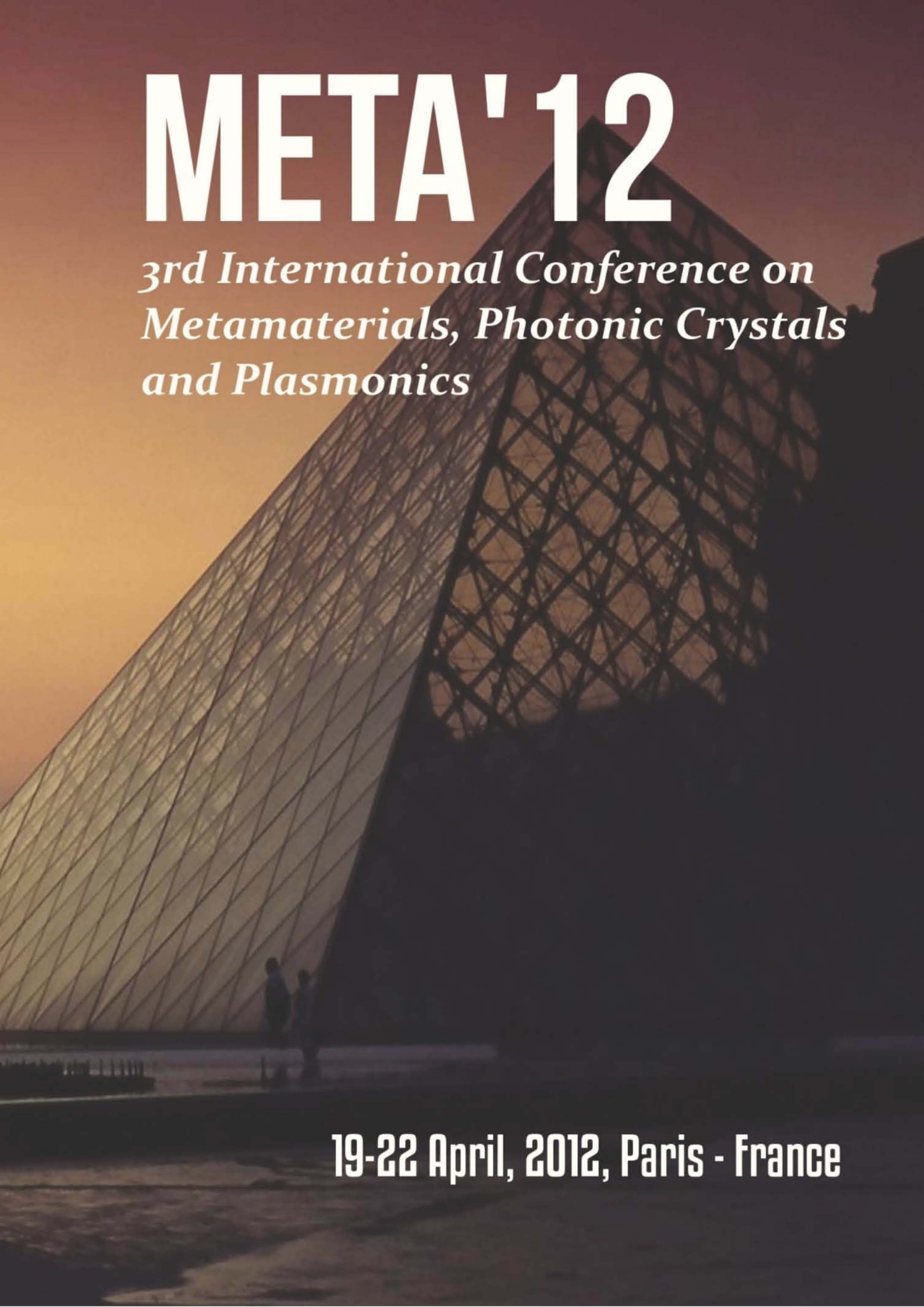

META'12

3rd International Conference on Metamaterials, Photonic Crystals and Plasmonics

19-22 April, 2012, Paris - France

META'12, Paris – France

3rd International Conference on Metamaterials, Photonic Crystals and Plasmonics

Edited by

Saïd Zouhdi | Paris-Sud University, France
&
Xavier Begaud | Télécom ParisTech, France

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Venue

META'12 will be held on April 19-22, 2012, at Télécom ParisTech, Paris, France.

Social Events

Conference Banquet
The Conference Banquet will be held at the famous Train Bleu in the Gare de Lyon on Saturday April 21st. This restaurant opened as part of the Grand Exposition in 1900 and the atmosphere is evocative of that period of great scientific progress and general optimism known worldwide as the *Belle Époque*. The cuisine is traditional French with modern touches and the decor includes the works of major artists, depicting contemporary events and the various destinations for travellers on the Paris-Lyon-Mediterranean Railway.

Guidelines for Presenters

Oral Presentations

Each session room is equipped with a stationary computer connected to a LCD projector. Presenters must load their presentation files in advance onto the session computer. Technician personnel will be available to assist you.

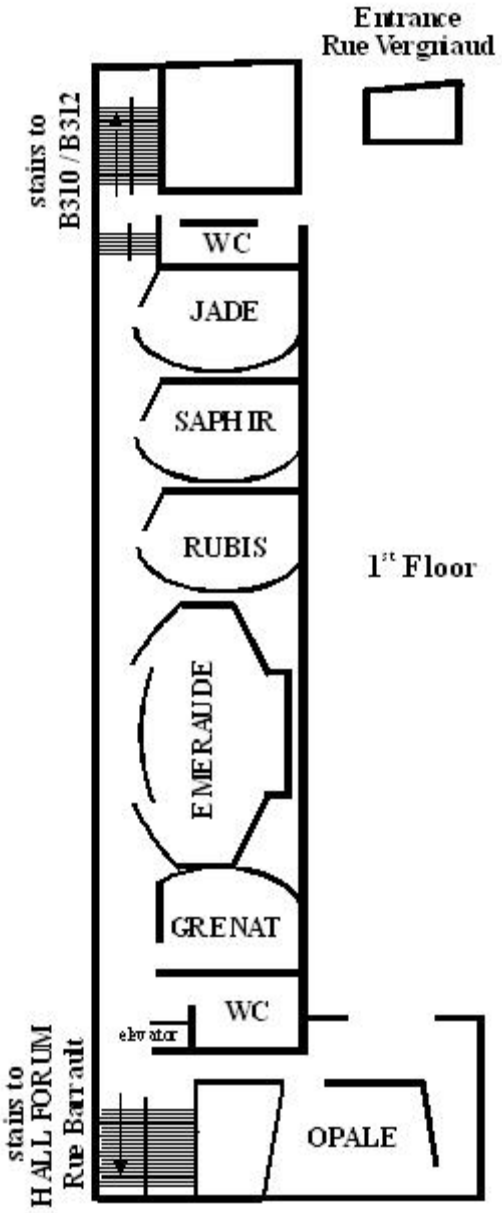
Scheduled time slots for presentation are 20mn for regular and invited presentations, 45mn for plenary talks, and 40mn for keynote talks, including questions and discussions. Presenters are required to report to their session room and to their session Chair at least 15 minutes prior to the start of their session.

The session chair must be present in the session room at least 15 minutes before the start of the session and must strictly observe the starting time and time limit of each paper.

Poster Presentations

Presenters are requested to stand by their posters during their session. One panel will be available for each poster. Pins or thumbtacks are provided to mount your posters on the board. All presenters are required to mount their papers one hour before the session and remove them at the end of their sessions.

FACILITY MAPS



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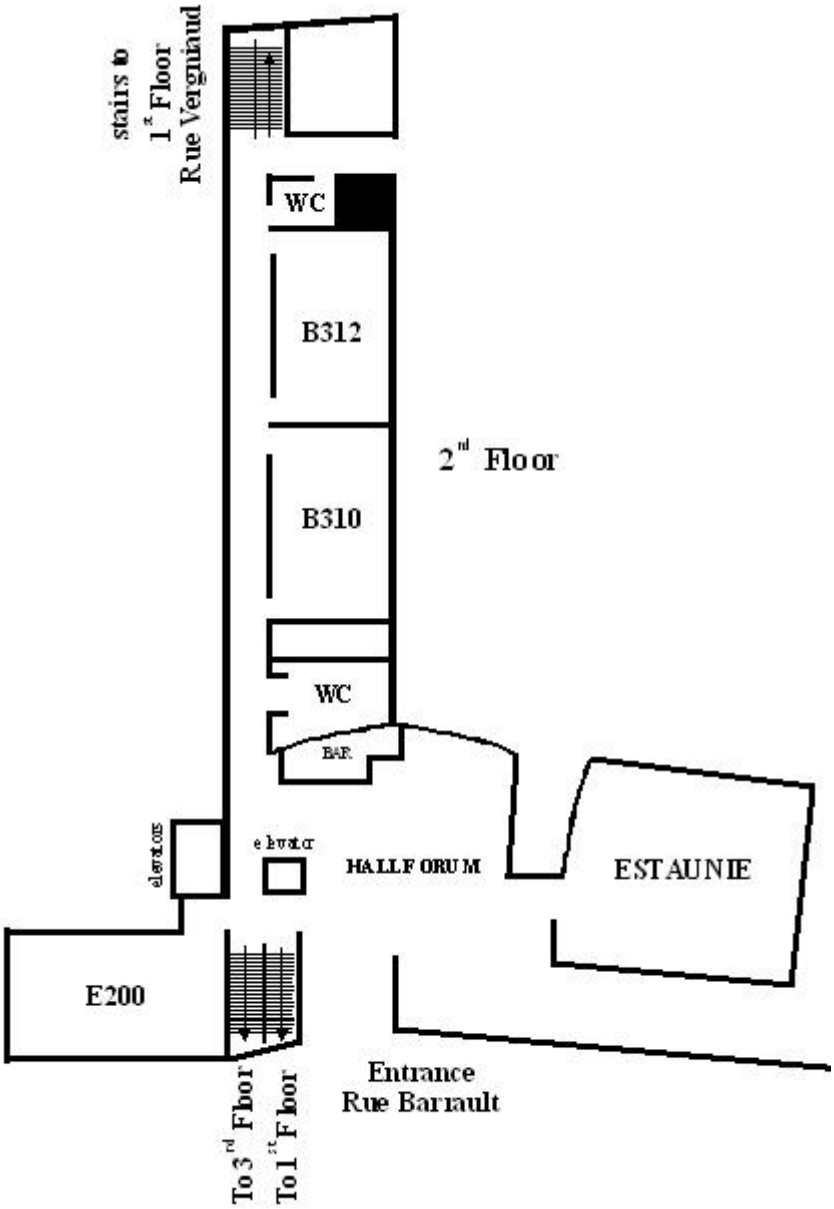

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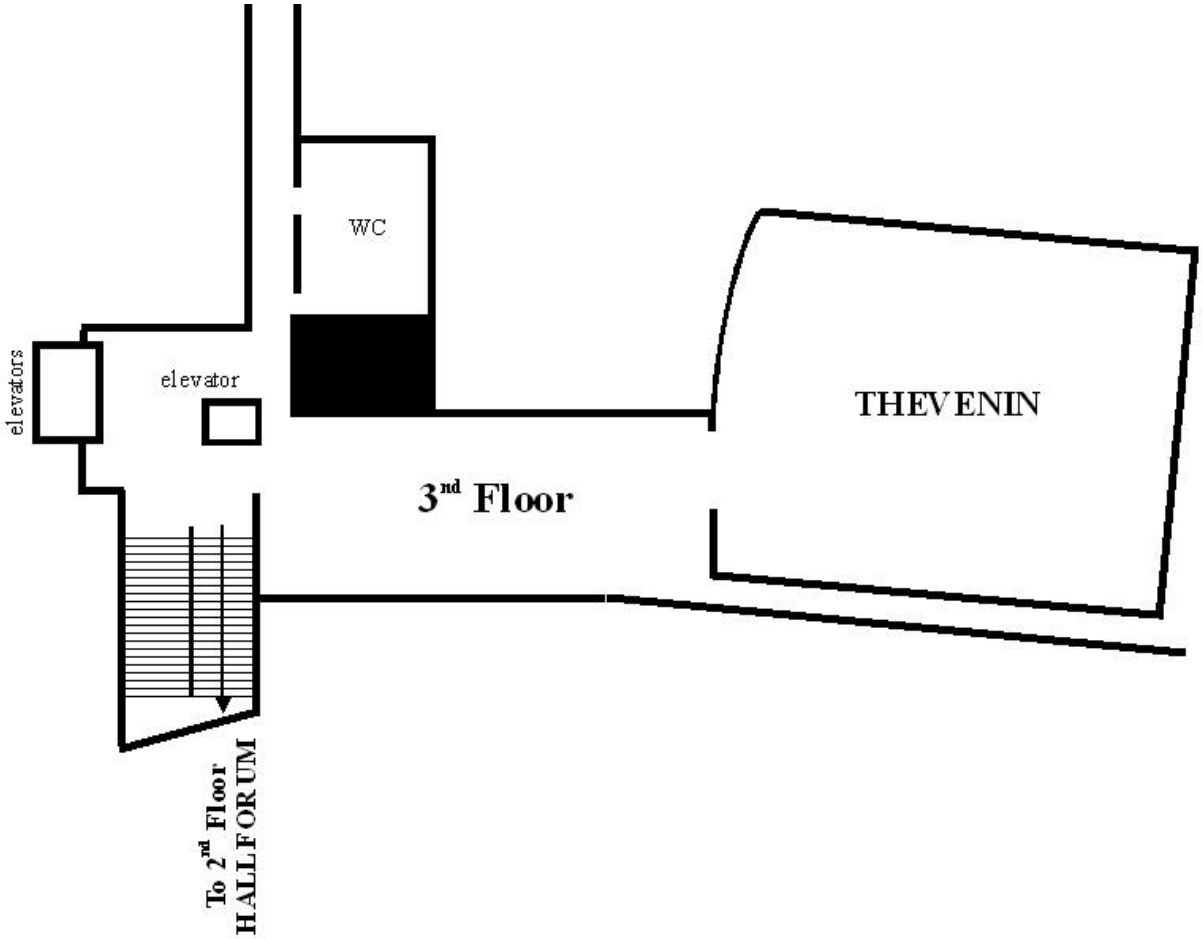
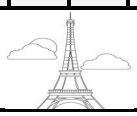
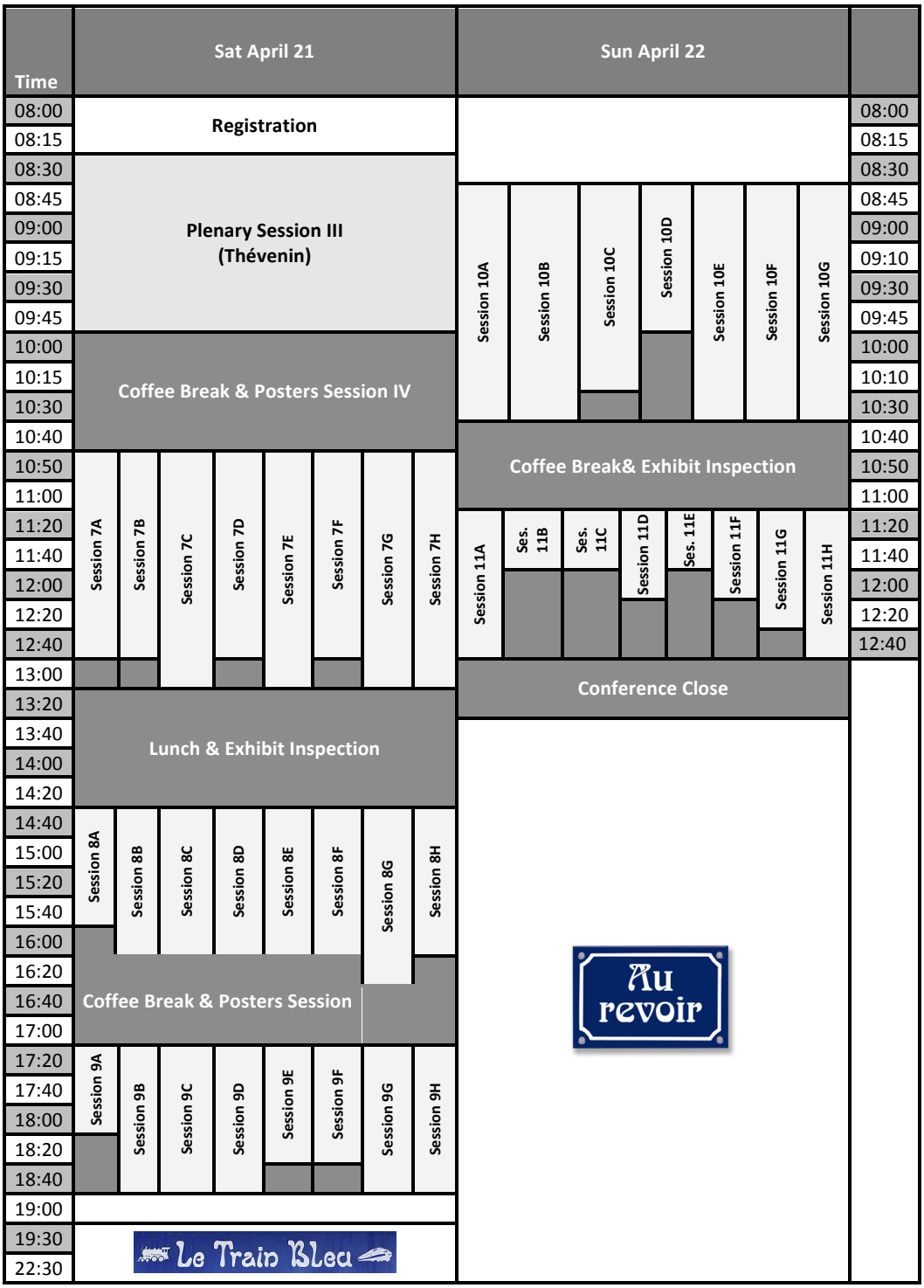


META'12 - PROGRAM OVERVIEW (1/2)

Time	Wed April 18	Thu April 19	Fri April 20	Time
08:00	Registration (15:00 – 18:30)	Registration	Registration	08:00
08:15				08:15
08:30			Plenary Session II (Thévenin)	08:30
08:45		Opening Ceremony (Thévenin)		08:45
09:00				09:00
09:15		Plenary Session I (Thévenin)		09:15
09:30				09:30
09:45				09:45
10:00			Coffee Break & Poster Session II	10:00
10:30				10:30
10:40		Coffee Break		10:40
10:50				10:50
11:00		Session 1A	Session 4A	11:10
11:20		Session 1B	Session 4B	11:30
11:40		Session 1C	Session 4C	11:50
12:00		Session 1D	Session 4D	12:10
12:20		Session 1E	Session 4E	12:30
12:40		Session 1F	Session 4F	12:50
13:00		Session 1G	Session 4G	13:10
13:10			Session 4H	13:20
13:30		Lunch & Exhibit Inspection	Lunch & Exhibit Inspection	13:30
13:45				13:45
14:00				14:00
14:20				14:20
14:40		Session 2A	Session 5A	14:40
15:00		Session 2B	Session 5B	15:00
15:20		Session 2C	Session 5C	15:20
15:40		Session 2D	Session 5D	15:40
16:00		Session 2E	Session 5E	16:00
16:20		Session 2F	Session 5F	16:20
16:40		Session 2G	Session 5G	16:40
17:00		Coffee Break & Posters Session I	Session 5H	17:00
17:20		Session 3A	Coffee Break & Posters Session III	17:20
17:40		Session 3B	Session 6A	17:40
18:00		Session 3C	Session 6B	18:00
18:20		Session 3D	Session 6C	18:20
18:40		Session 3E	Session 6D	18:40
19:00		Session 3F	Session 6E	19:00
19:30		Session 3G	Session 6F	19:30
22:00			Session 6G	22:00
			Session 6H	



META'12 - PROGRAM OVERVIEW (2/2)



TECHNICAL PROGRAM

Wednesday 18th April, 2012

15:00 - 18:30 ***Lobby***

Conference Registration

Thursday 19th April, 2012

08:30 - 17:30 ***Lobby***

Conference Registration

08:30 - 09:00 ***Thévenin***

Opening Ceremony

09:00 - 10:30 ***Thévenin***

Plenary Session I

Chaired by: Nikolay Zheludev

09:00 : Plenary talk
Three-dimensional complex plasmonic structures: Chirality, Coupling, and Sensing Applications
Harald Giessen

We are going to present fabrication methods for the manufacturing of 3D metamaterials. We are investigating their coupling properties and the resulting optical spectra. Hybridization of the electric as well as the magnetic resonances allows us to easily understand the complex optical properties. Lateral as well as vertical coupling can result in Fano-resonances and EIT-like phenomena. These phenomena allow construction of novel LSPR sensors with a figure of merit as high as five. Nanooptics can also aid antenna-enhanced hydrogen sensing and sensitive nonlinear optical nanoantenna-enhanced pump-probe experiments that detect mechanoplasmonic oscillations. Additionally, more complex structures can act as 3D plasmon rulers. By tuning from near-field to far-field coupling, additional phase shifts are introduced, and the classical analog of plasmonic electromagnetically induced absorption (EIA) is observed.

09:45 : Plenary talk
The Two Conflicting Narratives of Metal-Optics
Eli Yablonovitch

There are two conflicting narratives of Electromagnetics in metals: 1) The microwave circuit narrative in which metals, distributed capacitors, and distributed inductors function together in a high frequency circuit, albeit as distributed components. Here there is a rich tradition of various electromagnetic functions, including the antenna function. 2) This is countered by the optical-plasmonic narrative, in which metallic electromagnetics is thought to be dominated by plasmons, electromagnetic normal modes in which the inertia of the electrons plays a major role. Given that Electromagnetics is generally invariant with frequency, it is not clear why there need to be two separate narratives. Is metal-optics simply the high frequency version of microwave electromagnetics? There is great benefit in unifying our understanding of the two regimes of metallic electromagnetics, and to distinguish the occasional role of electron inertia. We find that some of the most important metal-optics functions are best understood as extensions of microwave electromagnetics: Antennas, for example, have been thoroughly under-estimated, and are well-poised to change the rules of optical physics.

Coffee Break and Exhibit Inspection

10:30 - 11:00

11:00 - 13:00 ***Thévenin***

1A: Photonic crystals I

Chaired by: Masaya Notomi

11:00 : Keynote talk
Recent Progress in Photonic Crystals - From Dynamic Control to Solar Cells -
Susumu Noda

I will review the recent progress in photonic crystals and their device applications, where 3D crysals, 2D crystals, dynamic control, thermal emission control, etc, will be discussed.

11:40 : Couplonics Of Cyclic Ternary Systems: From Coupled Periodic Waveguides To Discrete Photonic Crystals
Yann G. Boucher

In the context of coupled periodic waveguides, couplonicsrefers to the rigorous equivalence between continuous wave coupling and localized interactions. We extend it here to a cyclic ternary system, looked upon as the simplest discrete photonic crystal with actual periodic boundary conditions. A linear decomposition on a super mode basis enables one to reduce the original six-wave problem to three independent two-wave distributed Bragg reflectors (or 1D PC).

12:00 : Lifetime distribution of spontaneous emission from quantum dots in three-dimensional woodpile photonic crystals
Xue-Hua Wang, J. F. Liu, H. X. Jiang, C. J. Jin

Spontaneous emission lifetime distribution in the basic unit cell or on a plane of the excited quantum dots embedded in woodpile photonics crystals with low refractive index contrast are investigated. It is found that the spontaneous emission lifetime distribution strongly depends on the position and transition frequency of the emitters, and has the same symmetry as that of the unit cell. Furthermore, it is revealed that the polarization orientation of the emitters has significant influence on the lifetime distribution. These results may be supplied in probing the lifetime distribution or orientation-dependent local density of states in future experiments.

12:20 : Complex photonic bands in one-dimensional photonic crystals with periodic gain-loss modulation
Jesus Manzanares, Efrain Urrutia-Banuelos, Yohan Yasdid Rodriguez-Viveros, Damian Moctezuma-Eniquez, Paola Castro-Garay

We have calculated the photonic bands in a periodically modulated gain-loss photonic crystal. We have found that the dispersion relation predicts the existence of a new regime of photonic band gaps due to phenomena of absorption-gain interference. The origin of these gaps is a pure result of the periodic variation of the refractive index imaginary part (ni) The photonic structure shows an odd behavior as long as ni increases. However, we have found that the complex band structure is an appropriate resource to describe the electromagnetic fields in periodic gain-loss structures.

12:40 : Fabrication of photonic crystal structures combined with plasmonic structures
Max Schoengen, Jürgen Probst, Bernd Löchel

This article is about the fabrication and characterization of photonic crystal cavities as well as the embedding of plasmonic elements for the realization of plasmonic-photonic hybrid structures. We report on the fabrication process of these hybrid structures which were already postulated in previous studies. In this process we use the technique of overlay-exposure as part of the electron beam lithography for embedding gold structures in SiN-crystal-cavities. We found out that our positioning accuracy is below our detection limit of 1nm. The accuracy of our structuring is below 25nm. The plasmonic-photonic hybrid structures have been analyzed by photoemission electron microscopy and showed highly non-linear effects.

11:00 - 13:00 ***B310***

1B: Analytical and numerical modelling of complex materials and structures I

Chaired by: Le-Wei Li

11:00 : Biaxial Anisotropy: A Survey of Interesting Optical Phenomena in Graded Media
Aaron J. Danner, Alireza Akbarzadeh

Metamaterial devices, or any optical instruments designed from transformation optics almost always require tensor expressions for the permittivity and/or permeability. An experimental implementation is usually practical for only one

polarization as a result of this complexity. In this presentation, it will be shown that unusual and interesting behavior can result, however, when we allow general anisotropy in gradient index devices. It is possible, for example, for there to be four (not three) independent optical functions in a spherically symmetric device. Conical refraction in gradient index devices will also be discussed. Phenomena will be explained with photorealistic illustrations.

11:**20 : Analytical approach for CRLH based antennas design**
AitaI Thior, Anne-Claire Lepage, Xavier Begaud, Olivier Maas

This paper presents an analytical model for CRLH (Composite Right-Left Handed) antennas preliminary design. Objective of this work is to have a tool to estimate quickly the scattering and radiating characteristics of these CRLH structures. Afterwards, antenna designer can use these sets of parameters to converge to the desired specifications with a full 3D simulator.

11:**40 : Different configurations of metamaterials coupled with RF coil for MRI applications**
Mohand Said Khennouche, Frédérique Gadot, Benoît Belier, André de Lustrac

In this paper the effect of coupling metamaterial cells with a coil to achieve Magnetic Resonance Imaging (MRI) is investigated. Both an array and a single spiral-shaped metamaterial are associated to the coil antenna. The goal is to increase the sensitivity of the whole system and to improve the homogeneity of the RF magnetic field pattern. The spiral-shaped metamaterial associated to the antenna gave very promising results in simulation. We are currently fabricating a sample to confirm the results of the simulations.

12:**00 : Kilohertz magnetic field focusing in a pair of metallic periodic-ladder structures**
Debasish Banerjee, J. Lee, E. M. Dede, H. Iizuka

We have shown that when a pair of metallic periodic-ladder structures placed with a central gap, the normally incident magnetic field is focused on a spot of 3 mm (0.6 X 10-5 free space wavelength) full width at half maximum at a 1 mm distance away at 600kHz. The ladder structures are designed by exploiting the curl of the induced current at each unit cell in the periodic structure. In this talk, we will discuss details of analytical and numerical calculation results and progress towards experimental confirmation. This investigation paves the way for kilohertz magnetic field manipulations.

12:**20 : Study of a microstrip antenna on anisotropic metamaterials**
Cristhianne Vasconcelos, Adaildo D'Assunção, Maria Rosa Albuquerque, Gabriela Freitas

In this work, annular ring microstrip antennas (ARMSA) on metamaterial substrates are modeled and analyzed using full-wave analysis in conjunction with Ansoft HFSS. The influence of the permeability tensor on the resonant characteristics of the antenna is considered. Numerical results are presented as function of the metamaterial properties and antenna structural parameters.

12:**40 : Resonances of Circular, Square and Hexagonal Nano-Antennas**
Arnold McKinley, Tom White, Sudha Mokkapati, Ivan Maksymov, Kylie Catchpole

Meta-materials can exhibit highly unusual optical properties such as negative refractive indices, because of the resonances exhibited by their artificial atoms. Typically these are circular or square metallic loops that behave like resonant LC circuits in electronics. Loop and material characteristics provide the inductance and a small gap somewhere in the loop provides the capacitance. Such resonators have been demonstrated at frequencies ranging from themicro-wave (MW) region to the optical region. Some have circumferences that are small with respect to wavelength, but not all of them. A systematic study of the resonances of single-turn circular wire, circular disk, square disk and hexagonal disk loop antennas with one gap would help coalesce this dispersed knowledge into a cohesive whole. This current study relies on numerical simulations using gold as the base metal of construction. Resonances from the MW region through the lower THz regime into the optical region are examined in some detail for each geometrical shape, and are found to change both in position and in intensity dependent on their geometrical and material characteristics.

11:00 - 13:00 ***B312***

1C: Plasmonics and nanophotonics I

Chaired by: Anatoly Zayats

11:00 : Optimal structure for Resonant THz Detection of Plasmons-Polaritons in the 2D quantum wells
Anne-Sophie Grimault-Jacquin, Lei Cao, Frédéric Aniel

We investigate terahertz plasmon-polariton (PP) resonances for hetero-structures (AlGaN/GaN, SiGe/ Si/SiGe, AlGaAs/ GaAs and InAlGaN/ GaN) with grating coupler in order to find the optimal structure. We show by a parametric study (influence of geometry, temperature...) that the resonances are tunable in frequency allowing to a control of the terahertz detection and InAlGaN/ GaN present the highest PP resonances.

11:20 : Highly Efficient Surface Plasmon Launching and Decoupling
Alexandre Baron, Eloïse Devaux, Jean-Claude Rodier, Jean-Paul Hugonin, Emmanuel Rousseau, Cyriaque Genet, Thomas Ebbesen, Philippe Lalanne

We report on the design and experimental observation of a highly efficient unidirectional surface plasmon polariton (SPP) launcher composed of eleven grooves, each with distinct depths and widths. We show that under normal illumination by a focused Gaussian beam, unidirectional SPP launching with an efficiency of at least 52% is achieved experimentally with a compact antenna. Reciprocally, we report that the same device can efficiently convert SPPs into a highly directive light beam emanating perpendicularly to the sample.

11:40 : Palladium-Based Plasmonic Hydrogen-Sensing: Perfect Absorbers and Antenna-Enhanced Geometries
Andreas Tittl, Patrick Mai, Richard Taubert, Daniel Dregely, Jens Dorfmüller, Christian Kremers, Dmitry Chigrin, Harald Giessen

We present studies on two palladium-based plasmonic hydrogen sensing geometries: perfect absorbers and nanoantenna-enhanced systems. We will present experimental results for a perfect absorber hydrogen sensor working in the visible wavelength range that allows for the reliable and reproducible detection of hydrogen concentrations down to 0.5% in nitrogen. Furthermore, we will show how previously published experimental results on nanoantenna-enhanced hydrogen-sensing can be modeled and understood by including the often neglected effect of palladium lattice expansion in our numerical (FEM) calculations.

12:00 : Invited talk
Low-diffraction beaming in plasmonic crystals
V. A. Podolskiy, S. Inampudi, I. Smolyaninov

We analyze the propagation of electromagnetic modes guided by the periodic plasmonic structures, such as those experimentally studied in Science 317, 1699 (2007). Full-wave solutions of Maxwell equations are used to numerically derive the dispersion of the guided modes. The validity of low-scattering approximation is analyzed and analytical expression for the dispersion in low-scattering periodic plasmonic structures is derived. For selected frequency regions that are determined by the geometry, diffraction of guided modes is strongly suppressed, leading to formation of low-diffraction beams, previously observed in experiments.

12:20 : Classical analog of electromagnetically induced absorption in plasmonics
Richard Taubert, Mario Hentschel, Jürgen Kästel, Harald Giessen

The ability to manipulate the phase shift between two coupled plasmonic resonances in a controlled fashion has been unavailable up to now. Here we present a strategy to overcome this limitation by employing the benefits of near-field coupling on the one hand and retardation effects due to far-field coupling on the other hand. We theoretically and experimentally demonstrate that in the intermediate regime the coupling of a broad dipolar to a narrow dark quadrupolar plasmon resonance is possible while simultaneously allowing for a retardation-induced phase shift. This leads to constructive interference and enhanced absorption. The observed phenomena can thus be termed classical analog of electromagnetically induced absorption.

12:40 : Molecular detection with multi-functional plasmonic metamaterial
Cheng Kuang Chen, Shun Wang and Ta Jen Yen

A sensitive molecule detector is realized by strong plasmon-vibration coupling effects between functional groups and plasmonic meta-surfaces. Various plasmonic meta-surfaces are fabricated by a series of asymmetric spilt ring resonators (ASRRs) arrays that inherent strong localized plasmonic infrared field to enhance the spectral signature of molecular vibrations. The fabricated ASRRs structures exhibit multiple reflectance peaks, whose spectral positions are designable

by our standing-wave plasmonic resonance model, providing a design rule for this multi-mode plasmon-vibration sensor (MPVS). By employing unpolarized light, our experiment results perform significant plasmon-vibration resonances in the ultra wide band between subradiant mode and superradiant mode resonances. We further manifest that the superradiant modes possess greater sensitivity associated with stronger localized electromagnetic field than the subradiant mode. These unique merits enable the ASRR-based sensor a multi-functional biosensor and a potential label-free imaging devices

11:00 - 13:00 ***Saphir***

1D: Acoustic metamaterials I

Chaired by: Jensen Li and Johan Christensen

11:00 : Acoustic Resonators for Far Field Control of Sound on a Subwavelength Scale
Geoffroy Lerosey, Fabrice Lemoult, Mathias Fink

In this talk we will prove experimentally that broadband sounds can be controlled and focused at will on a subwavelength scale using acoustic resonators. We demonstrate our approach in the audible range with soda cans, that is, Helmholtz resonators, and commercial computer speakers. We show that diffraction limited sound fields convert efficiently into sub-diffraction modes in the collection of cans that can be controlled coherently in order to obtain focal spots as thin as 1/25th of a wavelength in air. We establish that subwavelength acoustic pressure spots are responsible of a strong enhancement of the acoustic displacement at focus. Finally we will present initial results of collective modes in arrays of elastic resonators which promise to be interesting candidates for a transposition of the concept to elastic waves.

11:20 : Functionally graded laminated phononic crystals with damages
Mikhail Golub, Chuanzeng Zhang, Sergey Fomenko, Tinh Bui

Elastic wave propagation in functionally graded periodically layered and damaged composites is investigated using the extended transfer matrix method and the boundary integral equation method. Two different models are developed to approximate the damaged layer, namely, a periodic array of cracks and continuously distributed springs in the layer. The focus of this analysis is on the wave transmission and reflection, band gaps, localization and resonance phenomena due to the influences of functionally graded properties and crack-like damages.

11:40 : Invited talk
A quasi two-dimensional acoustic metamaterial with negative bulk modulus
Victor Garcia-Chocano, Roge Gracia, Francisco Cervera, Daniel Torrent, Jose Sanchez-Dehesa

A quasi two-dimensional acoustic metamaterial with negative bulk modulus is proposed, fabricated and experimentally characterized. The structure consists of a two dimensional array of cylindrical boreholes opened to a waveguide. Experiments are performed using a slab of seven layers and the effective parameters are extracted from the measured transmission and reflection spectra. The skin depth is the region with negative modulus is also determined as a function of frequency. The data are well supported by a semi-analytical model based on multiple scattering and by finite elements simulations.

12:00 : Invited talk
Discrete Transformation Elastodynamics
Graeme Milton, Fernando Guevara Vasquez, Daniel Onofrei, Pierre Seppecher

A discrete version of transformation elastodynamics is introduced. This requires a new type of spring, which we call a "torque spring" where the forces at the end of the spring are equal and opposite but not directed in line with the spring. We show how torque springs can be constructed within the framework of linear elastodnamics, neglecting gravity and stability questions. The homogenization of a network of torque springs gives rise to metamaterials in which infinitesimal rotations cause stresses and stresses are not generally symmetric: the effective elasticity tensor does not satisfy the usual minor symmetries. We also construct a discrete model in which for linear elasticity the effective mass density is zero at all frequencies, but nonetheless the effective elasticity tensor is frequency dependent: the internal masses do not move when the material is translated but do move if the material is stretched. In any of these models the local displacement, and not just the local displacement gradient, needs to be small.

12:20 : Coupled resonant modes in acoustic metamaterials
Ying Cheng, Xiaojun Liu

Acoustic metamaterials constructed by resonant microelements in subwavelength scale were generally characterized by the effective medium approximation theory, which neglects the interaction between adjunct elements. In this paper, novel coupled resonance modes induced by the strong interaction in metamaterials composed of single-slit Helmholtz resonator arranged in two-dimensional square lattice are investigated. We rotate a portion of the resonator so that the adjacent resonator elements in GammaX direction have a twist angle ϕ. For the system with ϕ = 180deg, the coupling produces the symmetric coupled mode in in-phase oscillation and the anti-symmetric coupled mode in out-of-phase oscillation. The coupled resonance further produces the hybridization effect. Such coupled resonance modes may have novel applications in sound wave manipulation.

12:40 : Anomalous transmission of surface acoustic wave in 2D periodic structure of surface corrugations
Sergey Nikitov, Valery Grigorievskii, Iosif Kotelyanskii, Sergey Suchkov, Elena Mirgorodskaya, Alexander Grigorievskii, Valery Luzanov, Michail Fominskii

Propagation of surface acoustic waves on the substrate of YZ-cut of LiNbO3 with 2D periodic surface corrugations has been investigated. The distribution of wave amplitudes as well as SAW transmission and reflection coefficients have been calculated using a new method based on 2D-transfer matrices. Frequency dependencies of transmission and reflection coefficients for Rayleigh SAW propagating in a rectangular region occupied by the 2D periodic structure with three levels of height were measured. It has been shown that if the width of incident acoustic beam is narrower than the width of periodic structure, then a kind of channelization takes place for the incident wave, and an anomalous enhancement of transmission coefficient appears near the center frequency of Bragg stop band.

11:00 - 13:00 ***Rubis***

1E: Photothermal effects in plasmonics and metamaterials I

Organized by: Min Qiu and Min Yan

Chaired by: Min Qiu and Min Yan

11:00 : Invited talk
Photothermally actuated therapeutics
N. Halas

Noble metal nanoparticles with near-infrared optical, plasmon-based resonances (such as nanoshells) have become a practical and enabling tool for nanomedicine. Their efficacy in various therapeutic applications is based on their optical properties, and, directly or indirectly, on photothermal effects. In the context of cancer therapy, tumor remission near the 100% level has been achieved in subcutaneous tumors, based on uptake of nanoshells and subsequent near-IR illumination, which induced hyperthermic cell death. This approach has transitioned into clinical trials for a variety of soft tissue cancers. Near-IR resonant plasmonic nanoparticles can also be formulated to be light-triggerable vectors for gene therapy, offering a degree of kinetic control over the gene delivery process unachievable by other methods. A general oligonucleotide-bearing peptide ligand can be constructed and attached to nanoshells to effectively deliver either antisense DNA or siRNA upon near-IR illumination, demonstrating the triggered down regulation of GFP in H1299 lung cancer cells in both cases.

11:20 : Invited talk
Multidimensional optical storage based on plasmonic nanorods: continuous-wave operation
James Chon, Adam Taylor, Timothy Chow

In this paper, we discuss the continuous-wave laser readout on plasmonic gold nanorod based optical patterning, in spectral and polarization domains. We report 16 layer readout using continuous-wave confocal light scattering from gold nanorods at detuned surface plasmon resonance (SPR) peak wavelengths.

11:40 : Invited talk
Manipulation Light Absorption and Conversion in Thin Film Solar Cells with Ordered Nanostructures
Yalin Lu, W. Wang, M. Liu, K. Reinhardt, R. J. Knize

A major problem of current silicon thin film solar cells lies in low carrier collection efficiency due to short carrier diffusion length. Instead of improving the collection efficiency in a relatively thick solar cell, increasing light absorption while still keeping the active layer thin is an alternative solution. In this paper, simultaneous absorption enhancement in a thin film Si solar cell by incorporating a 2D periodic metal nanopattern and by adding a frequency conversion was studied using three dimensional finite element analysis and experimental demonstration.

12:00 : Accumulating microparticles and direct-writing micropatterns using continuous-wave laser-induced vapor bubble
Hui Liu, Ya Jian Zheng, Shing Zhu

Through the enhanced photothermal effect, which was achieved using a silver film, a low power weakly focused continuous-wave laser (532 nm) was applied to create a vapor bubble. A convective flow was formed around the bubble. Microparticles dispersed in water were carried by the convective flow to the vapor bubble and accumulated on the silver film. By moving the laser spot, we easily manipulated the location of the bubble, allowing us to direct-write micropatterns on the silver film with accumulated particles. The reported simple controllable accumulation method can be applied to bimolecular detection, medical diagnosis, and other related biochip techniques.

12:20 : Invited talk
Laser-induced heating and melting processes for fabrication of metallic, dielectric, alloy, and semiconductor nanoparticle structures
Carsten Reinhardt, Andrey Evlyukhin, Urs Zywietz, Arseniy Kuznetsov, Ventsislav Valev, Boris Chichkov

A novel method for high-speed fabrication of large-scale periodic arrays of metal, dielectric, alloy, and semiconductor nanoparticles with diameters of 40 – 200 nm has been developed. The method is based on the laser-induced transfer of nanodroplets from different continuous material films as well as from nanostructures materials, resulting in exact spherical particles arranged in arbitrary array geometries. Arrays of nanoparticles consisting of pure metal, metal alloys, and semiconductors have been realized. The size of the particles, their composition, and the geometry and period of the particle array can independently be controlled by lithographic structuring of thin material films. Hexagonal arrays of gold nanoparticles with diameters of 110 nm are demonstrated as effective large area sensor elements, providing a sensitivity of 365 nm/RIU and a figure of merit of 21.5 in the visible spectral range.

12:40 : Photothermal tuning of SOI waveguide with integrated plasmonic nanoheater
Xi Chen, Yiting Chen, Min Yan, Min Qiu

We propose a novel design of tunable silicon-on-insulator waveguide integrated with a plasmonic nanoheater. Excited with 980nm polarized pump light, the metallic nanoheater is able to efficiently convert the optical power into localized thermal power and drastically raise the surrounding temperature. With pump intensity of 1 mW/mum2, temperature of silicon waveguide can be raised by 245 K, corresponding to an increase of refractive index of silicon core by 0.049. Theoretically, a compact size Mach-Zehnder interferometer composed of our tunable SOI waveguide can achieve submicronsecond response time.

11:00 - 12:40 ***Emeraude***

1F: Large-area Nanofabrication of Photonic Nanostructures

Organized by: T. W. Odom

Chaired by: Teri W. Odom

11:00 : Au Nanofins and Double-nanopillars Fabricated by Nanocoating Lithography for Practical Plasmonic Sensor
Wakana Kubo, Takuo Tanaka

Au nanofins and double nanopillars were fabricated successfully with a wafer-scale through the nanocoating lithography technique. Each structure has own structural feature and shows plasmon resonances depending on its size and shape, resulting in a plasmon sensor. Au double nanopillars showed a high refractive index sensitivity of 1075 nm/refractive index units.

11:20 : Invited talk
Electrochemical Fabrication of Chiral Metamaterials
Paul Braun, Kevin Arpin, Sidhartha Gupta, Andre Radke, Martin schäferling, Harald Giessen

Chiral metamaterials are an important class of metamaterials that can be used to achieve negative refraction, circular dichroism, rotation of plan-polarized light, and various optoelectronic devices. Chiral architectures are inherently three-dimensional, and the fabrication of such metamaterials that operate in the visible to mid IR require precise fabrication technologies capable of achieving sub micrometer, multidimensional features. Herein, we explore the fabrication of chiral metamaterials using a combination of direct laser writing, genetic algorithms, proximity field nanopatterning, and metal electrodeposition. The optical properties of these structures are measured by FTIR and presented herein. Optimization of the measured chiral response is directed by computational studies.

