Taubner, Stanford University, Stanford, USA
Rainer Hillenbrand, CIC Nanogune Consolider, Donostia, Spain
Frank Neubrech, University of Heidelberg, Heidelberg, Germany
Annemarie Pucci, University of Heidelberg, Heidelberg, Germany

In this contribution we analyse the role of metallic antennas to effectively enhance the signal and contrast in molecular spectroscopy both in the optical and infrared regions of the spectrum. First, we report results on the largely enhanced spectroscopy signal from a few molecules of ODT deposited on a gold nanoantenna. The signal is detected directly in infrared absorption by means of a resonant mechanism of plasmonic-vibrational coupling giving rise to Fano-like profiles. Secondly, we predict a similar situation in near-field infrared microscopy of molecular layers where different line shape profiles can be found depending on the optical response of the substrate holding the molecular layer. We find a relatively large enhancement for metallic substrates, and an enormously enhanced signal and contrast for a resonant substrate material. This plasmon-vibrational coupling can provide a new mechanism to set the path towards single-molecule infrared direct detection.

09:20 **Analysis of near-field enhancement in the visible with layers of plasmonic resonant nanospheres**
Sergiy Steshenko, University of Siena, Italy
Filippo Capolino, University of Siena, Italy

In this presentation we analyze the near-field enhancement effects obtained in the visible domain by using arrays of resonant plasmonic nanospheres. We consider the excitation of a double-layer array of silver nanospheres by a single electric dipole and focus on two aspects: (a) the analysis of the field on the other side of the layers of nanospheres showing where the field is localized, and (b) what happens when the arrays of nanospheres are not aligned. The array scanning method (ASM) is used to carry out the analysis and evaluate the field maps.

10:00 **Coffee break**

Regular Session Room Ciudadela 2

Negative refraction

Chair: Filippo Capolino, University of Siena, Italy

08:20 **Causality-based conditions for negative refraction can give a flawed insight**
Paul Kinsler, Imperial College London, United Kingdom
Martin McCall, Imperial College London, United Kingdom

Using causality as expressed in the Kramers-Kronig relations, we derive a criterion for negative refraction that allows for the case of imperfect transparency at the observation frequency. Such conditions rely on the group velocity, not direction of energy-flow, so we discuss (with examples) their relationship to the usual NPV criteria.

08:40 **Numerical study of focusing by a composite right left handed metamaterial**
Ali Eren Culhaoglu, German Aerospace Center, Germany
Andrey Osipov, German Aerospace Center, Germany
Peter Russer, Technical University of Munich, Germany

A planar metamaterial slab with a relative permittivity and permeability *of* $\varepsilon_r = \mu_r = -1$ focus a wave originating from a point source on the one side of the slab into a focal point at the other side and therefore act as a collimating lens. It was shown theoretically that with such a configuration, imaging with a resolution below the diffraction limit can be achieved. In this work the effect of dispersion onto the imaging quality is investigated. Transmission of broadband pulses with a Gaussian spectrum through a Drude model based, impedance matched to free space, composite right/left handed (CRLH) slab is considered. The configuration is studied numerically via the transmission line matrix method.

09:00 **Negative refraction in moving media through spacetime algebra**
Marco Ribeiro, Instituto de Telecomunicações, Portugal
Carlos Paiva, Instituto de Telecomunicações, Portugal

Using spacetime algebra we introduce, in the context of Minkowski spacetime, a new technique that we call the vacuum form reduction. It is a straightforward and synthetic 4D analysis of electromagnetic wave propagation in moving media. This new tool avoids the cumbersome manipulations of dyadic 3+1 analyses. As an example of application we analyze negative refraction at a plane interface between two different moving half-spaces.

09:20 **Measurement of negative refractive index and design paradigms**
Vasundara Varadan, University of Arkansas, USA
Ruyen Ro, University of Arkansas, United States

The phenomenon of negative refraction has been demonstrated experimentally and by numerical simulation assuming Drude and Lorentz models for the permittivity and permeability that lead to a negative refractive index. In this paper we present direct experimental measurements of the permittivity, permeability and refractive index of combined wire-SRR samples and present some paradigms for tailored metamaterial design.

09:40 **Microwave magnetoelectric molecules and lattices based on magnetic-dipolar-mode ferrite disks**
Eugene Kamenetskii, Ben Gurion University of the Negev, Israel, Israel

The term "magnetoelectric" (ME) should presume the presence of mechanisms of interactions different from electromagnetic (EM) interactions. There could be, for example, natural ME crystals with the parity-non-conservation properties. Other examples are piezoelectric-ferromagnetic composites and magnetic ferroelectrics with a special mechanical character of ME interaction. In this paper, we show that there exist non-EM mechanisms of interactions between magnetic-dipolar-mode (MDM) ferrite particles which are, in fact, the ME interactions due to the symmetry breaking effects.

10:00 **Coffee break**

Special Session Room Luneta

THz Waves

Special session organized by Willie Padilla, Boston College, USA
Chair: Willie Padilla, Boston College, USA

10:20 **Metamaterial technology for bridging the Terahertz gap. Keynote talk**
Didier Lippens, University of Lille 1 /IEMN, France

In this presentation, we review the various technologies aiming at operating in the Terahertz spectral region. At these frequencies, there is a strong overlap between the microwave and optical technologies relying on metal-dielectric and full-dielectric artificial microstructures. For the former, we show how it is possible to relax the stringent requirement of an edge-illumination condition, which is commonly employed for multi-stacked split ring resonators and wire arrays. Various approaches can be envisaged for a front-side illumination with a merging of concepts and we illustrate this situation by means of sub-wavelength hole arrays operating around 0.5 THz. We study the possibility to tune the dispersion characteristics either by means of a Ferroelectrics thin film technology, with expected relaxation frequencies in the Terahertz frequency range. Also, the infiltration of metamaterial micrsotructures with Liquid crystals will be considered. With respect to the applications, special attention will be paid to the achievement of a negative-zero-positive index which is termed as balanced Composite Right and Left Handed (CRLH) metamaterials for a transmission line approach. This property is extended here to volumetric materials and opens novel possibilities in terms of Rainbow-type devices based on the high dispersion characteristics. For the full-dielectric route, a bulk-ferroelectric solution is investigated with cloaking being the targeted application and more generally to a better control of light propagation. Photonic Crystal technology is considered by taking advantage of negative refraction for focusing or isolating a region of space For all these topics, special emphasis will be paid to the characterization techniques by taking advantage of the recent advances in the Time Domain Spectroscopy (TDS) and photomixing along with Scanning Near field Optical Microscopy (SNOM).

11:00 **Spoof surface plasmon polaritons at THz frequencies. Invited talk**
Stefan Maier, Imperial College, United Kingdom
C. R. Williams, University of Bath, United Kingdom
S. R. Andrews, University of Bath, United Kingdom
Antonio Fernández-Domínguez, Universidad Autónoma de Madrid, Spain
Francisco García-Vidal, Universidad Autónoma de Madrid, Spain
Luis Marín-Moreno, Universidad de Zaragoza, Zaragoza, Spain

This invited presentation will present an overview of the spoof surface plasmon polariton concept, providing a means for creating a plasma response and hence a strong field confinement using structured metallic sur-faces at THz and microwave frequencies. Implementations for both planar and cylindrical structures with operating frequencies around 1 THz will be discussed, and application opportunities as well as constraints outlined.

11:20 **Effective media at terahertz frequencies. Invited talk**
Richard Averitt, Boston University, USA
Andrew Strikwerda, Boston University, USA
Hu Tao, Boston University, USA
Kebin Fan, Boston University, USA
Xin Zhang, Boston University, USA
John O'Hara, Los Alamos National Lab, USA
Hou-Tong Chen, Los Alamos National Lab, USA
Antoinette Taylor, Los Alamos National Lab, USA
Nathan Landy, Boston College, USA
Chris Bingham, Boston College, USA
Padilla Willie, Boston College, USA

Recent results using plasmonic and metamaterial composites to manipulate terahertz radiation will be presented with an emphasis on exploiting the substrate dielectric properties to enhance or control the overall effective medium response.

11:40 **Planar plasmonic terahertz guided-wave devices. Invited talk**
Ajay Nahata, University of Utah, USA
Wenqi Zhu, University of Utah, USA
Amit Agrawal, University of Utah, USA

We demonstrate the realization of planar plasmonic THz guided-wave devices, including straight waveguides, Y-splitters and 3dB-couplers, using periodically perforated metal films. These perforated films behave as effective media whose dielectric function can be broadly engineered.

Regular Session Room Ciudadela 1

Active and Nonlinear Metamaterials

Chair: Alexander Schuchinsky, *Queen's University Belfast, United Kingdom*

10:20 **Strong or weak nonlinear waves in metamaterial structures. Invited talk**
Allan Boardman, University of Salford, United Kingdom
Peter Egan, University of Salford, United Kingdom
Rhiannon Mitchell-Thomas, University of Salford, United Kingdom
Yuriy Rapoport, University of Salford, United Kingdom

The fundamental approach to a slowly varying amplitude formulation for nonlinear waves in metamaterials will be established. The extent to which negative phase behaviour has a fundamental influence upon soliton behaviour will be addressed and will include non-paraxiality, self-steepening and nonlinear diffraction. Examples, involving waveguide and polarization coupling and interferometer systems will be used to illustrate the concepts and potential applications. It is emphasized that it is particularly important to consider strongly nonlinear approach that seeks exact solutions to the nonlinear equations for a metamaterial guide. The investigations will show that, in contrast to the usual weakly nonlinear case, nonlinear modal fields emerge that can lead to new types of localised modes. The work will embrace "optical needles", autosolitons and some comments on vortices. Part of the methodology is based upon a novel boundary field amplitude approach, leading to useful and elegant eigenvalue equations.

10:40 **A bistable nonlinear left-handed transmission line. Invited talk**
David Powell, The Australian National University, Australia
Ilya Shadrivov, The Australian National University, Australia
Yuri Kivshar, The Australian National University, Australia

We experimentally demonstrate bistability in a nonlinear left-handed transmission line. This system is an analogue of nonlinear left-handed metamaterials, which were theoretically predicted to exhibit this phenomena. We show that the bistability is associated with the period doubling which at higher power may result in chaotic dynamics of the transmission line.

11:00 **Laser action in photonic crystal structures with active medium.**
Olga Kozina, Saratov Branch of the Institute of Radio-Engineering and Electronics of Russian Academy of Science, Russia
L. A. Melnikov, Saratov State University, Russia

We present the results of calculations of laser action in 1D and 2D PC with air/glass-doped layers. The spectral and spatial characteristics of finite length 1D and 2D PC with air-glass-doped medium was examined. The model of active medium corresponds to Nd $^{3+}$ doped glass. Both in-plane and out of plain propagation are investigated. Threshold conditions and laser characteristics are presented.

11:20 **Second harmonic generation in different metallo-dielectric multilayer**
Concita Sibilia, Universita' di Roma La Sapienza, Italy
Maria Cristina Larciprete, Universita' di Roma La Sapienza, Italy
Alessandro Belardini, Universita' di Roma La Sapienza, Italy
Marco Centini, Universita' di Roma La Sapienza, Italy
Mario Bertolotti, Universita' di Roma La Sapienza, Italy
Michael Scalora, Charles M. Bowden Research Facility, USA

We experimentally and theoretically investigate the second order nonlinear optical response of metallodielectric multilayer structures composed of Ag and Ta2O5 layers. Second harmonic generation measurements were performed in reflection mode as a function of incidence angle, using femtosecond pulses originating from a Ti:sapphire laser system tuned at lamda of 800 nm .

11:40 **Growing waves in drifted plasmas**
Oleksiy Sydoruk, SAOT, University of Erlangen-Nuremberg, Germany
Viktor Kalinin, Transense Technologies Ltd, United Kingdom
Richard Syms, Imperial College London, United Kingdom
Ekaterina Shamonina, SAOT, University of Erlangen-Nuremberg, Germany
Laszlo Solymar, Imperial College London, United Kingdom

Self-consistent wave solutions for structures consisting of drifting plasmas and dielectrics are presented and the appearance of growing waves in one of the models is shown. The role of collisions and diffusion is discussed and the direction of future work aimed at devices is indicated. The requirement for velocity matching implies that eventually periodic structures and space harmonics are needed so that these devices will form a new type of amplifying metamaterials.

Regular Session Room Ciudadela 2

Transmission-line, waveguide and planar metamaterials and applications

Chair: George Eleftheriades, *University of Toronto/ECE Department, Canada*

10:20 **Waves on chains of coupled metamaterial elements in the presence of retardation: Experiment and Simulation**
Oleksiy Sydoruk, SAOT, University of Erlangen-Nuremberg, Germany
Vadym Lomanets, Max Planck Research Group, University of Erlangen-Nuremberg, Germany
Eugen Tatartschuk, SAOT, University of Erlangen-Nuremberg, Germany
Georgy Onishchukov, Max Planck Research Group, University of Erlangen-Nuremberg, Germany
Ulf Peschel, Max Planck Research Group, University of Erlangen-Nuremberg, Germany
Ekaterina Shamonina, SAOT, University of Erlangen-Nuremberg, Germany

Waves propagating on chains of coupled resonators have recently received an increased attention due to their potential for signal guiding and processing from microwaves to optics. Various theoretical models for electric and magnetic resonators predict similar dispersion characteristics in the presence of retardation, but those dispersion characteristics have not yet been verified experimentally in the entire Brillouin zone. Here we report on an experimental and numerical study of the waves propagating on arrays of coupled split-ring resonators around 12 GHz. Dispersion characteristics extracted from the measurements and simulations are in a good agreement.

10:40 **G-band metamaterial-based compact filters**
Alejandro Lucas Borja, Universidad politécnica de Valencia. Université de Lille 1., Spain
Jorge Carbonell, Universidad politécnica de Valencia, Spain
Vicente E. Boria, Universidad politécnica de Valencia, Spain
Michel Chaubet, Centre National d'Etudes Spatiales (CNES), France
Didier Lippens, Université de Lille 1, France

The design of compact metamaterial-based planar filters operating at the G-band (150 GHz central frequency) is studied through the implementation of a split ring resonator loaded coplanar waveguide technology. Technological issues and filter application specifications impose severe constraints to the design, fabrication and RF assessment of this type of devices. Specifically, the filter selectivity issue is addressed as a trade-off between the acceptable insertion loss in the transmitted band and the achievable upper band rejection level. The addition of semi-lumped elements to previous unit cell implementations improves this critical design feature.

11:00 **Metamaterial made of pairs of conductors in planar technology: a z-transmission line approach**
Andrea Vallecchi, University of Siena, Italy
Filippo Capolino, University of Siena, Italy
Matteo Albani, University of Siena, Italy

In this presentation we show how a metamaterial can be designed by using pairs of tightly coupled conductors as constitutive elements. To model the propagation through the proposed layered metamaterials, we develop a transverse equivalent circuit network to be interposed in the transmission line model of propagation across layers, and show that reflection and transmission features of a periodic array of dogbone pairs is accurately predicted by this simplified model.

11:20 **On the use of SRR in multi-stopband waveguide filters**
Eva Rajo-Iglesias, Universidad Carlos III de Madrid, Spain
Oscar Quevedo-Teruel, Universidad Carlos III de Madrid, Spain
Malcolm Ng Mou Kehn, University of Manitoba, Canada

Split Ring Resonators (SRRs) provide an effective negative permeability within a given frequency band. This property can be used for loading conventional waveguides in order to create new passbands below waveguide cutoff frequency or stopbands after that frequency. This work explores different possibilities of creating multiple stopbands by using arrays of differently sized SRRs both, interlacing them over the shared surface of a dielectric slab and combining SRRs with different sizes of the elements in a middle slab position with side slab ones. Numerical and experimental results are presented.

11:40 **Dispersion characteristics of the planar 1D magnonic crystals**
Natalia Grigorieva, St.Petersburg Electrotechnical University, Russia
Boris Kalinikos, St.Petersburg Electrotechnical University, Russia

We present a general approach to the analysis of the dispersion characteristics of the planar magnetic periodic structures. The considered structure, based on a magnetic thin film with a metallic grating near one of its surfaces, exhibits the specific properties of magnetic metamaterial. It can be proposed as a test ground for experimental investigation of the linear and nonlinear properties of propagating spin waves (SW) in 1D magnonic crystals. Analytical theory of the dipole-exchange SW spectrum in such periodic structures is presented. A detailed discussion of the main dispersion parameters of the sample structure is given.

Poster Session Ciudadela Corridor (12:00 -13:15)

1 Linear and nonlinear optical phenomena in nanostructured photonic crystals, filled by dielectrics or metals
Vladimir Gorelik. P.N.Lebedev Physical Institute of RAS, Russia

In this report the results of linear and nonlinear optical properties investigations of globular photonic crystals, filled by dielectrics or metals, are presented

2 Ultra-slow light pulses in a nonlinear metamaterial
Giuseppe D'Aguanno, Nadia Mattiucci, Mark Bloemer. C.M. Bowden Research Facility, USA

We find the analytical expression for the threshold intensity necessary to launch ultra-slow light pulses in a metamaterial with simultaneous cubic electric and magnetic nonlinearity. The role played respectively by the permittivity, the permeability, the electric cubic nonlinearity, the magnetic cubic nonlinearity and the pulse duration is clearly identified and discussed.

3 Thin-film Sensing with Frequency Selective Surfaces Based on Improved Asymmetric Resonators
Ibraheem Al-Naib, Christian Jansen, Martin Koch. Technical University of Braunschweig, Germany

In this paper, a miniaturized rectangular asymmetric double split resonator is proposed. Moreover, a modified design for intensified field confinement in the gaps is suggested to further increase the sensitivity for thin-film sensing. A comparative study is demonstrated to show the potential of the proposed structure.

4 Ferrite magnetoelectric particles and arrays for microwave electrostatic-control spin-basedlogic devices and quantum computation
Michael Sigalov, Eugene Kamenetskii, Reuven Shavit. Ben Gurion University of the Negev, Israel

Recently, a new microwave magnetoelectric (ME) effect was found. The effect is based on the fact that magnetic-dipolar-mode (MDM) oscillations in quasi-2D ferrite disks are macroscopic quantum coherence states with topological vortex structures and eigen electric and magnetic moments. Based on our analytical, numerical and experimental studies we predict now microwave ferrite ME particles and arrays that allow the design of electrostatic-control spin-based logic devices at room temperature. The key advantage of the proposed architecture is that for logic operations one does not need current pulses. So both information storage and information manipulation are accomplished without charge transfer. We consider an implementation of quantum gates for quantum computation using macroscopically quantized MDM states in quasi-2D ferrite disks.

5 Nonreciprocal amplitude-frequency resonant response of metasandwiches "ferrite plate-grating of resonant elements"
Galina Kraftmakher, Valery Butylkin. Institute of Radioengineering and Electronics RAS, Russia

It is presented new microwave nonreciprocal properties of metasandwiches "ferrite plategratings of resonant elements" under propagation along structures. It is observed both nonreciprocal transmission at ferromagnetic resonance domain and nonreciprocal splitting of curve with band enhancement at domain of resonance in elements of grating under small magnetostatic fields. The results can be used for development of novel nonreciprocal meta-systems and informational technologies.

6 Effective parameters, pass-bands and backward waves in bianisotropic metamaterials under removal of chirality
Valery Butylkin, Galina Kraftmakher. Institute of Radioengineering and Electronics RAS, Russia

It is shown that metamaterials of gratings of oppositely arranged planar chiral elements are media in which chirality is nullified, resonant properties of permeability and permittivity being retained. It is found that there are: 1) a left-handed pass-band with simultaneously negative permeability and permittivity and backward wave, 2) right-handed pass-bands with positive permeability and permittivity and forward wave.

7 Periodic array of conducting ellipses as a frequency selective surface for polarization rotator
Adam Kusiek, Rafal Lech, Jerzy Mazur. Gdansk University of Technology, Poland

The analysis of a polarization rotator structure is presented in this paper. The polarizer is composed of N sections of frequency selective surfaces (FSS). Each FSS is composed of periodic array of conducting ellipses. The exact full-wave theory based on the mode-matching method, T matrix approach and the lattice sums is applied to analyze the structures. The validity of the approach is verified by comparing the results with those obtained from equivalent circuit models of conducting strips or wires gratings based on the transmission line theory.

8 Electromagnetic curtain effect of multilayered periodic structures
Rafal Lech, Adam Kusiek, Jerzy Mazur. Gdansk University of Technology, Poland

This paper presents the analysis of electromagnetic wave scattering by multilayered periodic structure composed of cylindrical dielectric posts which constitutes a two-dimensional (2-D) electromagnetic band gap (EBG) structure. The analysis is conducted with the use of several efficient numerical techniques such as the orthogonal expansion method, the T-matrix approach and the lattice sums technique. The scattering properties of the EBG structure are discussed. The electromagnetic curtain effect and its control are presented.

Poster Session

9 Normal incidence on stacked surfaces of split ring resonators
Jorge Carbonell, Alejandro Lucas Borja, Vicente E. Boria. Universidad Politécnica de Valencia, Spain
Eric Lheurette, Didier Lippens. Université des Sciences et Technologies de Lille, France

In this paper, the problem of a normally incident radiation illuminating a stack of Split Ring Resonator (SRRs) surfaces is analyzed. We start from the simple case of a single surface of SRRs being opaque to the incident radiation at a frequency close to the resonant frequency of the SRRs, with a typically rejecting frequency selective surface behaviour. Then, as a number of SRR surface layers are vertically stacked in the propagation direction, the electromagnetic behaviour of this artificial magnetic structure becomes more complex including interactions between the resonant elements, not only in the lateral dimensions but also in the transverse propagation direction. Some of these effects are not predicted by using an effective parameter approximation. The results of the transmission characteristics and the dispersion diagram for a unit cell problem are provided, together with a finite array situation. Experimental results currently on the way will be directly presented at the conference.