11:40 : Invited talk
Large-area plasmonic applications and fabrications
Se Hyun Ahn, Ting Xu, Jong G. Ok, Alex F. Kaplan, Yi-Kuei Wu and L. Jay Guo

Metal-insulator-metal plasmonic structures can be exploited for spectrum filter applications. Frequency-selective transmission and reflection spectra in the visible and IR range can be engineered for various applications. Such structures can be fabricated by large area continuous roll to roll nanoimprint technology.

12:00 : Programmable Soft Lithography for Scalable Plasmonics
Teri Odom

This talk will describe an all-moldable nanofabrication platform that can generate from a single masterlarge-area nanoscale patterns with programmable densities, fill factors, and lattice symmetries. Solvent-assisted nanoscale embossing (SANE) can increase the spacing of patterns up to 100% as well as decrease them down to 50% in a single step by stretching or heating a thermoplastic substrate. In addition, SANE can reduce critical feature sizes as small as 45% compared to those on a master by controlled swelling of patterned molds with different solvents. SANE can also produce different and reconfigurable lattice symmetries. We will describe how SANE followed by template stripping techniques can produce arrays of strongly coupled nanoparticles and three-dimensional bowtie nanoantennas with extraordinary properties that can be scaled for wide-spread applications

12:20 : λ3/1000 Plasmonic Nanocavities for Biosensing Fabricated by Soft UV Nanoimprint and Degassing Assisted Patterning
Andrea Cattoni, Petru Ghenuche, Anne-Marie Haghiri-Gosnet, Dominique Decanini, Jean-Luc Pelouard Pelouard, Stéphane Collin

In this work we present two Soft Lithography techniques for the nanoreplication at 20 nm scale on large surfaces: Soft UV Nanoimprint Lithography (Soft UV NIL) and Degassing Assisted Patterning (DAP). To validate these ultra-high resolution techniques, we demonstrate the fabrication of 1D and 2D arrays of λ3/1000 plamonic nanocavities on a large surface up to 1 cm2. The fundamental mode of the cavity presents total omnidirectional absorption of light, while the second-order mode exhibits a sharper resonance. This high quality factor plasmonic resonance leads to high refractive index sensitivity and a high figure of merit, and can offer new perspectives for efficient biosensing experiments in ultra-low volumes.

11:00 - 13:00 ***Estaunié***

1F: Quantum metamaterials I

Chaired by: Didier Felbacq

11:00 : Invited talk
Plasmon induced coherence in disordered semiconductors
J. Bellessa, C. Symonds, E. Homeyer, J. C. Plenet, Yu.N. Gartstein, V.M. Agranovich, S. Aberra Guebrou

In this work we show that the strong interaction between a surface plasmon and a set of localized independent emitters can lead to the formation of a macroscopic extended state, formed by the superposition of plasmon and excitations on a large number of molecules. The sample consists of an aggregated dye layer deposited on silver supporting surface

plasmons. The aggregated dye layer is constituted by an ensemble of short length independent chains whose emission is incoherent without metal. The diffusion and the spatial coherence of the emission of J-aggregated dyes on silver have been investigated with Young-type interferometric experiments, evidencing an in-phase emission of localized emitters separated by several microns. The extension of this coherent state over a large number of molecules could lead to energy transfer on a micrometer scale mediated by the plasmon.

11:**20 : Towards optical gain in plasmonic metamaterials**
Wayne Dickson, John McPhillips, Stephane Kena-Cohen, Antony Murphy, Daniel O'Connor, Steven Beckett, Robert Pollard, Paul Stavrinou, Donal Bradley, Stefan Maier, Anatoly Zayats

Manipulating and guiding light at physical dimensions below the diffraction limit of conventional optics necessitates optical elements appreciably smaller than the design wavelength. In this respect, the localised plasmonic resonances (LPR) of silver or gold nanoparticles present excellent advantages in terms of field confinement and enhancement. For nanoparticle synthesis, self-assembled anodic aluminium oxide (AAO) templates producing quasi-hexagonally ordered gold nanorods oriented perpendicular to a substrate benefit from low size dispersion and ease of fabrication. Nanorod resonances are dependent on their length, diameter, surrounding permittivity and near-field coupling between adjacent rods providing strong electromagnetic field enhancement.

11:**40 :** Invited talk
High power extraction in (THz) surface-emitting lasers using metallic resonators based on type-II photonic heterostructures
Gangyi Xu, Raffaele Colombelli, Ali Belarouci, Xavier Letartre, Suraj Khanna, Lianhe Li, Edmund Linfield, Giles Davies

We report high-power, single-mode surface-emission from THz quantum cascade (QC) lasers with a type-II photonic heterostructure (PHS) metallic resonator. Such resonator selectively excites the unusual radiative mode with significantly enhanced radiation efficiency. The PHS lasers (f 3.4 THz) exhibit record-high single-mode peak output powers, as well as directional single-lobed beam patterns.

12:**00 :** Keynote talk
Close encounters between nanoantennas: Bridging quantum and classical plasmonics
Javier Aizpurua

Plasmonic nanoantennas change dramatically their optical response when their constituent nanostructures are closely located in subnanometer proximity. In this regime, electron tunneling across a cavity between metallic surfaces is triggered out, producing an emergence and redistribution of antenna modes. A collapse of the near-field at the cavity is also associated with the tunneling events. We present a quantum corrected model (QCM) that allows for including these quantum effects in a classical description of the optical response of large-scale plasmonic systems. Based on this model, it is possible to study the effect of tunneling in realistic plasmonic configurations such as in plasmonic dimers or in bowtie antennas.

12:**40 :** Invited talk
Quantum fluids of light in nonlinear polaritonic systems
Cristiano Ciuti

I will review theory and experiments showing that light propagating in a nonlinear optical medium can behave like a superfluid. The nonlinear medium of choice is a semiconductor in which photons hybridize with optical excitations of the material, or excitons. The hybrid quanta, polaritons, behave like particles forming a superfluid. It has a rich phenomenology, which includes hydrodynamical formation of vortices and dark solitons, and emission of ßupersonic Cherenkov radiation"when hitting an obstacle. I will also discuss promising systems allowing for strongly correlated photon phases in arrays of nonlinear cavities and exciting new theory predictions of unconventional photon blockade effects.

Lunch and Exhibit Inspection

12:20 - 14:20

14:20 - 16:00 ***Thévenin***

2A: Metamaterials and negative index materials I

Chaired by: Ari Sihvola

14:20 : Keynote talk
Advances in using EBG Structures in Antenna Engineering: From Fundamentals to Novel Recent Applications
Yahya Rahmat-Samii

Advances in using EBG Structures in Antenna Engineering: From Fundamentals to Novel Recent Applications

15:00 : Invited talk
Biplasmonics: Biomolecular Detection and Identification with Metamaterial Nanoantennas
Hatice Altug

Detecting biomolecules such as proteins and studying their molecular structure functionality is crucially important for life-sciences. Infrared absorption spectroscopy is an important tool for functional studies of bio-molecules. Sensitivity limitations, however, hinders the applicability of the technique to single molecule/monolayer studies and also measurements in solutions. In this talk we will describe use of infrared plasmonic and metamaterial antennas to enable overcome many of these limitations. We will also show that use of plasmon hybridization and Fano-resonances in individually tailored antennas can be exploited to further extract information about proteins including their height and orientation.

15:20 : Optical forces on lossy double-negative optical trapping
Leonardo André Ambrosio, H. E. Hernández-Figueroa

Optical forces over lossy double-negative (DNG) spherical particles are theoretically analyzed for the first time, revealing how optical trapping can be achieved under such conditions.

15:40 : Design and Simulation of Novel Compact and Reconfigurable Double Negative Metamaterial unit cell
Behnam Zarghooni, Tayeb Denidni

In this paper, a novel reconfigurable unit-cell structure for planar double negative metamaterials is introduced. This structure is simulated in CST Microwave Studio and its constitutive parameters are extracted. According to the simulation results, this structure has a wider bandwidth and smaller size compared to other conventional structures.

14:20 - 16:00 ***B310***

2B: Graphene metamaterials

Chaired by: Stefan Maier

14:20 : THz bandwidth light-with-light modulation in graphene metamaterial
Andrey Nikolaenko, Evangelos Atmatzakis, Nikitas Papasimakis, Zhiqiang Luo, Ze Xiang Shen, Francesco De Angelis, Enzo Di Fabrizio, Nikolay Zheludev

We demonstrate that ultrafast nonlinear optical response of a monoatomic graphene can be order of magnitude resonantly enhanced by hybridization with a plasmonic metamaterial offering new applications in THz bandwidth optical switching.

14:40 : Mechanism of optoelectronic switch, operating on surface plasmon-polaritons in monolayer graphene
Yuliy Bludov, Mikhail Vasilevskiy, Nuno Peres

It is shown that one can explore the optical conductivity of graphene, together with the ability of controlling its electronic density by an applied gate voltage, in order to achieve resonant coupling between an external electromagnetic radiation and surface plasmon-polaritons in the graphene layer. This opens the possibility of electrical control of the intensity of light reflected inside a prism placed on top of the graphene layer, by switching between the regimes of total reflection and total absorption. The predicted effect can be used to build graphene-based optoelectronic switches.

15:00 : Edge plasmons in graphene
Weihua Wang, S. Peter Apell, and Jari M. Kinaret

Plasmon modes in graphene are influenced by the unusual dispersion relation of the material. For bulk plasmons this results in a $n^{1/4}$ dependence of the plasma frequency on the charge density, as opposed to the $n^{1/2}$ dependence in two-dimensional electron gas yet, bulk plasmon dispersion in graphene follows a similar $q^{1/2}$ behavior as for other two-dimensional materials. In this work we consider finite graphene nanostructures, semi-infinite sheets and circular disks, and study edge plasmons that are confined to the boundaries of the structures. We find that for abrupt edges graphene edge plasmons behave analogously to those in 2DEGs, but for gradual edge profiles, important distinctions arise. In particular, we show that for a linear edge profile, graphene supports fewer edge modes than a 2DEG, and the edge monopole plasmon dispersion in graphene follows a $q^{1/4}$ law in contrast to the q^0 behavior seen in 2DEGs.

15:20 : Graphene and topological insulators for plasmonics, nanophotonics and photonic crystals
Yury Efremovich Lozovik, O.V. Kotov, D.K. Efimkin, A.A. Sokolik

We discuss various applications of graphene and topological insulators as a constituents for for the elements of plasmonics, nanophotonics and photonic crystals. Plasmon polaritons in a monolayer and bilayer doped graphene embedded in optical microcavity are discussed. The dispersion law for lower and upper cavity plasmon polaritons was obtained. Peculiarities of Rabi splitting for the system are analyzed particularly, role of Dirac-like spinor (envelope) wave functions in graphene and corresponding angle factors were considered. Typical Rabi frequencies and frequencies of polaritons near polariton gap were estimated. The condition of existence of the lower pair of polaritons in the bilayer graphene system (corresponding to the antiphase plasmon mode) was obtained.

15:40 : Propagation of light in metamaterials and charge transport in graphene: study by analogy
Yurii Bliokh, Valentin Freilikher, Franco Nori

We show that electromagnetic waves in systems containing layers of right- and left-handed dielectrics obey, under some conditions, the same equations as the charge carriers in graphene superlattices created by inhomogeneous electrostatic potential. This analogy allows better understanding of unique transport properties of graphene and also offers possibilities to reproduce these properties in light tailoring photonic devices based on metamaterials.

14:20 - 16:00 ***B312***

2C: Acoustic and elastics metamaterials

Chaired by: Nicholas Fang

14:20 : Control of sonic metamaterial stopband
Alasdair Murray, James Bell, Euan Hendry, Ian Summers, John Sambles, Alastair Hibbins

The acoustic transmittance of a pair of closely-spaced plates, each perforated with a square array of subwavelength diameter holes, an acoustic double fishnet structure, is explored. For frequencies below onset of diffraction, there is a band of near-perfect acoustic attenuation at a frequency dictated by the periodicity of the array. Comparison of experimental data with analytical modeling shows that the observed response is due to a hybridization between pipe modes within the holes and the two dimensional resonance supported in the gap between the periodically perforated plates.

14:40 : Homogenization of phononic crystals with auxetic components
Irina Sabira Solis-Mora, Javier Flores-Mendez, Felipe Perez-Rodriguez

We present a homogenization theory for elastic phononic crystals. The theory provides explicit formulas for the calculation of the effective tensors of the acoustic response, which turns out to be nonlocal in the most general case. We have compared the predictions of our theory for 1D and 2D phononic crystals with those of previous local approaches. In particular, we have applied the developed theory to 1D phononic crystals composed of auxetic materials. We found that such systems exhibit metamaterial behavior at frequencies corresponding to the second band of the phononic dispersion.

15:00 : Mechanical Metamaterials with negative Poisson's Ratio
T. Bückmann, N. Stenger, M. Thiel, T. Kennerknecht, C. Eberl, M. Wegener

Auxetic materials attract attention due to their mechanical properties for over 100 years. These advanced materials with negative Poissons ratio are recently gaining special interest. State-of-the-art fabrication techniques allow for greater

design freedom and systematic investigation. We consider the characteristics and the design of structured polymeric materials with the aim to create three-dimensional (3D) mechanical metamaterials with negative Poissons ratios.

15:20 : Experimental Demonstration of Free Space Cloaking in Thin Elastic Plates
Nicolas Stenger, M. Wilhelm, M. Wegener

We report in our talk the first experimental results on free space cloaking thin elastic plates.

15:40 : Invited talk
Prediction of super absorbance with bubble meta-screens
Alice Bretagne, Valentin Leroy, Eric Lee, John Page, Arnaud Tourin

We present a simple model for optimizing the absorption of acoustic waves by a bubble meta-screen (a single layer of bubbles entrapped in a soft elastic medium). This model predicts a maximal absorption if the viscosity of the medium is chosen according to the geometry of the meta-screen. The case of a meta-screen close to a rigid interface is also presented, suggesting that super-absorption can be achieved with optimal viscosity.

14:20 - 16:00 ***Estaunié***

2D: Plasmonics and nanophotonics II

Chaired by: Martin Wegener

14:20 : Plasmon altered resonances in 1D plasmonic photonic crystals
Alexander Baryshev, Mitsuteru Inoue, Alexander Merzlikin

One-dimensional plasmonic photonic crystals (1D PPhCs) terminated by noble metals have been studied experimentally and analyzed theoretically. Such a PPhC supported (i) optical resonances (optical Tamm state and Fabry-Perot resonance) originating from periodicity of their lattices and (ii) the surface plasmons resonance on the noble metal layer. Parameters of the crystals and coupling conditions were chosen such that the optical Tamm state, the Fabry-Perot resonance and the surface plasmons resonance were excited simultaneously by light from a selected spectral range. Tuning the overlap of these resonances by a variation in coupling conditions resulted in phenomena where the optical Tamm state and the Fabry-Perot resonance were strongly modified –switched ON/OFF and interchanged by the stored energy – by slight alterations of the surface plasmons resonance.

14:40 : Power flow inside and outside cylindrical coated nano-particles
Samel Arslanagic

The power flow density associated with various types of active coated plasmonic-based nano-particles excited by a magnetic line source at optical frequencies is investigated. The results are compared to those of the corresponding structures made of epsilon-negative materials at radio frequencies.

15:00 : Keynote talk
Quantum plasmonics and plexcitonics
Peter Nordlander

A recently developed fully quantum mechanical approach for the description of plasmonic and excitonic nanoparticles and their interactions is presented. Quantum effects can have a pronounced influence on the electric field enhancements near the nanoparticle surfaces and on the optical properties strongly coupled nanoparticles. For closely spaced metallic nanoparticles, electron transfer and nonlocal screening can drastically reduce the electric field enhancements across the gap and result in a Charge Transfer Plasmon (CTP) where an oscillatory electric tunneling current flows between the particles, and strongly nonlinear effects can be induced. The energy of the CTP is found to depend strongly on the electronic structure of the junction and the presence of molecules inside the gap. For the coupled plasmonic-excitonic system where hybrid plexciton states are formed, quantum effects can strongly modify the optical spectrum and induce highly nonlinear response.

15:40 : Ultrafast Pulse Shaping with Plasmonic Systems
Dean Brown, Augustine Urbas

Coherent excitation in optical spectroscopy and photo-induced processes, like second harmonic generation and Raman spectroscopy, depend on temporal properties of ultrafast pulses. In this work, we explore what spectral phase is necessary in a material to influence these processes and discuss plasmonic systems that can be fabricated to have very large spectral dispersion properties that can positively affect both the temporal envelope of an ultrafast pulse and the phase of each spectral component.

14:20 - 16:00 ***Rubis***

2E: Bottom-up approach towards metamaterials and plasmonics I

Organized by: Dorota Pawlak

Chaired by: Dorota Pawlak

14:20 : A 3D Tunable Optical Metamaterial Made by Self-Assembly
Stefano Salvatore, Silvia Vignolini, Nataliya Yufa, Pedro Cunha, Morgan Stefik, Ulrich Weisner, Jeremy Baumberg, Ullrich Steiner

The realization of metamaterials working at visible light requires the assembly of architectures with structure control on the 10-nm length scale. Here we present a novel three-dimensional optical metamaterial, created by replicating with metal a template made by block self-assembly.

14:40 : Invited talk
Directionally solidified alkali halide eutectics as polaritonic metamaterials
Rosa Merino, Maria Acosta, Victor Orera

In this communication we report on fibrilar and lamellar alkali halide eutectics as polaritonic metamaterials. Anisotropic dielectric constants and hyperbolic dispersion can be achieved for a wide range of energies with large dielectric constant contrast between the components. The identification of the eutectic systems more prone to present homogeneous well-ordered microstructures together with appropriate phonon-polariton dispersion properties is reported. The microstructure of some of the selected systems, fabricated by directional solidification using the Bridgman method is presented. Some new ternary systems have also been explored, aiming at decreasing the domain size or to change the volume fraction of fibers into matrix.

15:00 : Invited talk
Bottom-up metamaterials and plasmonic elements with metallic nanoparticles as basic building blocks
Carsten Rockstuhl, Stephan Mühlig, Alastair Cunningham, Thomas Bürgi, Jose Dintinger, Toralf Scharf

We discuss our latest achievements in fabricating, characterizing and theoretically understanding metamaterials and plasmonic elements that are made from closely packed metallic nanoparticles and which are fabricated with bottom-up approaches that rely on self-organization.

15:20 : Invited talk
Fabrication of metallodielectric nanocomposites for plasmonic applications through directional solidification
Marcin Gajc, Andrzej Klos, Barbara Surma, Katarzyna Sadecka, Nikolay Zheludev, Andrey Nikolaenko, Dorota Pawlak

In this paper metallodielectric nanocomposites, obtained by directional growth of glass fibers doped with silver nanospheres, indium tin oxide (ITO)/antimony tin oxide nanoparticles (ATO) and simultaneously doped silver nanoparticles and erbium ions have been investigated. The manufacturing method is based on doping glass with plasmonic nanoparticles in directional glass solidification process. Our approach is a new bottom-up method of fabricating 3D metallodielectric nanocomposites with plasmonic properties. It enables manufacturing of isotropic bulk materials with plasmon resonances from metallic and semiconducting nanoparticles as well as it enables obtaining of plasmonic materials simultaneously doped with other agents like a rare earth ions in 3-dimensional matrices. Description of novel bottom-up fabrication process together with structural/optical characterization results will be presented.

15:40 : Invited talk
Dirac physics in metamaterials with nanoparticle clusters as meta-atoms
Vassilios Yannopapas and Alexandros G. Vanakaras

We report on the emergence of a Dirac point in the dispersion relation of a plasmonic metamaterial which is realized as a three-dimensional crystal (cubic or orthorhombic) whose lattice sites are decorated by aggregates of gold nanoparticles embedded in a high-index dielectric material. The dispersion relation is obtained by a rigorous two-stage multiple-scattering method for light which also provides the transmittance from finite slabs of the metamaterial. The Dirac-type dispersion lines of the photon modes are not a result of diffraction as in photonic crystals but due to subwavelength features and emerge from the gapless transition from a negative to a positive index band. The Dirac point is manifested as a dip in the spectrum of light transmittance through a finite slab of the metamaterial however, transmittance does not decrease diffusively but exponentially due to the inherent losses of gold in the given spectral regime.

14:20 - 16:00 ***Saphir***

2F: Acoustic metamaterials II

Organized by: Jensen Li and Johan Christensen

Chaired by: Jensen Li and Johan Christensen

14:20 : Invited talk
Implementation of Metamaterials for Transformation Acoustics Applications
Steven Cummer, Bogdan Popa

We review the detailed development and derivation of the concept of transformation acoustics and demonstrate several approaches for engineering materials with the acoustic properties needed to realize transformation acoustics devices.

14:40 : Phononic crystal based mode separation of a single-frequency bi-modal guided wave in a plate
Yoon Young Kim, Pyung Sik Ma, Hoe Woong Kim, Joo Hwan Oh

The separation of wave modes from a signal is possible as long as the modes propagate at different frequencies. The question is how to separate a multi-modal wave propagating at the same frequency into two modes. In this work, it is shown that two modes contained in a single-frequency bi-modal wave can be successfully separated by using an engineered phononic crystal. Specifically, guided elastic wave experiments were performed in a thin aluminum plate in the middle of which a phononic crystal is inserted for mode separation.

15:00 : Acoustic cloak with duplex communication ability constructed by multilayered homogeneous isotropic materials
Qi Wei, Ying Cheng, XiaoJun Liu

Based on the effective medium approximation, we propose a practical implementation of cylindrical acoustic cloak with duplex communication ability by concentric alternating multilayered structure of homogeneous isotropic materials, which can perfectly mimic the ideal radius-dependent and anisotropic ordinary lens. The proposal exhibits near-ideal cloaking performance such as low-scattering and shadow-reducing whenever the illumination incident from plane source or point source at a wide range frequency, thus can hide an object from the detection of acoustic wave. The acoustic wave radiated from external or internal source can pass through the cloaking shell with unchanged wavefront, which makes the cloaked object capable of exchanging information with the surroundings by acoustic wave for any purpose. More simulations on the acoustic far-field scattering patterns and total scattering cross-section are performed to investigate the layer number and frequency dependence of cloaking effect, and the results show that the thinner layers exhibit better cloaking effect.

15:20 : Granular crystals as phononic metamaterials for shear waves
V. Goussev, H. Pichard, A. Duclos, J.-P. Groby, V. Tournat

Phononic properties of discrete metamaterial, made of elastic cylinders arranged on a simple square lattice, are described analytically. The importance of the interactions between shear and rotational waves in granular phononic crystals is demonstrated. Control of these interactions extends the opportunities for shear wave band design in metamaterials.

15:40 : Invited talk
Transformation Acoustics: Virtual Pinholes and Collimators
Nicholas Fang, Jun Xu, Yun Jing

In this invited talk, we will present our preliminary study of a virtual hole and a broadband acoustic collimator, by combination of the concept of complimentary media with transformational acoustics. Such effect is exemplified by a segmental defect in the original cloak, which appears as if a dipole scatterer was under the acoustic imager. The potential application of such novel device concept in underwater communication and medical ultrasound will be also discussed.

14:20 - 15:40 ***Jade***

2G: Advances in metamaterials and plasmonics I

Organized by: Lei Zhou and Jiaming Hao

Chaired by: Beatrice Dagens and Nicolas Fang

14:20 : Invited talk
Activated Vibrational Modes and Fermi Resonance in Tip-Enhanced Raman Spectroscopy
Hongxing Xu

Tip-Enhanced Raman spectroscopy (TERS) is a high-sensitivity and high spatial-resolution optical analytical technique with nanoscale resolution beyond the diffraction limit of light, which was discovered more than one decade ago by Stoumlckle et al. In TERS a sharp metal tip is used to create a hot site to excite the localized surface plasmons and consequently enhance the electromagnetic field and Raman signals in the vicinity of the tip apex. Since the tip can be moved three dimensionally to control the position of hot site and the corresponding enhancement factor by changing the gap distance between the tip and the substrate, TERS thus overcomes one of the most severe restrictions in the application of surface enhanced Raman scattering (SERS), which usually requires roughness of metal surfaces or aggregations of metal nanoparticles to create hot sites, but hardly to be controlled.

12:00 : Invited talk
Modifying quantum dot emission using plasmonic crystal arrays of antennas
Gabriel Lozano, Said Rodríguez, Marc Verschuuren, Raquel Gomes, Zeger Hens, Jaime Gómez-Rivas

We present an experimental study of the modified emission of a layer of quantum dots (QDs), just a few nanometers thick, with plasmonic structures. We show that collective resonances in plasmonic arrays of nanoparticles can lead to a strong modification of the emission due to the modified density of optical states at which the excited QDs can decay and the diffractive coupling of plasmonic resonances into the far-field.

14:40 : Invited talk
Ultrafast and Ultracompact SPP Devices
Q. Gong, S. Yue, H. Yang, J. Chen, Z. Li

Ultracompact plasmonic devices including SPP unidirectional generator, splitter and all-optical switch were experimentally demonstrated based on asymmetric single-nanoslit. Ultrafast optical modulation based on plasmonic lens was experimentally studied.

15:00 : Invited talk
Plasmonic Nanocomposites
Mady Elbahri

In the field of plasmonics, much attention is paid to new approaches for the concentration and manipulation of light to improve the absorption and/or transmission of optical devices. In our research works, a new concept is introduced based on the interaction of a metal mirror with metallic nanoparticles embedded in dielectric matrix and fascinating optical devices are realized.

15:20 : Invited talk
Rotating Optical Axis for Transformation Optics
Jensen Li, Zixian Liang

Here we answer the following question: how general can we do transformation optics by confining the usage of a single type of anisotropic medium? We develop a scheme by using effective media of layers of varying optical axes.

It extends the recently demonstrated anisotropic carpet cloak at visible frequencies by assembling small pieces of the same anisotropic medium with optical axes in different directions. A wave expander and a virtual shifter are designed as examples.

Coffee Break and Exhibit Inspection

Poster Session I

16:00 - 17:00

I-1 : A polarization-/angle-insensitive, bandwidth-optimized, metamaterial absorber in the microwave regime
Alexandros Dimitriadis, Nikolaos Kantartzis, Theodoros Tsiboukis

A novel metamaterial absorber with significantly enhanced characteristics in the microwave X-band is presented in this paper. The behavior of the structure is thoroughly investigated under various cases of obliquely incident waves and its operational bandwidth is drastically improved by combining unit cells with properly scaled resonators. The overall performance of the proposed design is deemed promising for the fabrication of practical microwave absorbers.

I-2 : A compact equal power photonic crystal beam splitter with complete band gap based on the cavity resonance interface
Yuan-Fong Chau

A compact equal power beam splitter with complete band gap based on the cavity resonance interface (CRI) effect in photonic crystal waveguides is designed and analyzed. The finite-difference time-domain method is adopted to simulate the relevant structures of defect mode in a two dimensional square lattice circular dielectric rods of anisotropic photonic crystal. The device size reduction and flexibility in polarization dependence compared with the conventional power splitter can be attributed to the same resonant frequency for both transverse-magnetic and and transverse-electric polarization, because the photonic crystal structures designed here have a complete bandgap. This idea can be easily extended to more complex photonic crystal structures such as NxM CRI couplers, where N and M are the number of input and output waveguides, respectively.

I-3 : A Compact Slotted Coplanar-Waveguide (CPW) Fed Metamaterial Inspired Patch Antenna for the Wi-MAX Application
Mimi Wan Nordin, Mohammad Tariqul Islam, Norbahiah Misran

A metamaterial-inspired compact patch antenna resonating at 5.5 GHz for Wi-MAX application is proposed. The antenna is fed by a coplanar-waveguide (CPW) feedline that has been designed to have a characteristic impedance of 50 $Omega$. The compact antenna is also a wideband antenna with a bandwidth (below -10 dB) of 1.3 GHz in the said frequency range, with a gain of 2.2 dB. The size of the patch in terms of the free-space wavelength is λ0/15 x λ0/9 x λ0/29. The wide bandwidth of the antenna is achieved by inductively loading the single patch through the incorporation of the slot.

I-4 : A flexible metamaterial with negative refractive index at visible wavelength
Muhan Choi, Jeahyung Han, Byungsoo Kang, Choon-Gi Choi

A freestanding flexible metamaterial with negative refractive index was designed and fabricated at visible operating wavelength by setting the unit cell size below 200nm. The metamaterial has basically a multilayer fishnet structure with circular hole instead of the rectangular one to reduce the pitch size of the metamaterial. The metamaterial shows negative refractive index in optical regime between 570nm and 615nm with minimum index value near -2.

I-5 : A study on characterization of 2D photonic Quasicrystals
Sunmin Kim, Jong-Bin Yeo, Hyun-Yong Lee

Two-dimensional (2D) photonic quasicrystal template patterns have been fabricated by using multiple holographic-lithography method. 2D photonic quasicrystal arrangement could be controlled by the experimental conditions such as the incidence angle (theta), rotation angle (gamma). After the first exposure, the sample was rotated at the proper angle. The exposure was repeated n/2 times to get n-fold photonic quasicrystal. The PR pattern was used as the mask, wet etching of the Cr, reactive-ion etching of the Cr on the Si wafer. The shapes of the samples were confirmed by using

SEM and optical microscopy. The reflectivity of the samples was analyzed by using a UV-Vis-IR spectroscopy.

I-6 : A Study on natural Coral Stone – a Fractal Solid
Aloke Kumar Sarkar, Arnab Gangopadhyay, Aditi Sarkar

In this present work natural fractal material coral stone has studied. X-ray diffraction, dc and ac electrical characteristics are studied. From XRD data analysis it has been established that coral stone contains nano sized clusters which is supported by dc electrical measurement. The measured complex ac conductivity of coral is found to be increased with thickness of the sample. A scaling relation between ac conductivity and thickness has been also proposed here. Over all behavior of the specimen is that like a fractal system.

I-7 : A study on the 1D Photonic Crystal on Chalcogenide Galss for Infrared Lens
Dong-Sik Bae, Jong-Bin Yeo, Hyun-Yong Lee

Chalcogenide glass is known for infrared transmission materials and currently one of widely used optical materials. In this study, 1D photonic crystals (PCs) on chalcogenide glass for Infrared (IR) lenses were measured optical and structural properties. Base materials for IR lenses were prepared by a conventional melt quenching technique. The base prepared material was deposited on substrate by thermal evaporation method. The 1D PCs was realized periodic alternation films onto prepared sample by using sputtering method.

I-8 : A study on the multiple-exposure nanosphere-lithography process for two-dimensional complexed photonic crystals
Jong-Bin Yeo, Hyun-Yong Lee

Arrays of two-dimensional complexed photonic crystals (2D-cPCs) have been fabricated by a multiple-exposure nanosphere-lithography (MENSL) method utilizing a self-assembled nanosphere as a lens mask and an expanded He-Cd laser. The nanospheres were self-assembled on a photo-resist (PR). The nanospheres were self-assembled on a PR. Then, the masked PR was multi-exposed with a changing rotation angle (q) and tilt angle (g). The scanning electron microscopy reveals that MENSL is a useful tool for fabricating cPCs with various lattice structures.

I-9 : A study on the optical properties of Ti3O5 for reversible one-dimensional photonic crystals
Heon Kong, Jong-Bin Yeo, Hyun-Yong Lee

We have investigated the optical properties of titanium oxide (Ti3O5) for reversible one-dimensional (1D) photonic crystals (PCs). 1D PCs fabricated by multilayer consisting of 5-pair using sputtering technique from a Ti3Ox and SiO2 target with the different refractive index. The fabricated samples were annealed in an Ar atmosphere for 60min at various temperatures. The structural properties of Ti3O5 with crystalline to crystalline transition have been carried out through the X-ray diffraction (XRD). After exposure to laser, the optical properties of samples are being conducted and analyzed by Fourier transform infra-red spectroscopy (FTIR) and UV-vis spectrophotometer. In this study, designed 1D PCs utilizing Ti3O5 with crystalline to crystalline transition would have wide application in reversible optical devices.

I-10 : Approach methodology of Quantum Teleportation with binary XOR code for large scale security in Optical Transmission
Aris Skander, Messai Abederraouf, Mahri Omar, Mokhtari Hatem, Guebgoub Nassima, Merabtine Nadjim, Mosleh M-Elharti, Benslama Malek

Quantum teleportation, or entanglement-assisted teleportation, as an area of modern science and new branch of technology, should be seen both as a way to develop a new, and more basic concepts, tools, methods, laws and optical limitations security of information storage and transmission can and should be actually seen as an important driving force of the theory and practice of classical information and also more to more free space communication. Quantum optical protocol is a process by which a qubit (the basic unit of quantum information) can be transmitted exactly from one location to another, without the qubit being transmitted through the intervening space. The first goal of the paper is to discuss briefly the state art of quantum transmission and the photon polarization principal (photonic transmission principal), all practice of quantum research focused in quantum BB84 protocol and the fiber transmission limitation. Second goal is to survey some of the main problems, directions and challenges of quantum satellite transmission. The last goal is to review some of the main impacts the outcomes of understanding of quantum teleportation.

I-11 : Coherent absorption in thin layers of quantum dots

Gabriel Lozano, Giuseppe Pirruccio, Yichen Zhang, Said Rodríguez, Raquel Gomes, Zeger Hens, Jaime Gómez-Rivas

We demonstrate that the weak optical absorption in a thin layer of QDs can be overcome for certain frequencies and angles of incidence by interference of the light reflected at the different sample interfaces. This phenomenon, known as coherent perfect absorption, can be used to enhance the luminescence emission of the QD layer.

I-12 : Compact Fabry-Perot patch antenna based on metamaterials
Rachid Oussaid, K. Ouahiba

This work consists in designing a compact and a directive patch antenna with a Fabry-Perot cavity based on metamaterials. The designed Fabry-Perot patch antenna is of a resonant and compact model than the patch antenna having no cavity. This fact is emphasized by the obtained numerical results using simulation by the mean of HFSS software.

I-13 : Comprehensive circuit-theoretical method for analyzing hybridization modes in metamaterials
Yosuke Nakata, Takanori Okada, Toshihiro Nakanishi, Masao Kitano

We construct a comprehensive method to analyze hybridization modes in a certain general class of circuit networks representing metamaterials. By applying our method to some circuit models, we show that there exists an analogy between circuit models and quantum tight-binding models in solid-state physics. This analogy enables the synthesis of various metamaterials having dispersion relations similar to those for electrons in solids. Finally, we apply our theory to circuit networks with specific symmetries, and reveal the formation of flat bands in metamaterials.

I-14 : Conformal Transformation Optics Applied to Plasmonics: From Nanocrescents to Nanowire Dimers
D. Y. Lei, A. Aubry, S. A. Maier, J. B. Pendry

We describe a systematic methodology based on conformal transformation optics to analytically design and study plasmonic singular devices, which are capable of harvesting light over a broadband spectrum and converting the far-field energy into enhanced near field at structure singularities. Numerical simulations are performed by means of finite element method to verify the validity of quasi-static approximation assumed by the theory and predict the radiation losses effect on the light-harvesting effectiveness and superfocusing of near field energy.

I-15 : Control the phase by using the mimicking electromagnetically induced transparency in planar metamaterial
Junfei Zhao, Yewen Zhang

The mimicking electromagnetically induced transparency (EIT) can be achieved by the concentric double rings structure in planar metamaterial. The simulation for the transmission phase in the transparency window by Finite Difference Time Domain was studied and wide nearly linear tuning by variation of the structure parameter was achieved. By using this kind of planar structure, the phase of plane wave can be controlled clearly.

I-16 : Coupling between a sub-wavelength optical cavity and a plasmonic nanostructure probed by SERS
Julien Proust, Anna Rumyantseva, David Gosztola, Sergei Kostcheev, Jean-Louis Bijeon, Renaud Bachelot, Gary Wiederrecht, Jérome Plain

We report on the utilization of optical sub-wavelength quasi Fabry-Perot cavity coupled with the Raman microscopy to study the interaction between the localized surface plasmon resonance of gold nanoparticles and the surface plasmon resonance of a gold film. We show an enhancement of the Fabry-Perot oscillations when the distance between nanoparticle and gold film decrease.

I-17 : Coupling of Surface Plasmon with GaAs/AlGaAs Quantum Well Emission by Gold Nanoparticle Arrays
Hongwei Gao, Ning Xiang, Jun Lu, Kar Hoo Tung, Soo Jin Chua, Jinghua Teng

Coupling of localized surface plasmon resonance with Quantum Well (QW) emission was investigated via a period gold nanoparticle arrays on GaAs/AlGaAs QW. Gold nanoparticle arrays were fabricated by laser interference lithography. Plasmonic resonance wavelength was tuned by adjusting the size and shape of gold nanoparticles. Coupling effect was characterized by photoluminence. The enhancement of electron-hole recombination rate in a semiconductor quantum well (QW) through the coupling between the dipoles in the QW and the surface plasmons generated by metallic structure has the potential to play important role in future optical devices.

I-18 : Data Fitting of LED current calculation model to the measurement results of Indonesia home made IV meter
L. Hasanah, B. Mulyanti, T. Suartini, M. Khairurrijal

Verification of current calculation model in LED with the experimental result has been performed using data fitting. IV characteristic from current calculation model is compared with the measurement results of Indonesia home made IV meter. The fitting parameter used to compare the measured current with the theoretical one is only the electron effective mass. From the verification, the information about the material kinds of the LED was obtained. Therefore, the correlation between material type and the color emitted by LED could be analyzed.

I-19 : Design methodology to enhance high impedance surfaces performances
Michael Grelier, Anne-Claire Lepage, Xavier Begaud, Michel Jousset, Stephane Mallegol

A methodology is introduced for designing wideband, compact and ultra-thin high impedance surfaces (HIS). A parametric study is carried out to examine the effect of the periodicity on the electromagnetic properties of an HIS. This approach allows designers to reach the best trade-off for HIS performances.

I-20 : Design of a light-weight magnetic radar absorber embedded with resistive FSS
Sun Kui, J. Wang, H. Cheng, Y. Zhou

In this letter, the design of a light-weight magnetic radar absorber (RA) having broadband bandwidth in frequency range of 1-18GHz is demonstrated. A 5mm-thick magnetic RA with weak wave absorbing performance is obtained on the basis of polyurethane foam filled with flake ferrous microwave absorbent. The use of frequency selective surfaces (FSSs) results in a significant increase of the absorbing intensity and operating bandwidth of the RA. By selecting the unit dimensions and modulating the location and square resistance of FSS, a maximal operating bandwidth with the reflectivity below -10dB can be obtained. Experimental results are presented and compared to numerical simulations, and they demonstrated that the RA embedded with lossy FSS has a super broad bandwidth of 3.19-18GHz with the reflectivity below -10dB for the double-layer case. The density of the absorber is only 0.62g/cm3, which is far more less than that of the conventional magnetic coating RAMs.

I-21 : Design of broadband microwave absorber utilizing FSS screen constructed with coupling configurations
Sun Kui, J. Wang, H. Cheng, Y. Zhou

The design of a frequency selective surface (FSS) screen constructed using a coupling configuration to implement a broadband microwave absorber is presented in this paper. The reflectivity representation recognizes the characterization of the absorber. Simulation and measurement results are presented and analyzed. A coupling FSS screen is introduced in order to obtain a better bandwidth and absorption. The bandwidth with the reflectivity below -10dB could get 5.45-18GHz, compared with the 6.28-18GHz of the absorber with square patches FSS, provided that the thickness of the absorber is 4mm.

I-22 : Design of low loss meta-material coplanar waveguides on silicon for millimetre frequency applications.
Daniel Decle Colin, Zhirun Hu

In this work a new meta-material structure is proposed to reduce the substrate losses and conductive losses in silicon interconnection lines at millimeter frequencies in the range of 70-90 GHz. This new meta-material transmission line, make use of the metal layers provided by the technology to form a floating shield. The floating shield reduces the electric field that goes into the substrate, and makes a better distribution of the current density, reducing the substrate and conductive losses respectively. The periodicity of the structure allows the raise of slow wave propagation mode, which in turn allows building shorter transmission lines, providing an additional improvement in terms of losses. All the electromagnetic studies were carried out using the 3D-EM simulator HFSS.

I-23 : Designing singular plasmonic nanostructures for broadband collection and concentration of light
Yu Luo, John Pendry

On the basis of transformation optics, we present an analytical approach to systematically study and design a general class of singular plasmonic structures, and discuss their applications in broadband light harvesting and nanofocusing. Our analysis shows that the SP spectrum of a singular nano-particle is identical to that of an infinite metallo-dielectric system, and is therefore continuous rather than discrete. Detailed investigation will be presented on how the field

enhancement and light harvesting property of singular structures can be tailored by tuning the geometries.

I-24 : Development of self-organized SRR-like structures in SrTiO3-TiO2 eutectic
P. Osewski, S. Turczynski, K. Kolodziejak, D. Pawlak

In this paper we present growth of self-organized eutectic structures as a new method for obtaining metamaterials. Results of the development of the self-organized SRR-like structures obtained on the basis of SrTiO3-TiO2 eutectic will be presented. These include partial periodicity of the system as well as new results in manufacturing metallodielectric systems.

I-25 : Diplexer Based on Composite Left/Right Handed Transmission-line
Kafil Ahmed, Bal Virdee, Mohamad Farhat

This paper presents a compact microstrip three-pole diplexer whose multiband performances is created by using two composite right/left handed (CRLH) filters having a common input splitter. The two passband channels have high isolation between them which is critical in order to prevent undesired interaction which would otherwise adversely affect the diplexers passband response. Analysis of the diplexer using circuit models was verified via ADSTM (MoM).

I-26 : Directive properties of active coated nano-particles
Samel Arslanagic, Richard Ziolkowski

The directivity of a number of cylindrical and spherical active coated nano-particles excited by their respective sources of illumination at optical frequencies is investigated with a particular attention devoted to the influence of the source location and optical gain constant.

I-27 : Effect of oxygen atoms population on the formation of different morphologies of zinc oxide nanoparticles fabricated by DC arc
Saeed Parhoodeh, Mansoor Farbod, Morteza Zargar Shoushtari

Zinc oxide nanoparticles with different morphologies were fabricated successfully by generating DC arc plasma of pure zinc. Different ratios of oxygen and argon gas were used as fabrication atmosphere. The morphology evolutions of ZnO nanoparticles and the effect of atmosphere components on it were investigated by changing the ratios of atmosphere components. Morphologies and structures of the fabricated samples were analyzed by XRD, SEM and TEM. Comparison between the results of this study and our previous works showed that the morphologies of nanoparticles dominantly were determined by the oxygen partial pressure. It was also shown that the total pressure which was exerted on constituent components had a less important role in final shapes of nanoparticles.

I-28 : Electromagnetic modeling of plasmonic properties of gold nanoparticles embedded within a dielectric matrix deformed by swift heavy ions
Julien Cardin, Alexandre Fafin, Fabrice Gourbilleau, Pierre-Eugene Coulon, Abdallah Slablab, Giancarlo Rizza, Christian Dufour

The growing number of fields in which are studied the localized plasmon surface resonance such as light management for energy, enhanced field spectroscopy, or for integrated optical telecommunications bellow the diffraction limit is driving the development of modeling methods of these systems. In this paper, the electromagnetic properties of ion-deformed gold, sphere, prolate, nanorods and nanowires embedded within a dielectric matrix are simulated in a spectral range from visible to infra-red by means of Auxiliary Differential Equations (ADE) coupled to a Finite Difference Time Domain (FDTD) method. The electromagnetic field distribution is investigated in gold nanostructures in order to evidence the local field enhancement effect characteristic of the Localized Surface Plasmon Resonance (LPSR).