10 Experimental investigation of stop-bandwidth variation properties in EM waves shielding functional concrete block
Joongkwan Kim, Sungsoo Nam, Hoyong Kim, Hongmin Lee. Kyonggi Univ, South Korea

This work describes the experimental observation of stop-bandwidth variation of EM wave shielding concrete block which is made by using parallel resonators. The proposed 2-D parallel resonator consists of two copper plates, one via and filled with LTCC materials) inside. The stop band properties are measured at 60 days and 1 year. When three resonators are embedded into a concrete block (80 mm x 40 mm x 40 mm), the measured resonance frequency is 2.12GHz and the stop bandwidth (-30 dB) is 215MHz at 60 days. After one year later measurement, the resonance frequency and stop bandwidth (-30 dB) of the same concrete block is 1.97GHz and 90 MHz, respectively.

11 Defect effect over transmission through CPVC metamaterials dielectric grids
Eduardo Jose Sartori, Hugo Enrique Hernandez-Figueroa. UNICAMP - State University of Campinas, Brazil
Jose Eduardo Bertuzzo. Instituto de Pesquisas Eldorado, Brazil

The study with low cost dielectric grids has shown that this kind of structure is very similar, in its electromagnetic behaviour, to the grids constructed using expensive materials (such as acrylic, Teflon etc.). This paper presents some simulated and experimental results about the defect effect in a dielectric metamaterial grid, using CPVC pipes.

12 Figure of merit analysis of metamaterials
Yoonjae Lee, Yang Hao. Queen Mary, University of London, United Kingdom

We present a critical study on the figure-of-merit (FoM) associated with loss and bandwidth of the metamaterials based on resonant particles such as split-ring resonators (SRRs) The FoMs are calculated analytically and verified numerically for the metamaterials with various electrical sizes and densities for the constituent particles. High volumetric density and electrically large particles demonstrate superior FoMs for the construction of practical metamaterials.

13 Guiding properties of the "defected" semiconductor layer inserted in the dielectric periodic structure
Olga Kostylyova, Alexey Bulgakov. A.Ya. Usikov Institute of Radiophysics and Electronics of NAS of Ukraine, Ukraine

In this presentation the investigation of the semiconductor waveguide with dielectric layered periodic walls is carried out. The influence of the external field on the properties of the considered waveguide is studied. It is shown that properties of such waveguides can be controlled by means both of the choice of the periodic structure layer parameters and of the external magnetic field.

14 Properties of reflected and transmitted fields in tilted wire medium interface
Ali Vahdati, Ari Viitanen, Helsinki University of Technology, Finland

In this study the reflection and transmission coefficients for plane waves are presented for the interface of a wire medium where the direction of the wires are at an angle with respect to the interface. In general the reflection problem is divided into two polarizations. For ordinary fields the reflection from the wire medium interface is like the reflection from any isotropic dielectric medium. For extraordinary fields, which is considered in this study, due to spatial dispersion there exist two transmitted eigenfields in the wire medium and the reflection is more complicated requiring additional boundary conditions.

15 Experimental observation of wave propagation in stacked split rings resonators layers and their complementary structure
Mariem Aznabet, Mario Sorolla. Universidad Pública de Navarra, Spain

We investigate experimentally the electromagnetic propagation behavior inside stacked SRR and CSRR layers. We found that the nature of propagation inside both structures has been interchanged. Furthermore, we show that the longitudinal lattice plays a key role in generating left-handed behavior in stacked CSRR layers.

Poster Session

16 Homogenization models for the analysis of reflection properties of mushroom structures
Olli Luukkonen, Constantin Simovski, Igor Nefedov, Sergei Tretyakov. TKK Helsinki University of Technology, Finland
Mário Silveirinha, University of Coimbra, Portugal
Alexander Yakovlev, University of Mississippi, USA

In this paper, two homogenization models are presented for the analysis of mushroom structures. The differences of these models rise from the different way of modeling the array of metallic vias connecting the metallic patches to the ground plane. It is shown that for electrically thin mushroom structures the results of these models concur with each other. Furthermore, it is shown in this paper that the use of metallic vias in mushroom structures results in additional resonances for the TM- polarized incident fields.

17 Applying mode basis method to investigate a homogeneous waveguide filled bi-isotropic medium with constant parameters
Vladimir Tuz, Bogdan Kochetov. Karazin Kharkov National University, Ukraine

In time-domain, the Mode Basis Method for a homogeneous waveguide arbitrary connectedness filled a biisotropic medium with constant parameters is constructed. On this base the dispersive relations of such waveguide are obtained as implicit polynomials of angular frequency and propagation constant.

18 Considerations for EBG loss in antenna applications
Zhiyuan Duan, D. Lyndon,W. Scanlon. Queen's University, United Kingdom

The EBG (Electromagnetic Band Gap) structure is frequently considered as a lossless surface when working with external radiators. In practice there will be loss in many applications. This paper examines EBG loss performance in antenna applications. Simulations are validated experimentally using a reverberation chamber with good agreement.

19 Investigating the permittivity of three-dimensional metal
Zhiyuan Duan, D. Lyndon,W. Scanlon. Queen's University, United Kingdom

One dimensional and two dimensional metamaterials have been widely reported in the past decade. In this paper, 3D metamaterials consisting of metal particles randomly distributed in the host dielectric are presented. As the relative amount of the metal and dielectric has a strong impact to material behaviour, we assign several typical volume filling ratios of the spherical particles to evaluate their effects. The two port waveguide simulator is employed to verify the real and imaginary part of the effective permittivity.

20 Surface wave transformation by metamaterials with imposed macro periodicity
Nataliya Yashina, Petr Melezhik, Anatoliy Poyedinchuk. Institute of Radiophysics and Electronics of National Academy of Sciences of Ukraine, Ukraine
Gerard Granet. Universite Blaise Pascal, France

The subject of the presentation is the interaction of electromagnetic waves with a surface of metamaterial with periodic roughness. The dimension of periodicity is of the scale of the wavelength of scattering waves; effective parameters of metamaterials are supposed to be frequency dispersive and already defined. On the base of rigorous method and relevant efficient numerical algorithm several interesting effects and regularities emerging in the process of electromagnetic waves interaction with a periodic surface of metamaterial have been studied; among them the resonant transformation of surface waves. Examples, interesting for applications have been found out.

21 Investigation of reflection coefficient from ferrite-semiconductor periodic structure
Oksana Shramkova. Institute of Radiophysics and Electronics of the NAS of Ukraine, Ukraine

Features of the electromagnetic wave propagation in a structure that was fabricated by a periodic alternating ferrite and semiconductor layers are investigated. It is assumed that the magnetic field is parallel to the layers. We calculate the dispersion characteristics of eigenwaves and the dependencies of reflection and transmission coefficients on structure parameters, angle of wave incidence and magnetic field.

22 Ferromagnetic resonance in biphase magnetic microwires
Giovanni Andrea Badini Confalonieri, Jacob Torrejon, Manuel Vazquez. Instituto de Ciencias de Materiales de Madrid CSIC), Spain

Ferromagnetic resonance behaviour of biphase magnetic microwires is here introduced. Such microwires consist of an inner nucleus, and intermediate insulating layer and an outer magnetic layer and are prepared by combined quenching and drawing technique with electrochemical deposition. The composition of each magnetic phase is chosen so that they exhibit soft and hard magnetic behavior, and consequently the magnetization reversal process measured at low-frequency conditions consists of two large irreversible processes ascribed to each phase. Magnetic behavior around the ferromagnetic resonance has been investigated in a network analyzer in the frequency range up to 10 GHz for a series of selected biphase wires with different magnetic behavior (particularly that of the soft phase). The appearance of two absorption peaks is observed in biphase wires, the second one due to the presence of the second harder phase or to the change of the external part of the soft phase.

23 Closed-form Green's function of a HED within multilayer double negative and double positive media
Golge Ogucu. University of Gaziantep, Turkey

The closed-form spatial-domain Green's function of a horizontal electric dipole placed within a planar, multilayer structure comprised of double negative and positive media is studied. The formulation is based on the discrete complex images method. The result for the Green's function of the scalar potential is presented.

Poster Session

24 Frequency Response of a Novel Split Ring Resonator Array with Equilateral Triangle Shape Printed on Polytetrafluoroethylene(PTFE)/Woven Fiberglass Substrate

Jose Everardo Julião Ferreira, Jose Edimar B. Oliveire, Luiz Alberto de Andrade. Instituto Tecnológico de Aeronáutica, Brazil

This publication addresses the frequency response of a novel split ring resonator which relies on an equilateral triangle shaped microstripline electromagnetic structure printed on polytetrafluroethylene(PTFE)/woven fiberglass substrate. The performance of the proposed structure was investigated based on the dependence of its scattering parameters frequency response with respect to both, the ring geometry and the substrate electric permittivity. Numerical simulations revealed that the triangle shaped ring exhibits the typical resonant behavior associated to standard ring configurations; hence the proposed configuration may be useful as metamaterials. The publication gives details with respect to an equilateral triangle shaped ring with Polytetrafluoroethylene (PTFE)/Woven Fiberglass Substrate, having resonant frequency around 8GHz.

25 Magnetochiral effect in crystals of different symmetry

Andrey Khyshov, M.A. Novikov. Institute for Physics of Microstructures RAS, Russia

The theoretical research of magnetochiral effect is carried out on the basis of a tensor perturbation technique in crystals of different symmetry at various configurations of an external magnetic field and propagation direction of light. Different mechanisms of appearance of this effect are revealed. Experiments on measurement of various contributions to magnetochirality are made in a number of crystals.

26 Experimental demonstration of sub-wavelength imaging with magnification by a tapered wire medium lens in microwave range

George Palikaras, Pavel Belov, Yan Zhao, Yang Hao. Queen Mary, University of London, United Kingdom

An experimental investigation of sub-wavelength imaging with magnification by a tapered wire medium slab is presented for the first time, to the best of our knowledge. The magnifying slab is implemented by radially enlarging the distance between adjacent wires, and the operational frequency is tuned to coincide with the Fabry-Pérot resonance condition. A complex-shaped near-field source is used in order to test the device's imaging performance. It is demonstrated that dense arrays of metallic wires can be utilized to transmit images with deeply subwavelength resolution at significant distances in terms of the wavelength (roughly 3) at microwave frequencies, and the pattern details are magnified by a factor of 3. The resolution of imaging device is 15 times less than the wavelength and is determined by the granularity of the artificial material, which can be as small as required by a particular application. Such near-field lenses find applications in near-field microscopy and in medical imaging.

27 Analysis of negative refraction from anomalous phase in transmission spectrum

Concita Sibilia, Antonio Mandatori, Mario Bertolotti. Universita di Roma La Sapienza, Italy
J.W. Haus. University of Dayton, USA

We analyze the negative refraction of a simple Fabry-Perot system as a function of the sign of material permittivity and permeability is analyzed. It is shown that negative refraction is possible every time the transmission phase of the system shows an anomalous behaviour. if the permittivity or the permeability are complex the anomalous phase is no univocally related to the presence of a negative refractive index.

28 Novel powerful simulation tool for wavelength-scale analysis of an oblique plane wave interaction with multilayer metamaterial

Hovik Baghdasaryan, State Engineering University of Armenia, Armenia
T. Knyazyan, State Engineering University of Armenia , Armenia
T. Baghdasaryan, Yerevan State University, Armenia

An extension of the method of single expression (MSE) for correct analysis of plane electromagnetic wave oblique incidence on a wavelength-scale multilayer structure consisting of metamaterial layers is performed. The term metamaterial here means continuous artificial medium with arbitrary signs and values of permittivity and permeability. Corresponding Helmholtz's equation, boundary conditions and the expression for power flow density in complex media are derived in the terms of the MSE for TE and TM electromagnetic waves.The advantage of the MSE in description of electromagnetic waves behaviour in a medium in the form of a single expression permits to reveal the identity of double negative (with simultaneously negative signs of permittivity and permeability) continuous medium with double positive one.

29 About focusing problems by modify Veselago lenses

Alexander Anyutin, Russian New University, Russia

We analyze the negative refraction of a simple Fabry-Perot system as a function of the sign of material permittivity and permeability is analyzed. It is shown that negative refraction is possible every time the transmission phase of the system shows an anomalous behaviour. if the permittivity or the permeability are complex the anomalous phase is no univocally related to the presence of a negative refractive index.

13:15 **Lunch**

Special Session Room Luneta

Plasmonics

Special session organized by Richard W. Ziolkowski, *ECE Dept, University of Arizona, USA*, and Gennady Shvets, *The University of Texas at Austin, USA*
Chair: Gennady Shvets, *The University of Texas at Austin, USA*

14:50 **Ultrafast and quantum nanoplasmonics. Keynote talk**
Mark Stockman, Georgia State University, USA

This talk introduces and reviews new ideas and recent progress in ultrafast and quantum nanoplasmonics. It includes a brief Introduction to the topic and forefront, focus areas based partially on original contributions. A nanoscale quantum generator of surface-plasmon fields, SPASER, is of the focus points. We concentrate on dynamic, controllable, ultrafast localization of optical energy on the nanoscale. These localization processes cause variety of enhanced and localized nonlinear phenomena on the nanoscale, in particular, the nonlinear photoelectron emission coherently controlled by the phases of the ultrashort excitation pulses. We discuss extreme nanoplasmonics where phenomena develop on the spatial scale of a few nanometers and temporal scale of hundreds attoseconds. This includes the recently introduced idea of the attosecond nanoplasmonic field microscope. Another recent idea is that of spatiotemporal coherent control, which is a plasmonic counterpart of the time-domain synthetic aperture radar (SAR) [also called active electronically-controlled synthetic aperture (AESA) radar or active phased array radar (APAR)]. We present both theory and available experimental data, and discuss various applications of nanoplasmonics.

15:30 **Active plasmonic components and metamaterials. Invited talk**
Harry A. Atwater, California Institute of Technology, USA

Dispersion control and active materials integration have yielded plasmonic components including i) threedimensional single layer plasmonic metamaterials ii) all-optical, electro-optic and field effect modulation of plasmon propagation iii) plasmon-enhanced absorption in solar cells.

15:50 **Two-photon raman spectroscopy using the help of plasmonics. Invited talk**
Janina Kneipp, Harvard University Medical School, USA
Harald Kneipp, Harvard University Medical School, USA
Katrin Kneipp, Harvard University Medical School, USA

This talk discusses surface-enhanced hyper Raman scattering performed in the vicinity of gold and silver nanostructures and shows first applications of this efficient incoherent two photon vibrational probe. The reported results demonstrate the capabilities of plasmonics approaches in spectroscopy.

16:10 **Plasmonic nanostructures: from metamaterials to devices. Invited talk**
Anatoly Zayats, The Queen's University of Belfast, United Kingdom

Plasmonic metamaterials based on metal-dielectric nanostructures exhibit unique optical properties and find numerous applications in such diverse areas as optical communications, chemo- and biosensing, high-density data storage and many others. Surface plasmon modes can be tailored to specific applications and requirements by changing structural and dielectric parameters of the nanostructure. Here we discuss the design principles, modelling, fabrication and applications of plasmonic nanostructures for achieving light guiding and optical information processing.

16:30 **Coffee break**

Regular Session Room Ciudadela 1

Miniaturization with metamaterials

Chair: Irina Vendik, *St. Petersburg Electrotechnical University, Russia*

14:50 **Optimal design synthesis of miniaturized metamaterials**
Pai-Yen Chen, National Nano Device Laboratories, Taiwan
Chien-Hsin Chen, National Nano Device Laboratories, Taiwan
Hao Wang, National Chiao Tung University, Taiwan
Jin-Hua Tsai, National Nano Device Laboratories, Taiwan
Wei-Xin Ni, Linköping University, Taiwan

In this work, we present a genetic algorithm (GA) for the optimal design synthesis of metamaterials whose structures are numerically created by the filling-element methodology. We first use a representative design example, metamaterials with permeability of negative unity, to investigate GA's optimum search ability. Then, we use GA to design miniaturized magnetic metamaterials. The results show that GA-optimized magnetic metamaterials can possess the minimum electrical size of 0/14.8. Finally, we show that our approach is also effective for the synthesis of functional magnetic and electric metamaterials with optimal structures.

15:10 **Numerical and experimental studies of resonators with reduced resonant frequencies and small electrical sizes**
Tong Hao, University of Oxford, United Kingdom
Jiwen Zhu, University of Oxford, United Kingdom
David Edwards, University of Oxford, United Kingdom
Christopher Stevens, University of Oxford, United Kingdom

Methods on reducing resonant frequencies and electrical sizes of resonators are reported in this paper. Theoretical and numerical analysis has been used and the results for the broadside-coupled resonators from both studies exhibit good agreement. Initial fabrication techniques are proposed and measurement results are compared with simulations. Further high resolution techniques have been envisaged to enhance the performance of the resonators. This class of small resonators with low resonant frequencies indicates a variety of applications in the design of microwave devices.

15:30 **Investigation of vertical spiral resonators for low frequency metamaterial design**
Jiwen Zhu, University of Oxford, United Kingdom
Tong Hao, University of Oxford, United Kingdom
Christopher Stevens, University of Oxford, United Kingdom
David Edwards, University of Oxford, United Kingdom

This paper thoroughly explores the characteristics of vertical spiral resonators (VSR). They exhibit relatively high Q factors and sizes around a few percent of the free space wavelength, which make them ideal candidates for assembling metamaterial devices. A quasistatic model of VSR is obtained from simple analytical expressions, and the effects of certain geometrical parameters on the resonant frequency are investigated.

15:50 **Subwavelength resonators as metamaterial particles**
Kamil Boratay Alici, Bilkent University, Turkey
Filiberto Bilotti, University of Roma Tre, Italy
Lucio Vegni, University of Roma Tre, Italy
Ekmel Ozbay, Bilkent University, Turkey

In this presentation, electrically small metallic elements on planar substrates that operate at the MHz and GHz region and their potential applications in terms of numerical and experimental results will be presented.

16:10 **Compact quadrature phase shifter based on complementary spiral resonators (CSRs)**
Gerard Sisó, CIMITEC - Universitat Autònoma de Barcelona, Spain
Marta Gil, CIMITEC - Universitat Autònoma de Barcelona, Spain
Manuel Aranda, CIMITEC - Universitat Autònoma de Barcelona, Spain
Jordi Bonache, CIMITEC - Universitat Autònoma de Barcelona, Spain
Ferran Martín, CIMITEC - Universitat Autònoma de Barcelona, Spain

In this work, a compact quadrature phase shifter based on metamaterial transmission lines implemented by means of complementary spiral resonators (CSRs) in microstrip technology has been designed, fabricated and measured. The reported metamaterial device presents a size reduction of 77% as compared to the conventional one.

16:30 **Coffee break**

Regular Session Room Ciudadela 2

Optical metamaterials I

Chair: *Harald Giessen, Universität Stuttgart, Germany*

14:50 **The dispersion relation in metamaterials - from thin film to bulk. Invited talk**
Falk Lederer, University of Jena, Germany
Carsten Rockstuhl, University of Jena, Germany
Christoph Menzel, University of Jena, Germany
Thomas Paul, University of Jena, Germany

We derive the dispersion relation of Bloch modes in a fish-net metamaterial in the optical frequency domain. The dependence of the longitudinal wave vector component on the transverse one and the frequency, which govern diffraction and dispersive spreading of localized light excitations, respectively, is analyzed.

15:10 **Electromagnetically induced transparency in optical metamaterials**
Na Liu, Msc, Germany

We demonstrate theoretically and experimentally electromagnetically induced transparency in asymmetric metamaterial molecules using magnetoinductive coupling. This leads to magnetoinductively induced transpar-ency, as well as to electroinductively induced reflectance for complimentary structures. We increase the coupling strength by joining two split rings together, demonstrating the transition from EIT to Autler-Townes splitting.

15:30 **Energy and lifetime of the electric and magnetic resonances of gold-nanosandwich metamaterials**
Yasin Ekinci, Swiss Federal Institute of Technology Zurich, Switzerland
Mario Agio, Swiss Federal Institute of Technology Zurich, Switzerland
Andre Christ, Swiss Federal Institute of Technology Lausanne, Switzerland
Olivier J. F. Martin, Swiss Federal Institute of Technology Lausanne, Switzerland
Harun H. Solak, Paul Scherrer Institute, Switzerland
Jörg F. Löffler, Swiss Federal Institute of Technology Lausanne, Switzerland

We present an experimental and theoretical study on the optical properties of arrays of gold nanoparticle in-tandem pairs (nanosandwiches). Well-ordered Au pairs with diameters down to 35 nm and separation distances down to 10 nm were fabricated using extreme ultraviolet (EUV) interference lithography. The strong near-field coupling of the nanoparticles leads to electric and magnetic resonances, which can be well reproduced by Finite-Difference Time-Domain (FDTD) calculations. The influence of the structural parameters, such as nanoparticle diameter and separation distance, on the hybridized modes is investigated.

15:50 **A chiral metamaterial based on two coupled split-ring resonators**
Hui Liu, Nanjing University, China
T. Q. Li, Nanjing University, China
T. Li, Nanjing University, China
S. M. Wang, Nanjing University, China
Z. H. Zhu, Nanjing University, China
C. J. Cao, Nanjing University, China
S. N. Zhu, Nanjing University, China

The transmission property of a chiral metamaterial based on magnetic dimers is studied experimentally. Strong hybridization effect of magnetic resonance is established in this system and this introduces optical activity around the resonance frequencies. This coupled magnetic dimer system constitutes a new kind of tunable optically active medium and devices.

16:10 **Towards isotropic optical magnetism without strong spatial dispersion**
Constantin Simovski, TKK, Finland
Sergei Tretyakov, TKK, Finland

The idea of isotropic resonant magnetism in the visible range of frequencies known from precedent publications is developed having in mind achievements of the modern chemistry. Plasmonic colloidal nanoparticles covering a silica core form a cluster with resonant and isotropic magnetic response. The electrostatic interaction of nanocolloids decreases the resonant frequency of an individual complex magnetic scatterer (nano-cluster) compared to the previously studied variant of a planar circular nanocluster with same size. This means a reduction of the optical size of nanoclusters that presumably allows one to avoid strong spatial dispersion within the frequency range of the negative permeability.