17:00 - 18:40 ***Thévenin***

3A: Metamaterials and negative index materials II

Chaired by: David Smith

17:00 : Keynote talk
Boundary conditions for metasurfaces: idealization, materialization, realization

Ari Sihvola

In this talk, I will describe the conceptual differences between the various ways of modeling and analyzing complex surfaces and metasurfaces. The connection of surfaces with extended materials and their realizations is important. Idealization, materialization, and realization are processes that describe the connections between different levels of the modeling of complex media.

17:**40 :** Invited talk
Reflection and transmission of light at metamaterials
Falk Lederer, Carsten Rockstuhl, Thomas Paul, Christoph Menzel, Wojciech Smigaj, Philippe Lalanne

The appropriate description of light scattering (transmission/reflection) at a bulky artificial medium, consisting of a sequence of functional metamaterial and natural material films, represents a major challenge in current theoretical nano-optics. Because in many relevant cases, in particular in the optical domain, a metamaterial must not be described by an effective permittivity and permeability the usual Fresnel formalism cannot be applied. A reliable alternative consists in using a Bloch mode formalism known e.g. from the theory of photonic crystals. In this contribution we present the theoretical background and apply the formalism to the quite general problems of reflection/transmission at a metamaterial film sandwiched either between a homogeneous or a dissimilar metamaterial.

18:**00 : Reducing Radar Cross Section by Investigating Electromagnetic Materials**
S. Komeylian, F. Hojjat-Kashani

Decreasing Radar Cross section (RCS) is investigated in electromagnetic materials, i.e. double-positive (DPS), double-negative (DNG), epsilon-negative (ENG) and mu-negative(MNG) materials. The interesting properties of these materials strongly facilitate the manufacturing of structures with unusual electromagnetic characteristics. In this correspondence, we intend to derive the valid conditions for achieving transparency and gaining resonance for an electrically small cylinder by careful scrutiny in these materials.

18:**20 : Tuning the plasmonic regime in high temperature superconductor metamaterials**
Odeta Limaj, Valeria Giliberti, Alessandra Di Gaspare, Michele Ortolani, Gianluca De Marzi, Stefano Lupi

High temperature superconductors (HCTS) are one of the most promising candidates for active and tunable metamaterials in the terahertz range. In this work we demonstrate the restoring of the plasmonic regime and a good tunability of plasmonic resonances up to 3 THz across the superconducting transition of YBa2Cu3O7 films. A similar behavior can be obtained in other HCTS systems, showing an universal plasmonic response for superconducting materials.

17:00 - 18:40 ***Estaunié***

3B: Plasmonics and nanophotonics III

Chaired by: Peter Nordlander

17:**00 :** Invited talk
Light trapping in nanoparticle arrays beyond the quasi-static limit
Teri Odom

This paper will describe a new type of subradiant plasmon that can be continuously tuned in 2D arrays of large (100 nm) nanoparticles. The arrays support out-of-plane dipolar interactions that suppress radiative decay and amplify local fields. At the subradiant resonance wavelength, the incident light is trapped in the nanoparticle array plane, and accumulated plasmon energy results in strong nano-localized fields on each particle.

17:**20 : Confinement effect of the Localized Surface Plasmons on the coupling of gold nanolithographied structures: Application to Surface Enhanced Raman Scattering**
Nicolas Guillot, Cristiano D'Andrea, Andrea Toma, Pablo Albella, Remo Proietti, Barbara Fazio, Onofrio Marago, Enzo Di Fabrizio, Javier Aizpurua, Pietro Gucciardi, Marc Lamy de la Chapelle

The aim of this work is to show the effect of the confinement of the Localized Surface Plasmons (LSP), located on the surface of arrays of gold nanorods in dimers configuration, on the coupling efficiency and its direct incidence on the Sur-

face Enhanced Raman Scattering (SERS) intensity. We show that the nanoparticles size and the excitation wavelengths are key factors involved in the modification of the confinement of the LSPs. In fact, an increase of the nanoparticles aspect ratio and a decrease of the excitation wavelength result in a decrease of the LSPs confinement.

17:**40 :** Keynote talk
From nano bumps to vertical U-shape three-dimensional gold nano-ring and toroidal metamaterials in optical region
Ding Ping Tsai

Fabrication of nano bumps and vertical U-shape nano gold rings (110 nm x 60 nm x 40 nm) on a fused silica substrate has been successfully implemented by laser and e-beam lithography double exposure process. Plasmonic resonance modes of such particles are investigated by finite-element simulations and optical measurements, which are in excellent agreement with each other. Results show the manipulation of the light, and electromagnetic field solely depends on the resonance mode either enhanced between two prongs of vertical U-shape nano ring or enhanced around two prongs of vertical U-shape gold ring. The toroidal metamaterials can provide a compelling evidence of a resonant response attributed to a toroidal dipole excitation.

18:**20 : Two photon absorption cross-section enhancement of a dye by gold nanotriangles**
Jarrett Vella, Augustine Urbas

The ability of sub-wavelength, gold triangles to enhance the two photon absorption cross-section of an organic dye is investigated through finite element method calculations and experimental measurements. Hexagonal arrays of gold triangles were prepared using nanosphere lithography so that their localized surface plasmon resonance (LSPR) lies at 800 nm. A dye, AF455, capable of undergoing two photon absorption at 800 nm was then spin-coated onto the gold triangles. Several films of variable-thickness AF455 were prepared, with thicknesses ranging from 30 nm to 200 nm. The gold triangles were observed to either increase or decrease the two photon absorption cross-section of AF455, depending on the thickness of the dye layer. The dependence on AF455s two photon cross-section on its film thickness on gold triangles was predicted by finite element method (FEM) calculations. The simulations suggest the two photon absorption cross-section enhancement observed was due to the gold triangles LSPR, and they also suggest that the decrease in the two photon absorption cross-section of AF455 on the gold nanostructure is due to a complex optical reflection pattern generated by the gold triangles.

17:00 - 18:40 ***B312***

3C: Chiral and bianisotropic materials

Chaired by: Costas Soukoulis

17:**00 : Three-dimensional chiral plasmonic oligomers**
Mario Hentschel, Martin Schäferling, Thomas Weiss, Hans-Georg Kuball, Na Liu, Harald Giessen

We demonstrate a chiral optical response in stacked arrangements of plasmonic nanostructures. They exhibit resonant plasmonic coupling between particles of similar size and dipole moment. Moreover, we demonstrate that such particle groupings possess the capability to encode their three-dimensional arrangement in unique and well-modulated spectra making then ideal candidates for a three-dimensional chiral plasmonic ruler. Our results are crucial for the future design and improvement of plasmonic chiral optical systems, e.g., for ultrasensitive enatiomer sensing on the single molecule level.

17:**20 : Magneto-electric coupling in U shaped resonators near visible wavelengths**
Nicolas Guth, Bruno Gallas, Josette Rivory, Abdelwaheb Ourir, Johan Grand, Géraldine Guida, Julien de Rosny, Camille Jouvaud, Redda Abdeddaïm

We study of the optical properties of U shaped resonators made of gold synthesized by e-beam lithography. One electric-like resonant mode near 990 nm and one magnetic-like resonant mode near 885 nm are characterized. We show that the influence of magneto-electric coupling can be separated from that of spatial dispersion by performing measurements along the optic axes of the resonators. Our model provides a comprehensive description of the optical properties of U-shaped resonators in visible domain.

17:**40 : Experimental study on circular polarization dependent electromagnetically induced transparency phenomenon in chiral plasmonic metamaterials**
Yunhui Li, Hong Chen, Wing Yim Tam

In this paper microwave experiments are performed to verify the circular polarization dependent electromagnetically induced transparency (EIT) phenomenon in chiral plasmonic metamaterials. Both numerical simulation and microwave experiment demonstrate that, the EIT spectrum only emerges for only one of the circularly polarized lights, either the left-circularly-polarized or the right-circularly-polarized ones. Consequently, the obvious difference of transmission spectra for these two circularly-polarized waves leads to large circular dichroism in our very thin structures. Therefore, the chiral EIT medium may be promising for the slowing down or capturing of certain circularly polarized light.

18:**00 : Casimir Force with Chiral Metamaterials**
Rongkuo Zhao, Eleftherios Economou, Thomas Koschny, Costas Soukoulis

It was theoretically demonstrated that repulsive Casimir forces and stable nanolevitations can be obtained by using chiral metamaterials if the chirality is strong enough. Possible challenges exiting in our proposal will also be discussed.

18:**20 : Lagrangians and Hamiltonians for the electrodynamics of Wire-SRR and single-resonance-chiral metamaterials**
P. G. Luan

The Lagrangian densities for the electrodynamics of some dispersive metamaterials are proposed. The Euler-Lagrangian equations yield the correct Maxwell equations for the fieldquantities E, B, D, H and the equations of motion for the polarization P and magnetization M. The Hamiltonians of the systems are then derived using the standard Legendre transform. The resultant Hamiltonians are the same as the energy densities derived in our previous publications. This confirms the correctness of the energy density formulas. The Hamiltonians, in principle can be quantized canonically to give the quantum descriptions of the low energy (long wavelength) electromagnetic excitations in these dispersive metamaterials.

17:00 - 18:20 ***Emeraude***

3D: Structured and disordered media I

Chaired by: Yijun Feng

17:**00 : Nanometric hyperspectral imaging of surface plasmons in metallic disordered films**
Arthur Losquin, Odile Stéphan, Mathieu Kociak

Now being broadly used for mapping surface plasmons in highly symmetric nanoobjects, we will show how Electron Energy Loss Spectroscopy can be of great help to understand the properties of surface plasmon modes in complex media, such as disordered metal films.

17:**20 : Anderson localization in disordered dispersive media with metamaterials**
Ara Asatryan, Lindsay Botten, Michael Byrne, Valentin Freilikher, Sergey Gredeskul, Ilya Shadrivov, Ross McPhedran, Yuri Kivshar

Effects of dispersion and absorption on Anderson localization in randomly layered metamaterials have being studied analytically and numerically. It is shown that the radiation in one-dimensional disordered systems can be delocalized in μ or ε-near-zero disordered media - a newform of delocalization that occurs in one dimension. We have also demonstrated dispersion-induced suppression of Anderson localization in mixed stacks with either dielectric permittivity or magnetic permeability disorder. However, the presence of both forms of disorder enhances localization.

17:**40 : ZnSxSe(1-x) nanostructures arrays in porous anodic alumina templates**
Rishat Valeev, Eduard Romanov, Artemiy Beltukov

This work is focused on the development of the ordered ZnSxSe(1-x) nanostructures arrays by the method of condensation of thermally evaporated material in the pores of highly-ordered anodic alumina films in ultrahigh vacuum. The structure of ZnSSe@AAO (AAO – Anodic Alumina Oxide) composite was studied by SEM, XRD, SIMS and EXAFS-

spectroscopy methods. Luminescent characteristics of nanostructures were also investigated. The comparison with continuous ZnSxSe(1-x) thin films is provided.

18:00 : Artificial magnetism induced in TiO2 microspheres in the terahertz range
Riad Yahiaoui, H. Němec, C. Kadlec, F. Kadlec, P. Kužel, U-C. Chung, C. Elissalde, M. Maglione, P. Mounaix

In this paper we have designed fabricated and experimentally characterized different layers of TiO2-based metamaterials. Using the finite element method calculator (HFSS) and the terahertz time domain spectroscopy (THz-TDS), the resonant behavior of both magnetic and electric functions have been successfully demonstrated in the terahertz range.

17:00 - 18:40 ***Rubis***

3E: Bottom-up approach towards metamaterials and plasmonics II

Organized by: Dorota Pawlak

Chaired by: Mikhail Noginov

17:00 : Invited talk
Protein-guided assembly of (magnetic) nanostructures
Mitsuhiro Okuda, Jean-Charles Eloi, Sarah Ward Jones, Walther Schwarzacher

The iron storage protein ferritin may be used as a template for the growth of nanoparticles with diameter below 10 nm. Here we present two different methods of assembling the nanoparticles into regular patterns, one 3-dimensional and one 2-dimensional, each of which relies on protein interactions.

17:20 : Invited talk
Self-organized plasmonic materials based on spatially arranged nanoparticles: concepts and realizations
Toralf Scharf

Fabrication and characterization of plasmonic materials are discussed with respect to self-organization on different lengths scales. We focus on materials with heavy nanoparticles load. We will give examples of different kind of materials that show electromagnetic coupling of nanoscopic units. Realization of a more complex photonic structure will be discussed in detail.

17:40 : Fabrication and characterization of metallodielectric eutectic structures for photonics
Katarzyna Sadecka, Marcin Gajc, Andrzej Klos, Ryszard Diduszko, Barbara Surma, Andrey Nikolaenko, Dorota Pawlak

This work presents metallodielectric eutectic structures as promising materials with special electromagnetic properties. Metal-oxide eutectics such as Bi2O3-Ag and CuO-Ag have been obtained by the micro-pulling down method. Results of structural and optical measurements in the visible and infrared region will be presented.

18:00 : Invited talk
Self-organized assembling of three-dimensional plasmonic metamaterials
T. Tanaka

Metamaterial is an artificially designed material that consists of metal resonator array. Realization of three-dimensional metamaterials is still difficult, because numerous number of nanometer resonators should be made and embedded in a host medium to form metamaterial. In this paper, as a bottom-up approach to fabricate three-dimensional metamaterial structure, self-organized assembling of gold nanoparticles using programmable DNA-templating is developed and reported.

18:20 : Invited talk
Scalable Metamaterial by Self-Assembly
Won Park

We provide a comprehensive review of scalable fabrication of optical metamaterial by nanoparticle self-assembly. We present the recent results from a variety of self-assembly techniques including template-directed self-assembly, liquid

crystal based self-assembly, copolymer-based self-assembly and cage-molecule driven self-assembly.

17:00 - 18:40 ***Saphir***

3F: Acoustic metamaterials III

Organized by: Jensen Li and Johan Christensen

Chaired by: Jensen Li and Johan Christensen

17:00 : Acoustic surface evanescent wave and its associated physical effects
Minghui Lu, Xu Ni, Yan-Feng Chen

We explore acoustic surface evanescent wave (ASEW) that is the acoustic counterpart of spoof surface plasmon polaritons to modify its associated interesting acoustic phenomena. For example, extraordinary acoustic transmission (EAT) and collimation of sound waves are analyzed using microscopic theory of ASEW. Furthermore, ASEW is modulated to influence the EAT effect by coupling the Helmholtz resonance with Fabry – Pérot resonance, which is helpful to adjust the phase of output sound wave without changing the structure thickness and amplify the focusing intensity of a Fresnel zone plate. Therefore ASEW provides a new route to the design and integration of subwavelength acoustic devices.

17:20 : Negative refraction of sound in layers of perforated plates
J. Christensen, F. J. Garcia de Abajo

We present a theoretical study on the amplification of evanescent sound waves produced by coupling to trapped modes hosted by a fluidic planar waveguide. Total internal reflection at interfaces of different refractive indexes can be frustrated by the introduction of a slow slab waveguide which is leading to a gigantic field enhancement, useful for sensitive transducers and acoustic shock lithotripsy. The mechanism behind the evanescent field coupling that is also known as tunnelling barrier penetration in quantum mechanics is here adopted for its use in an acoustic superlens. The higher spatial harmonics produced by a subwavelength object can couple to trapped modes of the slow waveguide and be reproduced as an image at a distant plane. We suggest a practical implementation of these ideas by means of a silicone rubber slab containing positive acoustic wave propagation parameters.

17:40 : Invited talk
Dirac cone dispersions in photonic and phononic crystals
C. T. Chan, F.M. Liu, X.Q. Huang, Y. Lai, Z.H. Hang

We show that by employing accidental degeneracy, dielectric photonic crystals can be designed and fabricated that exhibit Dirac cone dispersion at k=0 at a finite frequency. Under some circumstances, effective medium theory can be used to relate the photonic crystal to a material with effectively zero permittivity and permeability at and near the Dirac point frequency. This concept can also be extended to acoustic and elastic waves. For the case of acoustic waves, we can find direct correspondence with the photonic crystal system. For the case of elastic waves, we show that Dirac cone dispersion at k=0 can be related to a special kind of elastic crystal in which only longitudinal wave is allowed in certain directions and only transverse wave is allowed in some other directions. Effective medium theory finds that this phononic crystal has effectively zero mass density and zero effective 1/ C44 at the Dirac point.

18:00 : Invited talk
Extraordinary acoustic shielding by an array of water-immersed PMMA cylinders
Zhengyou Liu

18:20 : Flat lens for Lamb waves focusing
Marc Dubois, Patrick Sebbah, Sébastien Guenneau, Nicolas Etaix, Ros Ing, Mohamed Farhat, Stefan Enoch

Flat lens concept proposed in 1968 by V.G. Veselago is extended to surface acoustic waves on a thin plate. A 45deg-tilted square lattice of circular holes drilled in a Duraluminium plate has been chosen to experimentally demonstrate focusing of flexural waves.

17:00 - 18:00 ***Jade***

3G: Transformational electromagnetics

Chaired by: Stefan Enoch

17:00 : Transformation-based Metamaterials for Enhancing the Ability of Computational Methods in Electromagnetics
Ozlem Ozgun, Mustafa Kuzuoglu

17:20 : Nonlocal Transformation-Optics Metamaterials
Giuseppe Castaldi, Vincenzo Galdi, Andrea Alù, Nader Engheta

We introduce a new framework for transformation optics based on nonlocal coordinate transformations in the spectral (wavenumber) domain, rather than in the conventional spatial domain. Our proposed approach allows a physically-incisive and powerful geometrical interpretation in terms of deformation of the equi-frequency contours, and may open intriguing venues in dispersion engineering of electromagnetic metamaterials.

17:40 : Transformation optics in plasmonics: from singular to blunt structures
Yu Luo, Dang Lei, Stefan Maier, John Pendry

In this contribution, a systematic analytical model is proposed, based on transformation optics, to investigate a general class of plasmonic nanostructures with blunt edges/corners. Comprehensive discussions will be provided on how the edge rounding at the sharp boundary affects the local field enhancement as well as the energy and bandwidth of each plasmonic resonance. Importantly, we will show that by optimizing the geometry of the nanostructure, it is possible to design a broadband light harvesting device with the absorption property robust to the edge bluntness.

Friday 20th April, 2012

08:15 - 09:45 ***Thévenin***

Plenary Session II

08:15 : Plenary talk
Frontiers of Plasmonics: enabling new applications
Naomi Halas

09:00 : Plenary talk
From Metamaterials to Metasystems to Metafunctions
Nader Engheta

Coffee Break and Exhibit Inspection

Poster Session II

09:45 - 10:50

II-1 : Polarizability matrix extraction for bianisotropic metamaterials from the scattering parameters of normally incident plane waves
Theodosios Karamanos, Alexandros Dimitriadis, Nikolaos Kantartzis

In this paper, a polarizability matrix retrieval method for bianisotropic metamaterials is introduced. By assuming that scatterers can be modeled by equivalent point-dipoles located at their centers, the induced dipole moments are analytically related to the incident field. Using transmission line models, the scattered fields are obtained for two individual cases of normal wave incidence. These fields can be, finally, combined with the incident field to produce the desired polarizability matrix in terms of the measured or simulated scattering parameters.

II-2 : Hydrothermal synthesis of ZnO nanorods and its application to photosensor
L. S. Chuah

In this work, vertically zinc oxide (ZnO) nanorods have been strongly synthesized through an uncomplicated hydrothermal process on silicon substrates without the aid of a catalyst. Silicon substrate with seed layer was then vertically inserted into the aqueous precursor solution. The as-synthesized ZnO nanowires have diameters between 100-140 nm and lengths around 1 microm. It exhibits a stable UV emission at around 382 nm. The current-voltage (I-V) characteristics of platinum (Pt) ZnO nanorods photosensor under dark and illumination conditions was studied. The ideality factor (n) and Schottky barrier height (SBH) were ascertained by the I-V method. Well-defined response to UV illumination in the forward-biased state because of the photogeneration of further electron – hole pairs.

II-3 : Electrophoretic core-shell particles for photonic crystal device
Young-seok Kim, Youngmin Kim, Gaehang Lee, Mingi Kwak

We synthesized electrophoretic core-shell particles which we will use as the building blocks of optical structures, we used these particles to assemble photonic crystalline structures that interact strongly with visible light. The system reported here shows important features such as a fast, reversible, and tunable optical response to electric fields by changing the silica shell thickness and surface charge control agents.

II-4 : Envelope solitons formation near the band gap in magnonic crystals
Svetlana Sheshukova, Evgeny Beginin, Yurii Sharaevskii, Sergey Nikitov, Maria Morozova

The features of envelope soliton formation in one-dimensional periodic ferromagnetic structure were considered. The model based on the coupled nonlinear Schrodinger equations was used for investigation. The opportunity of gap soliton formation was investigated experimentally.

II-5 : Excitation of surface plasmon polaritons in a SNOM tip
Viktor Palm, Mihkel Rähn, Vladimir Hizhnyakov

Demonstrated is a new technique for observation of the surface plasmon polariton (SPP) generation in a tapered metal-coated tip (a SNOM tip) terminating a multimode optical fiber. The mode-filtering effect of a SNOM tip is used to virtually eliminate most of the fiber modes, retaining only two of them. We utilize the fact that SPPs in the tip propagate slower than pure photons, and the propagation speed actually depends on the coupling strength between photons and plasmons. This results in an optical path difference (OPD) for different photonic fiber modes having different coupling strength to plasmons. The OPD value for a pair of modes can be easily determined by analyzing the mesoscopic spectral modulation of the output light. The fiber length dependence of OPD is studied to take into account the fibers inherent modal dispersion. The modal dispersion is shown to change its sign in the SNOM tip.

II-6 : Experimental study of EIT-Like phenomenon in a metamaterial plasma waveguide
Wusong Wang, Yewen Zhang

We demonstrate the realization of the electromagnetically induced transparency (EIT)-like transmission in a metamaterial plasmonic waveguide with double side defects based on transmission lines. The waveguide with a single side defect works as a plasmon resonator and the resonance wavelength is determined by the Fabry-Perot resonance of surface plasmon. While in a waveguide with double side defects, a transmission peak appears between the two resonators frequencies because of the destructive interference between the resonance modes of the two resonators, which indicates a pronounced EIT phenomenon. The experiment results agree well with simulations in microwave frequencies.

II-7 : Fabrication of three dimensional split ring resonators by stress-driven assembly method
Chih Ting Hsiao, Che Chin Chen, Shulin Sun, Kuang-Yu Yang, Pin Chieh Wu, Wei Ting Chen, Eric Plum, Nikolay Zheludev, Din Ping Tsai

This paper demonstrates a self-assembly strategy for fabricating three dimensional (3D) metamaterials. This strategy represents the desired 3D curving prongs of the split ring resonators (SRRs) erected by metal stress force with appropriate thin film parameters. Transmittance spectra and field distribution corresponding to each resonance modes are calculated by finite element method (FEM). The eigen-modes of the SRRs can be excited by normal illumination with polarization state parallel to the erected SRRs, which are unlike for the cases of planar SRRs. This method opens a promising fabrication process for the application of tailored 3D SRRs.

II-8 : Fano resonance in Multilayered nanodice
Adnan Khan, Giovanni Miano

A computational study of the plasmonic properties of a three dimensional multilayered nanodice has been investigated. Symmetry breaking has been initiated by offsetting the inner core with respect to the shell due to which a coupling between plasmon modes of different multipolar order results in additional Fano resonances. This metallodielectric nanostructure with reduced symmetry also reveals considerably high local-field enhancement.

II-9 : Focusing surface plasmons on Er3+ ions through of gold planar plasmonic lenses
Victor Anthony Garcia Rivera, Fabio Aparecido Ferri, Luiz A.O. Nunes, Euclydes Marega Jr

Gold plasmonic lenses consisting of planar concentric rings with different periods were milled with a Focused gallium Ion Beam on a gold thin film deposited onto an Er3+-doped tellurite glass. The plasmonic lenses were vertically illuminated with an argon ion laser (488 nm) highly focused by means of a 20x objective lens. The focusing mechanism of the plasmonic lenses is explained by using a simple coherent interference model of surface plasmon-polariton (SPP) generation on the circular grating as a result of the incident field. As a result, phase modulation can be accomplished by the groove depth profile, similar to a nano-slit array with different widths. This focusing allows a high confinement of SPPs which excited the Er3+ ions of the substrate. We analyze the influence of physical and geometrical parameters on the luminescence spectra. The variation of these parameters resulted in considerable changes of the luminescence spectra.

II-10 : High performance microwave antennas based on metamaterials
Meiqing Qi, Hui Feng Ma, Tie Jun Cui

Metamaterials have the advantage to control the electromagnetic waves freely, and hence they have a lot of potential

applications. One of the typical applications is the gradient refractive-index lens. In the earlier study and design of lens antennas, the metamaterials are used to control the wave fronts, i.e., to transform the spherical wave fronts into planar waves. In this presentation, through optimizing the lens refractive-index distribution, we introduce a method to control the electromagnetic wave amplitude and phase simultaneously on the lens aperture. By designing, the Taylor circle array amplitude and the flat phase of aperture field are achieved. We fabricate such new metamaterial lens antennas by using non-resonant metamaterial elements, which have a broad frequency band (covering from 12 GHz to 18 GHz in our experiment) with extremely high efficiency. The simulation and measurement results agree very well with high performance.

II-11 : Holographic metasurfaces for terahertz focusing: design, fabrication and experiment
Sergey Kuznetsov, Mikhail Astafyev, Miguel Navarro-Cía, Alexander Gelfand, Andrey Arzhannikov, Manfred Thumm

In this contribution we exploit the controlled reflection provided by metasurfaces together with holographic techniques to design non-profiled diffractive optical elements working at 334 GHz. The required metasurfaces are synthesized via an iterative algorithm, fabricated by photolithography and experimentally validated using a submillimeter-wave BWO spectrometer.

II-12 : Influence of Mn doping on structural and optical properties of ZnO nano thin films synthesized by sol-gel technique
Merzouk Hamid, Chelouche Azeddine, Saoudi Saada, Aksas Ali, Djouadi Djamel

Undoped and Mn-doped ZnO samples with different percentage of Mn content (1, 5 and 10 at l %) were synthesized by a dip-coating sol-gel method. X-ray diffraction (XRD), scanning electron microscopy (SEM), UV – VIS and photoluminescence spectroscopy are used to explore the structural, chemical and optical properties of the samples. The XRD spectra show that all the samples are hexagonal wurtzite structures. We note that doping favors c-axis orientation along planes (002). Up to 5at% of Mn doping level, c-axis lattice parameter shifts towards higher value with the increase of manganese content in the films. We note that a small doping (1%) lowered the refractive index while the thickness of the layers and the gap increases.

II-13 : Laser-ultrasonic investigation on Lamb wave band gaps in two-dimensional phononic crystal plates
Jingshi Wang, Ying Cheng, Xiaodong Xu, Xiaojun Liu

Phononic crystals (PCs) commonly consisted of two materials with huge contrasted elastic properties and mass densities are generally studied in theory such as the finite element method for many difficulties in the experiments. In this paper, the laser-ultrasonic non-destructive testing is introduced to investigate the propagation of Lamb waves in two-dimensional PCs plates. The existence of band gaps for low order Lamb wave modes is demonstrated experimentally. Crucial parameters such as the thickness of PCs plate and the periodical arrangement of scatterers are discussed in detail for the influence of location of band gaps. The finite element analysis agrees well with the result of laser-ultrasonic measurement.

II-14 : Limitations of superoscillation pupil filters
Heikki Hyvarinen, Shakil Rehman, Jani Tervo, Jari Turunen, Colin Sheppard

Superoscillations may occur in regions of a band-limited signal with small amplitude having oscillations faster than the fastest Fourier component of the signal. In optical region, superresolution can be achieved by appropriate design of pupil functions where the angular aperture determines the focal spot smaller than the Abbe diffraction limit outside the evanescent field region. The angular aperture cannot be increased indefinitely and the huge sidelobes cannot be avoided that are present in superoscillation filters. The limitations of using such kind of filters in practical applications are discussed through numerical examples.

II-15 : Multi-wavelength superlensing with layered phonon-resonant dielectrics
Peining Li, Thomas Taubner

A superlens usually has only a small wavelength range of operation. We use effective medium theory to show that a multilayered superlens consisting of polar dielectrics can be designed to have multiple operation wavelengths. Our proposed device made from layers of Strontium Titanate (STO) and Silicon Carbide (SiC) promises subwavelength imaging at both infrared and Terahertz (THz) wavelengths.

II-16 : New nanocomposite magneto-optical material for magnetic photonic crystals prepared by RF-magnetron co-sputtering of Bi3Fe5O12 and Bi2Dy1Fe4Ga1O12 materials system and two-stage annealing
Viacheslav Kotov, Mikhail Vasiliev, Kamal Alameh, Dmitry Balabanov, Vladimir Burkov, Vladimir Shavrov

RF co-sputtered batches of nanocomposite Bi3Fe5O12 – Bi2Dy1Fe4Ga1O12 films optimized (using composition adjustments implemented by varying the RF powers at each target) with respect to the annealing crystallization temperature resulted in obtaining a new MO nanocomposite material that exhibits simultaneously a high MO quality and magnetization direction perpendicular to the film plane, which are the properties necessary for many applications based on magneto-photonic crystals (MPC).

II-17 : Nano plasmonic imaging through metal coated CNT forest in the visible wavelengths
Muhan Choi, Byungsoo Kang, Choon-gi Choi

Imaging resolution enhancement based on the propagating plasmonic mode is demonstrated in metal coated CNT forest metamaterials. In order to make the pitch of the metallic nanorods have tens nm, bottom up fabrication using self-assembled block copolymer was used. The metamaterial allowed the target object to be imaged with 150 nm resolution at the wavelength 700 nm.

II-18 : Nanoantenna enhanced infrared spectroscopy of molecules
Jörg Bochterle, Frank Neubrech, Annemarie Pucci

Under certain conditions light interacts with the conduction electrons in metals. Such conditions are fulfilled for small nanoparticles with dimensions in the order of the wavelength of light or smaller. The resonant excitation is called localized surface plasmon resonance (LSPR) and features a large enhancement of the local electrical fields in the vicinity of the metal nanoparticles, which act in this case as nanoantennas. The strong fields are of great interest for sensing applications. Placing molecules in these hotspots, the plasmon can couple to vibrational bands of the molecule, which are in the infrared spectral range. When both resonance frequencies match, the coupling is maximal, giving rise to the strongest enhanced signal of the molecule. This principle has been proved for example to detect a self assembled monolayer of Octadecanthiol molecules which were chemisorbed to the surface of a gold nanoantenna.

II-19 : Nanocomposite C-Pd thin films – a new material with specific spectral properties
Justyna Keczkowska, Małgorzata Suchańska, Hovik Baghdasaryan

In this paper, the results of optical investigations for thin films of carbon-palladium (C-Pd) nanocomposites are presented. This films were prepared using two step PVD/ CVD method. The optical and Raman spectroscopy has been used to characterize the material. The multinanolayer model was used to explain the specific spectral properties.

II-20 : Nanooptical study of plasmonic antennas with fast electrons
Zackaria Mahfoud, Odile Stéphan, Anne-Laure Baudrion, Jérôme Plain, Mathieu Kociak

Plasmonic devices such as optical antennas, operating in the visible region of the electromagnetic spectrum are constrained to spatial dimensions of a few nm to hundreds of nm. As most of the physical properties of the plasmons vary on a very short scale, it is necessary to study this type of objects at the nanometer scale. We have performed Electron energy Loss Spectroscopy (EELS) spectral imaging in the IR-vis-UV regime in a Scanning Transmission Electron Microscope (STEM) on several types of coupled and uncoupled nanorods, either lithographed or chemically grown.

II-21 : Nanophotonics of Vanadium Dioxide Coatings for Smart Window Applications
Ghouwaa Philander, Malek Maaza, Emmanuel Iwuoha

Vanadium Dioxide (VO2) is a smart material which exhibits a phase transition at a temperature of 68 C in its pure and single crystalline form. The phase transition from the monoclinic semi-conducting form to the tetragonal metallic (rutile) form is also accompanied by a change in the optical properties of VO2. This simultaneous optical shift goes from an optically transparent to an optically opaque material where a change in solar radiation transmittance is observed. Although the introduction of a dopant into the lattice structure of VO2 has proven to decrease the transition temperature to near room temperature, the optical transmittance capability as well as the nature of the transition remains a challenge (1). This research involves the development of a doped VO2 coating for smart window applications with enhanced properties.

II-22 : Negative refraction in semiconductor metamaterials based on quantum cascade laser design for the mid-IR and THz spectral range
Jelena Radovanovic, Sabina Ramovic, Aleksandar Danicic, Vitomir Milanovic

We have considered the realization of metamaterials based on semiconductor quantum nanostructures, in particular, with the structural arrangement as in quantum cascade laser (QCL) designed to achieve optical gain in the mid-infrared and terahertz part of the spectrum. The entire structure is placed in a strong external magnetic field which facilitates the attainment of sufficient population inversion, necessary to manipulate the permittivity and enable left-handed regime

II-23 : Nonlinear Dynamics of Gap Solitons Generation and Propagation in 2D Bragg Grating Structure
Alexander Sadovnikov, Andrew Rozhnev

The process of the electromagnetic wave propagation in the 2D nonlinear Bragg grating structure has been studied. The cubic Kerr nonlinearity of materials was considered. The values of the cut-off frequencies were estimated with the modification of the effective refractive index method. The possibility of propagation of the signal which frequency lies within the band gap was demonstrated. The process of soliton tunneling and the multiple gap-soliton formation in the nonlinear 2D Bragg grating has been investigated for the different values of the structure parameters. Nonlinear dynamics in the tilted grating was also studied in detail.

II-24 : Novel dual-band hexagonal EBG structure
Mohamad Mantash, Anne-Claude Tarot, Sylvain Collardey, Kouroch Mahdjoubi

The design of a novel compact dual-band hexagonal EBG structure used as an AMC for 2.5/5.5 GHz WLAN applications is presented through parametric analysis of the unit-cell dimensions. Moreover a comparison with equivalent double-square AMC regarding operation bandwidth is carried out.

II-25 : Observation of light diffraction from self-assembled photonic crystals
Sunita Kedia, R. Singh

Diffraction of laser beam from the 111 plane of three-dimensional self-assembled polystyrene photonic crystals (PhC) is experimentally analyzed. Finite numbers of beams emerge out of the colloidal PhC when laser light diffracts from it. The arrangement of diffraction spots on the screen indicates the lattice arrangement in the crystal. The number of diffracted beams strongly depends upon the lattice constant and the incident wavelength. Localized diffraction spots are observed on the surface of the PhC when incident wavelength matches with the particle size of the crystal. The number of diffraction spots increases significantly as lattice constant increases compared to the incident wavelength.

II-26 : Optical forces in nanowire pairs and metamaterials
Rongkuo Zhao, Philippe Tassin, Thomas Koschny, Costas Soukoulis

We studied the optical force arising when isolated gold nanowire pairs and metamaterials with a gold nanowire pair in the unit cell are illuminated with laser radiation. The optical forces are much stronger than that in nanospheres due to their stronger electric and magnetic dipole resonances. The force can be attractive or repulsive at different frequencies. The optical force in a metamaterial that consists of a periodic array of nanowire pairs can change sign depending on the ratio of the size of the unit cell to the length of the nanowires.

II-27 : Optical negative index metamaterial of hexagonal arrays of metallic triangular nanoprisms
Mircea Giloan, Simion Astilean

Metamaterial slabs of hexagonal arrays of metallic triangular nanoprisms are studied. Constitutive parameters are calculated using standard retrieval method. Bi-layered structures show both electric and magnetic resonances, due to the symmetric and anti-symmetric hybridized plasmonic states. Hybridized modes frequencies can be tuned by shifting one layer relative to the other one. Negative index of refraction in the optical range is obtained as a result of hybridized states inversion.

II-28 : Optical properties of silver triangular nanoprisms.
Guedje Francois, Hounkonnou Norbert, Astilean Simion

The ability to provide large electric field enhancements make the triangular nanoprisms and branched nanoparticles

very attractive for applications in Surface-Enhanced Raman Scattering(SERS).Theoretical and experimental studies on the optical properties of triangular prisms in water solution are presented in this paper to determine how structural modifications and the incident field polarization affect the extinction spectrum and the enhanced local electric fields (E-field) around particles in wavelength range 300-100 nm.

10:50 - 12:30 ***Thévenin***

4A: Metamaterials and negative index materials III

Chaired by: Vladimir Shalaev

10:50 : Keynote talk
From Metamaterials to Metadevices
Nikolay Zheludev

We define metadevices as devices with all sorts of useful functionalities that can be achieved by structuring of materials responsive to external stimuli on a scale smaller than the operational length. We report an overview on our recent work on developing photonic and microwave electromagnetic metadevices, in particular metadevices exploiting phase change media, electrosctatic and opto- mechanical forces, coherent effects and nonlinear and quantum response of superconductors.

11:30 : All-Dielectric Infrared Metamaterials
Michael Sinclair

We describe the design, fabrication, and characterization of an all-dielectric metamaterial operating in the thermal infrared. The metamaterial is based on cubic dielectric resonators fabricated from Tellurium and arrayed on a Barium Fluoride substrate. As predicted by simulation, the metamaterial exhibits a magnetic resonance near 10 um wavelength, and an electric resonance at a shorter wavelength. The retrieved effective parameters reveal negative permeability (permittivity) in the vicinity of the magnetic (electric) resonance. This work represents a first step toward the development of low loss infrared metamaterials suitable for device applications

11:50 : Bandwidth constraints for passive superluminal propagation through metamaterials
Mats Gustafsson

Superluminal transmission of electromagnetic waves is usually observed in a narrow bandwidth range and the velocity outside this range is subluminal. In this paper, it is shown that the transmission coefficient for superluminal propagation though a periodic metamaterial structure satisfies a sum rule. The sum rule and its corresponding physical bound relate wavelength regions with a phase velocity above an arbitrary threshold with the thickness of the slab. The theoretical results are illustrated with numerical examples.

12:10 : Light tunable megnetic metamaterials
Polina Kapitanova, Stanislav Maslovski, Ilya Shadrivov, Dmitry Filonov, Pavel Voroshilov, Pavel Belov, Yuri Kivshar

The paper presents a new approach for designing electromagnetic metamaterials which can be tuned by light. The results of experimental study of magnetic resonance behavior of a tunable split-ring resonators loaded by a varactor diode and biased by a photodiode operated in photovoltaic mode are presented.

10:50 - 13:10 ***B310***

4B: Plasmonics and biomedical applications

Organized by: Tuan Vo-Dinh

Chaired by: Tuan Vo-Dinh

10:50 : Theranostic and multiplexed dot immunoassay applications of Au/Ag nanocages and nanocomposites
Nikolai Khlebtsov, Boris Khlebtsov, Eliza Panfilova, Vitaly Khanadeev, Alexander Shirokov, Larisa Matora, Georgy

Terentyuk

We report two novel biomedical applications of Au/Ag alloy nanoparticles called nanocages. In the first case, composite nanoparticles consisting of a nanocage core and a mesoporous silica shell doped with a photodynamic sensitizer Yb-2,4-hematoporphyrin were fabricated, characterized, and tested in vitro and ex vivo. In the second part of the study, Ag nanocubes and Au/Ag nanocages bioconjugates were applied to a multiplexed dot immunoassay.

11:**10 :** Invited talk
Development and Modeling of Surface Plasmon Resonance Imaging Biosensor Chips based on Gold Nano- and Micro-Structured Film
Michael Canva, Maha Chamtouri, Anuj Dhawan, Mondher Besbes, Hsin-Neng Wang, Andrew Fales, Julien Moreau, Tuan Vo-Dinh

Plasmonic imaging system has proven to allow dynamical reading of biochips allowing biomolecular interaction characterization and applications such as DNA point mutation diagnostic. Operational systems are currently based on propagating plasmons and research is presently mostly dedicated to studying and taking advantages of nano-micro-structured substrates, both theoretically and experimentally. Examples of applications are focused on genetic diagnosis of hereditary and acquired mutations, specifically cystic fibrosis and breast cancer.

11:**30 :** Invited talk
Monitoring cell metabolism using plasmon resonance energy transfer (PRET)
Olivier Martin

Plasmon resonance energy transfer (PRET) can occur when a metalloprotein interacts strongly with a metallic metamaterial. In this contribution, we investigate the conditions that enhance this phenomenon and show how it can be used to monitor the production of reactive oxygen species in living cells. An unprecedented sensitivity is demonstrated, which enables monitoring living cells in environmental conditions and studying effects such as the toxicity associated to Cd(II) exposure.

11:**50 :** Invited talk
Multiplexing and confinement in fluorescence correlation spectroscopy with an array of optical fibers.
Fiona Quinlan-Pluck, Quentin Wilmart, Emmanuel Fort, Neso Sojic, Sandrine Leveque-Fort, Samuel Gresillon

We use an ordered array of etched optical fibers and an electron multiplying charge coupled device camera to create a multi-points observation platform for fluorescence correlation spectroscopy (FCS). The etched optical fibers improve the resolution of standard FCS and create well separated correlation volumes. The latter avoids the common cross talk problem of multiplexed FCS. Thus our set-up performs multiplexed FCS with precise localisation and confinement. Measurements on fluorescent beads are compared with standard FCS. Correlations show that, in this new set-up, both spatial resolution and confinement within the range of confocal microscopy.

12:**10 :** Invited talk
Nucleic Acid Detection Using Plasmonic Coupling Interference (PCI) Nanoprobes
T. Vo-Dinh

We have developed a novel label-free approach using surface-enhanced Raman scattering (SERS)-based plasmonic coupling interference (PCI) nanoprobes for nucleic acid detection. To induce a strong plasmonic coupling effect and SERS signal, a nano-network of silver nanoparticles having the Raman label located between adjacent nanoparticles is assembled by Raman-labeled nucleic acid duplexes. The PCI method then utilizes specific nucleic acid sequences of interest as competitor elements of the Raman-labeled DNA strands to interfere the formation of the nucleic acid-cross-linked nano-networks in a competitive binding process, resulting in a reduced SERS signal. We illustrate the potential of the PCI technique for biomedical applications by detecting single-nucleotide polymorphism (SNP) and microRNA sequences involved in breast cancers. The results of this study could lead to the development of nucleic acid diagnostic tools for biomedical diagnostics and biosensing applications using SERS detection.

12:**30 : Graphene-based high-performance surface plasmon resonance biosensors**
Edy Wijaya, Nazek Maalouli, Rabah Boukherroub, Sabine Szunerits, Jean-Pierre Vilcot

Since their successful commercialization in the 1990s, surface plasmon resonance (SPR) biosensors have become a

central tool for the study of biomolecular interactions, chemical detection, and immunoassays in various fields. SPR biosensors gain their place by offering unparalleled advantages such as label-free and real-time analysis with very high sensitivity. To further push the limits of SPR capabilities, novel SPR structures and approaches are being actively investigated. Here we experimentally demonstrate a graphene-based SPR biosensor. By incorporating a graphene layer to the conventional gold thin film SPR structure, its biosensing sensitivity is significantly increased. This is shown in a typical affinity biosensing experiment to measure the real-time binding kinetics of streptavidin-biotin. In addition to higher sensitivity, we also obtain a much higher signal-to-noise ratio without the slightest modification of the usual measurement setup. This implies that a considerably lower limit of detection can be made possible with the novel structure. Moreover, our graphene-based SPR biosensors do not require sophisticated surface functionalization schemes as in conventional SPR in order to function. Previous reports have also suggested that graphene might effectively prevent non-specific binding of biomolecules on the sensor surface. With relatively simple fabrication methods and large scalability, these combined distinctive advantages can enable future generation of high-performance SPR biosensors.

12:50 : Plasmon Shaping using Molecular Lithography to Engineer Colorimetric Biosensors
Alasdair Clark

We report a new plasmonic biosensing technique which allows naked-eye detection of antibody affinity binding at extreme sensitivities. Employing an engineered approach to molecularly-driven plasmonic-coupling, we construct nano-complexes within protein nanoarrays using single biomolecular binding events. Precise molecular positioning of single colloid around pre-fabricated plasmonic nanostructures allows us to manipulate the plasmon supported by each resultant heterodimer to engineer a color-shift which is visible by eye.