16:30 **Coffee break**

Special Session Room Luneta

Extraordinary transmission

Special session organized by Javier Garcia de Abajo, *Instituto de Optica - CSIC, Spain*
Chair: Javier Garcia de Abajo, *Instituto de Optica - CSIC, Spain*

16:50 **Extraordinary transmission through subwavelength apertures: fundamentals and future prospects. Keynote talk**
*Thomas Ebbesen, ISIS, University Louis Pasteur and CNRS, France*Fundamentals and Future Prospects. Keynote talk

An overview of the present understanding of the extraordinary optical transmission through subwavelength apertures will be presented. Applications in a variety of areas will be discussed together with future prospects.

17:30 **Microwave and optical enhanced transmission through metal plates perforated by subwavelength holes. Invited talk**
Vitaliy Lomakin, University of California, San Diego, USA
Eric Michielssen, University of Michigan, Ann Arbor, USA

Phenomena of enhanced transmission through metal plates perforated by arrays of subwavelength holes are studied. Under time harmonic plane wave excitations the transmission enhancement is attributed to the presence of source-free fields supported by the perforated plate. The source-free fields can exist due to several types of slow waves supported by the array. Under beam excitation, transmitted fields comprise geometric rays, leaky waves, and lateral waves. Under transient plane wave excitations, there exist direct fields, resonances, and diffraction fields with slow time decay.

17:50 **Hole shape dependence of nonlinear optics in hole arrays, a role for slow plasmons. Invited talk**
Laurens (Kobus) Kuipers, FOM-Institute AMOLF, Netherlands

Recently, we showed that a "hot" hole shape exist for second harmonic generation in periodic arrays of rectangular nanoholes. For a specific aspect ratio of the holes the effective nonlinear susceptibility of the arrays is increased by an order of magnitude. We will experimentally prove the hypothesis that the enhancement of the nonlinear susceptibility is related to slow propagation of the fundamental beam through the array at the "hot" aspect ratio.

18:10 **Enhanced transmission in anisotropic periodic aperture arrays. Invited talk**
Alexander Schuchinsky, Queen's University Belfast, UK, United Kingdom
D.E. Zelenchuk, Queen's University Belfast, UK, United Kingdom

The phenomenon of enhanced transmission in the periodic arrays containing multiple sub-wavelength apertures in conductor screens is discussed. The use of several dissimilar apertures in the array unit cell gives rise to both electric and magnetic type resonances whose frequencies are controlled by apertures' aspect ratio and position in the unit cell.

18:30 **Social afternoon**

18:45 **Panel session** (Room Luneta)
Theoretical issues and practical aspects of Metamaterial Characterisation

Regular Session Room Ciudadela 1

Homogenization and effective medium modelling

Chair: Mario Silveirinha, *Universidade de Coimbra, Portugal*

16:50 **Limiting responses of ENZ particles in composites. Invited talk**
Ari Sihvola, Helsinki University of Technology, Finland

In this presentation polarizabilities of simple-shaped particles are analyzed. The plasmonic details in the negative permittivity domain are connected with the positive-permittivity behavior. Particular geometries carry over the plasmonic response to ENZ (epsilon-near-zero) materials, which brings forth interesting perspectives for material design with extreme parameters.

17:10 **A critical examination of the issue of validity of the effective medium approach to characterizing metamaterials. Invited talk**
Raj Mittra, Pennsylvania State University, USA
Lai-Ching Ma, Pennsylvania State University, USA

In this paper we critically examine the characteristics of metamaterials predicted by the "effective medium" approach for novel applications, e.g., superlensing, directivity enhancement and cloaking. We show on the basis of rigorous simulations that the "effective medium" approach often fails to predict the behaviors of metamaterials correctly.

17:30 **An analytical algorithm for obtaining a physically sound solution to the mixing formulae for metamaterials. Invited talk**
Alexey Vinogradov, Institute for Theoretical and Applied Electromagnetics, Russia
A. V. Dorofeenko, Institute for Theoretical and Applied Electromagnetics, Russia
Said Zouhdi, Laboratoire de Génie Electrique de Paris, France

The analysis of mixing formulae for calculation of effective parameters of composite material, containing inclusions with negative permittivity, was carried out. The problems, appearing in use of the Garnett and Brugeman approaches are fixed. Algorithms, leading to physically sound solutions are developed. The problem of refractive coefficient for media with arbitrary values of permittivity and permeability is discussed.

17:50 **Homogenization models for the analysis of surface waves on mushroom structures**
Alexander B. Yakovlev, University of Mississippi, USA
M.G. Silveirinha, University of Coimbra, Portugal
O. Luukkonen, Helsinki University of Technology, Finland
C.R. Simovski, Helsinki University of Technology, Finland
I.S. Nefedov, University of Coimbra, Finland
S.A. Tretyakov, Helsinki University of Technology, Finland

In this paper, homogenization models are proposed for the characterization of the spectrum of natural modes on dense mushroom high-impedance surface (HIS) structures. It is shown that mushroom structures below the plasma frequency support proper (bound) forward and backward modes, associated with the stopband properties of surface-wave propagation, and proper complex backward modes related to the backward radiation. Results obtained by different homogenization models are compared leading to important conclusions.

18:10 **About transport of energy, linear momentum and mass for electromagnetic waves in negative refraction media. Invited talk**
Victor Veselago, A.M. Prokhorov Institute of General Physics, Russia

The question on the forces acting on the media from electromagnetic radiation in the form of a flat wave is considered. The special attention is given to a case of media with negative index of refraction. It is shown that light pressure, characteristic for a wave in vacuum, in this case should be replaced with a light attraction. The general formula for change of mass of a radiator is discussed, for the case of emission of radiation on media with index of refraction distinct from unit.

18:30 **Social afternoon**

18:45 **Panel session** (Room Luneta)
Theoretical issues and practical aspects of Metamaterial Characterisation

Regular Session Room Ciudadela 2

Perfect lenses and imaging

Chair: Constantin Simovski, *TKK, Finland*

16:50 **New propagation effects in semiconductors in the UV range: inhibition of absorption, negative refraction, anomalous momentum states, and sub-wavelength imaging. Invited talk**
Michael Scalora, Charles M. Bowden Research Center, USA
V. Roppo, Universitat Politecnica de Catalunya, Spain
John V. Foreman, Duke University, USA
M. Centini, University of Rome La Sapienza, Italy
M.A. Vincenti, Politecnico di Bari, Italy
Neset Akozbek, Charles M. Bowden Research Center, USA
M.J. Bloemer, Charles M. Bowden Research Center, USA

We discuss novel propagation effects that occur in bulk semiconductors at frequencies above the absorption edge. These effects include the inhibition of linear absorption using phase-locked harmonic pulses, negative refraction, anomalous momentum states predicted in negative-index materials, and sub-wavelength imaging. These phenomena may help pave the way to new practical uses of semiconductors, in regimes that are currently thought to be uninteresting and mostly inaccessible.

17:10 **Mixing formula predictions for a composite near-field superlens**
Henrik Wallén, Helsinki University of Technology, Finland
Henrik Kettunen, Helsinki University of Technology, Finland
Ari Sihvola, Helsinki University of Technology, Finland

Different mixing rules can predict very different results for negative permittivity composites. In this presentation we compare classical mixing rules and quasistatic numerical simulations for a mixture with spherical holes in silver, with the aim to predict the effective material parameters for a composite near-field superlens.

17:30 **Influence of the losses on the super-resolution performances of an impedance matched negative index material**
Giuseppe D'Aguanno, Charles M. Bowden Research Center, USA
Nadia Mattiucci, Charles M. Bowden Research Center, USA
Mark Bloemer, Charles M. Bowden Research Center, USA

We discuss by a Poynting vector analysis how the losses of a negative index material (NIM) affect the resolution performances of a Veselago-Pendry lens and we analyze those performances in the framework of the Abbe crite-rion. Both the limit of high losses and low losses are explored. We find that the impedance matched NIM is able to resolve 30% better than the limit imposed by the Abbe criterion even when the imaginary part of the refractive index (the material losses) exceeds the absolute value of the real part of the refractive index. The NIM is de-scribed by a lossy Drude model with equal permittivity and permeability. By increasing the damping parameter of the Drude model we also explore the regime where both permittivity and permeability are positive and point out the conditions under which the metamaterial is still able to super-resolve.

17:50 **Negative refraction and sub-wavelength resolution below the diffraction limit using a semiconductor based superlens**
Maria Antonietta Vincenti, Politecnico di Bari, Italy
V. Roppo, Universitat Politecnica de Catalunya, Spain
A. D'Orazio, Politecnico di Bari, Italy
Nezet Akozbek, Charles M. Bowden Research Center, USA
M. Scalora, Charles M. Bowden Research Center, USA
M.J. Bloemer, Charles M. Bowden Research Center, USA

In this paper we describe a new way to achieve negative refraction and sub-wavelength resolution using semiconductors like GaAs or GaP. The exploitation of this basic property of semiconductors raises the possibility of new, yet-untapped potential and new applications in the UV and soft x-ray ranges.

18:10 **Optical vortices during a super-resolution process in a metamaterial**
Giuseppe D'Aguanno, Charles M. Bowden Research Center, USA
Nadia Mattiucci, Charles M. Bowden Research Center, USA
Mark Bloemer, Charles M. Bowden Research Center, USA
Anton Desyatnikov, Australian National University, Australia

We show that a super-resolution process with 100% visibility is characterized by the formation of a point of phase singularity in free space outside the metamaterial in the form of a saddle. The saddle point is connected to two vortices at the end boundary of the lens, and the two vortices are in turn connected to another saddle point inside the lens. The structure saddle-vortices-saddle is topologically stable. The formation of the saddle point in free space explains also the negative flux of energy present in a certain region of space outside the lens. The circulation strength of the power flow can be controlled by varying the position of the object plane with respect to the lens.

18:30 **Social afternoon**

18:45 **Panel session** (Room Luneta)
Theoretical issues and practical aspects of Metamaterial Characterisation

Special Session Room Luneta

Planar Metamaterials I

Special session organized by Ferran Martín, *Departament d'Enginyeria Electrònica, Universitat Autònoma de Barcelona, Spain*
Chair: Ferran Martín, *Departament d'Enginyeria Electrònica, Universitat Autònoma de Barcelona, Spain*

08:20 **Transmission-line metamaterial lenses and metascreens for free-space superlensing . Keynote talk**
George Eleftheriades, University of Toronto/ECE Department, Canada
Ashwin Iyer, University of Toronto/ECE Department, Canada
Alex Wong, University of Toronto/ECE Department, Canada

We review our recent activities on sub-wavelength focusing in free space. Two approaches are described. The first one is based on a negative-refractive-index transmission-line (NRI-TL) Veselago-Pendry lens which is fabricated using a layer-by-layer planar approach, without any vertical elements (e.g. vias). Due to the transmission-line approach used, this quarter-wavelength thick superlens features low insertion loss which enables 3 times better resolution than the diffraction limit. The second approach is based on the novel concept of the metascreen which comprises a planar metallic screen with an array of sub-wavelength spaced unequal slots. This latter approach is not sensitive to material losses. In both cases experimental results are presented.

09:00 **Design method for artificial lumped-element dual-passband filter by using compensation technology. Invited talk**
Min-Sou Wu, National Taipei University of Technology, Taiwan
Shau-Gang Mao, National Taipei University of Technology, Taiwan

This study introduces an analytical design method to synthesize dual-passband filter with the corresponding equivalent circuit. The design method utilizes the phase and impedance compensations technology to improve the frequency response within two passbands. The element values in the dual-passband equivalent circuit are dis-cussed to validate the reliability of the filter construction. The calculated results agree well with the measured data and thus verify the proposed design method. The dual-passband filter realized by the artificial lumped-element coplanar waveguide stub provides the advantages of compact size, DC elimination, and deep suppression between two passbands.

09:20 **A novel composite right/left-handed unit cell based on a lattice topology: theory and applications. Invited talk**
Frédéric Bongard, Ecole Polytechnique Fédérale de Lausanne, Switzerland
Julien Perruisseau-Carrier, Centre Tecnològic de Telecomunicacions de Catalunya, Spain
Juan R. Mosig, Ecole Polytechnique Fédérale de Lausanne, Switzerland

This paper presents recent work on a novel topology of composite right/left-handed transmission line (CRLH TL) based on the so-called lattice unit cell. This novel CRLH TL may exhibit an all-pass behaviour and a frequency-independent characteristic impedance. Potential improvements of well-known CRLH TL applications obtained by using the new proposed unit cell are discussed.

09:40 **Design of archimedean spiral resonators and bandwidth enhancement in filter applications invited talk**
Ozgur Isik, Macquarie University, Australia
Karu Esselle, Macquarie University , Australia

This paper focuses on Archimedean spiral resonators. An equivalent circuit model is derived for a preliminary design of monofilar Archimedean spiral resonators. The circuit parameters and resonance frequency are directly predicted by the geometry of the spiral. Numerical simulation results show that the predicted resonance frequency is accurate enough. Using a complementary bifilar spiral, a microstrip filter is built. The electric mode and magnetic mode resonances of the bifilar spiral are tuned to obtain a 6-fold increase in filter bandwidth.

10:00 **Coffee break**

Regular Session Room Ciudadela 1

Chiral and bianisotropic metamaterials

Chair: Ari Sihvola, *Helsinki University of Technology, Finland*

08:20 **Quantifying Chirality of Metamaterials**
Christoph Menzel, Friedrich Schiller University Jena, Germany
Carsten Rockstuhl, Friedrich Schiller University Jena, Germany
Thomas Paul, Friedrich Schiller University Jena, Germany
Falk Lederer, Friedrich Schiller University Jena, Germany

In an effort to stretch the concept of effective properties of metamaterials beyond permittivity/permeability and index/impedance, we introduce and compare here two approaches for retrieving quantitatively the effective chirality of metamaterials. The retrieval employs either the reflected and transmitted amplitude of a plane wave illuminating a finite slab or the dispersion relation of the pertinent Bloch modes in an infinite metamaterial. Both approaches are applied to characterize exemplarily a metallic gammadion deposited on a dielectric film and will show equal results if the metamatrial slab is sufficiently thick. The work emphasizes that chirality of metamate-rials exceeds by far that of natural materials and the has to be regarded as a bulk property.

08:40 **New insights into anisotropy and bianisotropy using geometric algebra**
Sérgio Matos, Instituto Superior Técnico, Lisboa, Portugal
João Canto, Instituto de Telecomunicações, and Department of Electrical and Computer Engineering, Portugal
Carlos Paiva, Instituto de Telecomunicações, and Department of Electrical and Computer Engineering, Portugal
Afonso Barbosa, Instituto de Telecomunicações, and Department of Electrical and Computer Engineering, Portugal

Plane wave propagation in bianisotropic media has been addressed in the literature through several mathematical formalisms. Recently, using geometric algebra, the authors have used two different approaches to this problem: (i) a general analytical framework for reciprocal bianisotropic media; (ii) a new geometrical perspective for reciprocal anisotropic media. In fact, although anisotropy is a particular case of bianisotropy, anisotropy has special geometric characteristics that are well worth a specific approach: by considering aligned electric and magnetic anisotropies (i.e., when the eigenvectors of the permittivity and permeability functions are the same) we have introduced a new classification scheme for anisotropic media. In this communication we will show how our general analytical framework for bianisotropy, which explores the new algebraic techniques brought up by geometric algebra, interplays with the geometric insights provided by our specific approach to anisotropy. In fact, by studying a general anisotropic medium using the two aforementioned approaches, the general analysis of bianisotropic media reveals new geometrical insights within the context of anisotropy.

09:00 **Miniaturised double periodic arrays exhibiting strong bianisotropy**
Carolina Mateo-Segura, Heriot-Watt University, United Kingdom
George Goussetis, Heriot-Watt University, United Kingdom

The strong electric to magnetic field coupling is demonstrated for perturbed periodic arrays of metal strips. Simi-lar effect is shown to occur in miniaturised designs. Full wave simulated results is presented and a miniaturised design reducing dimensions by a factor of $\mu/5$ is obtained.

09:20 **Dispersion and losses at air-dng and air-chiral interfaces**
João Canto, Instituto Superior Técnico, Lisboa, Portugal
Sérgio Matos, Instituto Superior Técnico, Lisboa, Portugal
Carlos Paiva, Instituto Superior Técnico, Lisboa, Portugal
Alfonso Barbosa, Instituto Superior Técnico, Lisboa, Portugal

When modeling metamaterials with negative parameters both dispersion and losses should be taken into account to uphold causality. In this communication we show that this is inescapable even when structures as simple as planar interfaces (either between air and a DNG medium or between air and a chiral medium) are addressed. We show that, only using a causal dispersion model, can we obtain results with reasonable physical behavior, thereby overcoming the strange results displayed by surface modes in the lossless dispersive case.

09:40 **DNA-like metamaterials: observation of polarization selectivity of electromagnetic properties**
Alexei Balmakov, Gomel State University, Belarus
Igor Semchenko, Gomel State University, Belarus

In the given work the phenomenon of interaction of the circularly-polarized waves of the microwave range with the DNA-like spiral structure is considered by a principle of electrodynamic similarity. The effect of polarization selectivity at interaction of right-handed double spirals with the electromagnetic radiation of left-circularly polarized waves is experimentally confirmed. The linearly polarized waves reflected from the flat sample, consisting of the right-handed double spirals, and turned into the left-circular polarization waves, which incident on the identical sample. Thus, the double reflection of waves from the identical samples of spirals was investigated. When the DNA-like right-handed spirals interacted with the electromagnetic waves, reflected by mirror-symmetrical left-handed spirals, the reduction of resultant waves and the polarizing selectivity has not observed.

10:00 **Coffee break**

Regular Session Room Ciudadela 2

Optical metamaterials II

Chair: Stefan Maier, *Imperial College, United Kingdom*

08:20 **Enhanced optical activity of on-waveguide planar chiral photonic crystals**
Kuniaki Konishi, Univ. of Tokyo, Japan
Benfeng Bai, University of Joensuu, Finland
Xiangfeng Meng, University of Joensuu, Finland
Petri Karvinen, University of Joensuu, Finland
Jari Turunen, University of Joensuu, Finland
Yuri Svirko, University of Joensuu, Finland
Makoto Kuwata-Gonokami, Univ. of Tokyo, Japan

We demonstrate that optical activity for the zeroth-order transmitted light in planar all-dielectric on-waveguide photonic crystals without in-plane mirror symmetry is enhanced by waveguide and Fabry-Pérot resonances and leads to a rotation of more than 25 degrees.

08:40 **Metallic meanders: an optimal design for visible negative index metamaterials**
Liwei Fu, 4th Physics Institute, University of Stuttgart, Germany
H. Schweizer, University of Stuttgart, Germany
H. Graebeldinger, University of Stuttgart, Germany
H. Guo, University of Stuttgart, Germany
N. Liu, University of Stuttgart, Germany
H. Giessen, University of Stuttgart, Germany

We report on a metallic meander structure which possesses a negative permeability with both a large amplitude and a large bandwidth down to blue wavelengths. With proper geometry parameters, low loss negative indices at visible wavelengths can be achieved in these metallic meanders. The structure is investigated in conjunction with a transmission line equivalent circuit model. The relationships between the circuit parameters and structure dimensions are studied and interpreted by quasi-static and radiative models. Experimental results are also presented.

09:00 **Optical properties of metal nanowire composites**
Ortwin Hess, Advanced Technology Institute and Department of Physics University of Surrey, United Kingdom
James H. Cook, Advanced Technology Institute and Department of Physics University of Surrey, United Kingdom
Kosmas L. Tsakmakidis, Advanced Technology Institute and Department of Physics University of Surrey, United Kingdom

We present results of a detailed theoretical study into the optical properties of tightly-coupled silver nanowires embedded in a glass matrix. Transmission and reflection spectra obtained on the basis of an adaptive finite-element numerical simulation algorithm reveal the possibility of obtaining broadband nearly perfect transmission, with vanishing reflection and absorption, by suitable geometrical arrangement of the nanowire elements. We discuss the influence of positional disorder present in the nanomaterial on this broadband transmission and the effect of varying the spacing and radius of the wires.

09:20 **Extraction of material parameters of multilayered nano-fishnet metamaterials from reflection and transmission coefficients**
Elizaveta Yankovskaya, SPb SU ITMO, Russia
Pavel Belov, Queen Mary University of London, United Kingdom
Constantin Simovski, Helsinki University of Technology, Finland

The full-wave numerical simulations of plane-wave excitation of the multilayered nano-fishnets are performed using the commercial software package CST MicroWave Studio. The reflection and transmission coefficients are calculated and the material parameters are extracted from the obtained data. The frequency dependencies of the effective permeability, the effective permittivity and the figure of merit were analyzed. The behavior of extracted material parameters of multilayered nano-fishnets depending on the number of single-fishnet-blocks and the thickness of air between the blocks is studied.

09:40 **Modelling the optical response of nanoparticles**
Viktor Myroshnychenko, Instituto de Optica (CSIC), Spain
Jessica Rodríguez-Fernandez, Departamento de Quimica Fisica and Unidad Asociada CSIC, Spain
Enrique Carbó-Argibay, Departamento de Quimica Fisica and Unidad Asociada CSIC, Spain
Isabel Pastoriza-Santos, Departamento de Quimica Fisica and Unidad Asociada CSIC, Spain
Jorge Pérez-Juste, Departamento de Quimica Fisica and Unidad Asociada CSIC, Spain
Luis Liz-Marzán, Departamento de Quimica Fisica and Unidad Asociada CSIC, Spain
Javier García de Abajo, Instituto de Optica (CSIC), Spain

The optical response of some highly anisotropic nanoparticles is modelled using a full 3D boundary element method. Their optical spectra exhibit a complex evolution and involve the presence of surface plasmon modes characterized by spectrally selective absorption. Excellent agreement between numerical calculations and experimental spectra is obtained.