10:50 - 12:30 ***B312***

4C: Active and Quantum Metamaterials I

Organized by: Arkadi Chipouline and Vassili Fedotov

Chaired by: Arkadi Chipouline and Vassili Fedotov

10:50 : Invited talk
Sub-wavelength imaging from Perfect lenses made with Quantum Metamaterials
Ki Youl Yang, Vincenzo Giannini, Alexey O. Bak, Hemmel Amrania, Stefan A. Maier and Chris C. Phillips

We study the potential of a novel quantum metamaterial for sub-wavelength imaging applications in the mid-Infrared. Because the in-plane and out-of-plane dielectric responses can be independently tuned, we can generate a negatively refracting anisotropic effective medium with losses, described by the figure of merit, FOM = Re(kperp)/Im(kperp) 200 (kperp is the wave vector), that are significantly lower than other systems. Finite element modeling studies indicate that these structures can function as so called perfect lenses, offering $\lambda/13$ spatial resolution at a mid-IR wavelengths of λ 10 mum.

11:10 : Invited talk
Nonlinear control of light in magnetooptic metamaterial waveguides and transformation-driven electromagnetic and acoustic field superfocusing energy concentrators
A. D. Boardman, P. Egan, M. McCall, Yu. G. Rapoport and V. Grimalsky

A general theory of magnetooptic waveguides is developed that embraces Cotton-Mouton, Polar and Faraday orientations. New nonlinear modes, together with a strongly nonlinear theory is developed first, with applications that involve coupled systems and gyrotropic nonreciprocity. Planar layered structures are selected to begin with and, ultimately, the complex Ginzberg-Landau cubic-quintic envelope equation is also developed, in order to understand certain dissipative conditions. Detailed light control is examined together with role of polarization interactions, as the nature of the metamaterial is changed towards an effective zero index. A nonlinear electromagnetic field (energy) concentrator is also considered, for spherically symmetric systems and a new method of investigating proves that superfocusing must be expected. The techniques deployed use complex geometrical optics and the full-wave nonlinear solutions. The nonlinear superfocusing leads to a dramatic appearance of hot spots. A new form of nonlinear switching is found when the input field intensity exceeds some threshold value. Acoustic analogues are presented and all of these concentrator effects will be controllable in a magnetooptic environment.

11:30 : Invited talk
Hybrid plasmonic metamaterials
V. P. Drachev

We will present experimental realizations of metamagnetics and negative index metamaterials for the visible range in active mode, gain assisted negative index materials with no losses, an example of plasmonic nanoantennas for photoluminescence kinetic parameters control and nonlinear materials engineering, experiments on a thermally tunable metamagnetic and a nanoslit lens, and experiments with bio-fabricated nanostructures.

11:50 : Invited talk
Active Metamaterials with Liquid-Crystals-Plasmonics
Iam Choon Khoo

We present our recent work on liquid-crystals-plasmonic materials and nano-structures that combine the unique physical and optical properties of both materials to enable a new generation of reflective, transmissive, modulation and switching elements and devices

12:10 : Invited talk
Semiconductor approaches for tunable metamaterials in the infrared
Igal Brener

Planar Metamaterials can couple strongly with dipolar excitations, such as phonons, free carriers and inter-sub-band transitions when placed in closed proximity. Some of these effects can be further exploited for active control and tuning of Metamaterials and provide the foundation for new electrically controlled photonic devices in the infrared

10:50 - 12:50 ***Saphir***

4D: Mid-infrared and THz plasmonics I

Organized by: Raffaele Colombelli and Yannick De Wilde

Chaired by: Raffaele Colombelli and Yannick De Wilde

10:50 : Invited talk
Phase control of light with plasmonic interfaces: Two- and three-dimensional laws of reflection and refraction
P. Genevet, F. Aieta, F. Capasso, N. Yu, M. A. Kats, Z. Gaburro and J. P. Tetienne

Arrays of optical antennas reflect and refract beams with angles that depend on the phase shift gradient along the surface with respect to the incident beam. These beams obey generalized Snells laws with negative refraction and reflection over certain ranges of the angle of incidence, as well as modified critical angles for reflection and critical angles for reflection. When the phase gradient forms an angle with the plane of incidence, the refracted and reflected beams are no longer coplanar, giving rise to a three dimensional generalization of the above laws that allows unprecedented opportunities to manipulate beams and engineer wavefronts.

11:10 : Experimental study of Surface Plasmons Polaritons on arrays of doped and un-doped semiconductors
Vilianne Ntsame Guilengui, Laurent Cerruti, Jean-Baptiste Rodriguez, Thierry Taliercio

We propose an experimental study of arrays of doped (InAsSb) and un-doped (GaSb) semiconductors. The optical properties of these structures are governed by the surface plasmon polaritons which appear at each interface. The technological process and the experimental characterization are presented. Optical properties are investigated by reflectance and highlight the impact of the geometrical and physical properties of both materials.

11:30 : Tunable terahertz near-field enhancement in two-dimensional plasmonic crystals
Artur Davoyan, Vyacheslav Popov, Sergey Nikitov

We study a terahertz near-field enhancement in two-dimensional electron systems supporting two-dimensional plasmons. We consider a periodically gated two-dimensional electron system, with a central gate finger biased independently from the rest of the grating. Such structure allows creating a tunable plasmonic cavity in a planar plasmonic crystal. We

demonstrate that at certain conditions plasmons resonantly excited in such plasmonic crystal can strongly pump the cavity plasmon modes leading to a deep sub-wavelength energy concentration with terahertz electric field enhancement factor up to 104

11:50 : Enhanced vibrational near-field spectroscopy of PMMA with infrared antennas
Jon Hoffmann, Thomas Taubner

The sensitivity of infrared far-field spectroscopy can be enhanced with infrared antennas. Using a scattering-type near-field optical microscope (s-SNOM), we measure spatially resolved infrared near-field spectra of a PMMA film that are enhanced by resonant infrared antennas. We find that the near-field amplitudes are enhanced over those obtained on non-resonant structures.

12:10 : Invited talk
Epsilon Near Zero Mode for active THz devices
Jean-Jacques Greffet, Simon Vassant, Alexandre Archambault, Francois Marquier, Fabrice Pardo, Ulf Gennser, Antonella Cavanna, Jean Luc Pelouard

We show that electron-THz radiation can be enhanced using an extremy confined mode that we call epsilon near zero (ENZ) mode. We demonstrate a 45% absorption of a normally incident 8.74 THz wave in the volume of a single quantum well with thickness 22 nm. We also demonstrate electrical modulation of this absorption.

12:30 : Invited talk
Plasmonic Nanostructures for Mid- and Far- Infrared Frequencies
Yanko Todorov, Cheryl Feuillet-Palma, Pierre Jouy, Angela Vasanelli, Carlo Sirtori

We report on our recent results on metal-dielectric-metal microcavities with small effective volume for enhanced light matter interaction. These periodic sub-wavelength structures cover only 25% of the surface and yet absorb more than 80% of the impinging radiation, thanks to a near field mechanism. By inserting within these microcavities quantum wells we were able to attain the ultra-strong light matter regime.

10:50 - 12:50 ***Rubis***

4E: Acoustic metamaterials IV

Organized by: Jensen Li and Johan Christensen

Chaired by: Jensen Li and Johan Christensen

10:50 : Phonofluidic properties of Phononic Crystal Waveguides
Rab Wilson, Julien Reboud, Yannyk Bourquin, Yi Zhang, Jon Cooper

We excite a cavity mode in a phononic crystal waveguide to trap and manipulate a droplet on a superstrate using surface acoustic waves (SAW) produced by a single interdigitated transducer (IDT) on LiNbO3. The cavity mode can be thought of as a stationary acoustic feature that gives rise to Langevin acoustic radiation pressure, the gradient of this pressure either induces movement of the drop towards the global antinode or pins it. This gives rise to an asymmetry in the velocity of the droplet relative to the direction to the SAW propagation. The magnitude of the force could be tuned using frequency allowing the droplet to escape from the acoustic trap and proceed to along the superstrate. Indeed the displacement of the drop could be finely controlled using frequency, moving the antinode position, such that we can obtain substantial control over the position of the drop via a single IDT.

11:10 : Invited talk
Anomalous behavior of overlapping hybridization and Bragg gaps due to coupling between scattering resonances
John Page, Charles Croenne, Eric Lee

The coupling between scattering resonances underlie many of the key properties of acoustic metamaterials. To study such effects, phononic crystals of nylon rods in a water matrix, exhibiting both hybridization and Bragg gaps around 1MHz, are investigated numerically and experimentally. The interaction between the two phenomena is tuned via the elastic properties of nylon, the lattice constant and the sample thickness. Atypical dispersion characteristics are found

near resonance and are attributed to the interaction between the resonant states of the rods.

11:30 : Spectral dispersion inside a Graded Phononic Crystal
Rubén Picó Vila, Vicent Romero-Garcia, Víctor José Sánchez-Morcillo, Kestutis Staliunas

A 2D Graded Phononic Crystal (GPC) is proposed to produce spatial dispersion inside the structure. It is composed of a square array of solid scatters in fluid. By gradually decreasing the longitudinal period, the filling fraction is diminished along the structure. The size of the bandgap of the equivalent complete structure is increased along the depth and, thus, the energy is accumulated inside the crystal due to the Bragg reflection at different depths.

11:50 : Determining the full transformed relations in transformation method
J. Hu, X. Lu

Transformation method provides an efficient way to control wave propagation by materials. The transformed relations for field and material during a transformation are essential to fulfill this method. However, there are no general methods to obtain the transformed relations for a general physic process all the results in literatures are derived case by case. As a result, the degree to which this transformation concept can be applied to other physical phenomena remains an open question. Recently, we present a general framework for determining the transformed relations of physical quantities in arbitrary PDE of first-order approximation according to the idea of transformation method. In this paper, we will summarize the progress of this work and discuss the potential wide applications of this method.

12:10 : Acoustic Metamaterials through Coiling up Space
Jensen Li, Zixian Liang

We show that by curving fluid perforations within a solid with proper control of phase delay, a two dimensional acoustic metamaterial with extreme indices can be constructed. It can be used to achieve a variety of wave manipulations including negative refraction in the effective medium regime and tunneling with a density-near-zero material.

12:30 : Invited talk
From periodically perforated plates to fluid-loaded phononic plates
Hector Estrada, Pilar Candelas, Francisco Belmar, Antonio Uris, F. Javier Garcia de Abajo, Francisco Meseguer

The study of periodically perforated plates and two-dimensional phononic plates has followed separated paths. Although the structure is roughly the same, the differences are produced by taking different perspectives for sound wave propagation, which are valid only if the coupling between the solid and the fluid is weak enough to be neglected. Here we explore a whole range of phenomena taking place in the same structure while interacting with sound waves incident from a surrounding fluid, including those taking place when perforated and phononic plates behaviour are mixed together. The rich physics and exotic effects provide new ways to control sound waves.

10:50 - 12:50 ***Emeraude***

4F: Photothermal effects in plasmonics and metamaterials II

Organized by: Min Qiu and Min Yan

Chaired by: Min Qiu and Min Yan

10:50 : Invited talk
Collective photo-thermal effects and chirality in plasmonic nanoparticles
Alexander Govorov

Plasmonic nanostructures are very efficient at generation of heat under optical excitation. Under certain conditions, optically driven gold nanoparticles (NPs) can significantly increase temperature of a medium or even melt a surrounding matrix. The heating and melting processes occur under light illumination and involve the plasmon resonance. Melting and heating of the matrix become possible if a nanoparticle size is large enough. Significant enhancement of the heating effect happens in assemblies of NPs owing to the heat accumulation effect and the plasmonic field amplification. As one of the current applications, the collective photo-thermal effect in NP assemblies (aggregates) is employed for heating and actuation of biological systems and media. If a nanostructure is of low symmetry, it may be chiral and exhibit

circular dichroism at the plasmonic frequency. In that respect, chiral nanoparticle assemblies (helices and pyramids) look especially interesting.

11:10 : Invited talk
Metamaterials for Tailored Thermal Infrared Emission
Willie Padilla, Xianliang Liu, Talmage Tyler, Anthony Starr, Tatiana Starr, Nan Jokerst

We investigate the use of metamaterial surfaces in order to tailor the emission of infrared radiation. Multiple metamaterial sublattices permit broadband control. We find excellent agreement between the emissivity and absorptivity of metamaterial surfaces – as predicted by Kirchhoffs law of thermal radiation.

11:30 : Invited talk
Recent progress in Heat transfer at the nanoscale
Jean Jacques Greffet

Recent experimental and theoretical progress in the study of heat transfer at the nanoscale mediated by surface waves will be presented.

11:50 : N-body theory of heat transport in complex plasmonic systems
Philippe Ben-Abdallah, Svend Age Biehs, Jean-Jacques Greffet, Karl Joulain

We introduced a theoretical framework to describe the near-field heat transfer in complex plasmonic systems made with $Ngt2$ objects in mutual interaction. A Landauer type formula is derived to evaluate the radiative heat flux exchanged between two bodies through a N-body system. An upper limit for the heat flux is deduced from this formulation. Finally, different thermal effects and potential applications which are directly related to multiple interactions are presented.

12:10 : Effect of thermal annealing on propagation loss of plasmonic waveguide
Yiting Chen, Jing Wang, Min Yan, Min Qiu

The propagation loss of a plasmonic stripe waveguide is measured before and after thermal annealing. It is found that the propagation loss of the waveguide at 980 nm is reduced by more than 50% (from 0.45 dB/microm to 0.2 dB/microm) after thermal annealing at 300 degC for 18 hours. The reduction in loss can be attributed to the improved gold surface condition and probably also to the change in the metals inner structure.

12:30 : Radiative cooling of nanoparticles close to a surface
Maria Tschikin, Philippe Ben-Abdallah, Svend-Age Biehs, Felipe Rosa

We define the thermal relaxation time of a nanoparticle which is heated with respect to its surroundings. In particular, we discuss the temperature and distance dependence of the thermal relaxation time for a nanoparticle close to a flat surface.

10:50 - 13:10 ***Jade***

4G: Advances in Metamaterials and Plasmonics II

Organized by: Lei Zhou and Jiaming Hao

Chaired by: Sergey Bozhevolnyi and Mady Elbahri

10:50 : Invited talk
Controlling Radiation Using Dark Plasmon Modes
Nicholas Fang, K. H. Fung

Plasmon enhanced photon absorption and emission in nanostructures plays an important role in many applications such as nanoantennas and nanolasers. In this invited talk, we will discuss our development of optical and electron probes for investigation of plasmonic nanostructures. In particular, the dark modes with forbidden photon transitions in sub-wavelength nanocavities are of great interest, as they promise energy conversion with high quantum efficiency. Using a focused electron beam spot, we selectively excite plasmons from the metallized nanocavities with fine spatial resolution (lt20nm) at real-time. The measured high resolution spectrum reveals unexpected high photon counts associated with

signatures of the dark modes, in contrast to common wisdom that such dark modes only couple weakly to the far field. We will also discuss the potential application of these plasmonic devices with ultra-small mode volume and high Purcell factors.

11:**10 :** Invited talk
Enhanced Nonlinear Effects in Metamaterials and Plasmonics
Andrea Alu, Christos Argyropoulos, Pai-Yen Chen

We present our recent findings on anomalous and enhanced nonlinear effects available in plasmonic nanoparticles and metamaterials. The large field enhancement in the vicinity of individual and collections of plasmonic nanoparticles ensures a significant boosting of nonlinear optical effects, which may be exploited in several exciting applications, in particular when combined with the exotic light interaction of plasmonic materials and metamaterials. We propose various setups in which these nonlinear effects may open exciting new venues for applications.

11:**30 :** Invited talk
Broadband invisibility cloak with multilayer of normal dielectrics
Yijun Feng, Xiaofei Xu, Junming Zhao, Shuai Xiong, Jinlong Fan, Tian Jiang

Taking advantage of a simple linear coordinate transformation we design a carpet cloak with homogeneous anisotropic medium and then practically realize the device with multilayer of alternating normal dielectric slabs based on the effective medium theory. Experimental tests have demonstrated pronounced cloaking effect in a very broad band from 8 GHz to 18 GHz due to the low loss, non-dispersive feature of the multilayer dielectric structure.

11:**50 : Optical magnetism of nonspherical Si nanoparticles**
Andrey Evlyukhin, Carsten Reinhardt, Boris Chichkov

In the framework of the discrete dipole approximation we develop a theoretical approach, allowing analyzing the role of multipole modes in the extinction and scattering spectral resonances of arbitrary shaped nanoparticles. The method is applied to nonspherical Si nanoparticles with resonant multipole responses in the visible optical range. It is shown that it is possible to design silicon particles for which the electric dipole and magnetic dipole resonances are located at the same wavelength under certain propagation directions of incident light, providing new possibilities in metamaterial developments.

12:**10 :** Invited talk
Metamaterial Absorbers and Antireflection Coatings: Experiments and Theory
Jiangfeng Zhou, John O'Hara, Li Huang, Dibakar Roy Chowdhury, Matthew Reiten, Abul Azad, Thomas Koschny, Costas Soukoulis, Antoinette Taylor, Hou-Tong Chen

When appropriately designed, ultrathin bi-layered metamaterials can achieve near-unity absorption or serve as antireflection coatings in a narrow frequency band over a wide incidence angle range. Expanding the bandwidth is possible through using multiple resonators in a unit cell with slightly different resonance frequencies. Impedance matching by tailoring effective permittivity and permeability has phenomenologically explained the experimental observations, however, we found that the underlying physical process is a Fabry-Perot resonance which does not involve the magnetic response. Our interference model has successfully explained the properties of metamaterial absorbers and antireflection coatings such as the spacer thickness dependent reflection and anti-parallel directions of currents.

12:**30 :** Invited talk
Opportunities in plasmonic metamaterials: From super imaging to perfect absorber
Lei Zhou

We review our recent efforts on studying the exotic electromagnetic (EM) properties of a certain type of palsmonic metamaterials and exploring the interesting applications of such systems, including subwavelength imaging and perfect EM wave absorption. Microwave experiments, in excellent agreement with full-wave simulations, were performed to verify all theoretical predictions.

12:**50 :** Invited talk
Specific surface mesoscopy in metamaterials and ways to avoid it
Mikhail Lapine, Lukas Jelinek, Ricardo Marques

We demonstrate that discrete structure and finite size of metamaterials lead to specific boundary effects which cannot be described with an effective medium approach. We analyse the peculiarities of these boundary effects, and provide guidelines for practical assembly of metamaterials to make their behaviour closer to the predictions of effective medium theory.

10:50 - 12:50 ***Grenat***

4H: The Consolider EMET project I

Organized by: Ferran Martin

Chaired by: Ferran Martin

10:50 : Invited talk
Selective mode suppression in coplanar waveguides using metamaterial resonators
J. Naqui, M. Duran-Sindreu, F. Martin

In this paper it is shown that split ring resonators (SRR) and complementary split ring resonators (CSRR) can be used to selectively suppress the odd (slot) mode and the even (fundamental) mode, respectively, in coplanar waveguides (CPW).

11:10 : Invited talk
Split-ring metamaterials for MRI applications
José Algarín Guisado, Marcos Lopez Terrones, Manuel Freire Rosales, Ricardo Marques Sillero

This works reviews the application in Magnetic Resonance Imaging (MRI) of split-ring slabs with different values of permeability. The present work studied metamaterials media for Magnetic Resonant Imaging (MRI) with different values of permeability. Slabs with permeability -1 behave as super-lenses which are able to improve the localization of the magnetic field pattern of MRI coils. This finds application in parallel MRI techniques for reduction of acquisition time. Moreover, slabs with permeability 0 and infinity can locally increase the Signal-to-Noise-Ratio (SNR), which is the essential parameter in MRI.

11:30 : Invited talk
Practical Application of Space Mapping Techniques to the Synthesis of CSRR-based Artificial Transmission Lines
Ana Rodríguez, Jordi Selga, Vicente E. Boria, Ferran Martín

The synthesis of artificial transmission lines based on metamaterial concepts (i.e. using Complementary Split Ring Resonators -CSRRs-) is not a simple task, since several interrelated design parameters are typically involved. A brief review of the synthesis of these unit cells through the use of space mapping techniques is presented. The most critical points related to the implementation of such techniques, as well as their solution in order to obtain an automated design method, are also discussed.

11:50 : Invited talk
Engineering the diffraction orders of the fishnet metamaterial for subterahertz dual-band backward wave propagation
Miguel Navarro-Cia, Carlos Garcia-Meca, Pablo Rodriguez-Ulibarri, Miguel Beruete, Alejandro Martinez, Mario Sorolla

In this contribution we exploit the interpretation of the fishnet metamaterial mode in terms of diffraction order of the internal mode (that supported in the parallel waveguide formed in-between metallic perforated layers) to design the fishnet such that the first two propagation bands under normal incidence display backward wave propagation. For the experimental validation of the dual-band effective negative refractive index response, a fishnet-like structure is fabricated to operate at the W-band of the millimeter-waves.

12:10 : Invited talk
Acoustic analog of graphene: Dirac cones of acoustic surface waves
Daniel Torrent, José Sánchez-Dehesa

The acoustic analog of graphene is presented in this work. The structure under study is a honeycomb lattice of cylindrical

boreholes drilled in a plastic plate. It is demonstrated that the spectra of acoustic surface waves propagating on the plate presents Dirac cones at the corners of the hexagons forming the Brillouin zone. Thus, the wave equation describing the field near this point is similar to the wave equation for electrons moving in graphene. The parameters defining this wave equation are obtained as a function of the physical properties of the holes in the honeycomb lattice. Experiments are performed and an excellent agreement with the theoretical predictions is found.

12:30 : Invited talk
Optical properties of metallo-dielectric nanospheres and their application to three-dimensional, isotropic, optical metamaterials
Ramon Paniagua Dominguez, Fernando López-Tejeira, Ricardo Marqués, Jose Sánchez-Gil

We will present our theoretical results on the optical properties of metallo-dielectric core-shell nanospheres and the possibility to use them as building blocks for three-dimensional, isotropic, optical metamaterials. In particular, it will be shown that, carefully choosing the geometrical parameters, it is possible to spectrally overlap a strong dipolar magnetic Mie resonance from a high-permittivity dielectric shell, and a localized surface plasmon resonance (LSPR) of a noble metal core. Since the strong electric and magnetic responses stem from every single meta-atom, no particular arrangement is needed. Moreover, the metamaterial proposal is isotropic and polarization insensible. Realistic configurations with Silver in the core and a semiconductor in the shell (Silicon or Germanium) will be demonstrated to operate in the near-infrared (1.2-1.55 microns).

Lunch and Exhibit Inspection

12:30 - 14:20

14:20 - 16:00 ***B312***

5A: Plasmonics and nanophotonics IV

Chaired by: Graeme Walter Milton

14:20 : Invited talk
Size, Shape, and Composition Effects on Plasmonic Properties of Nanoparticles
Emilie Ringe

Localized surface plasmon resonances are central to a multitude of sensing and signal transmission applications. Tuning of the plasmon energy and line width is critical to the design of such devices size, shape, and composition are commonly touted as powerful handles on plasmonic properties. New energy models, describing how kinetic enhancement at crystallographic defects and segregation in alloys influence shape, will be presented. Additionally, experimental results on single particle structure-function correlation on modeled shapes will be described.

14:40 : Collective plasmon response in arrays of metallic nanoparticles
Abdallah Slablab, Pierre-Eugène Coulon, Sandrine Perruchas, Thierry Gacoin, Julien Cardin, Isabelle Monnet, Kociak Mathieu, Arthur Losquin, Dominique Mailly, Giancarlo Rizza

Plasmonics aims to exploit the unique optical properties of metallic nanostructures to enable the routing and the active manipulation of light at the nanoscale. However, the broad plasmon resonance of individual NPs limits the potential applications. A promising way to improve the quality of the LSPRs in to create Fano resonaces. When light is incident on an array of NPs, it is scattered by different elements in the structure. The presence of order in the system enables the appearance of coherent effects among the various scattered waves. These new modes are called lattice surface modes (LSMs) and are characterized by very narrow symmetric and asymmetric (Fano) peaks. The LSMs modes represent a new decay channel for emitters and offer new routes for the design of nano-structured surfaces that enable a control of the spontaneous emission.

15:00 : Dispersion control of propagating surface plasmons on nanoporous gold
Neha Sardana, Jörg Schilling

The nanoporous gold is prepared using the dealloying method, by varying the dealloying times to control the pore size. Scanning electron Microscopy confirms the porous structure. Reflection measurements in the Kretchmann configuration

(prism coupling) are used to determine the dispersion relation of the surface plasmon on nanoporous gold/air interface. This is compared with the Bruggeman effective medium theory

15:**20 : Light funneling into single plasmonic nano-slit**
Haofei Shi, L. Jay Guo

Light funneling effect into single plasmonic nano-groove was experimentally observed and the corresponding effective funneling range was measured. The coupling between individual plasmonic elements was also elucidated base on experimental data.

15:**40 : Nonlocal response in plasmonic nanostructures**
Søren Raza, Giuseppe Toscano, Anti-Pekka Jauho, Martijn Wubs, Niels Asger Mortensen

We study the nonlocal response of a confined electron gas within the hydrodynamic model by calculating the scattering properties of relevant plasmonic nanostructures, which are commonly considered in local response theory. We show unique features of nonlocal response and emphasize its importance even for large structures with nanosized metallic features.

14:20 - 16:00 ***B310***

5B: Photonic crystals II

Chaired by: Sébastien Guenneau

14:**20 : Resonant and slow light self-collimation in photonic band gap metamaterials**
Emmanuel Centeno, Rémi Polles, Julien Arlandis, Antoine Moreau

This study deals with in photonic band gap materials based on metamaterials properties that consist in a periodic set of positive and negative index layers. These structures present new optical properties such as a zero-n gap, zero-phase delay transmission and self-collimation effect. Here, we theoretically demonstrate that self-collimation can be render resonant or combines with slow light regime in photonic band gap metamaterials.

14:**40 : Dispersion engineered wide slot photonic crystal waveguides for slow light operation**
Charles Caer, Xavier Le Roux, Laurent Vivien, Eric Cassan

We introduce a novel design of wide Slot Photonic Crystal Waveguides (SPCW) by structuring the slot as a comb. This allows performing dispersion engineering in order to achieve very low group velocities over a few nanometers bandwidth. This kind of SPCW offers opportunities to realize devices requiring strong interactions between light and an optically non-linear low index material by providing an ultra-high optical density while easing the filling of the slot due to its width. We will present dispersion engineering results by Plane Wave Expansion method and Finite Difference Time Domain analysis, followed by experimental realization.

15:**00 : Simultaneous multi-directional plasma etching for creating three-dimensional photonic nanostructures**
Katsuyoshi Suzuki, Kenji Ishizaki, Susumu Noda

We investigate an approach for simply creating three-dimensional (3D) photonic nanostructures based on a simultaneous, multi-directional etching technique. By only single-step simultaneous etching, 3D photonic bandgap crystals, which possess periodic arrangements of silicon in three dimensions, are successfully realized. Fabricated structures show high reflectance (gt95%) and strong attenuation of transmittance (-15dB). These results suggest that our proposed technique promises to open up an easy route toward creation of high-quality 3D photonic nanostructures.

15:**20 : Optomechanical Coupling in a Two-Dimensional Photonic Crystal Defect Cavity**
Isabelle Philp, Rémy Braive, Emanuel Gavartin, Isabelle Sagnes, Olivier Arcizet, Alexios Beveratos, Tobias Kippenberg

Periodically structured materials can sustain both optical and mechanical modes. Here we investigate and observe experimentally the opto-mechanical properties of a conventional two-dimensional-suspended photonic crystal defect cavity of diffraction-limited volume. Two families of mechanical modes are observed. At low frequency (below 200 MHz), drum modes of the whole membrane are observed, while at high frequency (around 1 GHz), the resonator exhibits

modes localized within the defect cavity, corresponding to a deformation of the core of the defect cavity surrounded by holes. Due to the strong confinement and co-localization of photons and phonons in these high-frequency localized modes, the coupling between light and these mechanical modes exceed 80 kHz, demonstrating high coupling of optical and mechanical modes in such structures.

15:40 : Smart magneto-optical photonic crystals
Alexander Grishin

We survey the most recent results on synthesis and properties of luminescent magneto-optical photonic crystals (MOPCs) based on rare earth iron and gallium garnet multilayers. Magnetron sputtered hetero-epitaxial MOPCs demonstrate optical nonreciprocity with a record high MO quality and a latching type (magnetic remnant) Faraday rotation. Being substituted with Er-ions, they take advantage of strong photoluminescence enhancement due to the light localization and Fe3+-to-Er3+ sensitizing effect. Strongly luminescent MOPCs promise built-in intelligence: ability to simultaneously recognize, process and store optical data, make color filtering, and amplify optical signals.

14:20 - 16:00 ***Thévenin***

5C: Technologies and applications I

Chaired by: Ortwin Hess

14:20 : Keynote talk
Exotic plasmonic crystals for nanophotonic applications
Anatoly Zayats

We will overview optical properties of plasmonic crystals, periodically nanostructured metal films, with complex crystal lattices. We will discuss their advantages and applications for spectral and polarization multiplexing/demultiplexing, extraction of light from LEDs and biosensing. Active functionalities and tuneability of their photonic properties using electronic, magnetic and optical controls will also be discussed.

15:00 : Interfacial roughness effect on high aspect superlens nanolithography
H. Liu, B. Wang, L. Ke, J. Deng, C. C. Chum, L. Shen, S. A. Maier and J. Teng

In this paper, we report an experimental and analytical study on the roughness effect of silver film induced by seed layers on the performance of superlens at 365 nm wavelength. The ability of Ag, Ag/Ni and Ag/Ge films serving as superlens were examined by characterization of the acquired sub-diffraction-limit photoresist patterns through AFM mapping. With a critical control of the interfacial roughness of dielectric-metal-photoresist and index-matching scheme, Ag exhibited the highest aspect nanostructure of about 45-nm depth with sub-50nm resolution (about one-eighth of illumination wavelength) and a corresponding intensity contrast of about 3. Followed by Ag/Ge the performance of Ag/Ni, was the next only to Ag. The characterization results obtained by AFM scanning agree well with the theoretical predications.

15:20 : Snug and boost negative-index metamaterial Vivaldi antenna
Adam Alhawari, Alyani Ismail, Mohamad Mahdi, Raja Syamsul Azmir Raja Abdullah

A unique slitting approach harmoniously marries the Vivaldi antenna and metamaterial together, where a single layer metamaterial piece is simply snug into the slit perpendicular to the middle antenna substrate. The major improvement in the spotlight is the capability of metamaterial to focus the entire beam to radiate onto the targeted direction. The comparison between modified Vivaldi antenna and the ones improved is introduced, concluding that the snug and boost method applied on the antenna is capable to fit broad sphere of ultra-wideband applications.

15:40 : Cloaking static magnetic fields
Carles Navau, Jordi Prat-Camps, Alvaro Sanchez, Mykola Solovyov, Jan Souc, Fedor Gomory

Invisibility cloaks for static magnetic fields have already been theoretically developed and studied. However they require an extreme fine tuning of the permeability components within the cloak. Here we propose different strategies by which magnetic cloaking behaviour can be achieved with a significant simplification of permeabilities arrangements, making these designs feasible with existing materials and technologies. An actual experimental realization is presented.

14:20 - 16:00 ***Emeraude***

5D: Bottom-up approach towards metamaterials and plasmonics III

Organized by: Dorota Pawlak

Chaired by: Carsten Rockstuhl

14:20 : Invited talk
Self-Assembled Optical Metamaterials for Linear and Nonlinear Response
Augustine Urbas

Metamaterials in optical frequencies have a tremendous range of application, many of which require large area materials with fine features. Self assembly can provide an efficient route to fabricating structured optical metamaterials. From enabling fundamentally new effects, such as optical magnetism, to creating tailored absorption and transmission spectra, designing optical properties through structure offers a new mechanism for manipulating light. These systems require nanometric features on structures frequently below 100nm in size in order to gain the desired properties set. To date, demonstrations have relied on electron beam lithography, focused ion beam milling and other high resolution techniques with limited ability to cover larger areas. This has limited experimental exploration of large area application of metamaterials. Self assembled systems can be used either directly as metamateials or as templating structures to create ordered arrays of meta-atoms. In addition, these techniques can be applied at the unit cell level to create complex, structured and active metamaterials. In this presentation, I will describe efforts to utilize self assembly techniques to create optical metamaterials. Systems designed to control fluorescence, nonlinear properties and optical absorption will be discussed.

14:40 : Invited talk
Hyperbolic metamaterials – looking from bottom up
Heng Li, T. Tumkur, Yu. Barnakov, E. Narimanov, M. Noginov

In this presentation we discuss physics and technology of metamaterials with hyperbolic dispersion based on arrays of silver nanowires grown in nanoscopic channels of alumina membranes.

15:00 : Invited talk
Metallic and semiconducting nanoantennas
Jaime Gomez-Rivas

Controlling the dispersion and directionality of the emission of nanosources is one of the major goals of Nanophotonics. In this presentation, we will discuss how this control can be achieved with subwavelength structures, known as nanoantennas, of defined shape and dimensions. The precise bottom-up nanofabrication of these structures allows to strengthen the near- and far-field coupling of resonances, which define the light emission of sources in their proximity.

15:20 : Electromagnetic properties of microfibrous TSAG-TSP eutectic composite
Andrzej Stefanski, Viktor Myroshnychenko, Javier Garcia de Abajo, Kamil Postava, Dorota Pawlak

Numerical analysis of electromagnetic properties of dielectric microstructured eutectic composites is presented. Materials composed of dielectric crystalline fibers placed in other dielectric crystalline material behave like metal-dielectric metamaterials under special circumstances. In those wavelength range methods developed for analysis of metal-dielectric metamaterials are used in exploration of the properties of these self-organized materials.

15:40 : Invited talk
3D Active Photonic Nanostructures
Elmina Kabouraki, Ioanna Sakellari, David Gray, Maria Vamvakaki, Maria Farsari

We present our most recent results on the fabrication of 3D high-resolution nanostructures containing Cadmium Sulfide (CdS) quantum dots (QDs) and exhibiting higher order diffraction patterns and stop-gaps at visible wavelengths. These are fabricated using direct laser writing (DLW) and novel, organic-inorganic hybrid materials.

14:20 - 15:40 ***Rubis***

5E: Active and Quantum Metamaterials II

Organized by: Arkadi Chipouline and Vassili Fedotov

Chaired by: Arkadi Chipouline and Vassili Fedotov

14:20 : Invited talk
Quantum metamaterials: concept and possible implementations
Alexandre Zagoskin

Quantum metamaterials - controllably quantum coherent artificial media - present a new direction of research at the interface of quantum information processing and physics of artificial electromagnetic materials. They can be thought of as built of qubits, which maintain coherence long enough for the electromagnetic pulse to travel across. The direct access to the quantum state of each constituent atom of a quantum metamaterial, together with the global quantum coherence of the system, provide novel opportunities to investigate the foundational questions of quantum-classical transition, a different view of adiabatic quantum computers, and a way to other interesting technological applications. I will review the current state and prospective directions of research in this field, including the possible realizations of quantum metamaterials in the microwave and optical ranges.

14:40 : Invited talk
Leveraging Enhancement of Metamaterials for Nonlinear and Quantum Optical Applications
David Smith

Metamaterials have become widely appreciated for their ability to enable new or difficult material properties, including complex distributions of constitutive parameters. The result is that we have at our disposal an expanded set of tools for controlling the propagation of light. Still, mimicking the intrinsic response of materials is just one function that metamaterials can provide enhancing nonlinearity and photodynamic processes is another feature that is yet in the early stages of being exploited. By gaining control over the field enhancement associated with metal nanostructures, new classes of quantum metamaterials are possible that not only control wave propagation but also couple strongly to fundamental radiative processes.

15:00 : Invited talk
Plasmonic nanoparticles, gain media and loss compensation
Vitaliy Pustovit, Alessandro Veltri, Filippo Capolino, Ashod Aradian

The resonant behaviour of single plasmonic nanoparticles in contact with gain media is studied theoretically, with a focus on the issue of loss compensation, resonance amplification and modification. Two approaches are presented. The first description is macroscopic and based on a simple, quasi-static continuum description of the gain medium, and shows that gain-assisted particle display unusual plasmonic responses, with features depending notably on the nature of the metal used (gold or silver). Results are discussed in two geometries, metallic nanoparticles in an infinite gain medium, and metal core-gain shell nanoparticles. The second model is microscopic and describes the situation of a metallic gold nanoparticle, surrounded with a corona of dye molecules or nanocrystals. A full analytical electromagnetic model is proposed, taking into account interactions, through a Green function formalism, between dye and particle, and also between dye and dye, both directly and mediated via the nanoparticle. The modes of the particle-and-dye system are studied, demonstrating that some modes, either emissive or absorptive, can be strongly amplified and dominate the response of the ensemble.

15:20 : Tunable coherent perfect absorption using a composite film
Shourya Dutta Gupta, Olivier Martin, Subhasish Dutta Gupta

Coherent perfect absorption (CPA) using a colloidal gold film is studied when the structure is illuminated using plane waves from either side at oblique incidence. Using standard transfer matrix approach, we show that the CPA dip can be tuned over the visible range of the spectrum by appropriately tuning the system parameters. Furthermore, the dependence of various system parameters on CPA has been studied and it is shown that a critical minimum value of absorption is needed for observing CPA.

14:20 - 16:00 ***Saphir***

5F: Mid-infrared and THz plasmonics II

Organized by: Raffaele Colombelli and Yannick De Wilde

Chaired by: Raffaele Colombelli and Yannick De Wilde

14:20 : Invited talk
Infrared Detectors with Plasmonic Structures
Sanjay Krishna

There is an increased interest in the integration of plasmonic structures with infrared detectors. The localized field enhancement could lead to increased signal to noise ratio, spectro-polarimetric control and dynamic gain. This increased functionality in the pixel could lead to the fourth generation of infrared detectors.

14:40 : Invited talk
Nanoantennas for field enhancement in the mid-IR and THz regime: Applications in SEIRA and cw THz emission
Stefan Maier

Metallic antennas with deep sub-wavelength gaps provide a powerful route for field enhancement in the infrared regime of the spectrum, facilitated by the lightning rod effect. In the mid-IR regime, this enables surface enhanced infrared absorption spectroscopy via Fano-type coupling between vibrational molecular states and antenna resonances. A first-principles parameter-free model of this effect will be presented. Furthermore it will be shown that nanoantennas at THz frequencies allow for order-of-magnitude improvements in the cw output of photoconductive photo mixers.

15:00 : Invited talk
Nanofocusing of mid-infrared light with antennas and transmission lines
R. Hillenbrand

We show that mid-infrared light can be focused to nanoscale spots (hot spots) by employing plasmonic antenna structures and transmission lines. Employing scattering-type scanning near-field microscopy, we are able to map the vectorial field distribution of nanoscale hot spots in antenna gaps, as well as mid-infrared energy transport and compression in tapered transmission lines.

15:20 : Terahertz Negative Index Material based on fishnet–like metamaterial
Nadia Soltani, Eric Lheurette, Didier Lippens, Frédéric Garet, Jean-Louis Coutaz

In this communication, we report first on the experimental assessment of fishnet-like metamaterial fabricated by stacking sub-wavelength hole metal arrays. The achievement of a negative refractive index is demonstrated by frequency and angle resolved Time Domain Spectroscopy transmission/reflection experiments for slab and wedge samples operating around 0.5 THz. Then, the studies are extended to chiral metamaterial (twisted motifs) and symmetry breaking devices (half moon apertures).

15:40 : Invited talk
Optics of free-standing nanostructure arrays: application to multispectral imaging
Stéphane Collin, Grégory Vincent, Petru Ghenuche, Nathalie Bardou, Riad Haïdar, Jean-Luc Pelouard

We report on the spectacular properties of free-standing arrays of metallic and dielectric nanostructures. We demonstrate nearly perfect resonant transmission (87 %) in metallic membranes with nanoslits mediated by plasmonic resonances. We report the fabrication of a mosaic of bandpass filters by changing the slit pattern in a single 25mmsup2 membrane. The filter array is integrated in a compact multichannel camera, and parallel multispectral imaging is achieved in the 2.5-5 microns wavelength range. We also provide the first experimental evidence of nearly perfect optical extinction in a single layer of free-standing dielectric nanorods. The sharp spectral opacity window, in the form of a characteristic Fano resonance, arises from coherent multiple scattering in the array.

14:20 - 16:00 ***Estaunié***

5G: Metamaterials for aeronautics and transports I

Organized by: André de Lustrac and Shah N. Burokur

Chaired by: André de Lustrac and Shah N. Burokur

14:20 : Invited talk
Axial ratio improvement of an Archimedean spiral antenna over a radial AMC reflector
Michael Grelier, Christopher Djoma, Michel Jousset, Stéphane Mallegol, Anne-Claire Lepage, Xavier Begaud

This paper presents a method to improve the circular polarization of an Archimedean spiral antenna over a particular Artificial Magnetic Conductor (AMC). Results have been compared with the same antenna over a more classical AMC reflector. With this method the axial ratio is less than 2dB from 1.75GHz to 3.8GHz, whereas it is greater than 3dB with a classical shape AMC reflector.

14:40 : Invited talk
MIMICRA Metamaterial Inspired Microwave Conformal Radar Antennas

Gérard Piau, Sajad Haq

The MIMiCRA Project will investigate the ability of novel and emergent high impedance metamaterial surfaces to reduce mass, footprint and profile of low frequency and broadband antenna types (the latter being relevant to surveillance applications) gains in these parameters may alternatively or synergistically improve antenna operating performance characteristics. Antennas of reduced size and profile may also contribute to reducing the radar cross-section and aerodynamic drag of aeronautic platforms, this is particularly relevant to low frequency communications antennas.

15:00 : Invited talk
Novel antenna concepts via coordinate transformation
Paul-Henri Tichit, Shah Nawaz Burokur, Xinying Wu, Dylan Germain, André de Lustrac

Using the idea of wave manipulation via coordinate transformation, we demonstrate the design of novel antenna concepts. The manipulation is enabled by composite metamaterials that realize the space coordinate transformation. We present the design, realization and characterization of three types of antennas: a directive, a beam steerable and a quasi-isotropic one. Numerical simulations together with experimental measurements are performed in order to validate the concept. Near-field cartography and far-field pattern measurements performed on a fabricated prototype agree qualitatively with Finite Element Method (FEM) simulations. It is shown that a particular radiation can be transformed at ease into a desired one by modifying the electromagnetic properties of the space around it. This idea can find various applications in novel antenna design techniques for aeronautical and transport domains.

15:20 : Keynote talk
Controlling light propagation in plasmonic and metamaterial structures
Yuri Kivshar

I will discuss our recent advances in the control of electromagnetic radiation by means of plasmonic and metamaterial structures, including a novel concept of the light-controlled metamaterials, nonlinear tunable fishnet structures, Airy plasmonics, and optical nanoantennas.

14:20 - 16:00 ***Grenat***

5H: The Consolider EMET project II

Organized by: Ferran Martin

Chaired by: Ferran Martin

14:20 : Invited talk
Super-resolution properties of the Spherical Geodesic Waveguides using the perfect drain
Juan Carlos González, Dejan Grabovičkić, Juan Carlos Miñano, Pablo Benítez

An analysis of the super-resolution properties of the Maxwell Fish Eye (MFE) has been done using an equivalent device known as Spherical Geodesic Waveguide (SGW). A microwave circuit comprising three elements: the SGW, the source and the drain (two coaxial probes) is designed and simulated in COMSOL. The super-resolution properties are analyzed using Scattering parameters of the microwave circuit for different position of the source and drain. The drain port is loaded with impedance Zd, which is properly calculated to act as the perfect drain, i.e. the incident wave is absorbed with no reflection or scattering.