10:00 **Coffee break**

Special Session Room Luneta

Planar Metamaterials II

Special session organized by Silvio Hrabar, *University of Zagreb, Croatia*
Chair: Silvio Hrabar, *University of Zagreb, Croatia*

10:20 **Selected applications of planar metamaterial transmission lines. Keynote talk**
Christian Damm, Technische Universität Darmstadt, Germany
Matthias Maasch, Technische Universität Darmstadt, Germany
Martin Schüßler, Technische Universität Darmstadt, Germany
Rolf Jakoby, Technische Universität Darmstadt, Germany

In this presentation we will give a summary of our work concerning the matching capabilities of artificial lines used as transmission line transformer. Basic theory will be given together with simulations and measurements of exemplary prototypes, and evaluation of theoretic matching bandwidth.

11:00 **Numerical and experimental investigation of homogenization of SRR-loaded rectangular waveguide. Invited talk**
Silvio Hrabar, University of Zagreb, Croatia
Davor Zaluski, University of Zagreb, Croatia

One of proposed interpretations of phenomenon of backward-wave propagation below the cut-off in SRR-loaded waveguide deals with the propagation in equivalent anisotropic Mu-Negative (MNG) metamaterial. Here, the correctness of this interpretation was tested by homogenization of numerically calculated in-cell distribution of the magnetic field as well as by the measurements on the experimental waveguide.

11:20 **Tunable and reconfigurable microwave devices based on metamaterial transmission lines. Invited talk**
Dmitry Kholodnyak, St. Petersburg Electrotechnical University, Russia
Polina Kapitanova, St. Petersburg Electrotechnical University, Russia
Irina Vendik, St. Petersburg Electrotechnical Universit, Russia

Metamaterial transmission lines with tunable capacitors allow designing novel tunable and reconfigurable microwave devices. This paper presents a design of tunable dual-band filter with a possibility to tune the lower pass band only or both pass bands simultaneously by tuning capacitors of the left-handed and right-handed artificial transmission lines. Design of a reconfigurable Wilkinson power divider providing either 0° or 180° phase difference between the output signals is also discussed.

11:40 **SRR- and CSRR-loaded metamaterial transmission lines: a comparison to the light of duality. Invited talk**
Ferran Martín, Universitat Autònoma de Barcelona, Spain
Francisco Aznar, Universitat Autònoma de Barcelona, Spain
Marta Gil, Universitat Autònoma de Barcelona, Spain
Jordi Bonache, Universitat Autònoma de Barcelona, Spain

In this paper, the main relevant characteristics of split ring resonator (SRR) and complementary split ring resonator (CSRR) loaded metamaterial transmission lines are pointed out and compared. To obtain a left handed pass band, the SRR-loaded lines (typically implemented in CPW technology) are also loaded with shunt con-nected strips (acting as shunt inductances). In CSRR-based left handed lines, the additional reactive element is a series gap (series capacitor). It is shown that the typical transmission zero frequency of these structures varies in a similar form (decreases) when the series gap and the shunt strip are widened (for the CSRR- and SRR-based lines, respectively). However, it has been found that the zero-phase shift frequency, that is, the frequency where the phase shift of the unit cell is null, does not depend on the geometry of the series gap or shunt strip. This simi-lar behaviour is interpreted to the light of the improved circuit models of the considered metamaterial transmis-sion lines (recently reported by the authors), and duality arguments. Although the compared metamaterial trans-mission lines are not exactly electromagnetic dual structures, their models are formally circuit duals

Regular Session Room Ciudadela 1

Cloaking

Chair: Andrea Alu, *University of Pennsylvania, USA*

10:20 **A homogenization route for control of transverse electric fields. Invited talk**
Stefan Enoch, CNRS, Institut Fresnel, France
Mohamed Farhat, CNRS, Insitut Fresnel, France
Sebastien Guenneau, University of Liverpool, UK
Alexander B. Movchan, University of Liverpool, UK

We analyze cloaking of transverse electric (TE) fields through homogenization of radially symmetric me-tallic structures. The two-dimensional circular cloak consists of concentric layers cut into a large number of small infinitely conducting sectors which is equivalent to a highly anisotropic permittivity. We find that a wave radiated by a magnetic line current source located a couple of wavelengths away from the cloak is almost unper-turbed in magnitude but not in phase.

10:40 **A radial-dependent dispersive FDTD method for modeling. Invited talk**
Yang Hao, Queen Mary College, University of London, United Kingdom
Christos Argyropoulos, Queen Mary College, University of London, United Kingdom
Yan Zhao, Queen Mary College, University of London, United Kingdom

A radial-dependent dispersive finite-difference time-domain (FDTD) method is developed to model metamaterials based on coordinate transformation. Such artificial materials have been applied in developing electromagnetic cloaking devices, plane wave concentrators and wave polarization rotators. By using the time-domain numerical technique, we shall be able to evaluate the transient response and operational bandwidth of the proposed metamaterials. It is demonstrated, for example, that the perfect "invisibility" from electromagnetic cloaks is only available for lossless metamaterials and within an extremely narrow frequency band.

11:00 **Broadband microwave cloaking with periodic networks of transmission lines**
Pekka Alitalo, TKK Helsinki University of Technology, Finland
Sergei Tretyakov, TKK Helsinki University of Technology, Finland

In this paper we present the design and full-wave simulations of two cylindrical cloaks based on the use of free-space-matched transmission-line networks. Because of the simple structure (no resonant inclusions, no strong dispersion), these types of cloaks offer very wide bandwidths as compared to other available cloaking techniques.

11:20 **Cloaking effect of an almost perfect lens**
Henrik Kettunen, Helsinki University of Technology, Finland
Antti Karilainen, Helsinki University of Technology, Finland
Sergei Tretyakov, Helsinki University of Technology, Finland
Henrik Wallén, Helsinki University of Technology, Finland
Ari Sihvola, Helsinki University of Technology, Finland

In this presentation we show numerical results of a cloaking effect achieved with a lossy near-perfect lens and a grid of electrically polarizable cylinders. The effect is based on resonant surface modes excited on the surface of the lens.

11:40 **Performance of non-ideal cloaks**
Ilya Shadrivov, Nonlinear Physics Centre, Australian National University, Australia
Nina Zharova, Institute of Applied Physics, Russian Academy of Sciences, Russia
Alexander Zharov, Institute for Physics of Microstructures, Russian Academy of Sciences, Russia
Yuri Kivshar, Nonlinear Physice Centre, Australian National University, Australia

We demonstrate analytic spatial transformation of the electromagnetic fields for arbitrary invisibility cloaks. We study the efficiency of nonideal electromagnetic cloaks and discuss the effect of scattering losses on the cloak invisibility.

Regular Session Room Ciudadela 2

Novel structures and applications II

Chair: Vasundara Varadan, *University fo Arkasnas, USA*

10:20 **Taming spatial dispersion in the wire-mesh metamaterial**
Angela Demetriadou, Imperial College of London, United Kingdom
John Pendry, Imperial College of London, United Kingdom

The wire-mesh metamaterial is an artificial plasma, with negative electric behaviour in the GHz frequency range. However, spatial dispersion spoils the simple local plasma model. In this paper, new wire structures are proposed, that manage to eliminate spatial dispersion and restore the simple local model.

10:40 **Electrodynamical theory of carbon nanotubes based metamaterials for terahertz, infrared and optical regimes**
Gregory Slepyan, Institute for nuclear problems, Belarus State University, Belarus
Sergey Maksimenko, Institute for nuclear problems, Belarus State University, Belarus
Michail Shuba, Institute for nuclear problems, Belarus State University, Belarus
Andrei Nemilentsau, Institute for nuclear problems, Belarus State University, Belarus

An electrodynamical theory of the metamaterial based on the different types of carbon nanotubes (CNTs) has been presented. The theory covers a wide frequency range from terahertz to optical frequencies. As a result, a number of general properties of CNT-based metamaterials have been revealed. These properties are very promising for potential applications of CNT-based metamaterials in nanoelectronics.

11:00 **Beam splitter based on wire media**
Igor Nefedov, Department of Radio Science and Engineering, Helsinki University of Technology, Finland
Jose Luís Martínez de Falcón, Universidad Pública de Navarra, Spain
Sergei Tretyakov, Department of Radio Science and Engineering, Helsinki University of Technology, Finland

In this paper we introduce a microwave beam splitter based on wire media. TEM modes are excited by an external source in a double wire medium which splits into two channels where the energy is transferred by the TEM modes. Numerical simulations illustrate excitation of the splitter by a plane wave and by a dipole.

11:20 **Eigenmodes analysis in collimating wire medium**
Xavier Radu, Université catholique de Louvain, Belgium
Christophe Craeye, Université catholique de Louvain, Belgium

The wire medium is capable of transporting evanescent waves via their transformation into propagating waves inside the medium. It has important advantages: a resolution that can be made as fine as wanted by considering very small spacings between elements and a very wide bandwidth. However, it should be noted that anomalous behavior may disrupt that bandwidth. This paper is related to the analysis of the anomalies with the help of the periodic method of moments.

11:40 **Effective medium approximations for electromagnetic compatibility analysis of integrated circuits**
Sonia Holik, University of Glasgow, United Kingdom
Timothy Drysdale, University of Glasgow, United Kingdom

Effective medium approximations are successfully used to homogenise integrated circuit wiring. In this way, the minimum reflectivity of a chip can be rapidly calculated, aiding electromagnetic compatibility analyses. Our approach has the potential to aid the calculation of interconnect equivalent circuit parameters, an otherwise extremely computationally demanding task.

Poster Session Ciudadela Corridor (12:00 -13:15)

1 Coupled surface states in one- and two-dimensional frequency dependent photonic crystals
Michael Bergmair, U. Dobramysl, K. Hinger. Johannes Kepler University Linz, Austria
I. Bergmair. Christian Doppler Labor and Profactor GmbH, Austria

We investigate one dimensional photonic crystals in the visible spectral region for propagation parallel to the layers. These modes are extending over some adjacent layers and it turns out, that the dispersion can be tailored by coupling surface plasmons of adjacent layers.

2 The polarization properties of thin anisotropic diffraction gratings
Gegham Zakharyan, R. S. Hakobyan, A.M. Galstyan. Yerevan State University, Armenia

The polarization properties of thin anisotropic diffraction gratings are studied theoretically. The theoretical description of polarization properties based on couple wave theory for thin gratings. The dependences of diffraction efficiency on polarization of incident beam investigated for different diffraction orders. The polarization state of diffracted beam also is studied.

3 Optical forces in metallic nanoparticles induced by fast electron beams
Alejandro Reyes-Coronado, Olalla Pérez, Nerea Zabala, Javier Aizpurua. Donostia International Physics Center, Spain

We study the optical forces induced by fast electron beams on a system of two gold nanoparticles. We calculate the electromagnetic fields induced by the electron beam taking into account retardation effects, and analyse the induced forces between the nanoparticles. The optical forces obtained are in the range of piconewtons.

4 Elliptical dichroism in planar chiral metamaterials
Sergei Zhukovsky. Institute of Physics, University of Bonn, Germany
Vladimir Galynsky, Andrey Novitsky. Department of Theoretical Physics, Belarusian State University, Belarus

We show that elliptically dichroic bulk media possess the optical properties of planar chiral metamaterials (PCMs), namely, co-rotating elliptical polarization eigenstates and asymmetric transmission for left/right-handed circularly polarized incident wave. The proposed model reveals the physics of PCMs apart from the effects of a specific structure design.

5 Plasmon-induced spontaneous magnetization of metallic nanoparticle pair in strong optical fields
Roman Noskov, Alexander Zharov. Institute for Physics of Microstructures, RAS, Russia
Maxim Tsarev. Nizhny Novgorod State University, Russia

We study the resonant nonlinear optical response of a metallic nanoparticle pair emerging because of a nonlinearity of individual nanoparticles. We derive the coupled equations for describing the interaction of nanoparticles, and find an instability of some nonlinear stationary states which leads to spontaneous symmetry breaking in the system. We show, in particular, that a noble-metal nanoparticle pair can possess the non-zero magnetic moment in the absence of the external magnetic field that potentially makes possible to create a novel class of optical metamaterials with nonlinear magnetic response depending on external electric field.

6 Fabrication of well-ordered metallic nanostructures using self-assembled polystyrene masks
Anna Ushanova, Harri Lipsanen. Helsinki University of Technology, Finland

In this paper we have described a practical method of low-cost fabricating the array of metallic nanoparticles and nanoholes by using self-assembled polystyrene masks and reactive ion etching. The method allows control over structural features of the metallic nanoparticles, including the lateral size, height and period.

7 Applying bio-molecule micro-contact printing to fabricate patterned gold nanoparticles
Yin-Cin Luo, Chei-Kwei Chang, Pai-Yen Chen. National Nano Device Laboratories, Taiwan
Chi-Hong Lin, Department of Biophotonic, National Yam-Ming University, Taiwan

In this work, a bio-molecule micro-contact printing (Bio-μCP) technique is proposed to fabricate periodical Au nanostructures on the glass substrate. The preliminary results are characterized by the atomic force microscope (AFM) and metallic patterns consisted of dense Au nanoparticles are observed. This technique provides the possibility and applicability of using Bio-μCP to massively produce patterned bio-molecule and metallic nanostructures for plasmonic device applications.

8 Resonant photon tunneling via surface plasmon polaritons through one-dimensional metal-dielectric metamaterials
Satoshi Tomita, Takashi Yokoyama, Hisao Yanagi. Nara Institute of Science and Technology, Japan
Ben Wood, John Pendry. Imperial College London, UK
Minoru Fujii, Shinji Hayashi. Kobe University, Japan

We have experimentally and numerically studied resonant photon tunneling (RPT) via surface plasmon polaritons through one-dimensional metamaterials consisting of alternating layers of Al and dielectric. We show that the RPT indeed permits evanescent light waves with large wavenumbers to be conveyed through the metamaterial. Furthermore, a shift of the RPT peak from the reflectance dip is observed.

9 Plasmonic enhancement of the optical-to-terahertz conversion on the surface of a nonlinear material with metallic nanoinclusions
Rostislav Mikhaylovskiy, Michael Bakunov. University of Nizhny Novgorod, Russia

We propose a way to increase the efficiency of the nonlinear optical rectification via using a composite material containing metallic nanoinclusions embedded in an electro-optic matrix. We show theoretically that the plasmonic enhancement of the optical field on the nanoparticles can increase significantly the effective nonlinear susceptibility of the composite medium and, thus, magnify the efficiency of the optical rectification. In particular, optical-to-terahertz conversion of a Ti:sapphire laser pulse on the surface of GaAs with inclusions of silver nanoparticles is considered. The generated waveform and frequency-angular distribution of the terahertz energy emitted from the surface of GaAs/Ag-composite are calculated. It is shown that inclusion of nanoparticles can provide an order of magnitude increase in the terahertz yield.

Poster Session

10 Near-field-light lens for nanofocusing of atoms
Haruhiko Ito, Mineto Sato, Takuya Sato., Tokyo Institute of Technology, Japan

We describe a near-field-light device used for concentration of neutral cold atoms with a resonant dipole force. The possibility of nanofocusing is discussed based on numerical analyses. The process correspond to squeezing of de-Broglie waves.

11 Extraordinary Transmission Through 2D Periodic Arrays of Rec-tangular Subwavelength Holes with Different Shape
Yu-Wei Jiang, L. D. Tzuang, Ming-Wei Tsai, Yi-Han Ye, Yi-Ting Wu, Chia-Yi Chen, Si-Chen Lee, National Taiwan University, Taiwan

The influence of the aspect ratio of rectangular holes on extraordinary transmission of periodic arrays of subwavelength holes was investigated. When the aspect ratio increased to infinity, the two dimensional hole array transformed to one dimensional gratings. The transmission peak position and shape were found to depend on the aspect ratio of holes. From the energy dispersion relation, the localized resonance modes appeared when the aspect ratio of holes increased to beyond 7. The condition for transition from propagating surface plasmon to localized mode was discovered.

12 Assessment of zero-average index band-gap limits in quasiperiodic metamaterial multilayers
Juan A. Monsoriu. Universidad Politécnica de Valencia, Spain
R. A. Depine, M. L. Martínez-Ricci. Universidad de Buenos Aires, Argentina
E. Silvestre, P. Andrés. Universidad de Valencia, Spain

We examine quasiperiodic multilayers arranged according to the Fibonacci sequence that combine ordinary positive index materials and dispersive metamaterials with negative index in certain frequency ranges. When the averaged refractive index, in volume, of the multilayer equals zero, the structure does not propagate light waves and exhibits a forbidden band. In this contribution we recognize some approximated analytical expressions for the determination of the upper and lower limits of the above zero-average refractive index band gap.

13 Metamaterials having the nearly-zero effective permittivity and effective permeability simultaneously,
Chul-Sik Kee, Jin-Kyu Yang, Chul Kang, Jongmin Lee. Advanced Photonics Research Institute, GIST, South Korea

Metamaterials are new electromagnetic materials to have properties difficult and impossible to find in nature. We show that a metamaterial with the nearly-zero effective permittivity and effective permeability simultane-ously, resulting in the nearly-zero index of refraction and the finite impedance, can be realized by making holes in a perfect metal film. The metamateiral allows the zeroth-order Fabry-Perot resonant transmission that is im-possible in natural finite films. Our result provides simple understanding of the complete transmission of light through structured perfect metal films.

14 Extraordinary Transmission and Negative Refraction in a Prism of Stacked Subwavelength Hole Arrays
Mario Sorolla, Miguel Beruete, Miguel Navarro-Cia. Universidad Pública de Navarra, Spain
Igor Campillo. CIC nanoGUNE, Spain

A prism engineered by stacking sub-wavelength hole arrays is shown as a route to negative refraction in the terahertz and optical wavelengths. We analyze in simulation and experiments at the near field zone, several propagation regimes and bands with orthogonal polarizations, and find that Negative Refraction is intimately linked to the Extraordinary Transmission resonance of subwavelength hole arrays. Negative indices of refraction start from near to zero values for the lower mode while for the second one is positive. The cross-polar component has positive refractive index within both bands. The way to engineering negative refraction devices at terahertz and optical wavelengths is open.

15 A Dispersive Finite-Difference Time-Domain Method for the Evaluation of Electromagnetic Cloaks
Christos Argyropoulos, Yan Zhao, Yang Hao. Queen Mary, University of London, United Kingdom

This paper presents a novel radius-dependent dispersive finite-difference time-domain (FDTD) method to simulate electromagnetic cloaking devices. The Drude dispersion model is applied to model the electromagnetic characteristics of the cloaking medium. The method can accurately model lossless and lossy cloaks with ideal or reduced parameters. With few modifications it is able to simulate media which are produced from coordinate transformations techniques such as concentrators and rotation coatings.

16 Realistic Spirals of Optimal Shape for Electromagnetic Cloaking
Igor Semchenko, Sergei Khakhomov, Andrey Samofalov. Gomel State University, Belarus

In this paper we study helical inclusions of a certain shape (called the "optimal shape"), such that the electric, magnetic, and magneto-electric polarizabilities are equal, and discuss unusual reflection properties of artificial materials based on such inclusions. In this presentation a new way of realization for a metamaterial electromagnetic invisibility cloak is introduced.

17 Effect of variation in physical dimensions of cloaked object on performance of plasmonic metamaterial cloak
Adnan Noor, Zhirun Hu. University of Manchester, United Kingdom

In this paper cloaking of metallic sub-wavelength rectangular bar by plasmonic cloak is investigated. Cloak parameters are obtained from analysis by Engheta. The cloak which is designed for cloaking spherical objects was used to cloak rectangular bars and cube. Effect of variation of on RCS was investigated using Hfss.

18 Propagation of electromagnetic waves in a semiconductor periodic layered waveguides in a magnetic field
Oksana Shramkova. Institute of Radiophysics and Electronics of the NAS of Ukraine, Ukraine

The eigenwaves of a layered periodic waveguide composed of alternating layers of dielectric and semiconductor placed into external magnetic field are considered in the work. The dispersion dependencies for finite medium and field distributions are obtained.

Poster Session

19 Surface polariton enhanced transmission in metamaterial wire gratings
Mauro Cuevas, Diana Skigin, Ricardo Depine. Departamento de Física,F.C.EyN,UBA, Argentina

We present a detailed analysis of the excitation of surface polaritons on one dimensional wire gratings made of metamaterials. Extraordinary transmission, intimately related to the excitation of surface polaritons, is found for gratings illuminated by both s-polarized and p-polarized incident waves.

20 Group velocity of the transmitted & reflected light from a dispersive dielectric layer
Mehdi Sharifi, Mostafa Sahrai. University of Tabriz, Iran

The reflected and transmitted light from a slab that is doped with three-level -type atoms are theoretically investigated. The effect of the relative phase between coupling and probe fields on the group velocity has been discussed. We show that in the presence of spontaneously generated coherence (SGC), the group velocity of transmitted light is phase dependent, while in the absence of this coherence the phase dependence of the group velocity disappears.

21 On the inhibition of linear absorption in opaque materials
M. Centini, E. Fazzio, F. Pettazzi, C. Sibilia. University of Rome La Sapienza, Italy
V. Roppo. Universitat Politecnica de Catalunya, Spain
J.W. Haus, Duke University. USA
M.A. Vinventi, J.V. Foreman, N. Akozbek, M.J. Bloemer, M. Scalora, Charles M. Bowden Research Facility. USA

We theoretically predict and experimentally demonstrate inhibition of linear absorption for phase and group velocity mismatched second and third harmonic generation in strongly absorbing materials, GaAs in par-ticular, at frequencies above the electronic band edge. A 100-fs pump pulse tuned to 1300nm generates 650nm and 433nm second and third harmonic pulses that propagate across the entire length of a 450μm-thick GaAs substrate without being absorbed. We attribute this to a phase-locking mechanism that causes the pump to trap the harmonics and to impress them with its dispersive properties.