14:40 : Invited talk
Strong Magnetic Enhancement in the Visible Range by Al Nano-hoops
María Lorente-Crespo, Rubén Ortuño, Carlos García-Meca, Alejandro Martínez

In this work, we show that an intense enhancement of the magnetic field can be achieved by placing aluminum nano-hoops periodically distributed and shortly spaced on top of a substrate. When the structure is illuminated by a plane wave propagating perpendicularly to the substrate plane, a virtual current loop is induced between adjacent nano-hoops and leads to a plasmonic resonance that provides the strong magnetic enhancement at visible wavelengths.

15:00 : Invited talk
ChessBoard Structure Evolution for RCS Reduction
JuanCarlos Iriarte, Amagoia Tellechea, Itziar Maestrojuan, Iñigo Liberal, Ainara Rebollo, Iñigo Ederra, Ramón Gonzalo

In this paper the evolution of the called ChessBoard structure to reduce RCS is presented. Initially, by combining PEC cells and AMC cells a single frequency RCS reduction is achieved. This narrow band limitation can be overcome by substituting the PEC by another AMC structure, guiding to a dual band behavior or a broadband one, with operational bandwidths around 40% of RCS reduction. Different cell configurations are being studied to be presented in the congress.

15:20 : Invited talk
Multiband Slot-Based Dual Composite Right/Left Handed Transmission Line
Elena Abdo-Sánchez, Teresa Martín-Guerrero, Carlos Camacho-Peñalosa

A dual Composite Right-/Left-Handed Transmission Line (CRLH TL) implementation that presents multiband behaviour is proposed in this contribution. The artificial TL is realized by loading a host microstrip line with alternate rectangular stubs and slots. The required series and shunt immittances are respectively provided by the slot and the stub. Due to the distributed nature of these immittances, the resultant phase response presents theoretically infinite RH and LH alternate bands, thus being appropriate for multiband applications. The design methodology is described with the help of the TLs-based equivalent circuit and highlights the simplicity for balance condition. Full wave simulated results of the dispersion characteristics and frequency response of a unit-cell are presented.

15:40 : Invited talk
Three-dimensional stereo filter metamaterial
Francisco Rodriguez-Fortuno, Nader Engheta

We present a three dimensional (3D) metamaterial that behaves as a lowpass, bandpass or stopband filter, depending on the polarization and direction of propagation of the incident plane wave. The metamaterial unit cell was designed exclusively using circuit theory and nanocircuit lumped element concepts, without requiring the initial use of wave concepts and/or numerical wave simulations, thus demonstrating the useful potential offered by this approach in the design of complex optical metamaterials.

Coffee Break and Exhibit Inspection

Poster Session III

16:00 - 17:00

III-1 : Photonic crystals properties for organic systems: from components to flexible optical circuits
Leo Peres, Sophie Fasquel, Laurent Ohyenart, Valérie Vigneras

Photonic crystals properties are numerically studied for photonic organic components and circuits. For components

applications, photonic crystals are theorically studied to improve opto-electronical performances such as solar cells and Oleds. In the case of solar cells, different nanostructures are tested in order to improve the absorption which is particularly low due to the difficulty to extract electrons/holes pairs of excitons. For the OLEDS applications, atemption is paid on the extraction of emitted light which is naturally guided in the multilayers structures. For circuits applications, a concept of multi-integrated photonic functions is developed. Finally, specific organic technological solutions for large scale and low cost fabrication are presented, from bottom-up to top-down approaches.

III-2 : Photothermal conversion of gold nanoparticles characterized by polymerization
Lama Zaarour, Safi Jradi, Jérôme Plain

Optical properties of metallic nanoparticles are mainly dominated by the Localized Surface Plasmon Resonance (LSPR) at optical frequencies. At this specific frequency, nano-particles exhibit intense absorption and light scattering attribute to the LSPR. Moreover, metal nanoparticles are able to transform absorbed light into heat. This photothermal conversion effect has been used for many applications. In particular, it has been used in the development of photothermal therapies (hyperthermia) for cancer treatment, as well as laser ablation as a means of malignant cell destruction. More recently, plasmonic heating has been used to promote drug release through polymer phase change, hybrid DNA cleavage, or enhanced diffusion. One of the challenges is to control the temperature in the vicinity of nanoparticles.

III-3 : Plasmon beams interaction at the surface of photorefractive crystals
Daria Ignatyeva, Anatoly Sukhorukov

We demonstrate the phenomena of the refraction and the total internal reflection of the weak signal plasmon beam from the inhomogeneity induced by the high-power reference plasmon at the interface between a photorefractive crystal and a metal. The trajectories of the signal plasmon are obtained via the geometrical-optics methods. We found that the phenomenon of the total internal reflection occurs above the critical value of the reference plasmon intensity depending on the signal plasmon initial tilt.

III-4 : Plasmon induced transparency in three dimensional magnetic meta-molecules
Pin Chieh Wu, Wei Ting Chen, Kuang-Yu Yang, Chih Ting Hsiao, Chen Jung Chen, Nikolay Zheludev, Din Ping Tsai

We report the first three-dimensional photonic metamaterial, an array of erected U-shape plasmonic gold meta-molecules, that exhibits plasmon induced transparency due to the magnetic field coupling between metamolecules. Using electron beam lithography with alignment technique, three erected U-shape gold nano rings are integrated in a unit cell with 600 nm periodicity both in x and y directions, covering the total area of 75acute75 microm2 on a fused silica substrate. The height of each gold nano ring is 110 nm. By introducing structural asymmetry, the magnetic field of the bright split ring resonator (SRR) couple to the other two dark SRRs result in an energy level splitting, which is similar with EIT-like spectra. A classical RLC circuit model was proposed to explain the coupling mechanism of EIT-like spectra.

III-5 : Plasmonic Metal Displacement Deposition on Porous Silicon for SERS Substrate Fabrication
H. Bandarenka, K. Artemyeva, V. Bondarenko, A. Panarin, S. Terekhov, I. Khodasevich, K. Kholostov, P. Nenzi and M. Balucani

Displacement technique was applied to form silver and copper deposits. Using porous silicon as a substrate gave a metal film nanoroughness. Morphology of the obtained samples was studied with scanning electron microscopy. Raman spectra of samples impregnated with rhodamin 6G solution were taken and their dependences on porous silicon morphology and metal deposition regimes were determined. Enhancement of Raman signal was detected from silver films deposited on meso- and macroporous silicon, and copper porous film obtained due to complete mesoporous silicon displacement by copper atoms. Since its discovery surface enhanced Raman spectroscopy (SERS) has been attracting a great attention of scientific community because of possibility to detect small amount of substances. This phenomenon takes a place due to an enhancement in the electric field provided by the surface.

III-6 : Plasmonic nanosensors in the treatment of cancer: An attempt to conquer the immortal illness
Saikat Das, Jari Turunen

In 2010, a survey conducted all over the world says that more than 7 million humans around the world died of cancer. One in three women and one in two men developed cancer during their lifetime. About 15 percent of all deaths worldwide, was attributed to cancer. In some nations, cancer will surpass heart disease to become the most common cause of death. This paper attempts to demystify the behaviour of cancer-the defining plague of our generation. Here, we present a

novel method based on silver nanoparticle-generated transient photothermal vapour nanobubbles. These intracellular plasmonic nanobubbles are effective in the diagnosis (by optical scattering) and treatment (by mechanical, nonthermal and selective destruction of target cells) of cancerous cells. Theoretical simulation of fused silica rod SPR sensors and optical fiber SPR sensors was carried out. Then these nanosensors were designed, fabricated and their sensitivities were measured experimentally. We introduce the nanosensors and describe how its size and environment can be harnessed to detect and treat cancer cells. This paper has been written from the quest to launch something that can eradicate this disease from our bodies and societies forever.

III-7 : Propagation Constant of a Rectangular Waveguides Partially Filled With Metamaterial Slab
Hedi Sakli, Wissem Fathalla and Taoufik Aguili

In this paper, the propagation constant of a rectangular metallic waveguides partially and symmetrically filled with single negative metamaterial slab is studied. A rigorous study of the transverse operator method (TOM) is described to study the propagation in this waveguides followed by an application of the Galerkins method. The results are compared to those previously published and they show a good agreement.

III-8 : Revealing Plasmonic Gap Modes in Particle-on-Film Systems Using Dark-Field Spectroscopy
D. Y. Lei, A. I. Fernandez-Dominguez, Y. Sonnefraud, K. Appavoo, R. F. Haglund Jr., J. B. Pendry, S. A. Maier

Polarization-controlled excitation of plasmonic modes in nanometric Au particle-on-film gaps is investigated experimentally using single-particle dark-field spectroscopy. Two distinct geometries are explored: nanospheres on top of and inserted in a thin gold film. Numerical simulations are performed to reveal the physical origin of the observed scattering peaks measured from individual nanospheres in these two configurations.

III-9 : Self-assembly of metallic nanoparticles into plasmonic rings
Thomas Lerond, Thomas Lerond, Julien Proust, Davy Gerard, Jérôme Plain

- Metallic nanoparticles are self-assembled into plasmonic nanorings by evaporation and driven using a template of dielectric microspheres. Well-ordered arrays of metallic nanorings over large areas are obtained. The inner and outer diameters of the rings, as well as the pitch of the array, are controllable. The optical resonances supported by the plasmonic rings are then characterized using extinction spectroscopy. This approach opens a simple and inexpensive road to create plasmonic structures that can find applications as metamaterials or substrates for enhanced spectroscopies.

III-10 : Size dependence of LC resonant wavelength of silver SRR
Toshihiro Okamoto, Tomoya Otsuka, Masaya Morizane, Tetsuya Fukuta, Shuji Sato, Masanobu Haraguchi, Masuo Fukui

We made silver split-ring resonator (SRR) using the nanosphere lithography method, and measured the LC resonant wavelength of single isolated SRRs at light wavelength region. They were confirmed that the LC resonant wavelength calculated from the size parameters were compared with the experiment experimental result, and there were correlation.

III-11 : Optical Frequency Detector Based on Stratified Isotropic Slab
K. Vytovtov, L. Mospan, S. Zouhdi

The frequency detector based on stratified isotropic structure is offered. The functioning principle is described. The spectral analysis of a frequency modulated signal is presented.

III-12 : Slow light Enhanced photonic crystal MZI modulator in silicon
Belkebir Hicham, Qarchi Abdelaziz, Bouzid Abdenabi

The aim of this work is to present a new design of high-speed, and ultra-compact optical modulation. The basic idea is to use a Mach-Zehnder interferometer in planar photonic crystal for which one of the two arms was structurally optimized to operate in the regime of slow modes, while the other arm operates in the regime of fast modes. the phase difference between the two optical pulses that travels in both channels strongly depends on the slowdown factor of the optimized photonic crystal slab. The exploitation of the free carriers dispersion effect in silicon provides a π phase difference on a very short length L and with a very low voltage.

III-13 : Spontaneous light emission modification from silicon nanocrystals coupled with surface plasmons
Julie Goffard, Davy Gerard, Patrice Miska, Anne-Laure Baudrion, Michel Vergnat, Jerome Plain

Silicon nanocrystals are good candidates for realizing optoelectronic devices on silicon substrates. Such devices are interesting as their growth could be compatible with the CMOS technology. However, their quantum efficiency and absorption cross-section are not high enough to give optoelectronics components with high performances. The use of localized surface plasmon-polaritons coupled to these nanocrystals could be a way to improve their efficiency.

III-14 : Steady-state two-level population inversion using photonic crystals
Hiroyuki Takeda

It is generally considered that steady-state population inversion is impossible in two-level systems. However, if it were possible to achieve two-level population inversion, it might provide new applications for optical materials. From this scientific interest, possibility of two-level population inversion has been discussed for a long time. Photonic crystals composed of periodic dielectric materials are considered as powerful candidates to achieve two-level population inversion at steady-states. I investigate the above property based on the semi-classical theory in which electrons and electromagnetic fields are treated quantum-mechanically and classically, respectively.

III-15 : Surface plasmon effects excitation from three-pair arrays of silver nanorings for subwavelength imaging
Yuan-Fong Chau, Huang-Yi Li

We studied, numerically, the characteristics of the surface plasmon of a system consisting of several pair arrays of silver nanorings. Effects from different numbers of pair arrays, illumination wavelengths, and the core refractive index of silver-nanocylinders are studied by using the finite element method. Results show that the peak wavelengths shift to NIR wavelengths when the solid silver nanodisks are instead of silver nanorings. The near-field intensities in the gaps of our proposed structures can be tuned much stronger with a redshift by varying the wavelength of the incident light. The main features of surface plasmon effects can be qualitatively understood from some simple models of three, six, eight, and twelve pairs of silver-shell nanorings.

III-16 : Surface plasmon in a nanosphere near to a semi-infinite medium
Patricio Ramírez-Rodríguez, Raúl García-Llamas

The Surface Plasmons excitation in spheres near to a semi-infinite medium is studied theoretically. The fields in each medium were expanded in multipolar expansion, and their coefficients were found by using the boundary conditions. Due to the presence of the plane there is not spherical symmetry and the vector addition theorem is used to evaluate the boundary condition at the semi-infinite medium, as a consequence, a matrix equation for the unknown coefficients is obtained. Numerical results for the problem will be presented.

III-17 : Thick metallic slabs with axially inhomogeneous holes in the hybrid transmission regime
Andriy Serebryannikov

A comparative study of transmission through thick metallic structures of several types that contain arrays of the holes, whose cross section is assumed to be piecewise constant, is carried out. In the studied structures, the cross section is variable so that the evanescent-wave and propagating-wave regimes may co-exist within the neighboring sections of a waveguide (hole) that connects the slab interfaces. It is shown that high transmittance can be obtained in these structures even if the evanescent-wave sections occupy the most part of the waveguide length.

III-18 : Time domain investigation of the tunneling modes in photonic
Liwei Zhang, Guiqiang Du, Yewen Zhang

We present a theoretical investigation into the energy transport and transient wave propagation in the metamaterial tunneling structures consisting of epsilon-negative (ENG) and mu-negative (MNG) materials. It is proved that the conjugated matched ENG/MNG bilayer and the (zero index material doped) photonic crystal heterostructure can work as a sub-wavelength resonator at tunneling frequency. While the tunneling modes need a certain time to achieve to steady state and the characteristic time increase (nearly) exponentially with the thickness of the ENG/MNG bilayer, while the characteristic time of the (zero index material doped) photonic crystal heterostructure is lager than that of ENG/MNG bilayer because of multiple interface reflection. Under the steady state, the waves in the single negative material structures are not evanescent, but a hybrid of traveling wave and reactive standing wave, and the phase difference between the electric field and magnetic field varies with the position.

III-19 : Tunable plasmon resonance modes on gold nanoparticles Er3+-doped germanium-tellurite glass

Victor Rivera, Yannick Ledemi, Sergio Osorio, Danilo Manzani, Fabio Ferri, Sidney Ribeiro, Luiz Nunes, Euclydes Marega

The plasmon resonance modes of gold nanoparticles embedded in an erbium doped germanium-tellurite glass are activated using laser lines at 808 and 480 nm in resonance with radiative transitions of Er3+ ions. The gold nanoparticles were grown within the host glass by thermal annealing at several times, leading to diameters lower than 1.6 nm. The resonance wavelengths determined theoretically and experimentally are 770 and 800 nm, respectively. The absorption wavelength of nanoparticles was determined by using the Frohlich condition. Gold nanoparticles provide tunable emission resulting in a large enhancement for the 2H11/2rarr4I13/2 (emission at 805 nm) and 4S3/2rarr4I13/2 (emission at 840 nm) electronic transitions of Er3+ ions, this is associate with the quantum yield of the energy transfer transition. We observed that up-conversion is favored by the excited-state absorption due to the presence of the gold nanoparticles coupled with the Er3+ ions within the glass matrix.

III-20 : Tunable triangular shaped metamaterial
Qarchi Abdelaziz, Belkebir Hicham, Mir Abdellah

in this paper, we propose a new shape of resonators at the microwave frequency regime. the structure not only exhibit a magnetic subwave length resonance band gap, but also the band gap due to the electric resonance. The effect of the changes in the dielectric permittivity and the thickness of the substrate on the band gap of this structure are numerically investigated using the finite elements method in order to tune the transmission spectra.

III-21 : Ultrasmall plasmonic cavity for refractive index sensor
Soon-Hong Kwon, Yoon-Ho Kim, Hong-Gyu Park

We propose an ultra small plasmonic cavity based on channel-waveguides of different widths. Plasmonic mode-gap due to cutoff frequency enables strong optical confinement in a subwavelength volume and also suppression of radiation loss. Because of strong field overlap with environmental material, the proposed plasmonic cavity can be used as one of best candidates for sensitive refractive index sensor.

III-22 : Variable control of group velocity in a metamaterial with field-gradient-induced transparency
Yasuhiro Tamayama, Toshihiro Nakanishi, Masao Kitano

We realize variable control of the group velocity in an electromagnetically induced transparency-like metamaterial. Its unit cell is designed to have a radiative mode and a trapped mode. The coupling strength between these two modes is determined by the electromagnetic field gradient. In this metamaterial with field-gradient-induced transparency, the group velocity at the transparency frequency can be varied by varying the incident angle of the electromagnetic plane waves. By tilting a single layer of the metamaterial, the group delay of a microwave pulse can be varied between 0.50 and 1.85 ns.

III-23 : Wave packet dynamics in nonlinear tunnel coupler composed of right-handed and left-handed materials
I. O. Zolotovskii, D. I. Sementsov, K. V. Borisova and E. I. Barykina

We investigate dynamics of a wave packet formed by tunnel-coupled forward and backward waves in a waveguide structure composed of materials with different in sign indices of refraction. Expressions for the wave packet duration and maximum group velocity are obtained taking into account second order dispersion, cubic nonlinearity and nonlinear dispersion. The possibility to control the velocity of forward wave by means of an external magnetic field is discussed.

III-24 : Analysis of Planar Structure with Patch Superconductor Material and PBG Substrate
Humberto Fernandes, Hugo Maia, Leonardo Cetano

The analysis of the resonance frequency, efficiency, quality factor and pattern fields of microstrip antennas array, with superconductor patch for high critical temperatures, and PBG (Photonic Band Gap) substrate, are presented. The concise full wave Transverse Transmission Line (TTL) method is used in the analysis. New results of the resonance frequency, efficiency, quality factor and pattern fields of microstrip antennas array are presented.

III-25 : A polychromatic approach to far field superlensing in the visible
Geoffroy Lerosey, Fabrice Lemoult, Mathias Fink

Conventional imaging devices such as optical lenses are limited in resolution by the so-called Rayleigh criterion to half the operating wavelength. Imaging below this resolution requires to record the evanescent waves that carry thinner spatial information of an object but decrease exponentially away from it. This can be achieved with near field scanning optical microscopy but requires a point-by-point scanning. The need for real time super resolution imaging has led to many proposals of superlenses or high numerical aperture lenses, whose resolutions are seriously limited by the properties of the materials available in the visible. Meanwhile, interesting sub-diffraction imaging methods based on scattering and structured monochromatic illumination have been demonstrated. Here we propose to use polychromatic light sources to beat the diffraction limit using a superlens made out of resonant plasmonic nanoparticles.

III-26 : Tunable Broadband Plasmonic Perfect Absorber at Visible Frequencies
Mehdi Keshavarz Hedayati, Babak Mozooni, Franz Faupel, Mady Elbahri

Metamaterials and plasmonics build up a new pioneering field in photonics which joins the features of photonics and electronics by coupling photons to conduction electrons of a metal as surface plasmons (SP). In the present work, we apply this concept for realization of perfect absorber based plasmonic metamaterials at THz frequencies. we demonstrate design, fabrication and characterization of a perfect plasmonic absorber in a stack of metal and nanocomposite showing nearly 100 % absorbance across a broad range of frequencies from ultraviolet to the near infrared. Our experimental results showed that the absorption peak of the stacks can be tuned upon varying the thickness and type of the spacer layer. The fabrication technique of our metamaterials is relatively simple, cost effective, and compatible with current industrial methods of MEMS which make our proposed systems outstanding candidates for opto-electronic applications.

III-27 : Random Laser Emission in Innovative Structured Optofluidic Channel
Patrick Sebbah, Kiran Bhakta, Xavier Noblin

We have designed an innovative structured PDMS microfluidic channel that we filled with an ethanolic dye solution. We report random laser emission attributed to the inherent randomness in this structure. A systematic study on the origin of random lasing, and its dependency on pump laser parameters is presented.

III-28 : Surface Plasmon Enhanced Luminescence Up-Conversion
Won Park, Elisabeth Rengnath, Dawei Lu, Xiaoqiang Yu, Zhihua Li, J.S. Lemaire, Chris Summers

We report surface plasmon enhanced up-conversion in NaYF4:Yb3+, Er3+ phosphor nanoparticles. A silver nanograting structure was used to produce a surface plasmon resonance at the energy of the Forster transfer process. The enhanced up-converted Er3+ luminescence intensity, and shortened decay time of the Yb3+ luminescence, confirms surface plasmon enhancement of the Forster transfer process between Yb3+ and Er3+.

17:00 - 18:40 ***Thévenin***

6A: Metamaterials and negative index materials IV

Chaired by: Takuo Tanaka

17:00 : Keynote talk
Bringing Gain in Metamaterials
Costas Soukoulis

The need for reducing or even compensating of the losses is a key challenge for metamaterial technologies. One promising way of overcoming the losses is based on incorporating a gain material into the metamaterial structure. Therefore, it is of vital importance to understand the mechanism of the coupling between metamaterials and the gain medium. In addition, these ideas can be used in plasmonics to incorporate gain to obtain new nano-plasmonic lasers. We will present our FDTD numerical new results with gain in metamaterials.

17:40 : Invited talk
Flexible metamaterials at visible frequencies
A. Di Falco

We report on our recent results regarding the realization and characterization of metamaterials on flexible substrates at visible wavelengths. We review the fabrication procedure and discuss the electromagnetic response for different

plasmonic structures, including nano-antennas, fishnet geometries, flexible membranes supporting Fano resonances and metasurfaces with response independent on polarization and angle of incidence.

18:00 : Visible negative refraction in natural indefinite material: MgB2
Jingo Sun, Bo Li, Ji Zhou

In this work, we report a nature indefinite permittivity in crystalline MgB2 that exhibits negative group refraction for blue-purple light. Based on the ellipsometry data reported in literature, the equifrequency contour (EFC) is verified to be hyperbolic which enables a negative refraction for all incident angles. The indefinite dielectric tensor is attributed to the two Drude dispersions with different plasma frequencies between two crystal directions, which are derived from the strong anisotropic crystal structure. Numerical simulations are performed to demonstrate the negative refraction behaviour and the focusing property as a hyperlens.

18:20 : Electromagnetic coupling in a planar periodic configuration of resonators
Camille Jouvaud, Julien De Rosny, Abdelwaheb Ourir

We study the electromagnetic coupling inside an array of 4 by 4 multi-gap split ring resonators. To describe the frequency splitting, we propose a simple model based on the approximation of each resonator as an electrical dipole and a magnetic dipole that are driven by the same complex amplitude. We show that the relative strength of the two dipoles strongly depends on cell symmetry. With this approximation, the dispersion relation can be obtained. The frequency response of the small size array can be also worked out. A singular value decomposition provides a powerful way to deduce the resonant frequencies. These results are comforted by numerical simulations. Finally, an experimental demonstration of a tunable antenna based on this study is presented.

17:00 - 18:40 ***B310***

6B: Characterization and modeling of metamaterials

Organized by: S. Weiss and A. Zaghloul and M. Hoque

Chaired by: S. Weiss and A. Zaghloul and M. Hoque

17:00 : Study and analysis of an electric Z-shaped meta-atom
Abdallah Dhouibi, Shah Nawaz Burokur, André de Lustrac, Alain Priou

A printed Z-shaped electric meta-atom is presented as an alternative design to the conventional electric-LC (ELC) resonator. We redesign the ELC resonator pattern to get a compact and a low cost electric resonator exhibiting a strong electric response. Our approach consists in redressing the resonator shape to accommodate higher inductance and therefore leading to a lower resonance frequency without being limited by fabrication tolerances. Simulation and measurement results show that the Z meta-atom exhibits an electric response to normally incident radiation and can be used very effectively in producing materials with negative permittivity.

17:20 : Mixed nonlinearity retrieval and spatial dispersion in nonlinear metamaterials
Stéphane Larouche, Alec Rose, David Smith

A method to retrieve both effective electric and magnetic nonlinear susceptibilities of metamaterials is presented. This method is applied to simplified unit cells with only electric nonlinearity to isolate the effect of spatial dispersion, which shows as a magnetic nonlinearity. A criteria for homogenization of nonlinear metamaterials is proposed.

17:40 : Characterization of Metamaterials through Parallel-Plate Waveguide Measurements
S. Weiss, A. I. Zaghloul, Y.M. Lee, T.K. Anthony

Metamaterials are usually characterized by analysis, simulation, or measurements. Constitutive parameters of the metamaterial medium and the corresponding refractive index have been measured using focusing dielectric lenses, and variations of the parameters with inclined angles and have been demonstrated. In this paper, a parallel-plate waveguide is selected as the transmission medium for performing the measurements of metamaterial parameters. Parallel-plate waveguides are the propagation media for some structures, such as a Rotman lens. In addition to proving the metamaterial characteristics, performing the measurements in a parallel-plate waveguide medium presents several challenges.

Among the challenges are the structural integrity, edge reflection and diffraction, and asymmetry of inclined incidence due to the finiteness of the ground planes. Calibration of the parallel plate structure to perform measurements in free-space medium is first addressed. Measurements of the refractions that result from inserting the metamaterial inside the parallel-plate structure are then performed.

18:00 : Calculation of Effective Material Parameters by Field Averaging Over Lattices with Non-Negligible Unit Cell Size
Keith Whites, Anthony Amert, Victor Gozhenko

The field averaging method for calculation of effective material parameters is reviewed and its limits explored. The method is then extended so that it can accurately calculate the effective material parameters of lattices where the unit cell size is appreciable (0.001 λ but still quasistatic). The new algorithm is verified by calculating the effective material properties of periodically placed particles suspended in free space, as the unit cell size becomes appreciable. Results of our proposed formulation are then compared with a standard algorithm.

18:20 : Analytical and approximate treatment of the scattering problem at the interface between two periodic metamaterials
P. Lalanne, W. Śmigaj, J. Yang, T. Paul, R. Rockstuhl, F. Lederer

We use the Bloch-mode orthogonality to derive simple closed-form expressions for the scattering coefficients at an interface between two periodic media, a computationally-challenging electromagnetic scattering problem that can be solved only with advanced numerical tools. Through comparison with fully-vectorial three-dimensional computations, the analytical expressions are shown to be highly predictive for various geometries, including dielectric waveguides and metallic metamaterials. They can thus be used with confidence for designing and engineering stacks of periodic structures.

17:00 - 18:40 ***Estaunié***

6C: Plasmonics and nanophotonics V

Chaired by: Rainer Hillenbrand

17:00 : Single crystal diamond cavities for nanophotonics
Igor Aharonovich, Jonathan Lee, Andrew Magyar, Evelyn Hu

Color centers in diamond offer excellent potential for nano-photonic devices that will enhance our understanding of light-matter interactions in room temperature. In this work we report a successful demonstration of engineering bright, nanometer scale diamond membranes and subsequent fabrication of optical cavities. We show coupling of emitters to microdisk cavities and photonic crystal cavities sculpted of the single crystal diamond membrane. Single emitters in diamond, such as the silicon-vacancy (SiV) or the nitrogen vacancy (NV) are promising solid state qubits for realization of quantum communications and nanophotonics applications1. In recent years there has been great progress in engineering and characterizing these defects in ultra pure diamond crystals. However, the challenge of effectively incorporating the emitters into practical photonic structures and devices remains outstanding. Sculpting optical structures from diamond is often challenging, as diamond cannot be readily engineered to have sacrificial layers.

17:20 : Quantum Surface plasmon resonance system based on electromagnetically -induced transparency
Chunguang Du

A scheme for a new kind of surface plasmon resonance system based on atomic electromagnetically induced transparency (EIT) is proposed. The system is composed of three layers: a prism, a thin metal film, and a hybrid dielectric consisting of EIT atoms and a background substance. It is found that the two-dimensional EIT system exhibits interesting properties, and the reflectivity of the incident laser beam and the excited the surface plasmons are both extremely sensitive to shifts in atomic levels and to variations of permittivity of the substrate. This EIT-SPR system may to be used for detecting very small variations of quantum properties of matters.

17:40 : Keynote talk
Spectral super-resolution in metamaterial composites
Graeme Walter Milton, Johan Helsing, Ross McPhedran

We investigate the optical properties of periodic composites containing inclusions having a frequency dependent negative electrical permittivity, with a very small imaginary part, in a normal material matrix. We consider the case where these inclusions have sharp corners, and following Hetherington and Thorpe, use analytic results to argue that it is then possible to deduce the shape of the corner (its included angle) by measurements of the absorptance of such composites when the scale size of the inclusions and period cell is much finer than the wavelength. These analytic arguments are supported by highly accurate numerical results for the effective permittivity function of such composites as a function of the permittivity ratio of inclusions to matrix. The results show that this function has a continuous spectral component with limits independent of the area fraction of inclusions, and with the same limits for both square and staggered square arrays.

18:20 : Enhancing coherent nonlinear-optical processes in nonmagnetic backward-wave materials
Alexander Popov, Mikhail Shalaev, Sergey Myslivets, Vitaly Slabko, Igor Nefedov

Novel concepts of nonmagnetic nonlinear-optical (NLO) photonic metamaterials (MMs) are proposed. They concern with coherent NLO energy exchange between ordinary and backward waves (BWs) through the frequency-conversion processes. Two different classes of materials which support BWs are considered: MMs with specially engineered spatial dispersion and crystals that support optical phonons with negative group velocity. The possibility to replace plasmonic NLO MMs enabling magnetic response at optical frequencies, which are very challenging to engineer, by the ordinary readily available crystals, are discussed. The possibility to mimic extraordinary NLO frequency-conversion propagation processes attributed to negative-index MMs is shown in some of such crystals, if optical phonons with negative group velocity and a proper phase-matching geometry are implemented. Here, optical phonons are used as one of the coupled counterparts instead of backward electromagnetic wave (BEMWs). The appearance of BEMWs in metaslabs made of carbon nanotubes, the possibilities and extraordinary properties of BW second harmonic generation in such a MM is another option of nonmagnetic NIMs which is described too. The possibility of creation of a family of unique BW photonic devices is discussed.

17:00 - 18:40 ***Emeraude***

6D: Bottom-up approach towards metamaterials and plasmonics IV

Organized by: Dorota Pawlak

Chaired by: Jaime Gomez-Rivas

17:00 : Invited talk
THz metamaterials made of polaritonic materials
M. Kafesaki

In this work we examine and discuss the potential of two-dimensional periodic systems made of polaritonic rods in a host to be used as THz metamaterials, giving properties such as negative magnetic permeability, negative refractive index and/or hyperbolic

17:20 : Stressed Ferroelectric Nanoparticles: Building Blocks for Metamaterial Applications
Dean Evans, S. A. Basun, G. Cook, V. Yu. Reshetnyak

Ferroelectric nanoparticles have proven to be extremely useful in several optical applications. The characterization of the ferroelectric properties of these materials will be discussed, as well as the enhancements achieved in beam coupling and display applications. The potential use of these building blocks for meta applications, such as metatronics, will also be presented.

17:40 : Invited talk
Laser-ablative synthesis of plasmonic nanomaterials for biological applications
Andrei Kabashin

This presentation will review our on-going research activities on laser ablative synthesis of colloidal plasmonic (Au, Ag) nanomaterials. Our approach is based on the employment of ultra-short laser radiation to ablate a solid target or colloidal micro/nano particulates in biocompatible aqueous solutions and thus form functional colloidal nanoparticles of variable size and low size dispersion. The surface of nanoparticles can be functionalized by the addition of proper chemicals

(biopolymers etc) during ablation process. Exhibiting exceptional purity and exempt of any residual contamination, the nanomaterials present unique structures for biological imaging and therapy, as well as for SERS-based sensing

18:00 : Invited talk
Plasmonic nanoparticles ordered in self-assembled materials
Clémence Tallet, Julien Vieaud, Olivier Merchiers, Sivasankaran Prathap Chandran, Ashod Aradian, Virginie Ponsinet

Disordered and ordered nanocomposites composed of polymers and gold nanoparticles are prepared, with characteristic sizes between 10 and 100 nm. Their optical properties are studied by spectroscopic ellipsometry and related to their detailed structural description obtained by transmission electron microscopy and small-angle X-ray scattering. This study allows discussing the use of self-assembly for fabrication of new optical materials.

18:20 : Invited talk
Bottom-up magnetoplasmonics and ultracompact standalone nanoantennas in the visible
Alexandre Dmitriev

I will discuss the advances in bottom-up nanofabrication with hole-mask colloidal lithography (HCL) for nanoplasmonics. HCL is a truly versatile bottom-up nanofabrication of low-dimensional structures at surfaces in ambient conditions. The key is that the method is simple enough, affordable, and can bring benefits in a plethora of research and technology areas, where one needs objects of 20-5000 nm, fabricated on an arbitrary surface and covering cm2 area.1 Two recent examples are magnetoplasmonics and nanoantennas. The brand new and rapidly developing field of magnetoplasmonics explores the mutual relation between magnetization and localized plasmons. Differently from the studies of propagating surface plasmons in ferromagnetic systems or the combination of plasmonic and ferromagnetic materials, our research explores the opportunities arising from the direct excitation of localized surface plasmons in purely ferromagnetic nanostructures. Ill show that new fundamental property exists in nanoscopic metallic ferromagnets – the localized plasmon resonances and the intrinsic magneto-optical activity combined bring forward the ability of this nanostructures to sensitively control the rotation of the polarization of the scattered light with the applied magnetic field. Essentially, it is an extension of the magneto-optical Kerr effect (i.e., the magnetic field-induced variation of the polarization of the light reflected by a ferromagnetic surface).

17:00 - 18:40 ***Rubis***

6E: Metamaterial and photonics applications I

Organized by: Humberto C. C. Fernandes

Chaired by: Humberto C.C. Fernandes

17:00 : Isotropic Metal-Dielectric Composites for Subwavelength Imaging
Zsolt Szabó, Yasaman Kiasat, Er Ping Li

After reviewing the requirements, which has to be satisfied by a metamaterial based subwavelength imaging systems a thin films lens is reported herein. The material of the lens is a composite of spherical Ag nanoparticles embedded in SiO2 host material. The image of the lens is calculated, by solving the Maxwell equations, with the Transfer Matrix method. The procedure applies Maxwell-Garnet mixing rule and high frequency effective medium theory to calculate the electromagnetic parameters of the composite material. The formula of the composite material, the optimum working frequency and the thicknesses of the layers are determined minimizing the absolute difference between the source and image. The details of the design procedure are presented and optimized configurations obtained under different constrains are discussed. The main advantage of the composite lens is that it can eliminate the hotspots present in the images of metallic superlens.

17:20 : Images and electrical signal correlation to find bubble sizes in liquids
Marcelo Marinho, Valentin Obac Roda, Emerson Carlos Pedrino

Bubble size distribution is an important characteristic of biphasic systems. The interfacial area of the bubbles is strongly related to the chemical reactions rates and mass transfer that occur when producing some types of metamaterials Intrusive probes are largely used to determine bubble size distribution in biphasic bubbling columns. Single probes can only measure the bubble diameter directly by measuring the length of a perforated bubble and determining their diameters

by using statistical analysis,. Although bubble sizes cannot be obtained directly by the use of analysis. In this work we present a setup to measure bubble sizes in a bubbling column made of air and water using a conductive probe. Monochromatic images from CCD camera are used to calibrate and validate the system.

17:40 : Graded photonic crystals for graded index lens
Fabian Gaufillet, Eric Akmansoy

A graded index lens made from graded 2D photonic crystal has been designed by the means of the Finite Difference Time Domain (FDTD) method. The gradient of index has been obtained by varying the filling factor of a flat slab of photonic crystal in the direction perpendicular to that of the propagation of the electromagnetic field. This gradient has been designed in such a way that the flat slab focuses a plane wave. As only a few layers are necessary, graded photonic crystals show their ability to efficiently control the propagation of light and may apply to various photonic devices, from the microwave range to the optical domain.

18:00 : New application to microstrip antennas with metamaterial substrate
Marinaldo Sousa Neto, Humberto Fernandes

The propagation characteristics of the rectangular microstrip patch antenna on metamaterial substrate are determined via full wave method, Transverse Transmission Line – TTL. Compared to other full wave methods, the TTL is an efficient tool to determine the resonant frequency, making possible a significant algebraic simplification of the equations involved in the process. Numerical results of resonant frequencies are found as functions of the metamaterial properties.

18:20 : Enhanced Absorption via Light Trapping using Cholesteric Liquid Crystals
Themos Kallos, Vassilios Yannopapas, Demetri Photinos

A device that utilizes photonic crystals to significantly enhance the absorption of incident circularly polarized radiation at visible wavelengths is studied. An optical diode based on cholesteric and nematic liquid crystals is utilized to create an optical trapping effect in both planar and cylindrical geometries. Via full-wave simulations it is shown that combining the proposed device with weakly absorbing materials results in the doubling of their overall absorption efficiency.

17:00 - 18:40 ***Saphir***

6F: Mid-infrared and THz plasmonics III

Organized by: Raffaele Colombelli and Yannick De Wilde

Chaired by: Raffaele Colombelli and Yannick De Wilde

17:00 : Near field Thermal signal detected by a dipolar tip
Karl Joulain, Yannick De Wilde, Arthur Babuty, Pierre-Olivier Chapuis, Philippe Ben-Abdallah, Jean-Jacques Greffet

In this work, we show how an electric and magnetic dipolar particle has its polarizability that is changed in a non-vacuum environment. This result is used to calculate the signal obtained by an apertureless Scanning Near-Field Optical Microscope (SNOM) when the tip is a dipolar particle. This signal only depends on the field without tip and on the particle and surface optical properties. We apply our theory results to the case of a thermally excited surface. We show that the measure obtained is a local surface spectroscopy.

17:20 : Mid-infrared sub-wavelength focusing of electrically-generated surface plasmons polaritons
Adel Bousseksou, Jean-Philippe Tetienne, Raffaele Colombelli, Rakchanok Rungsawang, Arthur Babuty, Leo Greusard, Yannick De Wilde, Gregoire Beaudoin, Isabelle Sagnes

We demonstrate a compact integrated device, electrically driven, which is able to recover and exploit the confinement properties of SPPs at long wavelengths. It operates in the mid-infrared by electrical injection, It generates plasmonic excitations whose dispersion is artificially tailored via proper patterning of a purely metallic surface. We illustrate the power of this approach by demonstrating bending, focusing and sub-wavelength energy concentration.

17:40 : Field Effect Transistor Plasma Oscillators for Terahertz Emission and Detection
Wojciech Knap, Dominique Coquillat, Nina Dyakonova, Frederic Teppe, Jeremi Torres

This is an overview of the recent experimental results of Montpellier TERALAB group concerning the application of plasma oscillations in field effect transistors (FETs) for the generation and detection of TeraHertz (THz) radiation. The loading effects on responsivity and ultimately high detctivity of single and Si-MOSFET are shown as well as gate voltage tunable emission from GaN/AlGaN HEMTs.

18:00 : Enhanced transmittance through periodic arrays of subwavelength slits in a metallic slab
F. Ghmari, I. Ghrissi, I. Mezni

We present Modal Multi-layer Method (MMM) calculations for transmission of electromagnetic waves through periodic arrays of slits in a metallic slab. The material in these calculations is Ag and the wavelength is varying fromto. The geometric parameters are the period d, the slit width and the thickness of the slab. The effect of these parameters on the transmittance is studied, both in transverse electric and transverse magnetic cases. The results show resonant transmittance peaks for subwavelength widths of the slits, depending on the wavelength and the polarisation. Although our conclusions agree with previous work by Garcia and Nieto-Vesperinas in witch calculations are conducts using exact FDTD method and a theoretical method. The last one helps the authors to interpret the origin of the resonant peaks of transmission intensity. Here, the interpretation of the enhancement of the transmittance in terms of Rayleigh anomalies, Fabry-Perot resonances or of surface plasmon polaritons, is outlined.

18:20 : Invited talk
Terahertz surface plasmonics on metamaterials
Benjamin Reinhard, Tassilo Fip, Martin Volk, Rene Beigang, Marco Rahm

We present studies on localized waves in the terahertz frequency range. With the help of single metamaterial layers, terahertz waves are strongly confined within thin dielectric films and on the surface of dielectric substrate materials.

17:00 - 18:40 ***Jade***

6G: Metamaterials for aeronautics and transports II

Organized by: André de Lustrac and Shah N. Burokur

Chaired by: A. de Lustrac and S. N. Burokur

17:00 : Invited talk
How can metamaterials help in aeronautics and transport?
M. Duran-Sindreu, P. Velez, F. Paredes, G. Zamora, J. Bonache, F. Martin

This paper focuses on three applications of metamaterials in aeronautic and transport: components for ground penetrating radar (GPR), multiband components (for GSM and GPS bands) and RFID tags for transport logistics

17:20 : Invited talk
Using extraordinary transmission material in compact diode-like unidirectional device
Miguel Beruete, Victor Torres, Miguel Navarro-Cia, Andriy Serebryannikov, Mario Sorolla

This work deals with unidirectional structures based on a stacked extraordinary transmission hole array loaded with a dielectric grating on one side. Under oblique incidence, transmission in the normal direction takes place only when illumination is on the grating side, whereas with illumination on the flat side, transmission is blocked. The structure considered here is substantially thinner than previous unidirectional structures designs.

17:40 : Invited talk
A Flat Profile Cooke Triplet made from Dielectrics
Saul Wiggin, Wenxuan Tang, Yang Hao, Ian Youngs

Transformation optics allows conventional lenses and antennas to better fit their environment. A planar profile Cooke Triplet is found by FDTD simulation to behave as well as the conventional Cooke Triplet. An all-dielectric device design is used so the device is broadband and has acceptable loss levels. The transformation designed triplet has better directivity than the conventional design.

18:00 : Invited talk
Multi-hierarchical metamaterials combining conductive inclusions and polymer matrices for Electromagnetic Interference Shielding
Isabelle Huynen, Nicolas Quiévy, Pierre Bollen, Yann Danlée, Christian Bailly, Thomas Pardoen

Multifunctional metamaterials under development in our group are based on a hierarchical combination, from nano to macroscale, of conductive inclusions and polymer matrices. The paper illustrates this hybrid approach for a metallic honeycomb filled with a carbon nanotube-reinforced polymer foam. The waveguide characteristic of the honeycomb combined with the electromagnetic properties of the foam lead to large power absorption above the cut-off frequency of the waveguide, situated in the GHz range. Below cut-off, electromagnetic shielding is also offered by total reflection at input interface of the hybrid, preventing the signal transmission.

18:20 : Invited talk
Fast Transient Analysis of cylindrical cloaks with cyclic symmetry
Arnab Bhattacharya, Christophe Craeye

A numerical method to treat cylindrical cloaks with cyclic symmetry using the Method of Moments (MoM) has been developed and presented in [1]. This method uses the Array Scanning Method (ASM) in the azimuthal direction and Infinite Linear Array approach along the axis of the cylinder. In this paper the method has been extended to perform fast transient analysis of such cylindrical cloaks in order to study pulse transmission and scattering cross-section over a large bandwidth. The method is also very well suited for treating metamaterial cloaks which are known to be highly dispersive.

17:00 - 18:40 ***Grenat***

6H: Plasmonic Nanodevices I

Organized by: Haifeng Wang and Cheng-Wei Qiu

Chaired by: Haifeng Wang and Cheng-Wei Qiu

17:00 : Invited talk
Plasmonic nanoantennas for directional light emission, color splitting, and sensing
Timur Shegai, V. D. Miljkovic, C. Langhammer, P. Johansson and M. Käll

To achieve highly directional emission on a nanoscale, it is necessary to accurately control the optical phase over sub-wavelength distances. Here, we discuss several ways to establish such a control by utilizing propagating plasmons in metallic nanowires, material asymmetry in Ag-Au and Pd-Au dimers and hybrid sub- and super-radiant modes in ultracompact directional nanoantennas.

17:20 : Invited talk
Infrared nanoantenna couplers for plasmonic slot waveguide
Andrei Andryieuski, Radu Malureanu, Andrei Lavrinenko

A slot plasmonic waveguide is promising solution as a replacement of electrical interconnects in the future optical integrated circuits. In this contribution we consider a set of compact solutions for coupling the infrared light from free space to the plasmonic slot waveguide. We systematically study various designs: dipole antennas outside the waveguide, antennas inside the waveguide and bow-tie antennas in the slots.

17:40 : Invited talk
Plasmon coupling in gold nanostructures
Jianfang Wang

We studied the plasmon coupling behaviors in structures containing gold nanocrystals. The investigated structures include clusters of gold nanocubes, end-to-end assembled gold nanorod dimers with angles varying from 0 to 180 degrees, gold nanorods supported on substrates, and heterostructures between large gold nanorods and small gold nanospheres. A number of interesting plasmon coupling phenomena were observed and examined. In addition to the sensitive dependence of the plasmon coupling on the gap distance between two neighboring gold nanocrystals, the plasmon coupling

was found to be strongly affected by the number of gold nanocrystals, the angle between gold nanorods, the dielectric properties of supporting substrates, and the position of a small perturbing gold nanosphere on the surface of a gold nanorod. Our improved understanding in the plasmon coupling will be useful for designing and fabricating complex assemblies, hierarchical structures, and macroscopic materials out of noble metal nanocrystal building blocks, much similar to the formation of molecules and macroscopic materials out of atoms, with desired plasmon-derived functions.

18:00 : Invited talk
Confined plasmonic modes in a nanocavity
Didier Felbacq, Aurore Castanié

The Surface Plasmons Polaritons in a nanocavity are studied. It is shown that up to three SPPs can be obtained at a given frequency, one having a negative group velocity. A detailed analysis of the unfolding of the dispersion curve as a function of the width of the layer of metal is given.

18:20 : Invited talk
Nanoplasmonic Meta-Lasers
O. Hess, J. Hamm, S. Wuestner, A. Pusch, F. Renn, K. Tsakmakidis

On the basis of a Maxwell-Bloch Langevin approach we study the dynamics of nanoplasmonic metamaterial lasers. We report that lasing of the bright negative-index mode is possible if the higher-Q dark mode is discriminated by gain, spatially or spectrally. The nonlinear competition during the transient phase is followed by steady-state emission where bright and dark modes can coexist. We analyze the influence of pump intensity and polarization and explore methods for mode control.

Saturday 21st April, 2012

08:15 - 09:45 ***Thévenin***

Plenary Session III

08:15 : Plenary talk
Negative Refraction and Light Bending with Plasmonic Nanoantennas
Vladimir Shalaev

09:00 : Plenary talk
Inside the Wavelength: seeing really small objects with light
John Pendry

Coffee Break and Exhibit Inspection

Poster Session IV

09:45 - 10:40

IV-1 : Near Field measurement of a backward wave propagation phenomenon inside a ring resonators structure
Zine Eddine Djeffal, Hakeim Talleb, David Lautru, Victor Fouad Hanna

This paper presents experimental results of measurements of near electric field in free space for a structure composed of periodic ring resonators. Simulation results performed using electromagnetic full-wave software show good agreement with the experiment results. Our results demonstrate that in a specific frequency band, a negative index behavior, supported by a backward-wave phenomenon, is present. This result confirms that in bianisotropic medium the magnetoelectric coupling can modify the well-known relation of index of refraction.

IV-2 : Numerical Analysis to Four Layers Slot Antenna with PBG
Humberto Fernandes, Humberto Andrade

The numerical analysis of the rectangular slot antenna with four layers, considering photonic band gap materials - PBG, is developed. The analysis developed in this work was performed using the concise full wave TTL - Transverse Transmission Line method. The complex resonant frequency and efficiency of this structure are obtained. Numerical-computational results are presented in graphical form in three dimensions (3D) for the resonance frequency as functions of the length and width of the slot, and for the radiation efficiency as a function of resonance frequency and height of the layers of substrate structure.

IV-3 : Surface waves at the interface between tunable LC-MTMs and Nonlinear media
Hala El-Khozondar, Rifa El-Khozondar, Said Zouhdi

The surface waves propagation at the interface between tunable MTMs and Nonlinear media is investigated. Tunable MTMs has refractive index which might be tuned to negative-zero-positive values. Nonlinear materials are assumed to have Kerr-like refractive index. The dispersion equation is analytically derived and solved numerically. Results display the different behavior of the propagating waves as the refractive index is tuned.

IV-4 : Effects of Disorder in Metamaterial Structures
Abdelwaheb Ourir, Agnes Maurel, Jean-François Mercier, Vincent Pagneux

We investigate a stratified media composed of alternating layers of right- and left-handed materials. The effects of disorder in this type of disordered metamaterials, notably the so-called λ-6 anomaly observed at intermediate wavelength values, are studied theoretically and experimentally.

IV-5 : Proposal for an analytical method to design all dielectric photonic metamaterials
Eric Cassan, Khanh Van Do, Charles Caer

An analytical method is proposed for the study of all-dielectric photonic metamaterials (ADPMs). By introducing the long-wavelength approximation into the equations of Hamiltonian Optics, a master relationship is obtained for the refractive index distribution needed to make light follow prescribed paths. Furthermore, this approach is in good agreement with numerical calculations performed with Finite Different Time Domain (FDTD) simulation. It is an alternative solution to the use of coordinate transforms for the study of ADPMs and can be used for a versatile design of new optical functions.

IV-6 : Loss-Compensation, Light Amplification and Lasing in Nanoplasmonic Metamaterials
O. Hess, K. L. Tsakmakidis, F. Renn, A. Pusch, J. M. Hamm, S. Wuestner

Nanoplasmonic metamaterials are an exciting new class of engineered media that promise a range of important applications, such as subwavelength focusing, cloaking and slowing/ stopping of light. At optical frequencies, using gain to overcome potentially not insignificant losses has recently emerged as a viable solution to ultralow-loss operation that may lead to nextgeneration active metamaterials. Here we report on extensive computational simulations based on an ab initio Maxwell-Bloch Langevin approach that grasps the coherent and quantum noise properties of the gain medium and thus amplified spontaneous emission medium together with dynamic nanoplasmonic coherence in metamaterials. For the generic example of an optically pumped nano-fishnet metamaterial with an embedded laser dye (four-level) medium exhibiting a negative refractive index we demonstrate the transition from loss compensation to amplification and to nanolasing. We report ultrafast relaxation oscillations of the bright negative-index mode with frequencies just below the THz regime.

IV-7 : Phase constant peculiarities of open cylindrical zero-index anisotropic metamaterial waveguide
L. Nickelson, A. Bubnelis, S. Asmontas

Here we present the phase constant dependencies of propagating eigenmodes of cylindrical anisotropic metamaterial waveguide when the metamaterial permittivity and permeability tensor components may take values closed to zero at certain frequencies. The eigenmode phase constant dependencies of open waveguides with several radii at the left handed and right-handed polarizations of microwaves will be shown here. There is an anomalous dispersion of phase constant eigenmodes. The first eigenmode propagates at the frequency range when the waveguide metamaterial is double negative. This mode is particularly important because small changes on the frequency scale produce large changes in the phase. We can watch packages of dispersion branches when their cutoff frequencies closed to the metamaterial electric and magnetic plasma frequencies.

IV-8 : Dispersion in media containing resonant inclusions: where does it come from?
Geoffroy Lerosey, Fabrice Lemoult, Mathias Fink

In this talk, we use a very simplified model in order to grasp the physics of an array of resonators in a homogeneous medium. We study a quasi one dimensional system, that is, a waveguide filled with a linear array of resonators. We first prove that, to a large extent, the response of such 1D medium is governed by a far field coupling between the individual elements. This coupling can be understood as Fano interferences between the incoming plane waves and the field reemitted by the resonators. We give a phenomenological description of this effect in terms of the frequency response of an oscillator, and confront it to the typical results obtained from near field coupling analysed in the tight binding approach. We develop a simple formalism based on the transmission matrix of the system that permits us to obtain the dispersion relation of quasi 1D metamaterials using solely the far field transmission coefficient of a single unit cell and the period of the medium. We verify our approach and the obtained formalism on various designs. Finally we prove that it also gives the shape of the hybridization band gaps, or equivalently of the negative effective properties of the media, and discuss their relation to the period of the medium and the response of the considered resonator.

IV-9 : Pseudo-volume-plasmon into arrays of doped and un-doped semiconductors
Thierry Taliercio, Vilianne N'Tsame Guilengui, Eric Tournié

This work presents a new quasi-particle, the pseudo-volume-plasmon (PVP), which exists in arrays of doped and un-doped semiconductors. The PVP is the homologue of the volume plasmon in noble metals. We propose a description of the physical properties of the PVP and a picture to identify similitudes and differences with the volume plasmon of bulk material.

IV-10 : General description of surface waves excited on metallic gratings with subwavelength patterns
Haitao Liu, Philippe Lalanne

Under illumination by a transverse-magnetic (TM) wave, the electromagnetic field scattered on metallic surfaces corrugated by one-dimensional periodic arrays of tiny indentations exhibits several general properties. In general, the field on the surface between the indentations does not contain any surface plasmon polariton (SPP). Exception occurs in a narrow energy band centered around l=lSP, the SPP-phased matched wavelength obtained when the momentum of the incident wave matches the SPP momentum of the flat interface. When l=lSP, the field on the surface is always purely plasmonic even at infrared frequencies, for which SPP are excited nonresonantly. These properties are derived under the sole assumption that the indentations are small compared to the wavelength and are independent of the indentations form or dielectric constant, of the incident field and of the existence of an eventual resonance or antiresonance. A simple and general formula describing the fraction of the surface field that is composed of SPP is also obtained.

IV-11 : Controlling the hybridization in stereometamaterials
Withawat Withayachumnankul, Christophe Fumeaux, Derek Abbott

The influence of dielectrics on the hybridization of a twisted pair of split-ring resonators (SRRs), or stereometamaterials, is investigated in this article. It is found that when the permittivity of the layer between the two SRRs is higher than that of free space, the electric dipole-dipole interaction plays a dominant role in determining the modes of resonance. On the contrary, for the case of a free-space intermediate layer, the resonance modes are mainly determined by the magnetic dipolar interaction. No mode crossing occurs in the latter case, as opposed to the former. A Lagrangian formalism can be used to characterize the interplay between the magnetic and electric couplings. The results suggest an additional degree of freedom to control the behavior of this fundamental metamaterial element.

IV-12 : Antireflection transparent conductive coating using photonic metamaterial
Jiaming Hao, Cheng-Wei Qiu, Min Qiu, Said Zouhdi

In this paper, we present a new type of antireflection transparent coating based on photonic metamaterial, which does not suffer from high loss and thickness coating, and also can be used as good conductive material due to super electrical conductivity of the component (noble metal). Broadband antireflection and greatly enhanced transmission are observed around optical communication frequency for both transverse electric (TE) and transverse magnetic (TM) polarizations. The performance is almost insensitive of the angle of incidence.

IV-13 : Active control of near-field heat transfer
Philippe Ben-Abdallah, Svend Age Biehs, Felipe Rosa, Karl Joulain, Peter van Zwol, Joel Chevrier

An overview of different strategies recently proposed to tune, by mechanical actuation or phase transition, the near-field heat transfer between two media is presented. These results open the way to an efficient active management of heat transfer at nanoscale.

IV-14 : Localized surface Plasmon Bragg grating on SOI waveguide operating at telecom wavelength
Mickael Fevrier, Philippe Gogol, Abdelhanin Aassime, Robert Megy, David Bouville, Jean-Michel Lourtioz, Beatrice Dagens

We propose to use metallic nanoparticles supporting localized surface plasmon resonance in order to realize Bragg grating on dielectric waveguide. We have developed an analytical model allowing experimental result interpretation.

IV-15 : Analysis of angle resolved spectroscopic measurements of a single metafilm on a dielectric substrate
Anatole Lupu, Petru Ghenuche, Stéphane Collin, Nathalie Bardou, Natalia Dubrovina, Nawaz-Shah Burokur, Rasta Ghasemi, André De Lustrac

We analyze the angle resolved spectroscopic measurements of a single metafilm formed by gold nanowires and split ring resonators on a Silicon substrate. We show that it behaves like a homogeneous layer at normal and oblique incidence in p polarization.

IV-16 : Surface polaritons at the interface between a metal and a layer of nanocrystal quantum dots
Yuliy Bludov, Mikhail Vasilevskiy

Surface plasmon-polaritons (SPPs) in a multilayer structure consisting of a metallic film and one or more layers of nanocrystal (NC) quantum dots (QDs) are studied. It is shown that there is resonance coupling between the plasmon-polaritons propagating along the metal/NC-layer interface and excitons confined in the dots, which produces a conside-

rable effect on the optical properties of the structure unless the dispersion of the QD size is too large. This coupling can be explored in order to selectively excite QDs of different size by making a layer-by layer assembled NC planar structure and using an attenuated total reflection (ATR) configuration for the SPP-enhanced excitation of the dots. It opens the possibility of control of the relative intensity of light of different color, emitted by the QDs of different size.

IV-17 : Plasmonic antennas for the confinement and enhancement of the magnetic field in the infrared spectral domain
Pavel Geshev, Ulrich Fischer, Thierry Grosjean

Metal structures of the shape of a diabolo and a dumbbell are proposed as plasmonic antennas for the confinement and enhancement of the magnetic field amplitude up to a factor 150 in the infrared spectral domain at the narrow metal neck of the structures. A Boundary Integral Equation Method is used for a numerical solution of Maxwell's equations applied to an axially symmetric scattering system with a radially polarized Bessel beam exciting the structure to calculate the magnetic and electric field around the contour of the particle.

IV-18 : Lab on Fiber Technology enables Nanophotonics within optical fibers
Alessio Crescitelli, Armando Ricciardi, Marco Consales, Emanuela Esposito, Antonello Cutolo, Andrea Cusano

We propose a valuable fabrication path enabling the realization of metallo-dielectric nanostructures directly on the facet of standard single-mode fibers, that involves conventional nanoscale deposition and patterning tools typically exploited for planar devices and here properly adapted to enable direct in-fiber operations. To prove the effectiveness of the proposed technological path, we report the realization of a first technological platform based on hybrid metallo-dielectric crystal able to support local surface plasmon resonances, and explore its potential for chemical and biological sensing as well as for acoustic wave detection.

IV-19 : Cascaded Logic Gates in Nanophotonic Plasmon Networks
Hongxing Xu

Modern electronics based on semiconductors is meeting the fundamental speed limit caused by the interconnect delay and large heat generation when the sizes of components reach nanometer scale. Photons as a carrier of the information are superior to electrons in bandwidth, density, speed, and dissipation. More over, photons could carry intensity, polarization, phase, and frequency information which could break through the limitation of binary system as in electronic devices. But due to the diffraction limitation, the photonic components and devices can not be fabricated small enough to be integrated densely. Surface plasmon polariton is quanta of collective oscillations of free electrons excited by photons in metal nanostrucrures, which offers a promising way to manipulate light at the nanoscale and to realize the miniaturization of photonic devices. Hence, plasmonic circuits and devices have been proposed for some time as a potential strategy for advancing semiconductor-based computing beyond the fundamental performance limitations of electronic devices, as epitomized by Moore's law.

IV-20 : A Fourier-Bessel Expansion Method Applied to Photonic Crystals and Photonic Quasi-Crystals
Scott Newman, Robert Gauthier

Fourier-Bessel functions are used in a biorthonormal basis expansion of the TE Polarized Maxwell's equations to numerically model photonic crystals, triangular lattice, and rotationally symmetric quasi-crystals, 12-fold. The technique provides both the wavelengths and field profile of states supported by the structures. These results are compared to literature and finite difference time domain simulations.

IV-21 : Modeling the angular distribution of radiation emitted by a luminescent dye embedded in a finite photonic crystal
Jesus Manzanares, Paola Castro-Garay, Yohan Jasdid Rodriguez-Viveros, Efrain Urrutia-Banuelos, Damian Moctezuma-Enriquez

In this work we present a numerical modeling of the angular distribution of radiation emitted from a luminescent dye embedded in a finite one- and two-dimensional photonic crystal (PC). We calculate the photonic band structure (PBS) and the density of states (DoS) using a classical approach. The Finite Difference Time-Domain (FDTD) formalism has been used to simulate the angular distribution of radiation. We have found the conditions where the luminescent-dye radiation is inhibited or enhanced by the PBS.

IV-22 : Dark-field hyperlens at near-infrared wavelengths
Henri Benisty, Francois Goudail

We investigate a hyperlens at l=1200 nm based on two fans of metal tips converging to a central zone where multiple nanoparticles have to be detected. The rich Green function of the system provides deep-subwavelength resolution, but sensitivity requires a novel dark-field scheme that we will detail, based on amplitude and phase control of the fields on the illumination fan.

IV-23 : Microwave scattered and absorbed powers by a multilayered zero-index anisotropic metamaterial-semiconductor cylinder
L. Nickelson and J. Bucinskas

We are going to present dependencies of scattered and absorbed powers of incident perpendicularly and parallel polarized microwaves by the six-layered metamaterial-semiconductor or semiconductor-metamaterial cylinders. The cylinders consist of a glass core that is coated by six metamaterial and n-Si alternative layers. The difference between these cylinders is in the order of following metamaterial and semiconductor layers. Here is presented characteristics of cylinder with the semiconductor external layer. The multilayered cylinders have the external radius equal to 2 mm. The glass core has a radius equal to 0.5 mm. Every coated layer has a thickness equal to 0.25 mm. The metamaterial is a uniaxial anisotropic medium with the electric and magnetic plasma resonances in the considered frequency range. Here was taken into account the dispersion of semiconductor material. We present dependencies on the n-Si specific resistivity. We are going to compare scattered and absorbed power dependencies on a displacement of metamaterial and semiconductor layers, the microwave polarization and the n-Si specific resistivity. We discovered specific dependencies of scattered and absorbed powers on the parameters.

IV-24 : Moment Methods in Spectral Domain for Crossed-dipole Frequency Selective Surface
S. Komeylian, F. Hojjat-Kashani

Thus far, various approaches have been exploited for analyzing Frequency Selective Surface (FSS) structures. In this paper, we aim to apply Moment methods in spectral domain for both periodic and finite crossed-dipole FSS. Superior validity of Moment methods in practice as well as simplicity of their analysis are main advantages of these methods.

IV-25 : Broad band focusing and demultiplexing of surface plasmons
Lin Li, Tao Li, Shuming Wang, Shining Zhu

We demonstrate experimentally a broad band focusing (bandwidth 100nm) and a demultiplexing element (resolution 12nm) of surface plasmon polariton (SPP) waves by well-designed nonperiodic nanoarray. Moreover, sublattice arrays are developed to achieve an improved demultiplexer and confocal SPP beams. The proposed scheme is designed totally in planar dimension, which indicates more practical application in photonic integrations.

IV-26 : Piezoelectric phononic crystal for active elastic wave-guiding
Joo Hwan Oh, Il Kyu Lee, Pyung Sik Ma, Yoon Young Kim

If active piezoelectric materials are used as inclusions in a phononic crystal (PC), a stop band can be changed to a pass band or vise versa just by electric switching. Here, we make a use of the property to create an active waveguides in an elastic body in a certain frequency range. The advantages of the wave-guiding are that no permanent geometry or material change is needed and that somewhat arbitrarily-shaped waveguides can be formed actively in PC structures. At the operating frequencies, a piezoelectric PC at an open-circuit state forms a stop band while a PC at a closed-circuit state forms a pass band. Therefore, a part of a piezoelectric PC at a closed-circuit state makes a waveguide through which elastic waves can pass.

IV-27 : Fabrication of 3D Gradient Index of Refraction Diffractive Metamaterials for Infrared Gratings and Holograms
Talmage Tyler, Scott Wolter, Matt Royal, Yu-Ju Tsai, Stéphane Larouche, David Smith, Nan Jokerst

Materials and fabrication options are discussed for the implementation of three dimensional graded index of refraction diffractive metamaterial gratings and holograms. Materials choices for infrared implementation, dielectric deposition options, planarization approaches, and nanopatterning are discussed for implemented 3D GRIN metamaterial gratings and holograms operating at λ = 10.6 um.

IV-28 : Polarization-independent Fano resonances in one dimensional arrays of core-shell nanospheres
Wei Liu, Andrey Miroshnichenko, Dragomir Neshev, Yuri Kivshar

We reveal the existence of polarization-independent Fano resonances in one-dimensional arrays of core-shell nanospheres which exhibit both electric and magnetic Mie resonances engineered to overlap spectrally with the same strength. The electric and magnetic Mie resonances can interfere simultaneously with the geometrical resonance (the so-called Wood's anomaly) of the periodic array, resulting in polarization-independent Fano resonances.

10:40 - 13:00 ***Thévenin***

7A: Plasmonics and nanophotonics VI

Chaired by: Yuri Kivshar

10:**40 : Quantum Plasmonics : Nonlinear Effects and Field Enhancement in a Plasmonic Nanoparticle Dimer**
Dana Codruta Marinica, Andrei Kazansky, Peter Nordlander, Javier Aizpurua, Andrey Borisov

A fully quantum mechanical investigation reveals that the optical properties of a coupled metal nanoparticle dimer can exhibit strong nonlinear effects. We show that both classical as well as linear quantum mechanical descriptions of the system fail even for moderate incident light intensities. The nonlinear discharge current between the two nanoparticles tends to neutralize the plasmon-induced surface charge densities on the opposite sides of the dimer junction. This effect reduces the coupling between the two nanoparticles and the field enhancement compared to linear theory. A substantial nonlinear effect is revealed already at incident powers of 10^9 W/cm^2 for interparticle separation distances as large as 1 nm and down to the touching limit.

11:**00 : From near-field optical imaging to fine control of an active photonic crystal nanocavity with a nanoantenna**
Mathieu Mivelle, Thanh Phong Vo, Fadi Baida, Ségolène Callard, Dusan Nedeljkovic, Thierry Grosjean

We address the study of the near-field coupling between an active photonic crystal nanocavity and a bowtie-aperture nanoantenna (BAN) engraved at the end of a metal-coated fiber probe. When the BAN is at distances larger than 400 nm from the nanocavity, it acts as a polarizing nanoprobe allowing detailed and accurate vectorial information about the electric optical near-field of the nanocavity mode without significant perturbation of the laser emission. For smaller distances, it is demonstrated that the nanoantenna strongly modifies the optical properties of the nanocavity. When the distance between the BAN and the nanocavity is lower than 200 nm, an extraordinary coupling between the two resonators cancels the laser emission from the nanocavity. This work shows that nano-antennas can be used to finely tune and control optical resonators such as photonic crystals. It paves the way toward a new class of complex hybrid systems based on the optical interaction between photonic crystals and nanoantennas.

11:**20 :** Invited talk
Coupled Optical Vortices in Plasmonic Nanostructures
Svetlana Boriskina, Wonmi Ahn, Bjoern Reinhard

The conversion of free phtotons into localized charge-density oscillations (surface plasmons) enables an efficient delivery of light into nanoscale volumes and facilitates technological innovation in various fields from biosensing to photovoltaics and quantum computing. Conventional plasmonic nanostructures for these applications are designed as nanoscale analogs of radioantennas and waveguides. We have recently introduced an alternative approach for plasmonic nanocircuit engineering that is based on molding the optical powerflow through coupled optical vortices around a landscape of local phase singularities pinned to plasmonic nanostructures. In this lecture we will discuss how this approach enables a rational shaping of the near- and far-field spectra of plasmonic nanostructures and we will then review first examples of its experimental implementation and applications in surface enhanced Raman spectroscopy.

11:**40 : Oxides and Nitrides as Plasmonic Materials**
Gururaj V. Naik, Jongbum Kim, Paul R. West, Naresh K. Emani, A. Boltasseva

New plasmonic materials used as building blocks instead of conventional silver and gold offer many advantages in the rapidly growing fields of plasmonics and metamaterials including low loss, compatibility with standard semiconductor nanofabrication processes, and tunability. Here we consider transparent conducting oxides that enable high-performance

metamaterial devices operating in the near-IR and transition-metal nitrides that can be substitutes for conventional metals in the visible range.

12:00 : Single metafilm effective medium behavior in optical domain: Maxwell-Garnett approximation and beyond
Natalia Dubrovina, Loic Le Cunff, Nawaz-Shah Burokur, Rasta Ghasemi, Aloyse Degiron, André De Lustrac, Alexandre Vial, Gilles Lerondel, Anatole Lupu

It is empirically shown by numerical modeling that a single metafilm formed by an array of cut wires on a Silicon substrate behaves like a homogeneous layer model for normal or oblique incidence.

12:20 : Keynote talk
fJ/bit nanophotonics for photonic network on chip
Masaya Notomi

We have recently realized various photonic devices operating with the consumption energy of around fJ/bit based on photonic crystal nanocavities, and also have demonstrated the capability of integration. We present that these systems are promising for dense photonic network on chip (NoC), which is expected to drastically improve the performance of processor chips.

10:40 - 12:40 ***B310***

7B: Mid-infrared and THz plasmonics IV

Organized by: Raffaele Colombelli and Yannick De Wilde

Chaired by: Raffaele Colombelli and Yannick De Wilde

10:40 : THz plasmonic using planar Goubau lines
Juliette Mangeney, Djamal Gacemi, Karine Blary, Jean-François Lampin, Thibault Laurent, Tahsin Akalin, Paul Crozat, Fanqi Meng

We measure the spatial distribution of surface plasmon mode propagating along planar Goubau lines, so-called Goubau mode. We show the radial nature of the Goubau mode and its confinement around the single conductor using a guided-wave spectroscopy system based on a freely positionable electro-optic probe.

11:00 : Invited talk
On Surface Plasmons, Babinet Metamaterials, and Enhanced light Transmission
Willie Padilla and W. C. Chen

Metamaterials are patterned metallic structures which permit access to novel electromagnetic responses impossible to achieve with naturally occurring materials. Babinet or inverse metamaterials yield the complimentary transmissive or reflective properties compared to metamaterials. On the other-hand, the interaction of light with periodic two dimensional hole arrays in thin metals can lead to enhanced light transmission, greater than that expected based on the hole size to wavelength. We elucidate the relationship between subwavelength aperture arrays and Babinet metamaterials and their relation on surface plasmons in the context of optical constants. Experimental results at terahertz frequencies are presented and supported by simulations.

11:20 : Invited talk
Infrared nano-spectroscopy and nano-imaging of Dirac plasmons in graphene
D. N. Basov

We have applied antenna-based infrared (IR) nano-spectroscopy and nano-imaging to investigate Dirac plasmons in monolayer graphene. This experimental technique enables IR imaging with nano-scale spatial resolution, and also allows one to investigate electromagnetic phenomena at wave-vectors on the order of the Fermi wave-vector in gated graphene. Nano-spectroscopy and nano-imaging experiments have uncovered rich optical effects associated with the Dirac plasmons of graphene. We were able to directly image Dirac plasmons propagating over sub-micron distances and reflecting from the edges of graphene flakes, all with a spatial resolution far exceeding the plasmon wavelength.

Furthermore, we employed new IR nano-optics capabilities to demonstrate the gate-tunable plasmonic properties of graphene and to investigate the coupling between Dirac plasmons and the phonon modes of polar substrates.

11:40 : Fano resonances and intersubband polaritons in metallo-dielectric photonic crystal slabs
Simone Zanotto, Riccardo Degl'Innocenti, Giorgio Biasiol, Lucia Sorba, Alessandro Tredicucci

The resonances of a periodic arrangement of metallic stripes on a dielectric guiding layer are investigated by employing a Fano approach for the transmission lineshape analysis. When the waveguide core layer is replaced by a multi-quantum well supporting an intersubband resonance, the bare photonic crystal resonance splits in two polaritonic resonances, fingerprint of strong light-matter coupling regime. We show that these polaritons inherit the lineshape from the bare photonic resonance, and that their position can be described by a suitable Hamiltonian formalism.

12:00 : Invited talk
Strong coupling of the cyclotron transition of a 2DEG in a THz metamaterial
Giacomo Scalari, Curdin Maissen, Dana Turcinkova, David Hagenmüller, Simone De Liberato, Cristiano Ciuti, Christian Reichl, Dieter Schuh, Werner Wegscheider, Mattias Beck, Jerome Faist

We report here experiments showing ultrastrong light-matter coupling in a terahertz (THz) metamaterial where the magnetic cyclotron transition of a high mobility two-dimensional electron gas (2DEG) is coupled to the photonic modes of an array of electronic split-ring resonators. We observe a normalized coupling ratio $Omega/\ omegaa$c = 0.36 between the vacuum Rabi frequency $Omega$ and the cyclotron frequency λc.

12:20 : Sub-diffraction-limit resonators operating on the fundamental monopolar resonance: application to THz polaritons
Elodie Strupiechonski, Gangyi Xu, Manuel Brekenfeld, Aaron Andrews, Yanko Todorov, Carlo Sirtori, Gottfried Strasser, Aloyse Degiron, Raffaele Colombelli

We demonstrate semiconductor optical resonators with sub-wavelength dimensions in all three dimensions of space. The maximum confinement is obtained for resonators with a diameter of 13 microm, which operate at a wavelength of λ = 272 microm. This corresponds to a λeff/6 confinement, where λeff is the wavelength inside the material (or λ/20, if the free space wavelength is considered). These highly sub wavelength devices operate on the fundamental monopolar resonance, which corresponds to the fundamental oscillation mode of split-ring resonators and it is usually inactive in optical resonators. As a proof of principle for cavity quantum electrodynamics experiments, we apply these resonators to THz ISB intersub-band polaritons.

10:40 - 13:00 ***B312***

7C: Plasmonic antennas and lenses I

Organized by: Tahsin Akalin

Chaired by: Tahsin Akalin

10:40 : Invited talk
Terahertz active transmission-line metamaterial antennas
Benjamin Williams, Amir Tavallaee, Philip Hon, Zhijun Liu, Qisheng Chen, Tatsuo Itoh

The paradigm for composite right/left handed (CRLH) transmission line 1D and 2D planar metamaterials developed in the microwave can be adapted to the THz frequency range and implemented in THz quantum-cascade (QC) laser metal-metal waveguide. In particular, these concepts can be used to design resonators and antennas for sub-wavelength THz QC-lasers. We present a leaky-wave antenna for a THz QC-laser that steers a beam in the forward direction as the laser frequency is changed near 2.7 THz, and propose a fully balanced CRLH design suitable for backward to forward beam steering.

11:00 : Invited talk
Spontaneous emission of plasmonic ring metamaetrial
Tatiana Teperik, Aloyse Degiron

Combining two concepts, metamaterials and nanoantennas, we present a theoretical study on the spontaneous emission (SE) of a plasmonic metamaterial (MM) composed of a square lattice of ring nanoantennas fed by dipole emitters. We show that the emission spectrum of such a MM exhibits two types of anomalies that leads to a strong SE enhancement. One type of anomaly is caused by the excitation of plasmons localized on the metallic rings and another type is the diffractive anomaly (Rayleigh's anomalies) associated with the opening of new diffraction orders into surrounding media. We predict a resonant Fano profile in the spectral overlapping of localized (discrete) particle resonance with the continuum of propagating diffractive anomalies.

11:**20 :** Invited talk
Plasmonic metamaterials based optical lenses and their extraordinary imaging properties
Zhaowei Liu, Changbao Ma

Optical lenses are widely used in various fields of sciences and technologies. We present a few plasmonic metamaterials based phase compensated lens designs and their special imaging properties. Other than the super resolving power, appropriately designed lenses may possess completely different imaging characteristics along forward and backward directions. The dispersive property of the images will also be discussed.

11:**40 :** Invited talk
Broadband and actively tunable arrayed plasmonic nanoantennas for optical communications and sensing
Ivan Maksymov, Andrey Miroshnichenko, Yuri Kivshar

We suggest a simple and efficient way to enhance the bandwidth and tune dynamically the operating frequency of arrayed plasmonic nanoantennas. We demonstrate the capability of arrayed nanoantennas to perform as a bistable optical device, which opens up novel opportunities for optical communication and other kinds of all-optical light control at the nanoscale. We also explore the use of arrayed nanoantennas for nanoscale optical sensing.

12:**00 :** Invited talk
Engineering the Directionality and Spectrum of Plasmonic Nanoantenna Honeycomb Arrays
Kursat Sendur, Rustu Tok, Cleva Ow-Yang

Unidirectional radiation and broadband spectral response are achieved using plasmonic nanoantenna honeycomb arrays. In this study, directionality and spectrum are engineered using the morphologic parameters of plasmonic nanoantenna honeycomb arrays.

12:**20 :** Invited talk
Nanoantennas: Design of broadband light harvesters and new applications as plasmonic sinks
Stefan Maier

We present a new design methodology for plasmonic nanocavities exhibiting a broadband light harvesting response. The broadband behavior is due to structural singularities, which via conformal transformations map into infinite planar structures allowing for broadband SPP excitation. Additionally, a new application of plasmonic nanocavities acting as sinks for the selective removal of unwanted states in active media will be introduced.

12:**40 :** Invited talk
Pencil-like radiation and spatial processing by extreme low effective electromagnetic parameters
Miguel Navarro-Cia, Victor Torres, Miguel Beruete, Francisco Falcone, Mario Sorolla, Nader Engheta

In this contribution, metamaterials with very low effective electromagnetic parameters will be used to design lenses, which subsequently will be exploited for directivity enhancement and Fourier optics. For the implementation of the metamaterial lenses, fishnet-like structures and arrays of waveguide at cut-off will be employed. In addition, the differences and similarities between these two approaches and conventional metallic lenses will be discussed.

10:40 - 12:40 ***Emeraude***

7D: Energy Transportation in Metamaterials I

Organized by: Yewen Zhang and Xiaodong Chen

Chaired by: Yewen Zhang and Xiaodong Chen

10:40 : Invited talk
Experimental study on the transient establishment of the tunneling mode in ENG/MNG structure
Liwei Zhang, Yewen Zhang, Xiaodong Chen, Xiaoming Liu, Hong Chen

we have experimentally shown that a conjugate matched ENG/MNG can work as a sub-wavelength resonator at tunneling frequency. While the tunneling modes need a certain time to achieve to steady state and the CT increases (nearly) exponentially with the thickness of the ENG/MNG bilayer. Under steady state, the waves in the single negative material are a hybrid of traveling wave and reactive standing wave, and the phase difference between the electric field and magnetic field varies with the position.

11:00 : Slow light modes in metamaterial waveguides
Tian Jiang, Junming Zhao, Yijun Feng

Through rigorous analysis of all possible oscillatory guided modes propagating in the slab and cylindrical dielectric waveguides with metamaterial cladding, we demonstrate that slow or even stopped light can propagate in the waveguides with specially selected parameters of the metamaterial. We propose the design of linearly tapered waveguides which could lead the propagating light to a complete standstill and validate the structure by full-wave simulation based on finite-difference time-domain method. For practical implementation, we present the possible realizations of the slow light waveguide structures with anisotropic metamaterial cladding which could be realized through multilayer structure with alternating metal and dielectric films, or isotropic metamaterial cladding consisting of plasmonic materials.

11:20 : Invited talk
Lower RCS Antenna by Left-Handed Material
Ruixin Wu, Jiang Zhu

We have theoretically studied the emission of a current line source surrounded by a cylindrical shell of left-handed material (LHM). We find the use of LHM shell greatly improvesthe directional emission of the line source, forming a kind of LHM antenna. In a broadband frequency range, the radar cross-section of the antenna is lower than that of a parabolic reflectorantenna with the same aperture size, making it useful in stealth antenna design.

11:40 : Invited talk
Comparison of tunneling times in isotropic and anisotropic media
Jelena Radovanovic, Igor Ilic, Petra Belicev, Vitomir Milanovic, Ljupco Hadzievski

In this paper, a comparative analysis of the tunneling times of EM wave propagating in isotropic and anisotropic media is presented. It is shown that due to the presence of anisotropy, two peaks emerge in the dependence of the dwell time on the incident wave frequency, one of which corresponds to the peaks of absorption and the group delay, while the other one is a consequence of anisotropy.

12:00 : Slow light in metal nanocomposites
Joachim Herrmann, Kwang-Hyon Kim, Anton Husakou

We propose a method for slowing down light pulses by using composites doped with metal nanoparticles. The underlying mechanism is related to the saturable absorption near the plasmon resonance in a pump-probe regime, leading to strong dispersion of the probe refractive index and significantly reduced group velocities.

12:20 : Vortexlike Power Flow at the Interfaces of Metamaterial Lens
Kai Fang, Liwei Zhang, Yewen Zhang

The metamaterial lens with DPS/DNS/DPS structure is realized by using the two-dimensional (2D) isotropic transmission line approach. We studied the vortexlike power flow at the interfaces of metamaterial lens and validated by Finite Difference Time Domain simulator. The computational results showing its different conditions near DPS/DNS and other

kinds of interfaces are obtained by CST STUDIO SUITE at different frequencies, and demonstrate the intuitionistic power location at the metamaterial lens interfaces.

10:40 - 13:00 ***Rubis***

7E: Plasmon amplification and lasing I

Organized by: Kristjan Leosson

Chaired by: Kristjan Leosson and Alexandra Boltasseva

10:40 : Invited talk
Laser Science in a Nano-scale Gap
Rupert Oulton, Ren Min Ma, Volker Sorger, Thomas Zentgraf, Guy Bartal, Xiang Zhang

We review recent progress on metal-based lasers with optical confinement approaching 1/20th of the wavelength at room temperature and discuss the broader impact of plasmonic light sources and their application

11:00 : Electrically pumped spaser
Dmitry Fedyanin, Aleksey Arsenin

We present a novel scheme of SPP amplification that utilizes compact electrical pumping and gives a possibility to design really compact on-chip optical interconnects. Also, we demonstrate theoretically and numerically an electrically pumped spaser based on this scheme.

11:20 : Invited talk
Noise in surface plasmon amplifiers
Pierre Berini, Israel De Leon

Surface plasmon amplifiers and lasers (oscillators) have been topics of investigation for about three decades, culminating in several recent demonstrations of amplification and lasing. Noise in such systems is of foremost importance as it constrains information capacity. An expression for the noise figure of high-gain surface plasmon amplifiers incorporating dipolar gain media has been obtained in terms of the spontaneous emission rate into the amplified SPP, taking into account the different energy decay channels experienced by dipoles in close proximity to the metallic surface [2]. Two amplifier structures are examined: a single-interface between a metal and a gain medium and a thin metal film bounded by identical gain media on both sides. A realistic configuration is considered where the SPP undergoing amplification has a Gaussian profile in the plane of the metal and paraxial propagation along the amplifiers length.

11:40 : Invited talk
Dipolar and quadrupolar plasmon LASER modes for core-shell composites
Rémi Vincent, S. Derom, G. Colas des Francs

Spasers are based on a combination of the localized plasmon field properties of the metallic material with an amplification medium. The optical properties of these compound systems are based on a compensation of the metallic losses trough the optical gain of the amplification medium. Recently it was demonstrated experimentally that coating a gold nano particle with a silica shell containing Oregon Green 488 allows to overcome the loss-of-surfaceplasmon resonance. One of the consequences of the compensation of the losses is an extremely large enhancement of the local field amplitudes (giant resonances).

12:00 : Invited talk
Experiment-fit time-domain modeling of high-optical-gain dyes for active plasmonic nanostructures
Nikita Arnold, Ludmila Prokopeva, Thomas Klar, Alexander Kildishev

To design and optimize active nanoplasmonic devices, accurate models of the interaction of light with organic dyes are required. Here, we present a numerical tool for time-domain modeling of high-optical-gain dyes that solves the general multiphysics problem of coupling the system of time-dependent multilevel rate equations with the classical electrodynamics of light propagation. We discuss the importance of introducing more realistic models, such as the 5-level and 6-level systems with split transitions that can be used for the analysis of pump-probe dynamics from experiment,

coherent effects, as well as the experiment-fit modeling of vibrational structure in the absorption and emission spectra of a given host-embedded dye.

12:20 : Invited talk
Loss compensation in long-range dielectric loaded surface plasmon polariton waveguides
Sonia Garcia-Blanco, Markus Pollnau, Sergey Bozhevolnyi

Loss compensation in long-range dielectric loaded surface plasmon polariton (LR-DLSPP) waveguides has been theoretically studied. Rare-earth-ion-doped potassium double tungstates have been proposed as gain materials because of the elevated gain that they can provide, together with a favorable refractive index. The effect of the waveguide geometry on loss compensation efficiency was thoroughly studied. A material gain as low as 12.5dB/cm was found to suffice to achieve full loss compensation in an optimized structure.

12:40 : Invited talk
Fluorescent polymers and ultra-thin gold films for plasmon amplification in the visible wavelength range
Malte Gather, Arni Ingason, Kristjan Leosson

We review recent progress in the development of fluorescent semiconducting polymers that can provide high optical gain at visible wavelengths. In order to amplify propagating surface plasmon polaritons in this wavelength range, plasmonic waveguides with sufficiently low propagation loss must be constructed. To this end, we have studied the formation of ultra-thin gold films on transparent polymer substrates, using high-resolution x-ray reflection and x-ray diffraction measurements as well as plasmon propagation loss measurements.

10:40 - 12:40 ***Estaunié***

7F: Metamaterials for diffractive components I

Organized by: Philippe Lalanne

Chaired by: Philippe Lalanne

10:40 : Keynote talk
Recent Progress on Optical Metamaterials and Transformation Optics
Martin Wegener

We review our recent experimental progress regarding optical metamaterials and transformation optics. Herein, we emphasize (i) reconstruction of the phase images in three-dimensional, visible-frequency, broadband, polarization-independent carpet cloaks (ii) tapered gold-helix metamaterials as circular polarizers with 1.5 octaves bandwidth (iii) collective effects in second-harmonic generation from split-ring-resonator arrays at telecom frequencies (iv) metamaterial bolometers.

11:20 : Invited talk
High performance diffraction gratings made by e-beam lithography
Uwe Zeitner, Maria Oliva, Frank Fuchs, Dirk Michaelis, Tino Benkenstein, Torsten Harzendorf, Ernst-Berhnard Kley

Gratings are essential components in different high performance optical set-ups such as spectrometers in space missions or ultra-short-pulse laser compression arrangements. Often such kinds of applications require gratings operating close to the technological accessible limits of today's fabrication technology. Typical critical parameters are the diffraction efficiency and its polarization dependency, the wave-front error introduced by the grating, and stray-light performance. Additionally space applications have specific environmental requirements and laser application typically requires a high damage threshold. All these properties need to be controlled precisely on sometimes rather large grating areas. Gratings with extensions of up to 200mm or above are not unusual anymore. The talk provides an overview on how such high performance gratings can be realized by electron-beam lithography. This approach is demonstrated by different examples. One of them is the design and fabrication of the grating for the Radial-Velocity-Spectrometer of the GAIA-mission of the ESA.

11:40 : Invited talk
Nanophotonics with subwavelength composites

Yeshaiahu Fainman

This paper explores the role of nanotechnology with focus on nanophotonics in dielectric, metal, and semiconductor inhomogeneous composition materials, devices and subsystems for optical communications, information and signal processing, and sensing.

12:00 : Diffractive optical elements for broadband operation
P. Lalanne, C. Sauvan

The efficiency of conventional diffractive optical elements with echelette-type profiles drops rapidly as the illumination wavelength departs from the blaze wavelength. We use the high dispersion of artificial materials to synthesize diffractive optical elements which are blazed over a broad spectral range (about one octave) or for two different wavelengths.

12:20 : Invited talk
Metamaterials for Diffractive Optics
David Smith, Stephane Larouche, Yu Ju Tsai, Talmage Tyler, Nan Jokerst

Metamaterials provide an new set of tools for the development of diffractive optics. Diffractive optics represent an excellent match for metamaterials, since very few metamaterial layers are needed to accomplish beam-forming or imaging functions. Given the inherent losses associated with metamaterials especially those formed using metal inclusionsdiffractive optics provide a viable compromise, and may ultimately provide an important connection to closely related transformation optical media. Here we describe the opportunities that metamaterials enable, providing recent examples of metamaterial based diffractive optics.