22 Non-Drude responses of cut-wire-grid structures in terahertz region
Keisuke Takano, Kyoji Shibuya, Takeshi Nagashima, Masanori Hangyo. Institute of Laser Engineering, Osaka University, Japan

We have investigated the electromagnetic responses of the wire-grid structures in the terahertz region when the cuts are made in the wires. It is found that the Drude response of the wire-grid structures are changed to insulators-like responses with large positive permittivity by introducing small cuts in the wires.

23 The investigation of carbon nanotubes as antennas
Anatoliy Kleschenkov, Alexander Lerer, Victoria Makhno, Pavel Makhno. Sothern Federal University, Russia

The solution of the boundary problem of diffraction and excitation of system of carbon nanotubes-vibrators is reduced to solving of the integral equation with a logarithmic kernel. After regularization, integral equations were solved by means of collocation method. The character of behavior of the current on the vibrator's ends was considered. The existence of resonances at the frequency range 0.1-1.0THz was shown

24 Theoretical analysis of dielectric block array metamaterial by transfer matrix method
Keita Izumi, Hiroshi Miyazaki. Department of Applied Physics, Tohoku University, Japan
Youji Jimba. College of Engineering, Nihon University, Japan
Kyouji Shibuya, Keisuke Takano, Masanori Hangyo, Institute of Laser Engineering, Osaka University, Japan
Naoki Matsumoto. Murata Manufacturing Co., Ltd., Japan

We report the optical property of the metamaterial composed of 2D dielectric cube or 1D square pillar array of TiO2 with high permittivity at terahertz frequencies. We found that effective permittivity or effective permeability becomes negative at resonance frequencies due to the presence of vortex-like electromagnetic field.

25 Resonant terahertz transmission through incommensurate metal hole arrays
Hlroshi Miyazaki, Keita Izumi. Department of Applied Physics, Tohoku University, Japan
Yoji Jimba, College of Engineering. Nihon University, Japan
Keisuke Takano, Masanori Hangyo. Institute of Laser Engineering, Osaka University, Japan
Fumiaki Miyamaru. Faculty of Science, Shinshu University, Japan

We present numerical investigation of terahertz transmission properties of metal hole arrays made of two incommensurate periodic lattices. It is found that transmission spectrum exhibits distinct coexistence of characteristic resonance peaks of the constituent periodic lattices. Coexistence feature is also confirmed by the electric field distribution.

26 Nonlinear composite right/left-handed transmission line for frequency doubler and short pulse generation
Stefan Simion, George Sajin, Florea Craciunoiu. National Institute for Research and Development in Microtechnologies, Romania
Romolo Marcelli. CNR Institute for Microelectronics and Microsystems, Microwave Microsystems Group, Italy
Giancarlo Bartolucci. University of Roma Tor Vergata, Italy

In this paper a balanced Non-Linear Composite Right/Left-Handed Transmission Line is designed and then analysed for applications of frequency doublers and short pulse generation. The circuit is an array of cascaded cells, each one consisting of series connected reverse biased Schottky-varactor diodes and parallel connected open-ended transmission line.

13:15 **Lunch**

Special Session Room Luneta

Tunable/reconfigurable/active metamaterials

Special session organized by Spartak Gevorgian, *Chalmers University, Sweden*
Chair: Spartak Gevorgian, *Chalmers University, Sweden*

14:50 **Frequency tunable / agile metamaterials. Keynote talk**
Willie Padilla, Boston College, USA

Artificial composite materials with designs that consist of both metallic and natural material parts have the ability to further extend the exotic properties of metamaterials. We overview these new metamaterial designs which yield frequency agility and tunability. Through external control a tuning of the resonance by 20 percent in frequency is demonstrated.

15:30 **Ferroelectrics, ferromagnets and multiferroics for negative refractive index. Invited talk**
Spartak Gevorgian, Chalmers University, Sweden

In the race for negative refractive index, along with using SRRs and other metal-dielectric structures, at-tempts of using natural materials are being made. In this review ferroelectrics/ferromagnets/multiferroics are considered as natural materials with natural negative permittivity/permeability/refractive index for applications at microwave and THz frequencies. While the natural multifarious are still in their infancy ("hot" research topic for physicists), the artificial multiferroics in the form of ferroelectric-ferromagnetic nano-composite metamateri-als may be/are considered for negative refractive index for applications in microwave terahertz and optical and devices. In addition to negative refractive index both intrinsic and artificial multiferroics offer dual (by electric and/or magnetic fields) tuneable properties.

15:50 **Beam steering in a planar anisotropic transmission-line metamaterial using ferroelectric varactors. Invited talk**
Anatoli Deleniv, Chalmers University of Technology, Sweden
Joshua Wong, University of Toronto, Canada
Vladimir Drakinski, Chalmers University of Technology, Sweden
George Eleftheriades, University of Toronto, Canada

In this work we investigate the possibility of signal routing using ferroelectrically-tuned planar metama-terial. The metamaterial comprises a planar square-celled grid, which is loaded with orthogonally oriented induc-tors and ferroelectric varactors. The structure is fad by a voltage source applied at the corner of the metamaterial sheet. Close to the resonance frequency, the signal is guided in the form of a beam with the orientation depend-ent on the operating frequency. With added tuning functionality, the metamaterial can be used for signal routing of a narrow band signal.

16:10 **Highly tunable structures for the THz range based on strontium titanate heterostructures and metamaterials. Invited talk**
Petr Kuzel, Institute of Physics, Academy of Sciences of the Czech Republic, Czech Rep.
H. Nemec, *Institute of Physics, Academy of Sciences of the Czech Republic, Czech Rep.*
F, Kadlec, *Institute of Physics, Academy of Sciences of the Czech Republic, Czech Rep.*

The physical principle of high tunability of SrTiO3 in the THz range is explained and possible applications in metamaterial science (heterostructures and rod-like composites) are experimentally demonstrated and discussed.

16:30 **Coffee break**

Regular Session Room Ciudadela 1

Extraordinary optical transmission I

Chair: Mario Sorolla, *Universidad Pública de Navarra, Spain*

14:50 **Field-enhancement and light-transmission in arrays of tapered nano-slits**
Pratap K. Sahoo, Paul Scherrer Institut, Switzerland
Harun H. Solak, Paul Scherrer Institut, Switzerland

We present arrays of tapered slits that yield extremely high field-enhancement factors due to a combination of plasmon resonance and the lightning-rod effect. The fabrication method based on shadow deposition is simple and robust. Measured transmission spectra show strong resonance features. Simulations are used to estimate the near-field enhancement factors.

15:10 **All-dielectric planar chiral metamaterials with giant optical activity in direct transmission: from theory to experiment**
Benfeng Bai, University of Joensuu, Finland
Kuniaki Konishi, University of Tokyo, Japan
Jari Turunen, University of Joensuu, Finland
Makoto Kuwata-Gonokami, University of Tokyo, Japan

We propose a new kind of all-dielectric planar chiral metamaterials (PCMs), based on waveguide grating design, which can produce tens-of-degree polarization rotation in zeroth transmitted order. The basic polarization properties of the PCMs as well as the enhancement mechanism of the optical activity by resonances are investigated.

15:30 **Transmission-Line Modeling of ENZ-based Supercoupling in Waveguide Transition Channels and Bends**
Andrea Alu, University of Pennsylvania, USA
Mario Silveirinha, University of Coimbra, Portugal
Nader Engheta, University of Pennsylvania, USA

Following our theoretical and experimental results on the supercoupling effect associated with ultranarrow channels filled with ε-near-zero (ENZ) materials, or equivalently with channels operating at cut-off, we present here our recent theoretical findings on the interpretation of these concepts in the framework of transmission-line theory. We show how, drastically different from Fabry-Perot resonant tunnelling, this anomalous resonant phe-nomenon is supported by a matching mechanism, produced and explained by the static-like and long-wavelength properties of ENZ metamaterials. Our theoretical results shed a new light on this anomalous phenomenon, which is verifiable in simple hollow metallic channels, highlighting some interesting venues for the realization and ap-plication of zero-permittivity metamaterials with particularly simple microwave technology. Extension of these concepts to optical frequencies is also envisioned and discussed.

15:50 **Extraordinary optical transmission with negative index of refraction**
Carlos Garcia-Meca, Nanophotonics Technology Center, Spain
Rubén Ortuño Molinero, Nanophotonics Technology Center, Spain
Francisco José Rodríguez-Fortuño, Nanophotonics Technology Center, Spain
Alejandro José Martínez Abiétar, Nanophotonics Technology Center, Spain
Javier Martí Sendra, Nanophotonics Technology Center, Spain

We present a metamaterial exhibiting extraordinary optical transmission and negative index of refraction in the same spectral band. The structure consists of a periodic metal film alternately perforated by slits and cylindrical holes displaying its properties at wavelengths around 600 nm (500 THz).

16:10 **Oblique Incidence and Negative Refraction Measurements through an Extraordinary Transmission Metamaterial Slab**
Mario Sorolla, Universidad Pública de Navarra, Spain
Miguel Beruete, Universidad Pública de Navarra, Spain
Miguel Navarro, Universidad Pública de Navarra, Spain
Igor Campillo, CIC nanoGUNE, Spain

We present simulation and experimental results of negative refraction through a metamaterial based on miniaturized Extraordinary Transmission stacked hole arrays working in the millimeter wave range. Two dimensional dispersion diagrams show the conditions under which negative refraction is expected. Due to the strong anisotropy of the structure a high variety of propagation modes appear inside the metamaterial, giving as a result positive and negative beam displacements depending on the wave polarization and angle of incidence. Experimental results using a quasi-optical bench in the millimeter wave band demonstrate negative refraction and, besides, good agreement with the simulation results is obtained. A discussion based on leaky waves serves to qualitatively explain the main features. The presented results may find application in the design of new lenses and devices both in the microwave and optical ranges.

16:30 **Coffee break**

Regular Session Room Ciudadela 2

Fabrication and measurements

Chair: Stefan Linden, *Forschungszentrum Karlsruhe, Germany*

14:50 **Fabrication and characterization of metamaterials using LTCC techniques. Invited talk**
Vasundara Varadan, University fo Arkasnas, USA
In Kwang Kim, University of Arkansas, United States

This paper describes the design and fabrication of 3-D metamaterials using Low Temperature Cofired Ceramics (LTCC) process. This is a major advance from the planar structures fabricated using PCB techniques. Metamaterials have been fabricated and characterized with plasmonic resonances in the range from 10 – 110 GHz.

15:10 **Towards the fabrication of two-dimensional plasmonic metamaterials in the visible range by nanoimprint lithography**
Vincent Reboud, Catalan Institute of Nanotechnology, Spain
N. Kehagias, University College Cork, Ireland
M. Striccoli, Universita di Bari, Italy
T. Placido, Universita di Bari, Italy
A. Panniello, Universita di Bari, Italy
M.L. Curry, Universita di Bari, Italy
J. Romero Vivas, Catalan Institute of Nanotechnology, Spain
M. Zelsmann, LTM-CNRS, France
D. Mecerreyes, CIDETEC-Centre for Electrochemical Technologies, Spain
J.A. Alducin, CIDETEC-Centre for Electrochemical Technologies, Spain
H. Doyle, University College Cork, Ireland
D. Iacopino, University College Cork, Ireland
G. Redmond, University College Cork, Ireland
C.M. Sotomayor Torres, Catalan Institute for Research and Advanced Studies, Spain

Sub-wavelength resolution microscopy can be based on 2D surface polaritonic crystals. The strong damping of the plasmon fields is an important limitation. We report a strong enhancement in the spontaneous emission intensity of dye chromophores-loaded in a printable polymer achieved by coupling the dye emission to surface plasmons of metallic nanoparticles.

15:30 **Accounting for power ''loss'' in metamaterials**
Vasundara Varadan, University of Arkansas, USA
Liming Ji, University of Arkansas, United States

In this presentation, a detailed accounting of apparent power loss in metamaterials is undertaken using experimental and numerical simulation data. Incident power – (reflected power + transmitted power) is the power that is unaccounted for. We try to account for this power in different metamaterial samples by studying ohmic power dissipation, dielectric dissipation, geometric dispersion or incoherent scattering due to multiple scattering and try to answer the question: where did the power go?

15:50 **Coupling between split rings: an experimental, numerical and analytical study**
Anna Radkovskaya, Moscow State University, Faculty of Physics, Dept. of Magnetism, Russia
Eugen Tatartschuk, School in Advanced Optical Technologies, University of Erlangen-Nuremberg, Germany
Frank Hesmer, Department of Physics, University of Osnabrueck, Germany
Chris Stevens, Department of Engineering Science, University of Oxford, UK
David Edwards, Department of Engineering Science, University of Oxford, UK
Ekaterina Shamonina, School in Advanced Optical Technologies, University of Erlangen-Nuremberg, Germany

Metamaterials as near field manipulating devices have been proposed in the past for a wide frequency range from radio waves to optics. Efficient design of structures with desired properties requires knowledge of microscopic properties of metamaterials including both properties of individual artificial "atoms" and mechanisms of "inter-atomic" interaction. The paper explores coupling mechanisms between singly split rings for arbitrary distance and relative orientation to each other. Various scenarios of electrical, magnetic and mixed type couplings and their dependence on the inter-element distance are studied. Effects of retar-dation are discussed. Coupling constants retrieved from the experimental data and from numerical simula-tions agree with those predicted by our analytical model.

16:10 **Fabric antennas integrated with metamaterials**
Rob Seager, Loughborough University, United Kingdom
Alford Charauya, Loughborough University, United Kingdom
Yiannis Vardaxoglou, Loughborough University, United Kingdom
Peter de Maagt, ESA, Holland

This paper reports the development of a miniaturised crossed dipole, for textile applications using metamaterial techniques. Furthermore, it extends the work to investigating the same spiralled structures as metamaterial surfaces to be used as miniaturised groundplanes.

16:30 **Coffee break**

Special Session Room Luneta

Superlenses, hyperlenses, other optical near-field imaging devices

Special session organized by Roberto Merlin, *University of Michigan, USA*
Chair: Roberto Merlin, *University of Michigan, USA*

16:50 **Mapping the near field using metamaterials: superlenses, hyperlenses, and indefinite permittivity materials. Keynote talk**
Gennady Shvets, The University of Texas at Austin, USA

Several approaches to imaging sub-wavelength features using metamaterials will be reviewed. Those include a standard superlens coupled with a near-field optical microscope; a tapered superlens enabling image manipulation (both magnification and demagnification); a hyperlens based on strongly anisotropic indefinite metamedia; a sub-wavelength phase plate. Recent experimental results demonstrating the propagation of strongly sub-wavelength negative index waves will be presented. Novel designs of strongly sub-wavelength negative index materials in the optical part of the spectrum will also be presented.

17:30 **Optical bulk metamaterials. Invited talk**
Xiang Zhang, University of california Berkeley, USA

Metamaterials are artificially designed subwavelength composites that possess extraordinary properties not existing in naturally occurring materials. In particular, they can alter the propagation of electromagnetic waves resulting in negative refraction, sub-wavelength focusing, and transmission of sub-wavelength information over a finite distance. Such unusual properties can be obtained by a careful design of the metal-dielectric composites on a deep sub-wavelength scale. The metamaterials may have profound impact in wide range of applications such as nano-scale imaging, nanolithography, and integrated nano photonics. I will discuss a few recent experiments demonstrating intriguing phenomena associated with Metamaterials. These include sub-diffraction limit imaging and focusing, low loss negative refraction and imaging in bulk optical metamaterials, and Negative-index Metamaterials (NIM) exhibiting negative phase propagation that can be accessed from free-space. I'll also discuss nano plasmonics for imaging and bio-sensing.

17:50 **The Hyperlens: recent developments. Invited talk**
Evgenii Narimanov, Birck Nanotechnology Center, Purdue University, USA
Z. Jacob, Birck Nanotechnology Center, Purdue University, USA
A. V. Kildishev, Birck Nanotechnology Center, Purdue University, USA

We present an approach to subwavelength imaging based on (meta)materials with strongly anisotropic dielectric response, and describe a new class of imaging devices capable of project-ing into the far field magnified images of subwavelegth objects. Using the methods of trans-formation optics, we extend our approach to imaging systems in planar geometry

18:10 **Near-field plates: subwavelength focusing and radiationless interference. Invited talk**
Roberto Merlin, University of Michigan, USA
Lei Jiang, University of Michigan, USA
Anthony Grbic, University of Michigan, USA

Using a modulated, grating-like surface, referred to as a near-field plate, we experimentally demonstrate cylindrical subwavelength focusing of microwave radiation in a pattern that mimics that of a negative-index slab. The resolution of the near-field plate is well beyond the diffraction limit.

21:00 **Conference dinner**

Regular Session Room Ciudadela 1

EBG-based structures

Chair: Bernard Jecko, *XLim Laboratory, University of Limoges, France*

16:50 **EBG Superstrate Antenna for WAAS bands. Invited talk**
Juan Carlos Iriarte, Universidad Pública de Navarra, Spain
Angel Osés, Universidad Pública de Navarra, Spain
Iñigo Ederra, Universidad Pública de Navarra, Spain
Ramón Gonzalo, Universidad Pública de Navarra, Spain

Multiband antennas can simplify considerably the complexity of receivers and transmitters, reducing the size and the mass of the conventional configurations. On the other hand, applications with high directivity requirements need array designs to comply with the directivity specifications using conventional technology. EBG superstrate designs have been satisfactory applied to single band applications using a single EBG superstrate layer. The number of number of radiating elements of conventional technology designs are considerably reduced when using EBG technology. Dual band configurations have also been designed in a single layer, but when working frequencies are too close a second EBG layer is needed. A dual layer EBG superstrate which can easily be adjusted to the desired operational frequencies is presented. The design has been realized to comply with the navigation antenna requirements of Wide Area Augmentation system (WAAS) application in L1 and L2 bands.

17:10 **Inductance-enhanced EBG structures for size reduction**
Noriaki Ando, System Jisso Research Laboratories, NEC Corporation, Japan
Hiroshi Toyao, System Jisso Research Laboratories, NEC Corporation, Japan
Tsuneo Tsukagoshi, System Jisso Research Laboratories, NEC Corporation, Japan
Takashi Harada, System Jisso Research Laboratories, NEC Corporation, Japan

Utilizing EBG structures in power planes is a new approach for the suppression of power noise. We have developed inductance-enhanced EBG structures that make it possible to miniaturize the dimensions of the unit cell with a high isolation at the lower frequency of interest.

17:30 **Low profile EBG resonator antennas**
Regis Chantalat, Cisteme Limoges, France
Lina Moustafa, XLim Laboratory, University of Limoges, France
Julien Drouet, XLim Laboratory, University of Limoges, France
Marc Thevenot, XLim Laboratory, University of Limoges, France
Thierry Monediere, XLim Laboratory, University of Limoges, France
Bernard Jecko, XLim Laboratory, University of Limoges, France

This paper deals with FSS placed close to a PEC surface often named high impedance surface. A new approach based on EBG resonator antenna theory is given. This paper describes the design, the working, the performances and the applications of the low profile EBG resonator antenna.

17:50 **3D EBG cavities: resonance frequency behaviour and effective resonant transmission scheme**
Irina Khromova, Public University of Navarra, Spain
Ramón Gonzalo, Public University of Navarra, Spain

The work is devoted to 3D EBG cavities resonant transmission. It shows, that woodpile air cavity resonance fre-quency goes up continuously or saturates with the cavity size increase, depending on the field polarization with respect to the cavity orientation. An efficient waveguide-cavity-waveguide coupling scheme of EBG resonant transmission is proposed.

18:10 **Efficient full-wave analysis of metamaterial pasive devices**
Felipe Catedra, Universidad de Alcalá, Spain
Eliseo García, Universidad de Alcalá, Spain
Iván González, Universidad de Alcalá, Spain
Carlos Delgado, Universidad de Alcalá, Spain

A numerical scheme that combines the Multilevel Fast Multipole Algorithm (MLFMA) and the Characteristics Basis Function Method (CBFM) has been developed for the analysis and design of antennas and microwave devices composed by metamaterials and other finite-sized multilayered periodic structures. The method has been tested considering several periodic structures achieving good results.

21:00 **Conference dinner**

Regular Session Room Ciudadela 2

Plasmonics I

Chair: Mark Stockman, *Georgia State University, USA*

16:50 **Purcell effect using pairs of gold nanoparticles**
Thomas Klar, TU Ilmenau, Germany
Moritz Ringler, LMU München, Germany
Alexander Schwemer, LMU München, Germany
Michael Wunderlich, LMU München, Germany
Alfons Nichtl, Roche Diagnostics, Germany
Konrad Kürzinger, Roche Diagnostics, Germany
Jochen Feldmann, LMU München, Germany

We show that plasmonic nanoresonators composed of two gold nanoparticles of distinct separation favour those spectral emission lines of fluorescent molecules which are in resonance with the nanoresonator while other emission lines of the vibronic progression are less pronounced. Hence the spectral shape of the fluorescence emission can be tuned by the distance between the two gold nanoparticles. This effect is similar to the well known Purcell effect in microcavities, however, we note that in case of a plasmonic nanoresonator its minimal size is not limited by the half of the wavelength.

17:10 **A study of intrinsic error in FDTD calculations of plasmonic system, and its physical analogue**
Hiroharu Tamaru, The University of Tokyo, Japan
Kenjiro Miyano, The University of Tokyo, Japan

A precision study of FDTD simulations on plasmonic systems suggested a class of error that remains with the reduction of space discretization, and its effect visible even for far-field observable quantities. Further study suggests its physical analogue may exist, which could help the design of less absorptive metallic structures.