10:40 - 13:00 ***Jade***

7G: Plasmonics and nanophotonics for sensing, imaging, and spectroscopy I

Organized by: Sang-Hyun and Alexandre Brolo

Chaired by: Sang-Hyun and Alexandre Brolo

10:40 : Plasmonic properties of silver nanocube monolayers on high refractive index substrates
Anatoli Ianoul, Adam Bottomley, Daniel Prezgot

Extinction spectra of nanocubes supported by a symmetry breaking dielectric substrate are very different from those in solution. In this work we varied the refractive index of the substrate in order to optimize the refractive index sensitivity (RIS) of supported silver nanocube monolayers. We found that on thin (5-7 nm) silicon films the RIS is characterized by the figure of merit (FOM) for the quadrupolar plasmonic mode as high as 5.0, making silicon supported silver nanocube monolayers a promising sensing platform.

11:00 : Invited talk
Nanoelectrochemistry and Spectroscopy from Plasmonic Structures
Alexandre Brolo

The effect of the applied potential of the properties of molecular species confined to sub-wavelenght nanoapertures in gold film were investigated. The plasmonic properties of the structure allowed the optical characteristics of the transmitted white light to be tuned when the applied potential drove an electrochemical process.

11:20 : Invited talk
Sensing and Trapping with Nano-Apertures in Metal Films
Reuven Gordon, Yuanjie Pang, Aftab Ahmed, Gabriela Cervantes-Tellez

This talk will present our recent results on sensing and trapping with nano-apertures in metal films. Recently we have managed to trap single bovine serum albumin particles (a protein with hydrodynamic radius of 3.4 nm), and sense the trapping event with signal to noise ratio 10. Continuing with sensing using hole-arrays, we have used engineering principles to reduce the noise and increase the signal to obtain sensitivity values comparable to large-scale commercial SPR sensors, but in an integration-friendly format for dense multiplexing.

11:40 : Invited talk
Improved Plasmonic Films via Template Stripping
David Norris

Template stripping can provide a high-throughput method for producing patterned metallic films for plasmonics. In general, template stripping utilizes the fact that coinage metals (e.g., silver, gold, and copper) will wet silicon substrates well but adhere poorly. Thus, by depositing such a metal on a patterned silicon wafer, the metal film can then be stripped off to reveal a smooth patterned interface that was templated by the substrate. Because the silicon substrate can then be reused, a simple solution for preparing many copies of the same plasmonic structure is obtained. The silicon wafers can also be patterned easily with a variety of techniques developed for microelectronics. Previously, we demonstrated that silver interfaces obtained via this approach could be ultrasmooth and exhibit surface plasmon propagation lengths approaching what is expected theoretically. Here we will demonstrate several additional benefits. First, because of reduced roughness, the dielectric function of the metal is considerably improved. Second, the approach can be extended beyond the coinage metals to refractory metals, semiconductors, and oxides, enabling a variety of structures for different applications. Finally, we will discuss the use of template stripping to reduce and even eliminate crystalline grain boundaries. Throughout the talk, we will use the fabrication of photovoltaic and thermophotovoltaic devices as examples.

12:00 : Invited talk
Correlating Structure, Geometry and Optical Properties of Plasmonic Nanoparticle Aggregates
Li-Lin Tay, John Hulse, Jeff Fraser

Small aggregates of plasmonic nanoparticle are known to sustain large surface enhanced Raman scattering (SERS) signals due to coupling of localized surface plasmon reosnances (LSPR) induced by the excitation radiation. Experimental measurements and theoretical calculations have both shown the intricate dependency of LSPR on individual nanoparticle structures. Very few studies have examined the correlation between SERS, LSPR and the structural geometry of small nanoparticle aggregates extensively. In this paper we will discuss results from our recent studies of the correlation between the geometry of small nanoparticle aggregates and their optical properties (SERS and LSPR).

12:20 : Invited talk
Biosensing using long-range surface plasmon-polaritons
Pierre Berini, Alex Krupin

The suitability and use of long-range surface plasmon-polaritons for biological and biochemical sensing is discussed. Emphasis is placed on sensors integrating metal stripe waveguides with microfluidic channels in straight and Mach-Zehnder interferometer geometries. Thiol-based chemistries and antibodies are used to render Au stripes selective to the target analyte. The sensing platform is capable of detecting analyte of mass within a very large range (from cells to proteins) with very competitive sensitivity and detection limit.

12:40 : Optical extinction in monolayer arrays of non-resonant nanorods
Petru Ghenuche, Gregory Vincent, Marine Laroche, Nathalie Bardou, Riad Haïdar, Jean-Luc Pelouard, Stephane Collin

We provide the first experimental evidence of sharp, resonant extinction in freestanding arrays of non-resonant nanorods. Nearly perfect optical extinction and strong absorption enhancement is shown for transparent and absorbing material, respectively. The results can be fully explained by a coherent multiple scattering model in periodic arrays of subwavelength nanorods.

10:40 - 13:00 ***Grenat***

7H: Plasmonic Nanodevices II

Organized by: Haifeng Wang and Cheng-Wei Qiu

Chaired by: Haifeng Wang and Cheng-Wei Qiu

10:40 : Invited talk
Magnetic response of upright meta-molecules in optical region
D. P. Tsai, W. T. Chen, P. C. Wu, C. T. Hsiao, K. Y. Yang, Y. W. Huang, C. Y. Liao, S. Sun, C. J. Chen, L. Zhou, G. Y. Guo,

V. Fedotov, V. Savinov, N. I. Zheludev

Single split ring resonator (SRR) composed of nonmagnetic metal can be used to implement a magnetic resonance. The LC response of SRR structures can be excited by an incident light with electric field perpendicular to two prongs of U-shape SRR or an incident light with magnetic field oscillating through the gap of U-shape SRR. In the case of erected SRR structures, the electromagnetic field solely depends on the resonance mode either enhanced between two prongs or around two prongs of single erected U-shape gold nano rings. The induced magnetic dipole of such erected SRR structures couple to each other also result in special electromagnetic spectra, such as plasmon induced transparency and toroidal dipole response, providing a novel plasmonic resonant mode in metamaterial.

11:00 : Invited talk
Maximizing light field enhancement at nano-scale for magnetic data storage
Haifeng Wang, Chin Seong Lim, Danqing Wang

The future 10 terabit per square inch magnetic data storage needs to use a light spot size of about 10 nm to warm up the recording media during magnetic writing. The only way to generate such nanometer light spot is to use optical antennas. However, when light is localized to such small scale, the optical efficiency is extremely low, usually below 1%, which makes it very difficult to transfer enough energy to warm up the disk for magnetic writing. This talk will center on the optical antenna design for efficient energy delivery and field localization for magnetic data storage.

11:20 : Invited talk
Visible–Infrared Metamaterials of Nanoscale Complementary Split Ring Resonators for Biological Sensing
Changzhi Gu, Zhe Liu, Xiaoxiang Xia, Haifang Yang, Baogang Quan, Junjie Li

Bio-sensing is an important application in the devices of plasmonic metamaterials. However, most of such metamaterial devices were basing on the separated metallic nano-structures and limited in the absorption effects at resonance frequencies. Here we present a novel bio-sensor basing on nanoscale complementary split ring resonators with unique function of controllable narrow band-pass. The nanostructures with unit size of 100 nm and slit width of 30 nm were fabricated by e-beam lithography and ion beam etching. And the detecting measurement result indicated that the nanostructure is sensitive to the solution of bovine serum albumin (BSA). This would pave a new way to the further application of plasmonic metamaterials in chemical/biological sensing.

11:40 : Hybrid plasmonic waveguide: PT-symmetry-breaking operation
Henri Benisty, Mondher Besbes

We investigate inverse-rib plasmonic waveguides with subwavelength confinement in the case of a first normal waveguide with losses coupled to a second one with nearly-balanced added gain. We find a smoothed version of the expected PT-symmetry breaking behavior but propose a way to restore its sharpness, and therefore to restore very high differential gain of the system.

12:00 : Non-perfectly-matched in-plane diffractions for generation of plasmonic Airy beam
Tao Li, Lin Li, Shining Zhu

We report a new approach of in-plane diffractions of surface Plasmon polariton (SPP) that can tune the beam phase almost at will. It is developed by so-called non-perfectly-matched Bragg diffractions in a non-periodic nano-array with respect to a propagation SPP wave. With this approach, a 3/2-power phase modulation is obtained for a SPP beam, by which a well-defined plasmonic Airy beam is experimentally achieved, exhibiting its unique properties, such as the non-dispersion, non-diffraction, self-bending, and self-healing. Due to the frequency tolerance of the non-periodic array structure, bicolor SPP Airy beams are demonstrated as well.

12:20 : Invited talk
Transformation optics and infrared metamaterials for optical devices.
R. Ghasemi, N. Dubrovina, P.-H Tichit, A. Lupu, A. de Lustrac

Using coordinate transformation, we study the design of optical devices using metamaterials at infrared wavelength. We demonstrate that the design is enabled by composite metamaterials that realize the space coordinate transformation and allow a control of the light in waveguide configuration. We present the design and the simulation of a waveguide taper and of the metamaterials necessary to its realization. Numerical simulations together with experimental measurements

are performed in order to validate the concept of the device and the realization of the metamaterials. FTIR measurements performed on fabricated metamaterials agree qualitatively with Finite Element Method (FEM) simulations. It is shown that this strategy, using the particular properties of the infrared metamaterials, allows a precise control of the light propagation with a low level of loss.

12:40 : plasmons mapping of individual ion-shaped nanoparticles
Coulon Pierre-Eugene, Slablab Abdallah, Perruchas Sandrine, Gacoin Thierry, Monnet Isabelle, Cardin Julien, Losquin Arthur, Kociak Mathieu, Rizza Giancarlo

In the last years, ion-shaping technique has been proposed as an innovative and powerful tool to manipulate matter at the nanometer scale. Deformation can be indirectly induced by embedding metallic NPs into an ion-deformable amorphous host matrix. With this technique, spherical particles can be transformed into prolate nanorods and nanowires as well as spatially oriented within the embedding matrix. Besides the fundamental aspects related to the ion-matter interaction, ion-shaping can also be used to give new insights into the plasmonic properties of metallic nanorods and nanowires. Here, Electron Energy Loss Spectroscopy (EELS) is used to study Localized Surface Plasmon Resonances (LPSR) in ion-shaped metallic nanoparticles with a nanometer-scale spatial resolution. This work represents the first attempt to investigate the potentialities of the ion-engineering technique to tune the optical features of the corresponding composite glass.

Lunch and Exhibit Inspection

12:20 - 14:20

14:20 - 16:00 ***Thévenin***

8A: Metamaterials and negative index materials V

Chaired by: Yahya Rahmat-Samii

14:20 : Ultra-thin Anisotropic Metamaterial Coating for Monopole Antennas
Zhi Hao Jiang, Micah Gregory, Douglas Werner, Pingjuan Werner

An ultra-thin anisotropic metamaterial coating is proposed which greatly enhances the impedance bandwidth of a monopole antenna to over an octave. The metamaterial coating has a high effective permittivity for the tensor component oriented along the direction of the wire monopole. The metamaterial was successfully applied to an S-band monopole, showing a broadening of the VSWR2 bandwidth from 0.4 GHz to 2.35 GHz in experiment, while preserving the radiation pattern at the same time.

14:40 : Omnidirectional transmission switching in epsilon-near-zero metamaterials
Simin Feng

Contrary to popular belief, conventional wisdom states that light bends away from the normal when it passes from high to low refractive index media, here we demonstrate that the transmitted power almost parallels to the normal for all angles of incidence when light passes from arbitrary high refractive index medium to epsilon-near-zero metamaterial. This counterintuitive to the conventional Snells law behavior is induced by material loss that switches the transmission angle from grazing to normal direction in epsilon-near-zero metamaterials. This property has potential applications in communications to increase acceptance angle and energy delivery without using optical lens and mechanical gimbals.

15:00 : Spin-wave modes in Ni inverted opal magnonic crystals
Andrey Stashkevich, Mikhail Kostylev, Yves Roussigné, Natalia Grigoryeva, Alexander Mistonov, Diter Menzel, Sergey Grigoriev, Nina Sapoletova, Kirill Napolskii, Andrey Eliseev, Andrey Lukashin

Studies of the microwave properties of Ni-based inverted ferromagnetic opals in the 2 – 20 GHz frequency band, backed by static characterization relying on SQUID measurements of remagnetization process, have been carried out. A theoretical model based on an array of weakly magnetically coupled, through dipolar interactions, ferromagnetic cylinders oriented along the preferred crystallographic directions, has been proposed. It satisfactorily explains, both qualitatively and qualitatively, major experimental results.

15:20 : Keynote talk
Metamaterials for Defense Applications
Augustine Urbas, Mark Spector, Steven Weiss

Metamaterials provide the ability to design materials properties to meet the unique needs of applications beyond what is possible with conventional materials. From spatially tailored dielectrics to tunable, dynamic metamaterial properties, these systems offer tremendous flexibility to application engineers. Many applications across the electromagnetic spectrum have been proposed from novel RF antennas to devices utilizing optical magnetism. In an effort to develop a full set of application tools and gain an engineering understanding of metamaterials, defense researchers have embarked on a series of application focused research efforts to apply metamaterials. These span a range of frequencies and a diversity of venues. The aim of this work is to gauge the readiness and maturity of metamaterials for the field. One of the key observations that emerges from such a pursuit are scientific questions and methods needs that can be returned to the research community to overcome challenges encountered in application venues. In some cases, we find limitations that are not consistent with the current understanding of a metamaterial system or identify a critical need in modeling a new phenomena or effect. With that in mind, such results from a number of application studies will be presented that span defense research interests.

14:20 - 16:00 ***Estaunié***

8B: Plasmonics and nanophotonics VII

Chaired by: Naomi Halas

14:20 : Keynote talk
Plasmonic nanocavities: Validity of the classical description and non-local effects on the nm-scale, and new applications as plasmonic sinks
Stefan Maier

Plasmonic cavities with nanometric gaps will be examined with a view on the limits of the classical description using macroscopic electromagnetism and the consequences of spatial dispersion on short length scales. Mode mapping using electron energy loss spectroscopy reveals that down to separations on the order of one nanometer, no quantum treatment is necessary. Effects of spatial dispersion are predicted using a transformation optics approach, and implementation of the hydrodynamic model into full-field classical simulations. Lastly, a new application of plasmonic nanocavities acting as sinks for the selective removal of unwanted states in active media will be presented.

15:00 : From localized to long-range plasmons in metallic nano-platelets
Nahid Talebi, Wilfried Sigle, Ralf Vogelgesang, Burcu Ogut, Lin Gu, Christoph Koch, Peter Van Aken

Using energy-filtered transmission electron microscopy, plasmonic resonances of Au-nano-platelets over a thin substrate is investigated. The experimental data reveals plasmonic modes which confined to the edges. The experimental results are verified by means of the finite-difference time-domain method, which show that the obtained modes are due to the excitation of wedge-plasmon modes.

15:20 : Optical coaxial metal dielectric nano-waveguides of complicated-form: optimization of the parameters.
Olga Kozina, Leonid Melnikov, Igor Nefedov

The properties of new optical waveguides with nanosize cross-section made of noble metals and glasses are described. This waveguide supports propagation of modes with unusual propagation properties. For optimization of the parameters of such waveguides the estimation of the field localization, losses, propagation length, velocity and others characteristics by FEM method has been used.

15:40 : Field enhancement in chain of magnetoplasmonic nanostructures
Melvin Essone Mezeme, Christian Brosseau

We apply first-principles methodology to study the spatial localization of electric field enhancement at plasmonic resonance and magnetic field enhancement at gyroresonance in a self-similar chain of magnetoplasmonic core-shell nanostructures (MCSN). Localized regions of high electric and magnetic fields in the vicinity of metal nanostructures can be created in a controlled manner by adjusting the physical parameters characterizing this system and the polarization of the

external harmonic excitations. We demonstrate the high degree of control achieved on electric field confinement, of the order of 103, down to a feature size of $\lambda/1000$ in self-similar chains of MCSN, where l denotes the free space wavelength of the resonant excitation. We also compare our findings with recent investigations in related plasmonic nanostructures.

14:20 - 16:00 ***B312***

8C: Plasmonic sensing I

Organized by: Harald Giessen and Na Liu

Chaired by: Harald Giessen and Na Liu

14:20 : Invited talk
Towards 3D plasmon rulers
Na Liu

We demonstrate a prototype 3D plasmon ruler based on coupled plasmonic oligomers in combination with high-resolution plasmon spectroscopy, rendering the retrieval of the complete spatial configuration of complex macromolecular and their dynamic evolution possible.

14:40 : Plasmonic axicon micro-lenses for chemical sensing
Jérôme Martin, Proust Julien, Gérard Davy, Bijeon Jean-Louis, Plain Jérôme

We report on the fabrication of plasmonic hybrid sensors made of a micro-axicon dielectric lens and a single metal nanoparticle. The dielectric lens produces a Bessel-like beam of light at its apex under plane wave excitation confining light in a narrow and intense beam with a low divergence. This Bessel-like beam can be used to optimize efficiently the excitation of a plasmonic nano-object and the collection of its far-field signal. This hybrid structure using the optical properties of a single metal nanoparticle can act as a highly sensitive plasmonic nanosensor.

15:00 : A smart plasmonic transparent conductor with a gas sensing ability
Mehdi Keshavarz Hedayati, Mohammad Jamali, Mojtaba Javaherirahim, Ahnaf Usman Zillohu, Mady Elbahri

Smart materials drawn the attention of the scientists due to their promising potential application in modern society. Among the demanded materials for opto-electronics, transparent conductors are highly requested and possibility to control their optical transparency opens up a new door in optical industry. Here we experimentally demonstrate a smart transparent conductive metal based on plasmonics. We show that by coating a thin silver film with polymeric/Spiro-molecules composite the transparency of the film not only be enhanced rather than the resonance transmission peak can be tuned by adjusting the coating thickness of Spiro-molecules content.

15:20 : Invited talk
Surface enhanced infrared spectroscopy: fundamentals and applications
Frank Neubrech

Resonantly excited electromagnetic near fields of metal nanostructures are used to enhance infrared vibrational signals of different molecules located in the vicinity of the structures. Accompanied with the signal enhancement is a change of the vibrational line shape due to the coupling between the plasmonic excitation and the vibrational one. In our presentation we will discuss this coupling effect and demonstrate possible applications for early disease diagnosis in medicine.

15:40 : Invited talk
Nanoplasmonic Spectroscopy Concepts for Nanomaterials Science and Catalysis
Christoph Langhammer

In this talk the potential of nanoplasmonic sensors, exploiting both direct and indirect nanoplasmonic sensing (INPS) schemes, for the scruitiny of processes in and on the surface of nanomaterials in situ and in real time will be discussed. Particular focus is put on catalysis, hydrogen storage and solar energy harvesting related applications

14:20 - 16:00 ***Emeraude***

8D: Allan Boardman symposium on Nonlinear waves and Metamaterials I

Organized by: Nikolay Zheludev and Vladimir Shalaev

Chaired by: Nikolay Zheludev and Vladimir Shalaev

14:20 : Invited talk
Giant linear and nonlinear optical activity in metamaterials
Eric Plum, Mengxin Ren, Vassili Fedotov, Jingjun Xu, Nikolay Zheludev

We report million-fold enhancement of nonlinear optical activity and metamaterial polarization spectral filters for any wavelength in the context of earlier chirality-based breakthroughs in the field of metamaterials including negative index and giant optical activity of planar interfaces.

14:40 : Invited talk
Tunable metamaterials
Ilya Shadrivov

In this talk we will overview several concepts for tuning metamaterial properties, including electronic, mechanical, optical and nonlinear tuning. We will present the tuning possibilities not only for linear, but also for nonlinear properties of metamaterials.

15:00 : Invited talk
Nonlinear plasmonics
Anatoly Zayats

We will overview opportunities provided by plasmonics for controlling light with light in nanostructures. These include ultrafast nonlinear plasmonic crystals, active plasmonic metamaterials, nonlinear elements of nanophotonic circuitry based on plasmonic waveguides, as well amplification of plasmonic signals to overcome propagation losses.

15:20 : Invited talk
Novel approaches to nonlinear metamaterials: a structural perspective
Mikhail Lapine, I.V. Shadrivov, D.A. Powell, Yu. S. Kivshar

We review our recent achievements with regards to nonlinear and tunable meta-materials constructed with a mechanical degree of freedom. This approach offers a wide range of possibilities, with the key highlights being the structural tunability, the magnetoelastic metamaterials, and metamaterials with conformational nonlinearity.

15:40 : Invited talk
Nonlinear metamaterial waveguides and cavities
Natalia Litchinitser, Apra Pandey, Gayatri Venugopal, Xi Wang, Jinwei Zeng, Alexander Cartwright

We proposed and demonstrated passive and active metamaterial-based waveguides and cavities enabling novel functionalities for the future optics on chip applications.

14:20 - 16:00 ***Rubis***

8E: Plasmonic antennas and lenses II

Organized by: Tahsin Akalin

Chaired by: Tahsin Akalin

14:20 : Invited talk
Photoconductive antennas loaded with meta-atoms for terahertz radiation
Masanori Hangyo, Keisuke Takano, Yui Chiyoda, Fumiaki Miyamaru, Tsubasa Nishida, Mitsuo Takeda, Hiromasa Suo, Seigo Ohno, Teruya Ishihara, Kazuhiro Murata

Meta-atoms are loaded to photoconductive antennas (PCAs) in order to control spectrum and polarization of emitted terahertz waves. PCAs loaded with split-ring resonators show characteristic enhancement of emission efficiency at specific frequencies. The chiral PCAs of gammadion type show elliptic polarization. These results indicate the way to design the spectrum and polarization of PCAs by loading meta-atoms.

14:40 : Invited talk
Sub-Wavelength Metallic Dimers: a Bright Transverse Bonding Mode Appears
Brice Rolly, Brian Stout, Nicolas Bonod

It is widely assumed that the brightest mode in sub-wavelength metallic dimers is the longitudinal mode. However, when the size of the particles is somewhat large (around 100 nm diameter), one can no longer apply a quasi-static reasoning, even when the nanogap is small compared to the wavelength. Full propagation expressions show that the transverse bonding mode becomes the brightest mode for small nanogaps, and evidence the key role of the transverse dipolar coupling in this phenomenon.

15:00 : Invited talk
Metamaterial-based optical components for seamless integration in compact THz measurement systems
Jens Neu, Bernd Krolla, Oliver Paul, Benjamin Reinhard, Viktoria Wollrab, Peter Weis, Juan Luis Garcia-Pomar, Rene Beigang, Marco Rahm

We present a variety of metamaterial-based optical components for THz waves as e.g. bandpass filters, wave plates, polarizers, modulators, gradient index (GRIN) lenses and near-field sensors. As central scope, we concentrate on the design, fabrication and characterization of a 3-layer metamaterial-based gradient-index lens that focuses THz waves around a center frequency of 1.3THz down to spot diameters of the order of one wavelength. The operation bandwidth of the GRIN lens was 300GHz. The plasmonic metamaterial structure that composed the GRIN lens was fully embedded in a highly transmissive polymer membrane and allowed high transmission of THz radiation through the lens. The thickness of the lens was smaller than one wavelength of the THz wave and thus enables application in ultra-compact, low cost THz inspection systems.

15:20 : Invited talk
Photoconductive Terahertz Sources Based on Plasmonic Gratings
Mona Jarrahi, Chris Berry

A terahertz photoconductive emitter based on a plasmonic grating is presented and characterized experimentally. The plasmonic grating enables high quantum efficiency and ultrafast operation simultaneously, eliminating the need to use a short-carrier lifetime substrate.

15:40 : Invited talk
Modulators for free-space terahertz radiation
Wai Lam Chan, Hou-Tong Chen, Antoinette Taylor, Igal Brener, Michael Cich, Jie Shu, Ciyuan Qiu, Victoria Astley, Daniel Nickel, Qianfan Xu, Daniel Mittleman

We describe two different strategies for electrical modulation of terahertz radiation. The first relies on active metamaterial arrays, while the second uses the extraordinary optical transmission through a sub-wavelength plasmonic structure. In both cases, the transmission is switched by using an external bias to control the free electron carrier density in the substrate. These modulators are characterized by high contrast, high speed, and low cross-talk, which enables applications in real-time terahertz imaging.

14:20 - 16:00 ***Saphir***

8F: Advances in Metamaterials and Plasmonics III

Organized by: Lei Zhou and Jiaming Hao

Chaired by: Lei Zhou and Andrea Alu

14:20 : Invited talk
Plasmonic solutions for coupling and modulation

Andrei Andryieuski, Victoriia Babicheva, Radu Malureanu, Andrei Lavrinenko

We present our design results for efficient coupling and modulation in plasmonic structures. Fiber coupling to a plasmonic slot waveguide is significantly increased by a metallic nanoantenna with additional reflectors or by the configuration of several connected antennas. We also show that the plasmonic four-layer waveguide with patterned ITO layer can modulate light with higher transmission and the same modulation depth as a waveguide with a uniform ITO layer

14:40 : Invited talk
Electrical excitation of surface plasmons with the STM
G. Dujardin, E. Boer-Duchemin, G. Comtet, T. Wang, Y. Zhang

Surface plasmon polaritons (SPPs) in metallic nanostructures offer new perspectives for integrating optics at the nanoscale. In particular, SPPs provide new methods for the transfer of information and energy at dimensions below the diffraction limit. Excitation of such SPPs on noble metal nanostructures is usually produced by using photon excitation. However, electrical excitation of surface plasmons would have a range of promises for combining nanoelectronics with nanophotonics. We will demonstrate that electrical excitation of surface plasmons by using the tip of a scanning tunneling microscope (STM) enables to produce SPPs with specific properties, (i) a very local electronic excitation, (ii) a 2D circular symmetry, (iii) a broad energy distribution, and (iv) a combination of localized and propagating surface plasmons that depends on the STM tip structure and composition.

15:00 : Invited talk
Multilayer metamaterials and their applications
Zhaowei Liu, Dylan Lu, Jimmy Kan, Eric Fullerton

Plasmonic metamaterials provide new opportunities for various inspiring applications. We present multilayer-based plasmonic metamaterials with well-designed hyperbolic dispersions, which provide higher plasmonic density of state. Multilayers with different material and geometry combinations have been fabricated with the thickness of each layer scaled down to a few nanometers by using physical vapor deposition. They have been characterized to further enhance the fluorescence decay rate as compared with single metal films. Other possible applications such as spontaneous recombination rate control, super-resolution imaging, and improved bio-microscopy are also discussed.

15:20 : Integrated Localized Surface Plasmon Waveguides
Mickael Fevrier, Philippe Gogol, Abdelhanin Aassime, David Bouville, Robert Megy, Beatrice Dagens

Compact plasmonic structures made of gold nanoparticles chains are inserted on silicon optical waveguides. We show that silicon-on-insulator waveguide TE mode can be almost totally transferred in a 5 gold nanoparticle plasmonic waveguide mode.

15:40 : Nonlinear responses in optical metamaterials: theory and experiment
Shiwei Tang, David J. Cho, Hao Xu, Wei Wu, Y. Ron Shen, Lei Zhou

We employed both theoretical calculations and experiments to study the nonlinear responses in optical metamaterials. The spectra of second-harmonic generations measured on a fishnet metamaterial are in quantitative agreements with calculations based on full-wave numerical simulations combined with field integrations, both exhibiting 80 times enhancements at the magnetic resonance frequency. Our calculations explained several interesting features observed experimentally, and suggested an optimal metamaterial structure to yield the strongest nonlinear signals.

14:20 - 16:20 ***Jade***

8G: Optical Emission from Metamaterials and Plasmonic Systems I

Organized by: Augustine Urbas

Chaired by: Augustine Urbas

14:20 : Invited talk
How can we predict the directivity of a particle antenna?
Brice Rolly, Brian Stout, Sébastien Bidault, Nicolas Bonod

We detail the physical mechanisms that govern the directivity of a single particle antenna coupled with an electric dipole emitter. It is well known that the size of the particle plays an important role in the directivity properties, and that small particles tend to collect the emitted light whereas large particles tend to act as reflectors. However, we demonstrate that the directivity can be extremely sensitive to the distance between the dipolar emitter and the particle, and that a particle can either highly reflect or collect light, depending on its distance with the emitter. We derive an analytical model that perfectly explains this unexpected sensitivity.

14:40 : Invited talk
Fluorescent hybrid gold nanoparticles and nanocapsules
S. Parola, F. Lerouge, J. Navarro, C. Cepraga, S. Marotte, A. Favier, M.-T. Charreyre, C. Monnereau, C. Andraud, J. Lermé, M. Lindgren, P. Baldeck

The development of new hybrid nanoplatforms which can combine optical properties of chromophores with inorganic nanomaterials is of increasing interest for biomedical purposes. Nanoparticles have been intensively investigated during the past ten years for similar applications, essentially for use as imaging contrast agent or drug delivery supports. A recent idea is to use them as multimodal probe with the aim to either combine diagnostic techniques or imaging and therapy. In this communication we describe the synthesis modeling and characterization of nanomaterials combining gold nanoparticles of different shape and size with chromophores. Two types of architecture will be presented, either chromophore included in capsules or chromophore surrounding the gold core. The impact of the architecture, size and morphology of the gold part on the spectroscopic properties will be discussed.

15:00 : Invited talk
Metamaterial-based integrated plasmonic absorber/emitter for solar thermo-photovoltaic systems
G. Shvets, C. Wu, B. Neuner III, J. John, A. Milder, B. Zollars, S. Savoy

We will present a concept of an integrated frequency selective absorber/emitter based on an ultra-thin plasmonic metamaterial for Solar Thermo-Photovoltaics (STPV) applications. By employing non-shiny metals (such as tungsten), the absorption spectrum of the metamaterial is designed to be broad-band in the visible range and narrow-band in the infrared range. A detailed balance calculation demonstrates the total STPV system eplusmnciency exceeding the Shockley-Queisser limit for emitter temperatures above Te = 1200K, and an eplusmnciency as high as 41% for Te = 2300K. Such emitter temperature is shown to be achievable under modest Sun concentration (less than 1000 Suns) because of the thermal insulation provided by the metamaterial. Experimental demonstration of the wide-angle frequency selective absorptivity will be presented, and its implications for developing broadband infrared absorbers/emitters will be discussed.

15:20 : Invited talk
Opto-electronic Devices Spontaneous Emission Faster than Stimulated Emission
E. Yablonovitch

For more than 50 years, stimulated emission has been stronger and far more important than spontaneous emission. Indeed spontaneous emission has been looked down upon, as a weak effect. Now, a new science of enhanced spontaneous emission is emerging, that will make spontaneous emission faster than stimulated emission. This new science depends upon the use of optical antennas to assist the spontaneous emission. The overall enhancement in spontaneous emission rate could be roughly 8 orders of magnitude! Under favorable circumstances the spontaneous emission rate could be comparable to the optical frequency itself, which would be unprecedented. This technology emerges at the present time owing to our ability to create metallic structures at the nano-scale, that can act as antennas for molecules and semiconductors. This new technology will enable Tera-Hertz-speed direct modulation nano-LED's, and it will make it possible for ordinarily non-radiating molecules to radiate, revolutionizing biological research, and bio-sensing. The latest device results will be presented for antennas on semiconducting structures

15:40 : Invited talk
Control of spontaneous emission with hyperbolic metamaterials and plasmonic structures
M. A. Noginov, E. E. Narimanov, J. Vella, A. Urbas, N. Noginova, Y. A. Barnakov, C. E. Bonner, M. Mayy, G. Zhu, T.U. Tumkur, H. Li

Following Purcell, the rate of spontaneous emission of atoms and molecules strongly depends on the emitters environment and the local density of photonic states. Numerous known examples of environments with engineering density of photonic states include cavities and photonic band crystals. The research in hyperbolic metamaterials (in which dielec-

tric permittivities in orthogonal directions have opposite signs), originally stimulated by tantalizing possibilities offered by the absence of diffraction limit in a hyperlens, has uncovered a number of novel effects resulting from a broadband singular behavior of the density of photonic states in these materials.

16:00 : Invited talk
Beyond Stefan-Boltzmann Law: Thermal Conductivity in Hyperbolic Metamaterials
Evgenii E. Narimanov, Igor I. Smolyaninov

We demonstrate that the broadband divergence of the photonic density of states in hyperbolic media leads to giant increase in radiative heat transfer, beyond the limit set by the Stefan-Boltzmann law. The resulting radiative thermal hyper-conductivity may approach the heat conductivity via electrons and phonons in regular solids.

14:20 - 16:00 ***Grenat***

8H: Quantum metamaterials II

Organized by: Didier Felbacq

Chaired by: Didier Felbacq

14:20 : Invited talk
Classical analog of two quantum-optic phenomena in metamaterials
Haitao Jiang, Yong Sun, Hong Chen

Recently, metamaterials with unique electromagnetic (EM) properties have attracted people's great interest. In metamaterials, the eclectic and magnetic response to incident light can be conveniently tuned. For example, the enhancement of electric and magnetic response can bring about effective negative permittivity (epsilon) and negative permeability (mu), respectively. Since the interactions of metamaterials and light can be manipulated by varying the structural and geometric parameters of metamaterials, metamaterials provide us a convenient platform to mimic a variety of quantum-optic phenomena such as electromagnetically induced transparency (EIT) and vacuum Rabi splitting. EIT in quantum optics occurs when atoms can transit via two pathways and make a destructive interference to inhibit absorption, which brings about slow-wave effect and strong group velocity dispersion.

14:40 : Invited talk
Nonlocality in Multilayered Metal-Dielectric Optical Metamaterials
Alexey Orlov, Alexander Chebykin, Pavel Voroshilov, Yuri Kivshar, Pavel Belov

We have accomplished rigorous dispersion analysis and showed clearly impact of nonlocality on properties of multilayered metal-dielectric metamaterial. The main discovered effect is an appearance of additional extraordinary waves in the metamaterial which leads to the splitting of the TM-polarized beam at the air-MDN interface.

15:00 : Quantum birefringence and ambidextrous quantum metamaterials
Alexandre Zagoskin, Sergey Saveliev

Quantum metamaterials are optical media comprised of controllable artificial quantum scatterers, which maintain quantum coherence for times exceeding the characteristic travel time of an electromagnetic wave through the system. Being an extended quantum object, a quantum metamaterial is predicted to have unusual properties, such as quantum birefringence – the superposition of states with different refractive indices, n1 and n2. Here we present analytical and numerical results on quantum birefringence in a realistic test system – an array of superconducting qubits. In particular, the case of ambidextrous quantum metamaterials (with n1n2lt0) is investigated.

15:20 : Invited talk
Exotic Properties and Applications of Quantum Metamaterials
Andrea Alu, Romain Fleury

We discuss here potential venues for applications and exotic features of quantum metamaterials. We explore the coupling of conventional electromagnetic metamaterials with quantum emitters and the wave properties of quantum metamaterials obtained by tailoring their effective band structure. We show anomalous enhancement effects in the quantum emission

properties of individual and collections of small emitters in the presence of metamaterials, as well as anomalous tunneling phenomena for quantum mechanical waves in artificial materials with anomalous band structures.

15:40 : Invited talk
Scattering-matrix approach to the radiative heat transfer between three arbitrary bodies
Riccardo Messina, Mauro Antezza

We calculate the heat transfer occurring in a three-body system when the three bodies are placed at three different temperatures and the system is immersed in an environment having a fourth temperature. The result is deduced in the framework of macroscopic electrodynamics and the result is expressed as a function of the classical scattering operators of each body. The approach is valid for any choice of shape and dielectric properties of the bodies. We discuss the theoretical derivation and give numerical results in the case of three parallel planar slabs of finite thickness. The interplay between surface properties and cross-interactions between the three bodies is discussed.

Coffee Break and Exhibit Inspection

Poster Session V

16:00 - 17:00

V-1 : Systematic Study of the Hydrogen-Sensing Performance of Buffered and Capped Pd and PdNi Layers for Plasmonic Applications
Nikolai Strohfeldt, Andreas Tittl, Harald Giessen

We present a systematic experimental study of the hydrogen-sensing performance of buffered and capped Pd and PdNi layers. We focus specifically on the aging behavior of the thin films and compare the magnitude of the sensor response as well as the response time for freshly evaporated and 4 and 11 day old samples. We find an optimized sample geometry consisting of a PdNi layer capped with 3 nm Pt and buffered with 10 nm of CaF2 that exhibits excellent signal stability and linear signal response in the concentration range from 0.5% to 3% hydrogen in nitrogen.

V-2 : Gold Nanocrescents for temperature sensing and local heating
Xuan Hoa Vu, Michael Levy, Thomas Barroca, Hong Nhung Tran, Emmanuel Fort

We show that gold nanocrescents can be used as efficient nano-thermosensors taking advantage of the anisotropy of their optical properties. Scattering or fluorescence correlation spectroscopy give access to the local temperature using their rotational Brownian motion. These plasmonic nanoparticules also provide an efficient local heating that can be fully characterized by this technique

V-3 : Experimental Observation on Building-up of Negative Refraction
Fangfei Li, Kai Fang, Yewen Zhang

V-4 : Temperature-agile and structure-tunable optical properties of VO2/Ag thin films
Yalin Lu

Combination of vanadium dioxides (VO2) semiconductor-to-metallic phase transition and Ags plasmonic properties actually results in very interesting optical reflection, transmission, and absorption behaviors. A double thin layer VO2/Ag presents a significant change in transmission when increasing the temperature from room temperature to over VO2s phase transition temperature of 68oC. Changing the layer thickness can also largely tune the optical properties, which could lead to a few potential applications in energy-saving and optoelectronic industries.

V-5 : All-dielectric photonic metamaterials operating beyond the homogenization regime
Khanh Do, Xavier Le Roux, Charles Caer, Delphine Morini, Laurent Vivien, Eric Cassan

Photonic metamaterials made of graded photonic crystals operating near the bandgap region are proposed for light manipulation around l=1.5microm. Proof-of-concept structures have been studied using Hamiltonian optics and FDTD simulation, fabricated, and characterized using far-field optical measurements. Experimental results are in good agreement with predictions, showing the interest of graded photonic crystals as an (ultra-low loss) alternative solution to the use of metamaterials combining dielectric and metallic materials with sub-wavelength unit cells.

V-6 : Spatial filtering and complex isofrequency contours in phononic crystals
V. Romero-Garcia, A. Cebrecos, R. Pico, V. J. Sanchez-Morcillo, K. Staliunas

Spatially modulated materials are characterized by both the temporal dispersion relation and the spatial dispersion relation. In this work we pay attention on the interpretation of the spatial filtering taking into account the presence of the evanescent waves. Extended plane wave expansion is used to calculate the isofrequency contours and the predictions are in good agreement with the Multiple Scattering simulations.

V-7 : Fano resonance in plasmonic nanocrosses
Niels Verellen, Pol Van Dorpe, Dries Vercruysse, Guy Vandenbosch, Victor Moshchalkov

Here, we show that a plasmonic nanocross geometry consisting of two or more conductively coupled nanobars, thus forming a single building-block nanocavity, can likewise support spectrally sharp Fano resonances in the visible and near infrared. Finite difference time domain calculations of absorption and scattering cross-sections, as well as charge density profiles, are used to reveal the nature of the different modes. Moreover, experimental spectra support these calculations.

V-8 : Analysis of Plasmonic-Photonic Resonances in Hybrid Metallo-Dielecric Quasicrystals
Armando Ricciardi, Alessio Crescitelli, Marco Consales, Alberto Micco, Emanuela Esposito, Vincenzo Galdi, Antonello Cutolo, Andrea Cusano

We report the evidence of plasmonic-photonic resonances in hybrid metallo-dielectric quasi-crystal nanostructures composed of aperiodically-patterned low-contrast dielectric slabs backed on a metal layer. Via both experimental and numerical studies, with specific reference to the Ammann-Beenker octagonal tiling geometry, we analyze the resonant phenomena and investigate the underlying physics. We show that, by comparison with standard periodic structures with the same filling factor, a richer spectrum of resonant modes may be excited, characterized by a distinctive plasmonic or photonic behavior. Concerning the possible applications, we explore the structure functionalization via high refractive index overlays, as well as its surface sensitivity to deposition of nanolayers of materials mimicking bio-molecular binding. Finally, in connection with the energy-harvesting field, we also present a comparative study on the application of 1-D periodic- and quasiperiodic-based nanostructures as backreflectors for thin-film solar-cell photovoltaics.

V-9 : Cloaking bending waves in thin heterogeneous plates
Sebastien Guenneau, Mohamed Farhat, Stefan Enoch, Michele Brun, Alexander Movchan

We analyse cylindrical cloaks designed to control either bending waves, or coupled in-plane pressure and shear waves in elastic plates. Whereas electromagnetic cloaks require symmetric rank 2 tensors of permittivity and permeability, our approach is based upon the introduction of an asymmetric rank 4 tensor of elasticity and a scalar density. For the special case of bending waves in thin plates, the cloak is described by a rank-2 Young tensor and a scalar density, which are both spatially varying coefficients appearing within a transformed fourth-order partial differential equation. These parameters are mimicked by concentric layers of homogeneous materials using averaging techniques. Applications could be in passive anti-earthquake systems.

V-10 : Metasurfaces: characterization and application as Partially Reflecting Surfaces for directivity enhancement of patch antennas
Riad Yahiaoui, Shah Nawaz Burokur, Valérie Vigneras, André de Lustrac

In this paper we propose to investigate a metasurface designed, fabricated and characterized for an operation at microwave frequencies. A good quantitative agreement has been observed between simulations performed using finite element method-based commercial code HFSS and experiments made using a free space setup, based on vector network analyzer and horn antennas. Our proposed metasurface has further been validated as a Partially Reflecting Surface in a Fabry-Perot cavity, with the aim to enhance the directivity of conventional microstrip patch antennas.

V-11 : A Parameter-Free Modeling Approach to Fano Resonances in Nanoscale Plasmonic Systems.
Vincenzo Giannini, Yan Francescato, Stefan Maier

When plasmonic resonances interact with sharp modes often the result is a Fanointerference processes. This happens because the plasmonic excitations are usually broader than the others resonances, and the characteristic narrow asymmetric Fano line-shape is obtained. The spectral shaping of plasmon resonances in metal nanostructures via controlled

plasmon hybridization and Fano interferences is receiving growing attention, due to the possibility of designing new materials with a controlled response to light at the nanoscale. We show that considering a plasmonic resonance in the original Fano model a simple and exact analytic relation can be found.

V-12 : Towards SP generation/amplification at telecom wavelengths using transverse-magnetic polarized semiconductor diode lasers
Daniele Costantini, Raffaele Colombelli, Adel Bousseksou, Mickael Fevrier, Beatrice Dagens, Alain Accard, Jean Decobert, Guanghua Duan, Leo Greusard, Rakchanok Rungsawang, Yannick De Wilde, Segolene Callard, Taiping Zhang

We propose and demonstrate that properly designed semiconductor laser active regions can compensate the large losses that plasmons experience in the telecom wavelength range. We show that laser devices based on tensile-strained quantum wells - hence emitting transverse magnetic polarized light - are suitable for plasmon generation via electrical injection. Experimental evidence is obtained using near-field microscopy measurements.

V-13 : Metaglass as a Non-local Effective Medium
Ralf Vogelgesang, Bruno Gompf, Igor Tsukerman, Alexandre Dmitriev

We show that a 2D metaglass made of gold nanodisks on a SiOx substrate exhibits nonlocal behavior as an effective medium. Specifically, our ellipsometric studies indicate a pronounced shift of the fundamental resonance peak as a function of the angle of incidence, even though the fully random metaglass exhibits no structural features commensurable with the resonance wavelength.