17:30 **Omnidirectional absorption in nanostructured metal surfaces**
Tatiana Teperik, Instituto de OpticaCSIC, Spain
Javier Garcia de Abajo, Instituto de Optica CSIC, Spain
Andrey Borisov, Universite de ParisSud, France
M. Abdesalam, University of Southampton, United Kingdom
P. N. Barlett, University of Southampton, United Kingdom
Y. Sugawara, University of Southampton, United Kingdo
J. J. Baumberg, University of Southampton, United Kingdom

We provide experimental and theoretical support for an omnidirectional absorption effect that relies on the excitation of localized plasmons.

17:50 **Plasmon guided modes in nanoparticle metamaterials**
Rebecca Sainidou, Instituto de Optica CSIC, Spain
F. Javier Garcia de Abajo, Instituto de Optica CSIC, Spain

Surface TE-polarized modes in nanostructured metallic metamaterial films, made of a monolayer of nearly-touching particles, are reported. The metamaterial behaves as a high-index dielectric, thus yielding strongly-confined guided TE modes, complementary to TM plasmons in continuous metal surfaces, but with larger confinement than plasmons in metallic waveguides of similar dimensions.

18:10 **Plasmon resonances in near-field coupled 2D au nanoparticle arrays**
Pratap Sahoo, Paul Scherrer Institut, Laboratory for Micro- and Nanotechnology , Switzerland
Yasin Ekinci, Swiss Federal Institute of Technology Zurich (ETH), Laboratory of Metal Physics , Switzerland
Andre Christ, Swiss Federal Institute of Technology Lausanne (EPFL), Nanophotonics & Metrology Laboratory, Switzerland
O. J. F. Martin, Swiss Federal Institute of Technology Lausanne (EPFL), Nanophotonics & Metrology Laboratory, Switzerland
Harun H. Solak, 1Paul Scherrer Institut, Laboratory for Micro- and Nanotechnology , Switzerland

We fabricate two-dimensional arrays of Au dots with 100 nm periodicity having controlled gap between the particles in a range from 50 nm to below 10 nm. Optical measurements show two reso-nances at 520 nm and 620 nm. Extensive experimental and FDTD simulation demonstrate that the low-energy resonance can be assigned as a collective surface plasmon resonance arising from the strong near-field coupling between the nanoparticles

21:00 **Conference dinner**

Special Session Room Luneta

Electrically small antennas and arrays

Special session organized by Richard W. Ziolkowski, ECE Dept, University of Arizona, USA
Chair: Richard W. Ziolkowski, ECE Dept, University of Arizona, USA

08:20 **The state-of-the-art in the design of electrically small antennas. Keynote talk**
Steven Best, MITRE, USA

In this presentation we discuss the current-state-of-the-art in the design of electrically small antennas. We begin by considering the fundamental performance limitations that are defined as a function of the antenna's electrical size. We describe conventional and Metamaterial based small antenna designs that closely approach these fundamental limits.

09:00 **Electrically small resonators: A path to efficient, electrically small antennas. Invited talk**
Richard W. Ziolkowski, University of Arizona, USA

Electrically small antennas are a critical enabling technology for wireless applications. The usually incompatible demands for electrically small, efficient, and broad bandwidth antenna systems often becomes further acerbated by practical demands of multi-functionality, low weight, low cost, and easy manufacturing. A variety of metama-terial-based and metamaterial-inspired antenna systems have been achieved recently that meet many of these demands. The essential features of these antennas, the experimental validation of their performance, and recent design extensions will be reviewed.

09:20 **Dual mode reconfigurable loop antenna with left handed loading. Invited talk**
Qing Liu, University of Birmingham, United Kingdom
Peter Hall, University of Birmingham, United Kingdom

Left handed loading concept has been applied to loop antenna structure to investigate the new properties that loop antennas have. A loop antenna using a ladder network with left handed loading can gain various modes. The zero order mode gives rise to omnidirectional pattern in the plane of the loop, with a circumference of one wavelength and good impedance. Different mode can be obtained at the same frequency range by tuning the value of loading components. This paper will review the work on left handed loop antennas and present a novel dual mode reconfigurable loop antenna with left handed loading.

09:40 **Null switching by small LH coaxial resonator antenna. Invited talk**
Hiroyuki Arai, Yokohama National University, Japan

In this presentation we will discuss about the principle of null switching by a small LH coaxial resonator antenna. A cardioid pattern is given by a combination of monopole and slot modes. A proposed structure excites a monopole-like mode radiation by a small magnetic loop on the resonator aperture and a figure-of-eight pattern by an additional wire near the aperture. The wire position changes the a null angle and gives the null switching function. A mechanism for the switching is verified by the simulation.

10:00 **Coffee break**

Regular Session Room Ciudadela 1

Transformation electromagnetics

Chair: Ross McPhedran, CUDOS, University of Sydney, Australia

08:20 **Applications of transformation optics techniques to cloaking, antenna shielding, and other novel optical devices. Invited talk**
Do-Hoon Kwon, Pennsylvania State University, USA
Douglas Werner, Pennsylvania State University, USA

The spatial transform technique is applied to non-circular annular cloak designs and to the electromagnetic cloaking of antennas in multiple-antenna environments. Two-dimensional polarization splitter and right-angle bend designs are also presented.

08:40 **A coordinate transformation approach to indefinite materials and their perfect lenses**
Luzi Bergamin, European Space Agency, Netherlands

It is shown that a recently found generalization of coordinate transformations allows a geometric interpretation of many indefinite media, including perfect lenses made therefrom.We show that the perfect lens proposed by Smith and Schurig consists in a combination of time reversal and space inversion and derive alternative designs of perfect lenses made from two slabs of indefinite materials.

09:00 **Design of adaptive optics by finite embedded coordinate transformations**
Marco Rahm, Duke University, USA
John B. Pendry, Imperial College, UK
David R. Smith, Duke University, USA

We will explain how finite embedded coordinate transformations can be applied to the design of novel, exotic optical elements other than cloaks, which under certain circumstances can be reflectionless. As an example, a tandem parallel-beam-shifter/beam-splitter device will be discussed to show the potential of the new transformation-optical approach.

09:20 **Generalized field transformations using metamaterials**
Sergei Tretyakov, TKK Helsinki University of Technology, Finland
Igor Nefedov, TKK Helsinki University of Technology, Finland
Pekka Alitalo, TKK Helsinki University of Technology, Finland

In this paper we generalize the concept of field-transforming metamaterials (introduced at the first edition of this Congress) and show that one can design bi-anisotropic metamaterials which "perform" the most general linear mapping of fields E0(r), H0(r) into a new set of fields E(r), H(r). We show what electromagnetic properties of the transforming medium are required if the transformed fields are arbitrary linear functions of the original fields, and analyse the basic properties of these media (reciprocity and passivity). The coefficients of these linear functions can be arbitrary functions of position and frequency, which opens a possibility to realize various unusual devices.

09:40 **Analytical modelling of the transmission of complex electromagnetic images through an array of ENZ narrow channels**
Mario Silveirinha, Universidade de Coimbra, Portugal
Nader Engheta, University of Pennsylvania, USA

Following our recent theoretical and experimental works that demonstrated that epsilon-near-zero materials may enable a dramatic transmission enhancement in scenarios where an electromagnetic wave is squeezed through a very tight narrow channel, here we use homogenization methods to study the transmission of complex electromagnetic images through a (not necessarily periodic) array of channels partially filled with ENZ-materials. Taking into account the anomalous properties of ENZ-materials, and using a nonlocal homogenization formalism with suitable additional boundary conditions, we are able to calculate the transmission coefficient of a complex array of ENZ channels using analytical methods. Our theory suggests that ENZ materials may enable complex manipulations of electromagnetic signals in the nanoscale, such as compressing, expanding and bending subwavelength images.

10:00 **Coffee break**

Regular Session Room Ciudadela 2

Plasmonics II

Chair: Martin Wegener, Institut für Angewandte Physik, Universität Karlsruhe (TH), Germany

08:20 **Fabricating metal-dielectric structures for plasmonic components and metamaterials. Invited talk**
Alexandra Boltasseva, Technical University of Denmark, Denmark
Rasmus B. Nielsen, Technical University of Denmark, Denmark
Claus Jeppesen, Technical University of Denmark, Denmark
Anders Kristensen, Technical University of Denmark, Denmark
Reuben M. Bakker, Purdue University, USA
Hsiao-Kuan Yuan, Purdue University, USA
Zhengtong Liu, Purdue University, USA
Alexander V. Kildishev, Purdue University, USA
Vladimir M. Shalaev, Purdue University, USA

In this contribution we report on experimental realization of different metal-dielectric structures that can be used as plasmonic components for guiding of electromagnetic radiation along metal-dielectric interfaces via excitation of surface plasmon polaritons (SPPs) or as plasmonic metamaterials. Different fabrication approaches based on lithographic and deposition techniques are considered. Recent advances and challenges in fabrication of plasmonic structures are also discussed.

08:40 **Propagation characteristics in circular hollow plasma waveguide**
Ari Viitanen, Helsinki University of Technology, Finland

In this study the propagation factors and decay factors of waveguide consisting of a hollow rod in plasma are considered. The characteristics of two separate modes are presented. The field equations inside and outside the waveguide are evaluated and using the continuity conditions of the tangential fields lead to eigenvalue equations of the corresponding mode. The eigenvalue equation is solved. The results show that one mode is a backward wave and the other mode is a forward wave. The value of the propagation factor for both waves approach to infinity in lossless case when the frequency approaches to the plasma resonant frequency.

09:00 **Scaling down the split ring:a study on electric field distrubution**
Eugen Tatartschuk, School in advanced optical technologies, Germany
Ekaterina Shamonina, School in advanced optical technologies, Germany
Laszlo Solymar, Imperial College, United Kingdom

Using electric field distributions in and around a singly split ring of scalable dimensions we show how modes of surface plasmon polaritons affect what is regarded in the literature as a pure LC resonance. Plasmonic effects are expected to influence both resonant properties of individual elements and mechanisms of interaction between elements and need to be accounted for.

09:20 **Surface polaritons in corrugated metamaterials**
Mauro Cuevas, UBA, Argentina
Ricardo Depine, UBA, Argentina

We present a detailed analysis of the excitation of surface polaritons (SPs) on the periodically corrugated boundary of a metamaterial (MM). New effects are identified in regimes corresponding to MMs exhibiting negative refraction. We present results obtained by solving both the associated homogeneous and inhomogeneous problems.

09:40 **Design and verification of metamaterials composed of microplasmas**
Osamu Sakai, Kyoto University, Japan
T. Shimomura, Kyoto University, Japan
D.-S Lee, Kyoto University, Japan
K. Tachibana, Kyoto University, Japan

Microplasmas, which are generated in discharge gases, are potential components which make metamateri-als tunable and dynamic. They have high electron density corresponding to electron plasma frequencies at 10 GHz-1 THz below which their permittivity becomes negative. We demonstrate outline for generation of metamaterials composed of microplasmas; theoretical design, electrode preparation, and experimental verification.

10:00 **Coffee break**

Special Session Room Luneta

Nano-antennas

Special session organized by Bert Hecht, Department of Experimental Physics 5 (Biophysics) University of Würzburg, Germany, Germany
Chair: Bert Hecht, Department of Experimental Physics 5 (Biophysics) University of Würzburg, Germany, Germany

10:20 **Nano-antennas coupled to single emitters: field confinement, angular directivity and enhanced rates. Keynote talk**
Tim Taminiau, ICFO - Institute of Photonic Sciences, Spain
Fernando Stefani, ICFO - Institute of Photonic Sciences, Spain
Niek van Hulst, ICFO - Institute of Photonic Sciences, Spain

Antennas have been used for more than a century to control the emission and collection of radio and mi-crowave radiation. Nano-antennas, the optical analogue, are of great interest as they allow unique control of both absorption and emission at the nanometer scale, beyond the optical diffraction limit. In this presentation we will focus on resonant optical nanoantennas in close proximity to single emitters (such as molecules, Q-dots). By controlled coupling of single molecules to a resonant antenna, both in experiment and theory, we show localized excitation (25 nm), enhanced excitation and emission, directional emission (full 90 redirection) and strong direc-tivity (over 200x) using multi element antennas.

11:00 **Modification of single molecule fluorescence by nanoantennae: radiation pattern, spontaneous emission and quenching. Invited talk**
Vahid Sandoghdar, ETH Zurich, Switzerland
Hadi Eghlidi, ETH Zurich, Switzerland
Nassir Mojarad, ETH Zurich, Switzerland
Stephan Götzinger, ETH Zurich, Switzerland
Mario Agio, ETH Zurich, Switzerland

The coupling of nanostructures with emitters opens ways for the realization of man-made subwavelength light emitting elements. We present an overview of our experimental and theoretical efforts in the modification of fluorescence when an emitter is placed close to a nanoantenna. We discuss the enhancement and reduction of molecular excitation and emission rates in the presence of metallic nanoparticles and emphasize the role of plasmon resonances. We also examine the spectral and angular emission characteristics of the molecule-particle system. The experimental findings are in excellent agreement with the outcome of theoretical calculations.

11:20 **Linear and nonlinear optical response of metal nanoantennas. Invited talk**
Rudolf Bratschitsch, University of Konstanz, Germany
B. Wild, University of Konstanz, Germany
T. Hanke, University of Konstanz, Germany
J. Merlein, University of Konstanz, Germany
A. Leitenstorfer, University of Konstanz, Germany

We present a tuneable bowtie nanoantenna and measure its linear optical response via dark-field scattering spectroscopy. Nonlinear optical properties of nanoantennas are investigated via excitation with femtosecond laser pulses.

11:40 **Impedance matching and emission properties of single emitters and optical antennas. Invited talk**
Jer-Shing Huang, University of Würzburg, Germany
Paolo Biagioni, University of Würzburg, Germany
Thorsten Feichtner, University of Würzburg, Germany
Bert Hecht, University of Würzburg, Germany

The concept of impedance matching will be discussed in the context of optical antennas. We will consider optical transmission lines connected to optical antennas to demonstrate the applicability of the impedance concept at optical frequencies. We will then use the results to optimize the coupling of single quantum emitters to optical antennas in view of applications like high resolution optical microscopy, single molecule sensing, and highly efficient sources of single photons.

Regular Session Room Ciudadela 1

SRRs: Theory and experiment

Chair: Michael Wiltshire, Imperial College London, United Kingdom

10:20 **Modeling of electrically thin SRR layers for magnetic resonance imaging applications**
Lukas Jelinek, Universidad de Sevilla, Spain
Ricardo Marques, Universidad de Sevilla, Spain

In this contribution a model for electrically thin SRR layers will be shown. The model is based on a quasistatic equivalent circuit of the SRR and Lorenz-like homogenization, taking into account magnetoinductive coupling between close neighbors and approximate form of interaction with far neighbors. Applications in quasimagnetostatic imaging are envisaged.

10:40 **Resonant frequency of singly split single ring resonators: an analytical and numerical study**
Oleksiy Sydoruk, University of Erlangen-Nuremberg, Germany
Eugen Tatartschuk, University of Erlangen-Nuremberg, Germany
Ekaterina Shamonina, University of Erlangen-Nuremberg, Germany
Laszlo Solymar, Imperial College, United Kingdom

Although the singly split single ring is structurally simple, no analytical expression for its resonant frequency is available. Assuming a two-dimensional geometry, we derive here an analytical expression for the resonant frequency of the split-ring resonator. The predictions of the analytical model are then compared with numerical simulations leading to good agreement.

11:00 **Theory of distorted magneto-inductive ring resonators**
Richard Syms, Imperial College London, United Kingdom
Ian Young, Imperial College London, United Kingdom
Laszlo Solymar, Imperial College London, United Kingdom

An analytic theory of periodically perturbed magneto-inductive waveguides is developed and used to determine the mode spectrum of distorted MI ring resonators. A set of coupled equations is first established from the recurrence equations for an infinite set of coupled elements, and used to determine the dispersion equation. Solutions for ring resonators are then found using periodic boundary conditions, which give simple predictions for resonance splitting.

11:20 **Split-ring metamaterial superlenses for magnetic resonance imaging applications**
Manuel J. Freire, University of Seville, Spain
Ricardo Marques, University of Seville, Spain

In this work, metamaterial superlenses made of split-ring resonators working in the MHz range are analyzed for its possible application in magnetic resonance imaging. Specifically, the ability to increase the penetration depth of surface coils is demonstrated in a laboratory environment.

11:40 **Modelling the coupling between microstrip ring-resonators and transmission lines by a microwave circuit-board approach**
Jaime Esteban, Universidad Politécnica de Madrid, Spain
Juan E. Page, Universidad Politécnica de Madrid, Spain
Carlos Camacho, Universidad de Málaga, Spain

This contribution describes a microwave circuit-based approach to obtain the equivalent circuit of microstrip ring resonators coupled to a transmission line, considering the coupling structure and the resonator structure as separate elements. The method can be applied to a wide range of resonators, and used to accurately predict the behaviour of circuits containing several resonators as well as to take advantage of existing synthesis techniques.

Regular Session Room Ciudadela 2

Extraordinary optical transmission II

Chair: Vitaliy Lomakin, University of California, San Diego, USA

10:20 **Manipulating the transmittance of a nano-perforated conducting film by a magnetic field**
Yakov Strelniker, Bar-Ilan University, Israel
David J. Bergman, Tel Aviv University, Israel

We studied theoretically and numerically the transmission of light through a sub-wavelength perforated metal film, as well as through a homogeneous metal film with Drude ac conductivity tensor, in the presence of a static magnetic field. Both perforated and homogeneous metal films are found to exhibit a magneto-induced light transparency and a decreasing of reflectivity due to cyclotron resonance.

10:40 **220 GHz and 2.3 THz subwavelength double periodic hole array exhibiting extraordinary transmission**
Mario Sorolla, Universidad Pública de Navarra, Spain
S. A. Kuznetsov, Budker Institute of Nuclear Physics SB RAS, Russia
A. V. Gelfand, Institute of Semiconductor Physics SB RAS, Russia
N. I. Fedorinina, Institute of Semiconductor Physics SB RAS, Russia
Miguel Navarro, Universidad Pública de Navarra, Spain
Miguel Beruete, Universidad Pública de Navarra, Spain
Igor Campillo, CIC nanoGUNE, Spain

In this work, it is shown the experimental result of the phenomenon of extraordinary transmission through double periodic arrays of subwavelength holes around 220 GHz and 2.3 THz. The fabrication of the prototypes has been done by depositing a thin Aluminum layer over a polypropylene wafer. Our Finite Integration Time Domain simulation confirm the resonant total transmission at wavelengths close to the long period of the array. Using an AB MillimetreTM Quasioptical Vector Network Analyzer in the range between 40 GHz and 260 GHz, the transmission response measurements of the millimeter wave prototypes have been performed. The vacuum Fourier-transform spectrometer "Bruker IFS 66v/s" is used for the 2.3 THz measurements within the spectral range 40-700cm-1. These results can give rise to interesting applications in the emerging THz Metamaterials field.

11:00 **Analytical solution for extraordinary transmission through thin metallic screens perforated with small holes**
Ricardo Marqués, Universidad de Sevilla, Spain
Francisco Mesa, Universidad de Sevilla, Spain
Lukas Jelinek, Universidad de Sevilla, Spain
Francisco Medina, Universidad de Sevilla, Spain

In this contribution an analytical solution for the problem of extraordinary transmission through thin perfect conducting plates periodically perforated with sub–wavelength holes is proposed. An equivalent circuit is found, in agreement with previous results by the same authors.

11:20 **Propagation modes on the stacking of different-oriented enhanced transmission wafers**
Mario Sorolla, Universidad Pública de Navarra, Spain
Miguel Navarro, Universidad Pública de Navarra, Spain
Miguel Beruete, Universidad Pública de Navarra, Spain
Francisco Falcone, Universidad Pública de Navarra, Spain
Igor Campillo, CIC nanoGUNE, Spain

A deep analysis of the diverse modes, that become propagative in a set of quasi-self-complementary subwavelength hole array which have been stacked with different orientation, has been carried out under normal incidence. It is shown that, all-copolar configuration aside, the co-cross-co- polar configuration of 3 stacked wafers can allow having two frequency pass-bands which suggests the possibility of designing a dual-band Extraordinary Transmission polarizer. This result confirms once again the potential applications that this structure has in the field of polarization, since single-band-, dual-band-polarizer and polarization rotator have been proposed with it.

11:40 **Effect of internal and external surface plasmons in the enhanced transmission through double-layer metallic hole arrays**
Rubén Ortuño, Nanophotonics Technology Center, Spain
Carlos García, Nanophotonics Technology Center, Spain
Francisco José Rodríguez, Nanophotonics Technology Center, Spain
Alejandro José Martínez, Nanophotonics Technology Center, Spain
Javier Martí Sendra, Nanophotonics Technology Center, Spain

Transmission enhancement through double-layer metallic structures patterned with subwavelength hole arrays due to both internal- and external-surface plasmons is presented. The resonant frequency strongly depends on the dielectric layer parameters and can be characterized by using an effective-permittivity model. The spatial distribution of the electromagnetic field plays an important role in determining the transmission resonances.

Poster Session Ciudadela Corridor (12:00 -13:15)

1 Comparison of combined-field and electric-field volume integral equations for modelling double-negative metematerial antennas and scatterers
Oleksiy Kim, Olav Breinbjerg. Technical University of Denmark, Denmark

Two volume integral equation formulations for modelling magneto-dielectric objects are compared in terms of accuracy and computational efficiency. The first is the combined-field integral equation (CFVIE), in which the unknown quantities are both the electric and magnetic fields, while the second is the electric-field integral equation (EFVIE) with a single unknown quantity - the electric field. A resonant double-negative metamaterial spherical shell is analysed as an example.

2 Radiation properties of a multiband stacked circular microstrip antenna with 2-D defected ground structure (DGS)
Ridho Chayono, Misao Haneishi, Yuichi Kimura. Saitama University, Japan

This paper presents a multiband stacked circular microstrip antenna with 2-D defected ground structure slab for multiband applications. Two half-ring slots are embedded into the circular patch on the top side of the upper layer. Four resonant frequencies with a stable high-gain performance of around 8.0 dBi can be obtained.

3 Zeroth order leaky-wave antenna with modified shunt inductor arms
Yongjin Kim, Junghan Kim, Hoyong Kim, Hongmin Lee. Kyonggi University, South Korea

In this paper, composite right/left-handed (CRLH) transmission line (TL) based zeroth order leaky-wave antenna (ZOLA) with modified shunt inductor arms is proposed. It is designed by using low temperature co-fired ceramic (LTCC) material to reduce the size of antenna. By modifying the form of shunt inductor arms, its direc-tion of current flow path on the shunt inductor arms is same as the series arms. As a result, the maximum gain of the proposed antenna is enhanced. The simulated result shows that the proposed antenna has compact size, broad impedance bandwidth, and broadside radiation pattern at zeroth order mode.

4 Characteristics of a microstrip antenna on double-negative metamaterials
Yaxuan Zhu, Wai-Yip Tam. Hong Kong Polytechnic University, China

we studied the miccrostrip antenna printed on DNG metamaterial substrate.We found that other modes are introduced in addition to fundamental mode. Better bandwidth can be achieved for fundamental mode. With proper selection of DNG metamaterials, it is possible to achieve good bandwidth at resonant frequencies of all the modes.

5 Metamaterial enhanced high gain slot antenna
Hung-Hsuan Lin, Chun-Yih Wu, Ta-Chun Pu, Rui-Hung Chen. Industrial Technology Research Institu, Taiwan

A high gain low-profile slot antenna design using metamaterial technology operating at WiMAX 3.5-GHz band is proposed in this work. Instead of using a reflector, a metamaterial superstrate, composed of stacked S-shaped split-ring resonators, is applied to modify the radiation pattern and enhance antenna gain. In addition, the proposed structure can be made in economic 4-layer via-less FR-4 printed circuit boards. Therefore applying this technology to commercial applications becomes more practical. With one thin metamaterial superstrate (1.14 mm thick) covered on a two-sides radiating slot antenna, the whole composite can achieve a maximum gain of 9.8 dBi on the side that metamaterial superstrate is covered. Furthermore, when the slot antenna is covered with metamaterial superstrates on its both sides, gain can be enhanced in both directions.

6 Design of highly directive cavity-type configurations comprising a low profile antennas covered by EBG superstrates
Nader Farahat, Katherine Lugo, Rodney A. Gomez. Polytechnic University of Puerto Rico, Puerto Rico
Raj Mittra, Lai-Ching Ma. Pennsylvania State University, USA

We present a technique for designing antenna/EBG superstrate composites to yield enhanced directivities. We begin by studying the underlying mechanism that governs the performance of theses antennas by investigating the canonical problem of a line source in a rectangular waveguide. The above problem is solved by constructing the Green's function corresponding to the line source in the rectangular guide. Although the above model is only two-dimensional, we show that it can be used to predict the performance of antenna/superstrate composites. Finally, we demonstrate this by modeling several highly-directive 3-D antenna EBG composites.

7 Metamaterials using for radiation enhancing of coaxial transmission line
Boris Panchenko, Marat Gizatullin, Sergey Knyazev, Sergey Shabunin. Ural State Technical University, Russia

A new kind of subwavelength antenna as a coaxial line open-end embedded in hemispherical core-shell system is analysed. The opportunity of an efficient directive radiator design is proved theoretically and numerically.

8 On the improvement of stability of artificial magnetic conductor based on genetic algorithms
Nadia Lassouaoui, Habiba Hafdallah Ouslimani, Alain Priou. University Paris X, France
Zhirun Hu. University of Manchester, United Kingdom

A frequency selective surface to achieve a high-impedance surface is studied. The unit elements are L-shaped rectangular loops printed on a grounded dielectric slab. The characteristics of the FSS and the dielectric substrate are optimized using genetic algorithms in order to improve the stability of the resonant frequency with respect to the incidence angles for the two transverse magnetic and electric polarization modes of the incident wave. Numerical results are presented.

Poster Session

9 Bandwidth broadening of dual-frequency printed dipoles loaded with Split Ring Resonators
Francisco Javier Herraiz, Luís Enrique García, Daniel Segovia. Carlos III University in Madrid, Spain
Vicente González, Universidad Politécnica de Madrid, Spain

In this paper dual-frequency printed dipoles are presented. They are based on conventional antipodal printed dipoles loaded with Split Ring Resonators (SRRs). This approach provides an additional resonance in the vicinity of the self-resonant frequency of the SRRs. Moreover, SRRs with different radii are used in order to increase the bandwidth of the additional resonance. Two prototypes are manufactured and measured, showing good results.

10 Design of SRR-based patch antennas
Oscar Quevedo, Eva Rajo. Universidad Carlos III de Madrid, Spain

In this article, a new microstrip patch antenna based on SRR (Split Ring Resonator) is proposed and studied. The presented design uses a SRR shape (with grounded pins), having a semi-planar structure. The radiation pattern of the proposed antenna is omnidirectional in the azimuth plane with a broadside null and the principal advantages of the antenna are the compactness, its easy manufacturing and low cost. In contrast, the principal disadvantage is a limited efficiency.

11 Use of double layer frequency selective surfaces to realize broadband resonator antennas
Lina Moustafa, Marc Thevenot, Thierry Monediere, Bernard Jecko. University of Limoges, France
Regis Chantalat. Cisteme, France

A double layer Frequency Selective Surface (FSS) is proposed as a means to enhance the bandwidth of an Electromagnetic Band Gap (EBG) resonator antenna. It builds a low profile EBG resonator used as the EBG antenna upper interface. Antenna is fed by a patch placed inside the cavity at the proximity of its ground plane. The antenna operating bandwidth is significantly improved by virtue of employing the double layer FSS. Results of an antenna application at 5GHz are shown.

12 Simple manufacturing process of an artificial magneto-dielectric substrate applied to planar antennas
Anne-Claude Tarot, Wafa Abdouny, Ala Sharaiha. University of Rennes, France

Artificial electromagnetic media with extraordinary properties (often called metamaterials) attract increasing attention in the microwave community. Artificial magneto-dielectric substrates are nowadays considered as one of the most promising ways to miniaturize microstrip antennas. In the present paper we propose an artificial magneto-dielectric substrate, composed of an array of stacked SRR, to reduce the size of a patch antenna. A prototype is realized and measured. A theoretical study of patch antenna on this magneto-dielectric substrate is presented. A prototype of antenna has been realized with an original and simple method and measured around 5GHz to valid theoretical results.

13 Frequency scanning capabilities of a long slot in a metamaterial-based waveguide
María Navarro-Tapia, Carlos Camacho-Peñalosa. Universidad de Málaga, Spain
Jaime Esteban. Universidad Politécnica de Madrid, Spain

Frequency-scanning capabilities of continuous-type leaky-wave antennas have been usually restricted to radiation directions within the forward quadrant. With the appearance of metamaterial-based waveguides it has been possible to spread the spatial range of scanning angles to the backward quadrant, including broadside. This paper presents the improved scanning capabilities of a long-slot leaky-wave metamaterial antenna. Analytical and simulated results are in reasonable agreement. They confirm not only the frequency-scanning capabilities of such a type of antennas, but also the validity of the numerical analysis technique employed.

14 Revisiting the Q factor of PIFA antennas for dielectric and magnetic media
Constant Niamien, Syvain Collardey, Anne Claude Tarot, Kouroch Mahdjoubi. University of Rennes, France

The classical transmission line model of PIFA antennas is reduced to two parallel admittances. The first admittance is a pure conductance and represents the radiating slot. The second one is a pure susceptance and represents the PIFA cavity composed of a quarter wave transmission line. This extreme simplification allows a better understanding of the role played by the various antenna parameters (geometry, electromagnetic constants, etc) in the antenna performances and especially in the quality factor.

15 A novel model of sectoral M-EBG antenna for WiMAX applications
Dina Serhal, Mohamad Hajj, Regis Chantalat, Bernard Jecko. University of Limoges, France

In this paper, we focuse on the principle of metallic electromagnetic band-gap (M-EBG) antennas. First, we propose a novel design of sectoral EBG antenna inspired from directive one. Then, we develop a method in order to improve antenna performance by using metallic walls along the structure. Moreover, we investigate two FSS (frequency selective surface) models of M-EBG antenna in both TE and TM polarization. A parametrical study of the FSS is carried out, and simulation results are reported and discussed. Finally, the multi-source technique is used in order to improve antenna performances in terms of directivity and radiation band-width.

16 Parabolic lens by stacked subwavelength hole arrays exhibiting negative refraction
Miguel Navarro, Mario Sorolla. Universidad Pública de Navarra, Spain

We show the design of a planoconcave parabolic negative index metamaterial lens operating at millimeter wavelengths fabricated by using stacked subwavelength hole arrays. Theory predicts power concentration at the focal point of the parabola when the refractive index equals -1. Similar planoconcave devices in terahertz and optical wavelengths are envisaged.

Poster Session

17 Modelling and design guidelines of metamaterial-based artificial dielectric for the miniaturization of microwave passive circuits

David Dubuc, Katia Grenier. LIMMS/CNRS-IIS University of Tokyo, Japan
Daisuke Yamane, Zhang Rui, Yuheon Yi, Hiroyuki Fujita, Hiroshi Toshiyoshi, IIS University of Tokyo, Japan

This paper presents a numerical modelling of metamaterial-based artificial dielectric transmission lines. This modelling permits to efficiently predict the effective permittivity and permeability of periodically arranged metallic posts integrated into the substrate of a microstrip line. Thanks to this modelling, design guidelines for the miniaturization of microwave passive circuits has been settled down. Associated proof of concept demonstra-tors are under process and will be presented at the conference.

18 Design of dual-band bandpass filter with single open ring resonators (SORRs), open split ring resonator (OSRR) and dual open split ring resonator (DOSRR)

Juan Hinojosa, Juan de Dios Ruiz. Universidad Politécnica de Cartagena, Spain

A dual-band bandpass filter with two single ring resonators (SORRs), an open split ring resonator (OSRR) and a dual open split ring resonator (DOSRR) which is etched in the ground plane is proposed in this letter. Mi-crostrip SORs, OSRR and DOSRR generate two passbands and add transmission poles and zero to improve the response of the proposed bandpass filter and isolation between the two passbands.

19 Miniaturization of coplanar waveguide bandstop filter with spiral resonators

Ibraheem Al-Naib, Martin Koch. Technical University of Braunschweig, Germany

We propose a miniaturized bandstop filter based on complementary spiral resonators etched into a single metal layer. Multiple turn complementary spiral resonators are employed to achieve a high degree of miniaturization. These structures could be of interest for applications in bandstop filters where miniaturization and compatibility with planar technology are key issues.

20 Control of the electromagnetic response of dual-period arrays

Marcelo Lester. Univ. Nacional del Centro de la Pcia. de Buenos Aires, Argentina
Diana Skigin, Ricardo Depine. Univ. de Buenos Aires, Argentina

We present a novel way to control the efficiency of the diffraction orders by a dual-period structure. The unit cell is formed by a set of parallel wires with subwavelength cross section. By selection of particular combinations of the geometrical parameters, the diffracted efficiencies can be either intensified or minimized. In addition, a blaze-like effect is produced when the plane that contains the wire axes of each unit cell is not coincident with the periodicity direction. We developed a scalar model that permits us to design structures that either enhance or cancel out a given diffraction order. Numerical results obtained with a rigorous vectorial method show that these effects are independent of the constitutive parameters and the cross section profile of the wires.

21 Absorption of electromagnetic waves of millimeter waveband

Anatoly Rinkevich, Dmitry Perov, Vladimir Ustinov. Institute of Metal Physics, Russia
Mikhail Samoilovich, Svetlana Klescheva. Central Research Technological Institute "TECHNOMASH", Russia

Frequency dependence of absorption coefficient has been measured in 3D-nanocomposites based on SiO2 nanosphere packages. The measurements are carried out in frequency range from 26 to 38 GHz. The 3D-nanocomposites contain nanoparticles of ferrite spinels in the inter-sphere voids. Comparison is outlined be-tween the nanocomposites with different compositions.

22 SRR and CSRR millimeter wave metasurfaces

Mario Sorolla, Mariam Aznabet, Miguel Navarro, Otman El Mrabet, Miguel Beruete, Francisco Falcone. Universidad Pública de Navarra, Spain
Sergei A. Kuznetsov. Budker Institute of Nuclear Physics SB RAS, Russia
A. V. Gelfand, N. I. Fedorinina. Institute of Semiconductor Physics SB RAS, Russia

In this work we present experimental results of metasurfaces made of two dimensional arrays of split rings resonators and its complementary particle at millimeter waves. The measurements have been done from 40 GHz up to 260 GHz and high-order resonances have been observed. A good agreement between simulation and experiments has been observed. These results can give rise to interesting applications in the emerging THz Metamaterials field.

23 Accurate analysis of planar metamaterials using the RLC theory

Radu Malureanu, Andrei Lavrinenko. DTU Fotonik, Denmark

In this work we present an attempt to construct an accurate analytical approach within the RLC theory for analysis of resonances exhibited by a plane composition of thin metallic pads on a dielectric substrate. We employ formulas to calculate inductances including the mutual ones, capacitances and also the pads' resistance considering the variation of permittivity due to small thicknesses. Results are tested versus experimental ones taken from literature, showing nice matching. Such strategy can be used for fast and reasonably accurate evaluation of resonant properties of planar metamaterials thus opening doors for efficient optimization.

24 Experimental demonstration of phase resonances in metallic compound gratings with subwavelength slits in the millimeter wave regime

Mario Sorolla, Miguel Navarro-Cia, Miguel Beruete. Universidad Pública de Navarra, Spain
Diana C. Skigin. Universidad de Buenos Aires, Argentina

In this presentation we show for the first time experimental evidence of phase resonances in metallic periodic structures in which each period comprises several subwavelength slits of the same width. We have analyzed and measured the response of these structures in the millimeter wave regime and show that phase resonances are characterized by a remarkable minimum in the transmission response, as predicted by numerical calculations. We compare our experimental results with those obtained by simulations and obtain a very good agreement between them.

Poster Session

25 Modeling of metamaterial-based transmission lines considering radiation loss
Tack-Gyu Kim, Bomson Lee. Kyunghee University, South Korea

The equivalent circuit for the MTM-based TL is modeled considering radiation effects due to the inclusion of a series capacitor and shunt inductor. The radiation rates are derived from it. In addition, simple closed-form solutions for the design of RLH-TL are provided. The radiation rate formulas for any load conditions using the S-parameters obtained from EM simulations or measurements are also derived.

26 Metamaterial dual band CE power amplifier
Francisco José Arques,V. GonzáleZ, J.L. Jiménez. Universidad Politécnica de Madrid, Spain
F.J. Herraíz, D. Segovia. U. Carlos III, Spain

In this paper the use of Composite Right/Left Hand (CRLH) and Extended Composite Right/Left Hand (ECRLH) transmission lines in dual band power amplifiers are proposed. The CE power amplifier presents ad-vantages over conventional amplifier such as larger efficiency and low bias supply and what it is more, the fact that the fundamental class in bipolar transistor. Procedure of design and equations are presented.

27 Metamaterial based RF bandpass filter in suspended substrate
Geelani Tumcherla Shaik, Horst Schenkel. Alcatel-Lucent, Germany
Georg Fischer. Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
Jürgen Detlefsen. Technical University of Munich, Germany

This paper describes the design of high selective, low ripple metamaterial microstrip bandpass filter for Tx Band EGSM base stations. For the new filter the same stringent requirements apply. With this new technology we can reach high stopband attenuation and low insertion loss by reducing size and cost of a filter. This could be great advantages for all RF systems which uses transmit and receive bands simultaneously.

28 Investigation of a 2-D lattice of spiral resonators and metallic strip wires as a planar left-handed structure
Nilufer Ozdemir, Stephanie Eggermont, Isabelle Huynen, Dragos Dancila. Université catholique de Louvain, Belgium

The behavior of a planar structure composed of a novel 2-D lattice of spiral resonators and metallic strip wires deposited on a dielectric substrate is investigated. From the full-wave simulations, it is observed that the structure exhibits a transmission peak in the region where the real part of the extracted effective permittivity and permeability become negative, a property that implies a left-handed structure behavior. The simulation results indicate that the transmission peak occurs around 123 MHz at which the current magnetic resonance imaging systems operate.

29 Design and characterization of metamaterial antenna for the L-band frequency
Ouslimani Habiba, Lu Yang Zhou. University Paris 10, France

In this paper, we present the design and the optimization of high impedance surface (HIS) structures used to build a compact dipole metamaterial antenna in the L-band frequency. The performances of the antenna are characterized by HFSS simulations and by measurements. The reflectivity and the pattern radiation are presented.

13:15 **Lunch**

Student Paper Competition Ciudadela Corridor (12:00 -13:15)

1 Taming spatial dispersion in the wire-mesh metamaterial

Angela Demetriadou
Imperial College of London. London, United Kingdom

The wire-mesh metamaterial is an artificial plasma, with negative electric behaviour in the GHz frequency range. The transverse modes are convincingly reproduced by the artificial medium, but the longitudinal mode is strongly dominated from spatial dispersion, spoiling the simple local plasma model. In this paper, new wire structures are proposed, that manage to eliminate spatial dispersion and restore the simple local model.

2 DNA-like metamaterials: Observation of polarization selectivity of electromagnetic properties

Alexei Balmakov
Gomel State University. Gomel, Belarus

In the given work the phenomenon of interaction of the circularly-polarized waves of the microwave range with the DNA-like spiral structure is considered by a principle of electrodynamic similarity. The effect of polarization selectivity at interaction of right-handed double spirals with the electromagnetic radiation of left-circularly polarized waves is experimentally confirmed. The linearly polarized waves reflected from the flat sample, consisting of the right-handed double spirals, and turned into the left-circular polarization waves, which incident on the identical sample. Thus, the double reflection of waves from the identical samples of spirals was investigated. When the DNA-like right-handed spirals interacted with the electromagnetic waves, reflected by mirror-symmetrical left-handed spirals, the reduction of resultant waves and the polarizing selectivity has not observed.

3 Parabolic lens by stacked subwavelength hole arrays exhibiting negative refraction

Miguel Navarro-Cia
Universidad Pública de Navarra. Pamplona, Spain

We show the design of a planoconcave parabolic negative index metamaterial lens operating at millimeter wavelengths fabricated by using stacked subwavelength hole arrays. A staircase approximation to the ideal parabola profile has been done by removing step by step one lattice in each dimension of the transversal section. Theory predicts power concentration at the focal point of the parabola when the refractive index equals -1. The possibility to design similar planoconcave devices in the terahertz and optical wavelengths could be open.

4 An electrically small monopole-like antenna with embedded metamaterial high-μ matching network

Titos Kokkinos
Loughborough University. Loughborough, United Kingdom

An electrically small, superdirective, two-element, microstrip-based, single port, endfire array is reported in this paper. The proposed endfire array is composed of two low-profile folded monopoles that attribute their operation to an embedded metamaterial high-μ matching network. Given the self- resonant characteristics of the employed radiating elements and the extremely low coupling between any pair of them, the array feeding network, that properly sets the array superdirective mode, is composed exclusively of a180° ring hybrid and conventional microstip lines. The resulting two- element array is compact, easily fabricated, low-cost and can deliver directivities up to 3 dB larger than those of the single element.

5 3D EBG cavities: Resonance frequency behaviour and effective resonant transmission scheme

Irina Khromova
Universidad Pública de Navarra. Pamplona, Spain

The work is devoted to 3D EBG cavities resonant transmission. It shows, that woodpile air cavity resonance frequency goes up continuously or saturates with the cavity size increase, depending on the field polarization with respect to the cavity orientation. An efficient waveguide-cavity-waveguide coupling scheme of EBG resonant transmission is proposed.

6 Surface polaritons in corrugated metamaterials

Mauro Cuevas
Departamento de Física,F.C.EyN,UBA. Buenos Aires, Argentina

We present a detailed analysis of the excitation of surface polaritons on one dimensional wire gratings made of metamaterials. Extraordinary transmission, intimately related to the excitation of surface polaritons, is found for gratings illuminated by both s-polarized and p-polarized incident waves. Particular attention is paid to analyze and compare electromagnetic responses in two kinds of regimes: a) those where the material of the wires has a transmissive behavior and b) those where this material has a totally reflecting behavior.

7 Cherenkov emission of terahertz surface plasmon polaritons from a superluminal optical spot on a structured metal surface

Maxim Tsarev
University of Nizhny Novgorod. Nizhny Novgorod, Russia

We propose to launch surface plasmon polaritons at the terahertz frequencies on a periodically structured metal surface by using a femtosecond laser pulse creating a moving spot of nonlinear polarization in the strip of an electro-optic material deposited onto the surface. We calculate the radiated fields and angular-frequency distribution of the radiated energy for two structures one-dimensional grating and two-dimensional array of holes. The proposed technique can be used to perform surface terahertz spectroscopy.

Special Session Room Luneta

Cloaking and transformation electromagnetics

Special session organized by Nader Engheta, University of Pennsylvania, USA
Chair: Willie Padilla, Boston College, USA

14:50 **Transformation optics with metamaterials: A new paradigm for science of light. Keynote talk**
Vladimir Shalaev, Purdue University, USA
W. Cai, Purdue University, USA
A.V. Kildishev, Purdue University, USA
U. Chettiar, Purdue University, USA
V. P. Drachev, Purdue University, USA
H.-K. Yuan, Purdue University, USA

A new paradigm of engineering space for light with transformation optics will be discussed. Metamaterials are expected to open a gateway to unprecedented electromagnetic properties and functionality unattainable from naturally occurring materials, thus enabling a family of new "meta-devices". We review this new emerging field and significant progress in developing metamaterials for the optical part of the spectrum. Specifically, we describe recently demonstrated artificial magnetism across the whole visible, negative-index in the optical range, and promising approaches along with challenges in realizing optical cloaking.

15:30 **Plasmonic cloaking: Fundamentals and novel potential applications. Invited talk**
Andrea Alu, University of Pennsylvania, USA
Nader Engheta, University of Pennsylvania, USA

We present our latest results on cloaking applications using homogeneous plasmonic layers. Following our recent ideas for realizing a cloaking shell capable of drastically suppressing the total scattering of moderately-sized objects, here we investigate potential applications of interest. Possibilities of multi-frequency response and applications for non-invasive probing, reduced antenna coupling and energy extraction are envisioned.

15:50 **Superantenna made of transformation media. Invited talk**
Ulf Leonhardt, University of St Andrews, Scotland
Tomas Tyc, University of St Andrews, Scotland

Based on the ideas of conformal mapping, we propose a device that concentrates all light rays hitting a certain cross section into a single point, thus acting as a ``superantenna''. Other rays pass the device unaffected, so the device is invisible for them.

16:10 **Interaction and finite wavelength effects in cloaking by plasmonic resonance. Invited talk**
Ross McPhedran, University of Sydney, Australia
Nicorovici Nicolae, University of Sydney, Australia
Gerard Tayeb, Insitut Fresnel, France
Stefan Enoch, Insitut Fresnel, France
Graeme Milton, University of Utah, United States
Lindsay Botten, Sydney University of Technology, Australia

In this presentation we will discuss two aspects of electromagnetic cloaking using the mechanism of plasmonic resonance. The first of these is the possibility of combining several cloaking bodies, with the aim of having them collaborating to improve the cloaking action, for example by covering different frequency regions or different spatial regions. We show that such combined cloaking has to be carefully arranged to work, as the general trend is combative rather than collaborative action. Secondly, we consider finite wavelength plasmonic cloaking, and in particular how to overcome the "ostrich effect", where the larger cloaking body hides a smaller body but not itself. We show that to overcome this, both the cloaking body and its target must be smaller than the wavelength by a factor of order ten.

16:30 **Coffee break**

Regular Session Room Ciudadela 1

Metasurfaces and metafilms

Chair: Alexander Feresidis, Department of Electronic and Electrical Engineering, Loughborough University, United Kingdom

14:50 **Complex effective permittivity of carbon loaded dielectric films with printed metallic square rings. Invited talk**
Brian Glover, Los Alamos National Laboratory, USA
Keith Whites, South Dakota School of Mines and Technology, USA
Milo Hyde IV, Air Force Institute of Technology, USA
Michael Havrilla, Air Force Institute of Technology, USA

The X-band complex permittivity of several carbon loaded lossy dielectric films is presented. This effective permittivity is further engineered by printing electrically small, closed metallic rings onto these commercially available sheets. The ability to increase the imaginary part of such a lossy sheet's effective permittivity while simultaneously increasing the real part is experimentally demonstrated and shown to be accurately modeled with a simple approximate effective media formula.

15:10 **Properties of pulses in the layered structure with negative index material slab and two-layered thin film superconductor-nonlinear dielectric**
Mariya Golovkina, Povolzhskaya State Academy of Telecommunication and Informatics, Russia

In this paper the characteristics of nonlinear impulses propagating in waveguide structure containing a negative index material slab and a thin two-layered film superconductor-Kerr nonlinear dielectric is considered. It is demonstrated that the coupling of impulse to the flux-line lattice in thin superconducting film can change its ve-locity significantly.

15:30 **Amorphous glass-coated Fe-Si-B microwires for microwave absorption applications**
Elena Gallego, Universidad Pública de Navarra, Spain
Iñaki Pérez-Landazábal, Universidad Pública de Navarra, Spain
Cristina Gómez-Polo, Universidad Pública de Navarra, Spain
Iñigo Ederra, Universidad Pública de Navarra, Spain
Ramón Gonzalo, Universidad Pública de Navarra, Spain
Giovanni Badini, Instituto de Ciencia de Materiales, Spain
Manuel Vázquez, Instituto de Ciencia de Materiales, Spain

The aim of this paper is to describe the magnetic properties of amorphous glass-coated microwires and their ap-plications in microwave absorbing materials. Fe-rich amorphous glass-coated microwires show excellent soft magnetic properties and a rectangular hysteresis loop (bistable behavior), which makes them interesting for a wide variety of applications. This work focuses on the design of radio-absorbing composites in the GHz range, based on geometrical and compositional parameters of the structure. Experimental results of the performance of a composite made from a dielectric matrix and Fe-Si-B microwire inclusions are reported.

16:10 **Coffee break**

Regular Session Room Ciudadela 2

Terahertz metamaterials
Chair: Ramón Gonzalo, Universidad Pública de Navarra, Spain

14:50 **Polarization-dependent extraordinary optical transmission through Ag film perforated with periodical Archimedean spiral aperture array**
Lawrence Tzuang, National Taiwan University, Taiwan
Chang Yi-Tsung, National Taiwan University, Taiwan
Ye Yi-Han, National Taiwan University, Taiwan
Jiang Yu-Wei, National Taiwan University, Taiwan
Wu Yi-Ting, National Taiwan University, Taiwan
Lee Si-Chen, National Taiwan University, Taiwan

The polarization-dependent extraordinary optical transmission through a silver film perforated with Archimedean spiral-hole arrays was investigated. This effect comprised of surface plasmon resonances (SPR) and spiral resonances (SR) allows 45% transmission of radiation at a wavelength of 80 μm with only 1 μm gap between adjacent metal wires. More evidence on the existence of SPRs and SRs were found by measuring the dispersion relation of transmission through oblique incidence. This typical chiral structure shows great polarization dependence with a shift of SR wavelength up to 13 μm and a slight shift of the SPR modes which is very sensitive to the geometry of the structure.

15:10 **Left-Handed Metamaterial based on elliptical subwavelength apertures arrays for THz applications**
Eric Lheurette, IEMN, France
Jorge Carbonell, ITEAM, Spain
Charles Croënne, IEMN, France
Didier Lippens, IEMN, France

We present a design of Left-Handed Metamaterial for operation in the THz frequency domain. The structure uses metallic thin films periodically patterned with subwavelength apertures stacked between low loss di-electric spacer layers. The influence of periodicity along the lateral directions (normal to the incident wave vec-tor) is studied via an eigenmode approach in order to derive the dispersion. These results are completed by an analysis of complex transmission spectra through finite dimension structures. It is shown that the use of elliptical apertures increases the transmission level close to unity around 500 GHz with 10 % relative bandwidth.

15:30 **Terahertz metamaterials composed of TiO2 cube arrays**
Kyoji Shibuya, Osaka University, Japan
Keisuke Takano, Osaka University, Japan
Naoki Matsumoto, Murata Manufacturing Co., Ltd., Japan
Keita Izumi, Tohoku University, Japan
Hiroshi Miyazaki, Tohoku University, Japan
Yoji Jimba, Nihon University, Japan
Masanori Hangyo, Osaka University, Japan

We investigate dielectric metamaterials composed of TiO2 cube arrays. The effective electromagnetic parameters are retrieved from complex transmission and reflection coefficients of the sample obtained by terahertz time domain spectroscopy (THz-TDS). The retrieved parameters show the negative permeability and permittivity around 0.28 THz and 0.38 THz, respectively. The negative refractive index metamaterials can also be realized by combining two sets of TiO2 cubes with appropriate sizes.

15:50 **Near-field amplitude and phase mapping of infrared surface polaritons**
Andreas Huber, Max-Planck-Insitute of Biochemistry, Germany
N. Ocelic, Nano-Photonics Group, Max-Planck-Insitute of Biochemistry, Germany
Rainer Hillenbrand, Nanooptics Laboratory, CIC NanoGUNE, Donostia - San Sebastian, Spain

We demonstrate that propagation, interference and focussing of mid-infrared surface polaritons can be studied with extreme subwavelength-scale spatial resolution by scattering-type scanning near-field optical microscopy (s-SNOM). Pseudoheterodyne interferometric detection thereby yields amplitude and phase images which also allow real space measurements of the complex-valued surface polariton dispersion. The studied sample is a polar crystal (SiC) on which propagating surface phonon polaritons (SPs) are excited by metal antenna structures. Owing to the wavelength-independent resolution of s-SNOM, our method could find interesting applications in characterizing the wavefront evolution of surface polaritons on structured surfaces, metama-terials and photonic devices in the visible to terahertz spectral regime.

16:10 **Cherenkov emission of terahertz surface plasmon polaritons from a superluminal optical spot on a structured metal surface**
Maxim Tsarev, University of Nizhny Novgorod, Russia
Michael Bakunov, University of Nizhny Novgorod, Russia

We propose to launch surface plasmon polaritons at the terahertz frequencies on a periodically structured metal surface by using a femtosecond laser pulse creating a moving spot of nonlinear polarization in the strip of an electro-optic material deposited onto the surface.

16:30 **Coffee break**

Special Session Room Luneta

Extreme metamaterials

Special session organized by Vladimir Shalaev, Purdue University, USA
Chair: Vladimir Shalaev, Purdue University, USA

16:50 **Metamaterial effective material parameters: Are two tensors enough? Keynote talk**
Sergei Tretyakov, Helsinki University of Technology, Finland
Constantin Simovski, Helsinki University of Technology, Finland

We discuss the effective medium modelling of artificial materials where spatial dispersion effects are essential, for instance artificial magnetic metamaterials formed by split rings or dual-bar particles. We show that the artificial magnetic response is a spatial-dispersion effect of the second order. Since there exist other effects of the same order or stronger, we conclude that in many situations it is not possible to properly describe the composite in terms of only its effective permittivity and permeability: more parameters are necessary. We conclude with some examples of effectivemedium description for various geometries and excitations of metamaterial inclusions.

17:30 **Extreme control of light with metamaterials. Invited talk**
Alexander Kildishev, Purdue University, USA
Wenshan Cai, Purdue University, USA
Uday Chettiar, Purdue University, USA
Evgenii Narimanov, Purdue University, USA
Vladimir Shalaev, Purdue University, USA

The presented conceptual work is focused on optical metamaterials designed for extreme control over the flow of light at both the nano- and macroscopic scales. These extreme metamaterials incorporate the innovative theories of transformation optics (TO) and the hyperlens, and they are pertinent to the important areas of optical cloaking, sub-wavelength sensing, super-resolution imaging, and magnifying hyperlenses. Increasing attention has been applied to creating an electromagnetic cloak of invisibility based on various schemes, including dipolar scattering cancellation and TO, but practical applications of TO go far beyond just cloaking. TO theory, built on fundamental variational principles, allows the control of light in an extreme and ultimate manner by providing a general recipe for obtaining complex spatial distributions of anisotropic permittivity and permeability. Using these distributions, a "curvilinear" optical space is made, creating a channel for the desired flow of light.

17:50 **Transition metamaterials. Invited talk**
Natalia Litchinitser, The State University of New York at Buffalo, USA
Andrei Maimistov, Moscow Engineering Physics Institute, Russian Federation
Ildar Gabitov, University of Arizona, USA
Roald Sagdeev, University of Maryland, College Park, USA
Vladimir Shalaev, Purdue University, USA

We predict resonant enhancement of electromagnetic (EM) waves propagating at oblique incidence in metamaterials, with dielectric permittivity and magnetic permeability gradually changing from positive to negative values. Our study reveals several unique features of the resonant enhancement in "positive-to-negative transition" metamaterials that are likely to enable a variety of applications in microwave, terahertz, and optical frequency ranges, including sub-wavelength transmission, novel antennas, and low-intensity nonlinear optical devices.

18:10 **Non-local effects in strongly-interacting plasmons. Invited talk**
Javier Garcia de Abajo, CSIC, Spain

Non-local effects in the optical response of noble metals are shown to produce significant blueshift and near-field quenching of plasmons in nanoparticle dimers, nanoshells, and thin metal waveguides. Compared with a local description relying on the use of frequency-dependent dielectric functions, we predict resonance shifts as large as 10% and field-intensity reduction of an order of magnitude at inter-particle distances or metal thicknesses below 2 Å. A roadmap is presented to design plasmon resonances in nanometer metallic elements with application to optical antennas and improved photovoltaic, light-emitting, and sensing devices.

18:30 **Closing ceremony** (Room Luneta)

Regular Session Room Ciudadela 1

Fundamental theory
Chair: Ismo Lindell, Helsinki University of Technology, Finland

16:50 **Topological description of metamaterials**
Michael Zedler, TU Munich, Germany
Susanne Hofmann, TU Munich, Germany
Uwe Siart, TU Munich, Germany
Peter Russer, TU Munich, Germany

In this contribution we show that space-discretising numerical schemes can be considered the unifying framework for a theory of metamaterials. Implementations of these schemes lead to either Drude or Lorentz dispersion with their immanent properties and hence limitations. Next, this perspective on metamaterials being physical implementations of space-discretising schemes is extended to 2D and 3D.

17:10 **Triple-spacetime metamaterials**
Luzi Bergamin, European Space Agency, Netherlands

In this paper an extension of the coordinate transformation approach to artificial media as introduced by Pendry and Leonhardt is presented. It is based upon the fact that two different transformations acting on (E, B) and (D, H), resp., establish a symmetry of Maxwell's equations, but change the constitutive relation. This allows a geometric interpretation of non-reciprocal (epsilon and mu not symmetric) and so-called indefinite media.

17:30 **Uniaxial IB (axion-skewon) medium interface as isotropic soft-and-hard surface**
Ismo Lindell, Helsinki University of Technology, Finland
Ari Sihvola, Helsinki University of Technology, Finland

The class of uniaxial IB media involving 5 medium parameters is defined as a special case of the previously defined class of more general IB (axion-skewon) media. The problem of plane-wave reflection from and transmission through the interface of a uniaxial IB-medium half space is analyzed. It is shown that, for general values of the medium parameters, the reflection is similar to that from a soft-and-hard surface (SHS). However, unlike the anisotropic SHS boundary, the uniaxial IB interface is isotropic in the plane of the interface, thus defining a novel class of electromagnetic boundaries.

17:50 **Using antiunitary group elements for scattering problems with magnetic media**
Victor Dmitriev, Federal University of Para, Other

In this paper we demonstrate how to apply the magnetic group symmetry and the theory of irreducible corepresentations to scattering problems with magnetic media.

18:30 **Closing ceremony** (Room Luneta)

Regular Session Room Ciudadela 2

Optical Metamaterials III
Chair: Anatoly Zayats, The Queen's University of Belfast, United Kingdom

16:50 **Some backward wave structures for slow light and light wheels. Invited talk**
Sailing He, Zhejiang University, China
Yi Jin, Zhejiang University, China
Jinlong He, China Jiliang University, China
Yuqian Ye, Zhejiang University, China

Some slow light and light wheels based on some backward wave structures are considered. A slow waveguide is designed by inserting a dielectric slab in a two-dimensional periodic structure with a negative effective refractive index. A linearly tapered waveguide is also used to study if different frequency components of light can be trapped at different positions of waveguide. A light wheel is also formed by using a conventional waveguide and a one-dimensional periodic waveguide. This composite waveguide can also be used to obtain a low group velocity and act as a cavity of high quality factor.

17:10 **Electric and magnetic resonances in arrays with elements made of tightly coupled silver nanospheres. Invited talk**
Sergiy Steshenko, University of Siena, Italy
Andrea Vallecchi, University of Siena, Italy
Filippo Capolino, University of Siena, Italy

We analyze metamaterials whose constitutive unit cell consists of a single, a pair, or a cluster of four nanospheres. Reflection, transmission and absorption characteristics show that the so called magnetic resonance, associated with antisymmetric modes or loop modes, significantly affects the electromagnetic response of arrays made of these constitutive cells.

17:30 **Synthesis and optical properties of Au nanorods oriented parallel to each other**
Koichi Awazu, AIST, Japan
Xiamin Wang, AIST, Japan
Makoto Fujimaki, AIST, Japan
Junji Tominaga, AIST, Japan
Hirohiko Aiba, Waseda University, Japan
Shinji Fujii, Waseda University, Japan
Yoshimichi Ohki, Waseda University, Japan
Tetsuro Komatsubara, University of Tsukuba, Japan

Here we report that elongated Au nanoparticles oriented parallel to each other can be synthesized in SiO2 by irradiation by 110-MeV Br10+. The major to minor axis ratio is increased with increasing fluence of the ion beam. The peak of the plasmon resonance was shifted to the blue as the major to minor axis ratio increased. The ex-perimental data matched the theoretical examination.

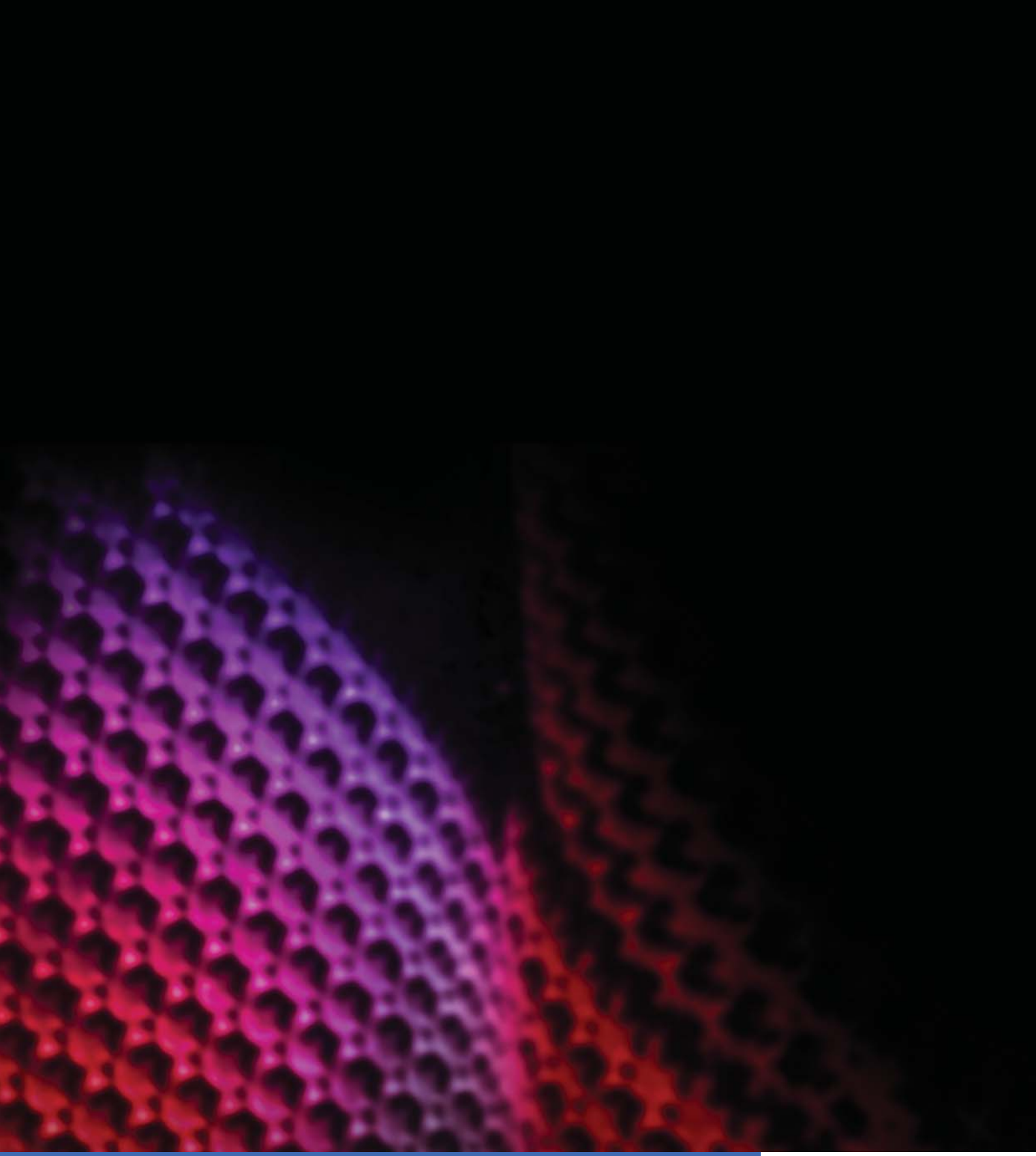
17:50 **Manipulate light propagations and polarizations through meta-materials**
Lei Zhou, Fudan University, China

Meta-materials are artificial electromagnetic (EM) materials composed by subwavelength local resonance structures of electric and/or magnetic type, and thus possess arbitrary values of permittivity and permeability dictated by such resonance structures. Many novel EM properties, such as the negative refraction and the superlensing effect, were predicted or discovered based on meta-materials. In this talk, we review our recent efforts in understanding the exotic EM properties of meta-materials, and employing such novel materials to manipulate the light propagations and polarizations. The results include how to manipulate EM wave polarizations, including a complete polarization conversion, by using meta-materials, and how to manipulate EM wave transmissions through a waveguide through inserting different types of anisotropic meta-materials.

18:10 **Electromagnetic properties in a plasma photonic crystal and its dispersion relation in complex wave number space**
Teruki Naito, Kyoto University, Japan
Osamu Sakai, Kyoto University, Japan
Kunihide Tachibana, Kyoto University, Japan

In this paper, the electromagnetic properties in a plasma photonic crystal are investigated theoretically and experimentally in the frequency range where plasmas act like a lossy and metallic material. As a result, we find that it is important to consider the dispersion relation in a complex wave number.

18:30 **Closing ceremony** (Room Luneta)



METAMATERIALS´2008

Pamplona 21-26 September

upna Universidad Pública de Navarra
Nafarroako Unibertsitate Publikoa