V-14 : Purcell factor of plasmonic nanoantennas
Christophe Sauvan, Jean-Paul Hugonin, Philippe Lalanne

Purcell factor is a widely used figure of merit for spontaneous emission modification in optical microcavities. It has been recently shown that the standard definition of Purcell factor does not apply to describe spontaneous emission in dissipative systems such as plasmonic antennas that consist of metallic nanostructures. We show that the definition of Purcell factor can be generalized to dissipative systems by correctly handling the losses (due to absorption and/or radiation) in the electromagnetic treatment of spontaneous emission. We apply our generalized formalism to single and coupled antennas and show that spontaneous emission near dissipative nanostructures is accurately described by a complex Purcell factor, whose imaginary part reflects the presence of dissipation in the system.

V-15 : Tamm plasmon polaritons in composite structures composed of the metal film and truncated photonic crystals
Guiqiang Du, Liyong Cui, Liwei Zhang, Haitao Jiang

Tamm plasmon polaritons (TPPs) are studied theoretically and experimentally in heterostructures and sandwiched structures with the metallic film and truncated photonic crystals. Different from conventional surface plasmon polaritons, TPPs can be realized in both the transverse electric (TE) and transverse magnetic (TM) polarizations, and they can be excited from a free space. Because of nonreciprocal electromagnetic field distributions of TPPs, the structures possess strongly nonreciprocal absorption and reflection. Moreover, two tunneling peaks or a narrow transmission band can be realized in sandwiched structures for both polarizations due to the coupling effect between two TPPs.

V-16 : Analysis of Artificial Dielectric Lens with Metallic Rectangular Chips for Terahertz Wave Band and Physical Explanation by Periodic Model
Takehito Suzuki, Tomonari Suzuki, John Young, Keisuke Takano, Hideaki Kitahara, Masanori Hangyo

Optical devices for the terahertz wave band are being developed now and require better designs. This paper analyzes an artificial dielectric lens with metallic rectangular chips for the terahertz wave band. This paper also provides an explanation of the phenomena by use of a periodic model. The periodic analysis model, extracted from the full one by assuming periodicity, confirms the phase delay as the mechanism that produces the focusing effect. Furthermore, the results of full model confirm the focusing length is longer with the larger periodicity of rectangular metal chips along the direction transverse to the propagation direction. It also indicates a nonuniform change for the periodicity along the propagation direction and the longer focusing length with narrower rectangular chips. The results of the full model analysis are qualitatively consistent with those of the periodic model one. This implies that the design for an exact size lens is possible through use of the periodic model.

V-17 : Selective emitters design and optimization for high efficiency thermophotovoltaic applications
Elyes Nefzaoui, Jérémie Drevillon, Karl Joulain

Existing thermophotovoltaic (TPV) devices have low efficiencies since the wavelength range of optimal photovoltaic (PV) conversion is very small compared to the emitter spectral range. Selective emitters are a very promising solution to this problem. We developed numerical tools to design and optimize such emitters. Some of the resulting structures composed of four layers of metals and semiconductors are presented in this paper. We also show that the usual PV devices efficiency limits (30% for crystalline silicon under solar radiation, according to Shockley-Queisser model) can be easily overcome thanks to these structures.

V-18 : Extraordinary Nonreciprocal Effects in Magnetoplasmonic Nanogratings
Lukas Halagacka, Mathias Vanwolleghem, Kamil Postava, Béatrice Dagens

The combination of nonreciprocal magneto-optical materials and strong field confinement via surface plasmon polariton coupling on metallic interfaces or nanostructures, has led to discovery of a large variety of strongly enhanced magneto-optical phenomena. We will illustrate this by two recently discovered novel phenomena. First we show how EOT when properly combined with a MO substrate leads to an anomalous switching of the magneto-optic effect. Subsequently, it is shown how also in integrated magnetoplasmonic structures enhanced nonreciprocal effects appear. Evanescent coupling to narrow subwavelength air slits in thin ferromagnetic metal films leads to an extraordinary dispersion of the fundamental Bloch modes.

V-19 : Magnetic Resonant Metalens for Far Field Subwavelength Imaging
Abdelwaheb Ourir, Geoffroy Lerosey, Fabrice Lemoult, Arnaud Tourin, Mathias Fink, Julien de Rosny

We introduce a new class of metalens: the magnetic metalens which is composed of planar periodic array of split ring resonators (SRR). The metalens effect is mainly due to magnetic coupling between SRRs. For the first time this principle has been applied to image a complex mu-shaped subwavelength structure with a resolution lower than 1/15 of a wavelength.

V-20 : Collective electronic excitations near Silver nanowire by fast electron beam
Xiuli Zhou, Ted Norris

The electronic energy loss generated by fast electron moving through the electron gas near the interface region of Silver nanowire and air is investigated. Electronic energy loss spectrum (EELS) measurement performed in scanning transmission electron microscopes provides a nanometer space resolution and the spectra peak around 3.5 eV are obtained. The theoretical analysis on the nanosphere and infinite long nanocylinder are used to understand the energy loss. The calculation results yield the energy loss probabilities when electron beam transmit perpendicularly near the interface region of the Ag nanowire. It implies the EELS originate both from the dipole and multipole surface Plasmon resonance. Finite element method simulations have shown the power flow distribution characteristics around the similar regions, which present the relation between the local density of states of photons and the experimental spectra.

V-21 : Antenna array directivity enhanced by metamaterial-based subwavelength cavity
Mondher Labidi, Belgacem Aouedi, Jamel Belhadj Tahar and Fethi Choubani

In this paper we study the influence of metamaterials on the performances of an array of 2 times 4 microstrip patch antenna operating at about 10 GHz. For this purpose, metamaterials are based on Artificial Magnetic Conductor (AMC) and on inductive and capacitive planar structures. These structures providing High Impedance Surfaces (HIS) and Partially Reflective Surfaces (PRS). Application of these structures allows to improve the performance of antenna, increase the gain and offer a good directivity.

V-22 : Photogenerated current enhanced by surface plasmon resonance in metal grating
Dong-Jin Lee, Bo-Soon Kim, Seung-Gol Lee, Se-Geun Park, El-Hang Lee, Beom-Hoan O

Photodetection using surface plasmon polariton in metal grating is discussed at visible range. The device consists of amorphous silicon on metal grating forming a Schottky contact thereon and supporting surface plasmon resonance that is strongly confined and localized to the metal grating.

V-23 : Periodic anti-reflective layer design for the thin film solar cell using the topology optimization procedure

H. Soh, Jeonghoon Yoo

This study suggests a systematic design approach of an anti-reflective layer for the purpose of improved wave absorbing efficiency using the topology optimization procedure. Starting from the pyramid textured initial structure, multi-layered structures composed of silicon and transparent conductive oxide are introduced for a specific wavelength between 500-800nm.

V-24 : Bianisotropic superstrate effect on rectangular microstrip patch antenna parameters
C. Zebiri, F. Benabdelaziz, M. Lashab

In this paper, the effects of the superstrate chirality on the resonant frequency and bandwidth of rectangular microstrip patch in a substrate-superstrate configuration are investigated. The problem is rigorously formulated via integral equation. This equation is solved using Galerkins moment method the complex resonance frequencies for TM01 mode are studied with sinusoidal basis functions. The obtained theoretical results show that the decrease is more important for high permittivity loading and negative chirality element.

V-25 : Main and higher mode absorption dependencies of open semiconductor plasma waveguide on the total hole concentration and percentage of heavy holes
Arturas Bubnelis, Liudmila Nickelson

We present the phase and attenuation constants of open magnetoactive p-Ge rod waveguides. Dispersion characteristics of p-Ge with two component hole charge carriers waveguide are calculated when the ratio of heavy holes concentration in the material is equal to 15%, and 85% of the total free carrier concentration. Our algorithm allows analyzing the very high waveguide losses. There are the degeneration and the transformation of higher hybrid modes at some heavy holes concentrations. The waveguide broad bandwidth can be considerably extended due to the fact that the losses of the higher modes are considerably larger in comparisons to the main mode loss at the certain heavy holes concentration.

V-26 : Liquid-Crystals-Plasmonics (LCP)-– Route to New Electro- and Nonlinear Optical Materials
Iam Choon Khoo, Yi Ma, Yanghui Zhao, Tony Huang

We present our recent work on liquid-crystals-plasmonic materials and nano-structures that combine the unique physical and optical properties of both materials to enable a new generation of reflective, transmissive, modulation and switching elements and devices.

17:00 - 18:00 ***Emeraude***

9A: Allan Boardman symposium on Nonlinear waves and Metamaterials II

Organized by: Nikolay Zheludev and Vladimir Shalaev

Chaired by: Nikolay Zheludev and Vladimir Shalaev

17:00 : Invited talk
Spatial optical solitons
Y. Kivshar

I will review some recent advances in the physics optical spatial solitons and nonlinear localized modes as well as their links to the modern topics of photonics such as the study of arrays of plasmonic particles or lattices of nonlinear split-ring resonators. I will specifically emphasize the great contribution of Allan Boardman into the field of optical solitons and nonlinear guided waves.

17:20 : Invited talk
Stopped Light in Metamaterials
O. Hess, K. Tsakmakidis

We present an overview of recent advances in the field of slow- and stopped-light in metamaterial and plasmonic waveguides. We elucidate the mechanisms by which these configurations can enable complete stopping of light and we show how, by using gain, dissipative losses can be overcome in the slow- and stopped-light regimes.

17:**40 :** Invited talk
Dissipative loss in metamaterials and plasmonics
P. Tassin, Thomas Koschny, Maria Kafesaki, Costas M. Soukoulis

We present a comparison of different conductors and their resulting dissipative loss when used in metamaterials and plasmonic systems. For resonant metamaterials, we derive a figure-of-merit for the performance of conducting materials, and we apply it to metals, conducting oxides, high-Tc superconductors and graphene. For metamaterials, we discuss the dissipative loss of surface plasmon polaritons on graphene.

17:00 - 18:40 ***B310***

9B: Plasmonics and nanophotonics VIII

Chaired by: Hala J. El-Khozondar

17:**00 :** Invited talk
Dynamic Tuning and Symmetry Lowering of Fano Resonance in Plasmonic Nanostructure
Yonghao Cui, Jianhong Zhou, Venkata Tamma, Won Park

We present dynamic tuning and symmetry lowering of Fano resonance in gold heptamers embedded in flexible polydimethylsiloxane (PDMS) membrane. Under mechanical stress, the Fano resonance exhibited distinct behavior for different polarizations. Also, the symmetry lowering changes the nature of resonance, making optically inactive mode into optically active mode. Detailed group theoretical analysis is presented.

17:**20 : Tunable Plasmonic Resonance in Core-Shell Nano-Particles**
Dean Evans, Igor Pinkevych, Tim Sluckin, Augustine Urbas, Victor Reshetnyak

We discuss different approaches to describe the effective dielectric function of composite heterogeneous materials and ways to control their plasmonic frequency. We present a theoretical modelling for the effective dielectric function and plasmonic resonance control in core-shell type metallic nano-particles.

17:**40 : Terahertz magnetic plasmon propagation through a chain of planar split-ring resonators**
Withawat Withayachumnankul, Christophe Fumeaux, Derek Abbott

A subwavelength terahertz waveguide is presented in this article. The waveguide is made by cascading multiple planar split-ring resonators in one dimension. The structure can support magnetic plasmon propagation via induced oscillating currents along the chain. The simulation results show that the structure effectively transports energy at terahertz frequencies. A realization of this terahertz waveguide will lead to a wide range of applications, in particular on-chip terahertz communication channels.

18:**00 : Novel physics in photonic crystal nanolasers : Dynamics and Coherence**
A. Beveratos, D. Elvira, X. Hachair, R. Braive, G. Beaudoin, I. Robert-Philip, I. Sagnes, V. B. Verma, S. W. Nam, B. Baek, E. A. Dauler, G. L. Lippi, M. J. Stevens, I. Abram

We investigate the optical response of nanolasers of diffraction-limited volumes operating at 300 K and 1,55 mum, in terms of coherence and dynamics. In such lasers with ill-defined threshold, we propose and demonstrate that it is possible to distinguish between spontaneous and stimulated operation can be made on the grounds of the dynamical laser response. We also demonstrate that light produced from such lasers is not fully coherent even four times above threshold, due to the small number of photons and emitters.

18:**20 : Explicit formulas for surface plasmons on a smooth curved interfaceMathematics,**
Maria V. Perel, Dmitry Yu. Zaika

Propagation of surface plasmons along an arbitrary smooth interface between two media is studied asymptotically in the short-wavelength limit. The leading order term of the electromagnetic field of a surface plasmon differs only by a factor from its EM field in the case of a planar interface. Results enable one to control the enhancement of the surface plasmon field and its spatial localization by altering the interface geometry.

17:00 - 18:40 ***B312***

9C: Plasmonic sensing II

Organized by: Harald Giessen and Na Liu

Chaired by: Harald Giessen and Na Liu

17:00 : Invited talk
On the usage of Fano resonances for sensing
Olivier Martin, Benjamin Gallinet

Fano resonances in plasmonic metamaterials provide unique features that can be used for sensing with unprecedented sensitivity. However, the best conditions for sensing are not necessarily apparent in the far-field response of such structure. In this contribution, we will discuss how Fano resonances can be put to their best use for sensing and show how the largest figure of merit can be obtained.

17:20 : Arrays of doped and un-doped semiconductors for sensor applications
Thierry Taliercio, Vilianne N'Tsame Guilengui, Eric Tournié

This theoretical work propose to use a lamellar grating of doped semiconductors as the active region of a nanoplasmonic biosensing device. Working with highly doped semiconductors instead of a metal allows controlling the value of the plasma frequency. It is possible to reach the plasma frequency close to the range of detection of the sensor to improve its sensitivity. It is possible to reach a red-shift of the plamsonic resonance of 10.2 nm for a 10-2 refractive index unit (RIU) increase.

17:40 : Invited talk
Fano-resonant asymmetric metamaterials for ultra-sensitive spectroscopy and identification of molecular monolayers
G. Shvets, C. Wu, A. B. Khanikaev, K. Alici, N. Arju, R. Adato, A. A. Yanik, H. Altug

Engineered optical metamaterials present a unique platform for biosensing applications owing to their ability to confine light to nanoscale regions and to their spectral selectivity. Infrared plasmonic metamaterials are especially attractive because their resonant response can be accurately tuned to that of the vibrational modes of the target bio-molecules. Here we introduce a novel infrared plasmonic surface based on Fano-resonant asymmetric metamaterial (FRAMM) exhibiting sharp resonances caused by the interference between sub-radiant and super-radiant plasmonic resonances. Owing to metamaterials asymmetry, the frequency of the sub-radiant resonance can be precisely determined and matched to the molecules vibrational fingerprints. A multi-pixel array of FRAMMs is used as a platform for multi-spectral biosensing of nanometer-scale monolayers of recognition proteins and their surface orientation, as well as for detecting chemical binding of target antibodies to recognition proteins.

18:00 : Invited talk
Improving refractive index sensing by tailoring the lineshape and measuring the phase of plasmonic resonances
Pol Van Dorpe, Niels Verellen, Kristof Lodewijks, Jian Ye, Liesbet Lagae

Plasmon resonances are known to exhibit a large sensitivity to the local refractive index. In order to establish an accurate measurement of the resonance wavelength position, it is beneficial if the resonance linewidth is narrow. We have been tailoring the lineshape of plasmonic resonances using symmetry breaking and the excitation of Fano resonances and by measuring the phase of the resonances. Substantial improvements are reported.

18:20 : Hole-Mask Colloidal Nanolithography for Large-Area Low-Cost Metamaterials and Resonant SEIRA Substrates
Jun Zhao, Stefano Cataldo, Frank Neubrech, Bettina Frank, Chunjie Zhang, Paul Braun, Harald Giessen

We use low-cost hole-mask colloidal nanolithography to manufacture large-area resonant split-ring metamaterials, and measure their infrared optical properties. This novel substrate is applied for antenna-enhanced SEIRA measurement using ODT and deuterated ODT, which demonstrates easy adjustability of our material to the vibrational modes.

17:00 - 18:40 ***Thvenin***

9D: Negative group delay (NGD) devices

Organized by: Blaise Ravelo and Mohammad Mojahedi

Chaired by: Blaise Ravelo and Mohammad Mojahedi

17:00 : Invited talk
Gain compensated symmetric loaded transmission line exhibiting bidirectional negative group delay
Greg Bridges, Miodrag Kandic

A microwave circuit capable of bidirectional lossless negative group delay signal propagation is presented. The circuit comprises two symmetric resonator loaded transmission lines with active gain compensation and coupled through power combiners. We demonstrate the circuit is conditionally stable and capable of transmitting a finite bandwidth pulse in both directions.

17:20 : Invited talk
Dispersion Engineering: From Negative Index to Negative Group Delay
Mo Mojahedi

Principles of Dispersion Engineering in terms of control and manipulation of the signs associated with various delay terms (phase delay, group delay, and group delay dispersion) are formulated. The application of Dispersion Engineering paradigm in design of systems with negative index of refraction or negative group velocities is discussed.

17:40 : Invited talk
Neutralization of RC- and LC-disturbances with NGD effects
Blaise Ravelo

This letter introduces a neutralization technique of degradations caused by RC and LC passive effects in the microelectronic systems. It is based on the use of the negative group delay (NGD) circuits. For the RC-effect, a 1st order NGD cell operating in base band is used. To cancel the RLC effects, a 2nd order NGD cell was proposed. The feasibility of the technique is confirmed by simulations and experimentations with circuits implemented in hybrid technology.

18:00 : Invited talk
Experimental Measurement of Reverse Doppler Effect with Tunable Composite Right/Left Handed Transmission Line
Zhuang Li, Ye Wen Zhang

The reverse Doppler Effect only is observed in metamaterial with both negative permittivity and negative permeability. A new way to observe reverse Doppler Effect using a simple circuit configuration is presented. The experimental results show good agreement with the theoretical prediction.

18:20 : Invited talk
Microwave NGD circuit using LNA
Blaise Ravelo

In this letter, a negative group delay (NGD) circuit topology comprised of a low noise amplifier associated with RLC-series resonant network operating at RF/microwave frequencies is investigated. The theoretical approach illustrating the functioning of the NGD circuit proposed is established by considering the amplifier S-parameters. Synthesis relations enabling to choose the NGD device parameters according to the desired NGD value and S-parameters are also established. To demonstrate the relevance of the theoretic concept, a microwave device exhibiting NGD function at around 1.25 GHz was designed and tested. The major benefit of the NGD device proposed is that it is capable to exhibit positive transmission gain and faculty of biasing and matching in the NGD bandwidth.

17:00 - 18:40 ***Rubis***

9E: THz and infrared plasmonics for microscopy

Organized by: Tahsin Akalin

Chaired by: Tahsin Akalin

17:00 : Invited talk
Antenna-based infrared nanospectroscopy
R. Hillenbrand

We demonstrate nanoscale resolved IR imaging and spectroscopy by recording the elastically scattered light from the tip of an atomic force microscope tip acting as infrared antennas. Applications such as electronic and photonic device characterization will be presented.

17:20 : Invited talk
Terahertz Near Field Microscopy
Tahsin Akalin

THz near field microscopy is usually based on the scattering of free space wave by a metallic tip. An alternative to this is based on the use of guided wave on a single metallic strip. The planar Goubau line highly confines the THz wave and brings it to the sample. The resolution is highly subwavelength in different topologies.

17:40 : Invited talk
Ultrathin electromagnetic absorbers for mm- and submm-waves: from fundamentals towards applications in bolometric sensors
Sergey Kuznetsov, Andrey Arzhannikov, Manfred Thumm, Andrey Paulish, Alexander Gelfand, Victor Fedorinin, Miguel Beruete, Miguel Navarro-Cía, Mario Sorolla

We overview the results of theoretical and on-going experimental investigations of electrically ultra-thin metamaterial-inspired absorbers operating in the range of millimetre and submillimetre waves and intended for integration with spectrally-selective bolometric devices. The attainability of values up to 180 for the ratio of the free-space wavelength to the absorbers thickness is experimentally demonstrated. The first prototypes of imaging and spectrophotometric detectors utilizing metamaterial-based radiation-sensitive pixels are presented.

18:00 : Invited talk
Surface plasmon waves in near-field THz microscopy and local THz spectroscopy
Oleg Mitrofanov

Surface plasmon waves can provide a solution for sub-wavelength resolution imaging and for local spectroscopy at Terahertz (THz) frequencies. Although the surface waves are non-radiative in nature, they can be excited by free-space propagating beams on metallic discontinuities and by tightly focused beams. Using the sub-wavelength aperture near-field microscopy we investigate excitation and guiding of THz surface plasmon waves for applications in THz microscopy and local spectroscopy.

18:00 : Invited talk
Chip–Based Plasmonic NanoAntennas and Circuits
Hatice Altug, Ronen Adato

We demonstrate an analogue to the radio frequency (RF) monopole antenna, realizable within the constraints of ubiquitous planar chip-based fabrication. Our planar design is unique in that it circumvents a major obstacle preventing the straightforward scaling of the antenna size down to reduce its operational wavelength namely that the semi-infinite ground plane present in the RF design, requires a three dimensional structure. Here, we show that a long nanorod oriented perpendicular to the excited antenna arm functions as a reflector, providing a means with which to realize a monopole antenna element that is compatible with planar chip-based fabrication and therefore large-scale integration.

17:00 - 18:20 ***Saphir***

9F: Metamaterials for diffractive components II

Organized by: Philippe Lalanne

Chaired by: Philippe Lalanne

17:00 : Invited talk
Metamaterials and the New Limits of Subwavelength Focusing
Reuven Gordon

This talk will outline new limits for subwavelength focusing when using metamaterials. The talk will also discuss approaches to achieve subwavelength focusing in the visible and new electron energy loss spectroscopy approaches to probe the local response of metamaterials in the visible-IR regime.

17:20 : Multi-wavelength holograms from plasmonic metamaterials
B. Walther, C. Rockstuhl, C. Helgert, T. Pertsch

The dispersive nature of plasmonic metamaterials and their ability to tailor the optical response renders them promising candidates for versatile optical elements. Here we present new approaches how optical metamaterials can be used to achieve complex diffractive elements, i.e. holograms. Besides the theoretical and numerical exploration of devoted encoding schemes for these elements, we present experimental results concerning the fabrication and the characterization of metamaterial holograms. For the first time, we demonstrate metamaterial holograms operating simultaneously at different wavelengths.

17:40 : Invited talk
Probing the generalized laws of reflection and refraction with plasmonic metasurfaces
Alexander Kildishev, Xingjie Ni, Naresh Emani, Alexandra Boltasseva, Vladimir Shalaev

The control of phase with thin metamaterial layers (metasurfaces) can play a fundamental role in generating synthetic scattering diagrams of macroscopic objects. Thin metasurfaces can introduce additional spatially non-uniform phase in the incoming wave, thereby producing non-conventional reflection and refraction of light waves. We discuss the generalized laws of reflection and refraction and overview the experimental proof-of-concept studies performed first at Harvard at a wavelength of 8 microm and then at Purdue for a broad, near-IR range.

18:00 : Invited talk
Transformational Plasmonics
Stefan Enoch

Transformational optics is shown to enhance the control of the electromagnetic wave trajectories within metamaterials with unconventional functionalities such as a beam splitter, a toroidal carpet etc., all of which are specially designed for surface plasmon polaritons (SPPs) propagating on a metal plate.

17:00 - 18:40 ***Jade***

9G: Plasmonics and nanophotonics for sensing, imaging, and spectroscopy II

Organized by: Sang-Hyun Oh and Alexandre Brolo

Chaired by: Sang-Hyun Oh and Alexandre Brolo

17:00 : Invited talk
Evaluation of SERS labeling of CD20 on CLL cells using optical microscopy and fluorescence flow cytometry
Christina MacLaughlin, Edward Parker, Chen Wang, Gilbert Walker

Aims: To evaluate the chemical design and ability of surface-enhanced Raman scattering (SERS) gold nanoprobes to recognize cell surface receptors, probes are targeted to CD20 on cells using rituximab. Materials amp Methods: SERS nanoparticles were prepared by adsorbing a Raman-active dye onto the surface of Au nanoparticles of different shapes, coating the particles with 5kDa polyethylene glycol (PEG) and conjugating rituximab to functional groups on PEG.

Targeting of CLL cells by the NPs was evaluated by dark field microscopy, Raman spectroscopy, and flow cytometry with competitive binding and fluorescence detection. Results amp Conclusion: Rituximab-SERS Au NPs selectively labeled CD20 molecules on the surface of patient derived B lymphocytes, as evaluated using multiple detection methods. Evidence of CD20 clustering was observed.

17:20 : Electromagnetic analysis of super-resolution through a microlens
Baile Zhang, G. Barbastathis

Super-resolution in imaging through a transparent microlens has attracted lots of attention because of its exciting and promising experimental results with remarkable resolution improvement. However, the underlying theoretical foundation of the super-resolution still is not well understood. Here we use vectorial electromagnetic analysis to calculate the resolution through a microlens and find that traditional electromagnetic imaging theory does not lead to the experimentally verified high-resolution record in literature. Therefore there must be some unknown mechanism behind the reported phenomena that hasn't been fully discovered.

17:40 : Single-particle plasmon resonance nanospectroscopy of Mott-transition in correlated electron materials
D. Y. Lei, K. Appavoo, Y. Sonnefraud, R. F. Haglund Jr., S. A. Maier

A novel spectroscopic technique based on single-particle plasmon resonance is developed and used to study the metal-insulator phase transition of vanadium dioxide (VO2) - a prototypical correlated insulator. Two characteristics responsible for the Mott transition are observed indirectly by monitoring the plasmon response variation of individual Au nanoparticles deposited on a thin VO2 film when thermally cycling through the metal-to-insulator transition of VO2. This nanospectroscopy technique opens promising possibilities for studying the phase transition in a general class of correlated electron materials with simultaneous nanoscale spatial resolution and ultrasensitive spectroscopic characterization.

18:00 : Invited talk
Negative Index of Refraction at Ultraviolet Frequencies
H. Lezec, T. Xu, M. Abashin, A. Agrawal, K. Chau

In a left-handed medium (LHM), characterized by simultaneously negative electric and magnetic polarization responses, electromagnetic waves propagate with opposite directions of energy flow and phase velocity [1]. The ability of LHMs to sustain backwards waves leads to counter-intuitive phenomena such as negative phase refraction, where phase-fronts are refracted to the same side of the surface normal upon transmission of an electromagnetic plane wave incident from free space. In the ideal case of an isotropic LHM, the angles of the incident and transmitted wave-vectors obey Snells law, and the medium can be described by a constant, negative, index of refraction n. Since wave-vector and Poynting vector are strictly anti-parallel in an isotropic LHM, energy is refracted at the same angle. In particular, a low-loss, isotropic LHM with n=-1 could be used to build a far-field flat lens, with superlens potential for non-diffraction-limited imaging beyond the near-field region.

18:20 : Invited talk
Plasmonic hot spot and pattern generation for sensor applications
Byoungho Lee, Hwi Kim, Il-Min Lee, Kyoung-Youm Kim

Plasmonic field synthesis is a fundamental technology that enables to realize various two-dimensional surface plasmon field patterns and light beaming useful for practical applications as well as fundamental research. There are considerable researches on plasmonic field synthesis and control such as surface Plasmon (SP) hot spots, SP vortices, SP Fourier optics, and SP transformation optics. Recently, advanced plasmonic field synthesis such as active control of SP fields, broadband SP field generation, SP Airy beams, and SP transformation optics are actively researched.

17:00 - 18:40 ***Grenat***

9H: Plasmonic Nanodevices III

Organized by: Haifeng Wang and Cheng-Wei Qiu

Chaired by: Haifeng Wang and Cheng-Wei Qiu

17:00 : Invited talk
Chiral Surface Plasmon Polaritons on Metallic Nanowires
Hongxing Xu

The interaction of chiral micro- and nano-objects with circular polarized light is a topic of fundamental interest in various scientific fields. Since surface plasmon polaritons (SPPs) can overcome the diffraction limit of light, enabling the manipulation of light at the nanometer scale, three dimensional chiral plasmonic nanostructures are a topic of intensive current interest. Here, we show that chiral SPPs can be generated by linearly polarized light incident at the end of a nanowire with cylindrical symmetry, whose structure is not chiral at all, exciting a coherent superposition of three specific nanowire waveguide modes. Rather, the chirality is accomplished by the superposition of low-order surface plasmon modes (m = 0 and m = plusmn1) with a $\lambda/2$ phase delay excited by linearly polarized light at one end of the nanowire. With quantum-dot-based fluorescence imaging, the chiral SPPs can be clearly observed on the nanowires. Interestingly, the chirality of the SPPs is still preserved in the emitted photons at the distal end of the nanowire, which makes a nanowire as a broad bandwidth subwavelength $\lambda/4$ converter of the linearly polarized input light. This discovery may create new opportunities for the design of nanoscale integrated photonic components, and provides a subwavelength circular polarized light source that may be useful as a local probe of enantiomeric molecules and other reduced-symmetry nanoscale systems.

17:20 : Invited talk
A self-powered nanosensor based on semiconducting nanowires
Xianying Wang, S.F. Xie, J.H. Yang

We report the fabrication of the first generation batteryless sensors that use one-dimensional semiconducting nanowires. These nanosensors take advantage of a unique interaction mechanism between chemical species and semiconductor nanowire surfaces that induce an electric potential between the two ends of nanowires or between the exposed and unexposed nanowires. The nanosensors have fast response time (better than 1s), relatively high sensitivity and don't require external power.

17:40 : Invited talk
Plasmonic nano-antenna for nanolithography and high density data storage
Xianfan Xu

18:00 : Invited talk
The Near Field Characteristics of the Focused Field Embedded in a InSb Super Resolution Layer
P.H. Urbach, A.C. Assafrao, S.F. Pereira

We present a rigorous numerical model to study the characteristics of the focused spot embedded in a Super Resolution Near Field (Super-RENS) stack layer. The model is based on experimental evidences of the super resolution layer state change. The results indicate that a focused spot beyond the diffraction limit can be achieved in the near field domain.

18:20 : Heating in plasmonic nanoantennas imaged by digital heterodyne holography
Sarah Suck, Ariadna Martinez-Marrades, Stephane Collin, Nathalie Bardou, Yannick De Wilde, Gilles Tessier

We report a method based on heterodyne numerical holography associated to photothermal excitation for full field imaging of heating in plasmonic systems. A modulated pump laser (l=532 nm) heats the nanostructures, creating local refractive index changes. This modulation is detected using a probe and a local oscillator beam (l=785 nm), frequency-shifted to create a hologram beating at low frequency. The possibilities of this non-contact full field imaging method, which delivers signals directly proportional to the local temperature increase induced by dissipative phenomena, will be illustrated on nanodisc chains and rod pairs.

Sunday 22nd April, 2012

08:30 - 10:30 ***Thévenin***

10A: Metamaterials and negative index materials VI

Chaired by: Christian Brosseau

08:30 : Mutual Coupling Reduction for MIMO antennas using MNG metamaterial substrate
Belgacem Aouadi, Mondher Labidi and Jamel Belhadj Tahar

Next-generation wireless systems incorporate multiple-input multiple-output (MIMO) techniques to fructify their performance goals. In this study, a Negative metamaterial (MNG) substrate is developed in order to efficiently suppress the electromagnetic coupling between the proposed antennas at about 21.32 GHz.

08:50 : Wave propagation in lossy MTMs surrounded by linear and nonlinear media with arbitrary nonlinearity
Hala El-Khozondar, Z. I. Al-Sahhar, M. M. Shabat

The dispersion relation in a system consists of a lossy metamaterials (MTMs) film surrounded by a linear substrate and a nonlinear cladding with an arbitrary nonlinearity is derived. The surface plasmonic (SP) wave at the interfaces between metamaterials (MTMs) and the nonlinear cover is recovered by taking certain limits. Results are presented by plotting the SP frequency as a function of the nonlinearity at chosen damping factors. Both the real and imaginary parts are studied. For comparison, the imaginary part is set to zero and curves are reproduced.

09:10 : Bandpass waveguide filter with multispurious rejection
Ali Molaei, Saeed Fallahzadeh, Mina Nazari

In this paper, spurious passband suppression in waveguide bandpass filter by means of split ring resonators (SRRs) is proposed. The bandpass waveguide filter is designed using complementary split ring resonators (CSRRs). Then, the split ring resonator (SRR) arrays are loaded in the waveguide to reject multiple spurious passbands. Simulation results show that for a 3rd order bandpass filter, a rejection level exceeding 35dB is obtained in the first three spurious passbands, while the desired passband is maintained unaltered.

09:30 : Below/Above Cutoff Dual Metamaterial Band in Cylindrical Media
Seyyed Ali Hassani Gangaraj, Majid Tayarani, Ali Abdolali

In this paper we considered a magnetic anisotropic media in cylindrical coordinate with scalar permittivity and diagonal tensor permeability. A PEC (Perfect Electric Conductor) boundary condition assumed at the radius a. We solved the Maxwell equations inside the medium for radius less than a. Actually this structure is an anisotropic cylindrical waveguide. Then, we extracted the characteristic equations for dominant TE modes for such a structure. By focusing on this equation we achieved several analytical conditions for different situations of wave propagation such as left hand, right hand or even evanescent mode depending on different signs of cylindrical permeability components. After that, we concentrated our attention on left hand property and we have achieved below/above cutoff dual metamaterial band in cylindrical waveguide. Negative effective permittivity and permeability are obtained.

09:50 : Sub-wavelength modes in uniaxial metamaterial clad fibers
Shaghik Atakaramians, Alexander Argyros, Simon Fleming, Boris Kuhlmey

We discuss the conditions in which guided and plasmonic modes exist in air-core fibers with anisotropic, uniaxal metamaterial cladding. We illustrate that these hollow-core fibers can offer single/multi-mode sub-wavelength guidance, with diameters more than ten times smaller than the operating wavelengths.

10:10 : Spontaneous Radiation in Hyperbolic Media
Ivan Iorsh, Alexander Poddubny, Pavel Belov, Yuri Kivshar

We study the spontaneous emission of a dipole emitter embedded into a hyperbolic media. It has been recently reported that the density of states in the hyperbolic medium diverges and thus the spontaneous emission rate of a point dipole

will diverge as well. In our work we show how the accounting for the finite dipole size lifts this divergence and obtain rigorous analytical expressions for the emission rate of the finite size emitter. We also study a spontaneous emission rate of the point dipole placed in metal-dielectric metamaterial which in the effective medium approach can be described as a hyperbolic media. We show that effective medium approach may greatly understimate the Purcell factor in such structures due to the presence of effective nonlocality.

08:30 - 10:30 ***B310***

10B: Plasmonics and nanophotonics IX

Chaired by: Javier Aizpurua

08:30 : Plasmon-assisted enhancement of the magnetic nonlinear-optical response in nickel nanorods
Victor Krutyanskiy, Elena Gan'shina, Irina Kolmychek, Sergey Lobanov, Tatyana Murzina, Anatoly Murphy, Robert Pollard, Andrey Stashkevich, Anatoly Zayats

We have studied experimentally and numerically linear and nonlinear magnetooptical properties in the arrays of aligned Ni nanorods. We demonstrate that the spectra of magneto-optical and nonlinear magneto-optical Kerr effects are found to be amplified in the vicinity of the resonant excitation of plasmonic modes related to Ni nanorods. The observed high sensitivity of magneto-optics and nonlinear magneto-optics to plasmonic properties maybe advantageous for diagnostics of plasmonic excitation in magnetic nanostructures.

08:50 : Invited talk
Plasmonic Behavior in Symmetry Broken Nanostructures
X. Zhu, Z. Fang, J. LI, F. Lin

Surface plasmon polariton (SPP) as the collective vibration of electro-magnetic field at the interface between metallic and dielectric media, has unique properties in the propagation, focusing and waveguiding, it has found applications in nano-optics and nano-phononic devices. In this contribution, we will show our latest results of Plasmonics properties in symmetry broken nanostructures, such as the subwavelength focusing of SPP in unsymmetrical metallic rings, and the Fano resonance in Ag nanodisks. Combing Scanning Near-field Optical Microscopy (SNOM) and spectroscopy technique, we characterized such unique properties and numerical simulations. The other properties of SPP will be also discussed, such as the conversion and detection of plasmon polariton (SPP), plasmonic propagation, field enhancement, coupling between devices, as well as the design of new plasmonic nanostructures and their characterization.

09:10 : Control of surface plasmon polaritons via magnetic field
Andrey Kalish, Vladimir Belotelov, Stepan Andreev, Vladimir Tarakanov, Anatoly Zvezdin

The properties of the surface plasmon polaritons in plasmonic structures of different types containing magnetooptical materials are investigated. It is shown that magnezation influences on the plasmon properties such as the propagation constant, the field distribution and the polarization state, leading to the possibility of efficient control of plasmons by magnetic field.

09:30 : Nanoplasmonics At The Last Nanometer
Joel Yang, Huigao Duan, Antonio Fernandez-Dominguez, Michel Bosman, Stefan Maier

We demonstrate a unique combination of capabilities involving (1) electron-beam lithography at sub-5-nm length scales on ultrathin membranes, (2) electron energy-loss spectroscopy (EELS) down to 0.3 eV, and (3) full electromagnetic simulation of plasmon excitation by electrons to uncover the phenomena occurring when two nanoprisms are brought closer than 1nm. The smallest dimensions of structures as investigated by EELS and imaged in a transmission electron microscope were of a 0.5 nm gap and a 3 nm wide conductive bridge between these nanoprisms. The good agreement between our experimental results, electromagnetic calculations, and LC circuit models evidences the gradual evolution of the nanoprisms plasmonic resonances towards the quantum coupling regime.

09:50 : Ultrafast laser pulses and plasmonic metamaterials: from second harmonic generation to nanojets
Ventsislav Valev, Victor Moshchalkov, Thierry Verbiest

Just as natural materials derive their properties from those of their constituent atoms and molecules, artificial metama-

terials derive their properties from those of their nanoengineered unit cells. We have developed novel methods for visualizing the localized field-enhancements of plasmonic metamaterials unit cells. Based on the use of ultrafast laser pulses, these methods combine user-friendliness and high resolution.

10:10 : Nano-Signature of Surface Charge Spatial Distribution of Metal Nanoparticles Irradiated Off-Resonance
Xuan Zhou, Claire Deeb, Davy Gérard, Alexandre Bouhelier, Prashant Jain, Jérôme Plain, Soppera Olivier, Pascal Royer, Gary Wiederrecht, Renaud Bachelot

We report on the imaging of localized electric field on a metal/dielectric interface of gold nanorods irradiated out of their resonance. The surface polarization charges caused by the discontinuity of electric field at metal/dielectric surface provide a tiny local field enhancement. At some precise positions on the nanorod surface, the resulting effective local field intensity becomes high enough to overcome the threshold dose of a photo-sensitive formulation, and hence the polymerization process is initiated. We finally end up with a cross-linked 3D polymer structure that is actually molding the spatial distribution of the surface charges held on the metal/dielectric interface.

08:30 - 10:10 ***B312***

10C: Photonic crystals III

Chaired by: Susumu Noda

08:30 : Optical control of the quality factor of photonic crystal nanocavities for cavity quantum electrodynamics
Milo Swinkels, Chaoyuan Jin, Robert Johne, Thang Hoang, Leonardo Midolo, Peterus van Veldhoven, Andrea Fiore

We demonstrate the quality-factor (Q-factor) tuning of a photonic crystal nanocavity by thermo-optically bringing it into resonance with a different nearby cavity. Q-tuning of up to a factor 2 has been observed. The spontaneous emission rate of quantum dots in the cavity has also been measured, a lifetime depending on the spectral alignment of the two cavities has been found.

08:50 : Rigorous Analysis of Line Source Radiation in Photonic Crystals
Vakhtang Jandieri, Kiyotoshi Yasumoto

A novel formulation of radiation from a localized line source placed in photonic crystals composed of periodic arrays of circular cylinders is proposed. The method employs the spectral domain approach. The spectral response of the photonic crystals to the line source excitation is efficiently calculated using the Lattice Sums technique, T-matrix approach and the generalized reflection and transmission matrices. Radiated field in the far-zone is numerically studied. The physical insight into how the radiation pattern is modified in the presence of the photonic crystals is given based on the theoretical studies.

09:10 : Dispersion engineering for photonic crystal based nanophotonic devices
Maxence Hofman, Xavier Melique, Didier Lippens, Olivier Vanbesien, Geoffroy Scherrer, Benoit Cluzel, Frédérique de Fornel, Muamer Kadic, Wojcieh Smigaj, Sébastien Guenneau, Boris Gralak

In this communication, we report on the design, the fabrication and the near field optical microscopy of (i) a Negative Index Material (NIM) flat lens, (ii) a GRadient INdex (GRIN) slab and (iii) a two-dimensional cloaking device. They were all fabricated on the basis of a InP-based photonic crystal technological platform and show the possibility of sub-wavelength focusing by NIM or GRIN principles and wave reconstruction for a reflector cloak through transformational optics.

09:30 : On the properties of bulk plasmon-polariton modes in layered superlattices
A. Bruno-Alfonso, E. Reyes-Gómez, Solange Cavalcanti, Luiz Oliveira

We have theoretically studied the field intensities of both transversal and longitudinal components of an electromagnetic field incident upon a one-dimensional layered system that alternates air and a metamaterial. Special attention is devoted to frequencies around the electric and magnetic bulk plasmons. It is shown that plasmon polaritons nearby such frequencies display field profiles concentrated in the metamaterial, where the field component parallel to the stacking direction is essentially uniform and dominates the perpendicular one. The dominant role played by the longitudinal field component in the opening of the bulk plasmon-polariton gap near the resonant plasmon frequency is discussed. Above

this gap, in the center of the Brillouin zone, the mode is plasmon-like, whereas below the plasmon-polariton gap it is essentially a photonic mode.

09:50 : Electrostatic tuning of double-layer photonic crystal nanocavities
Leonardo Midolo, Thang Hoang, Sangnyung Yoon, Peterus van Veldhoven, Richard Noetzel, Lian Li, Edmund Linfield, Matthias Lermer, Sven Hoefling, Andrea Fiore

We present the fabrication and characterization of tunable photonic crystal cavities on double semiconductor layers using an electrostatic nano electro mechanical system (NEMS). We demonstrate large (10nm) tuning of cavity modes on InP. We also report about a novel device design based on vertically coupled one-dimensional (1D) photonic crystal nanobeams on GaAs.

08:30 - 09:50 ***Emeraude***

10D: Near-field optics and nano-optics I

Chaired by: Christophe Craeye

08:30 : Optical control of a sub-diffraction light grid for surface imaging beyond the diffraction limit
Anne Sentenac, Jules Girard, Geoffroy Scherrer, Andrea Cattoni, A. Haghiri-Gosnet, Anne Talneau, Benoit Cluzel, Frederique de Fornel, Roland Ayuk, Ugo Giovannini, Emeric Mudry

We create experimentally at the surface of a nanostructured cover-slip, a periodic light pattern, with a period smaller than one third of the illumination wavelength (l=633 nm), which can be translated and rotated just by changing the illumination angle. We show that this high frequency light grid can be used in a far-field optical microscope to provide images well beyond the diffraction limit, comparable to that obtained with a near-field microscope.

08:50 : Invited talk
Electron energy loss spectroscopy on photonic metamaterials
Stefan Linden, Felix von Cube, Stephan Irsen

Scanning transmission electron microscopy in combination with electron energy loss spectroscopy is a powerful method for the characterization of the spatial and spectral distribution of plasmonic modes in photonic metamaterials. Comparison of the EELS maps of a split-ring resonator and the corresponding complementary split-ring resonator allows a direct visualization of Babinets principle. Additionally, we investigate nearfield coupling effects in split-ring resonator dimers and split-ring resonator arrays.

09:10 : Poynting vector enhancing nanoantenna
Jonghwa Shin, Yong-Hee Lee

Many metallic structures of various shapes have been previously proposed as antennas to achieve localized enhancement of electric fields. Two spheres with a narrow gap between them or bowtie antennas are among such examples. Here, authors present a different set of structures that can enhance not only the electric field but also the magnetic field at the same location. With the design principles introduced here, one can manipulate the direction and relative phase of the magnetic field vector phasor such that the resulting enhanced electric and magnetic field vectors form a greatly enhanced Poynting vector.

09:30 : Carbon nanotube solar cells employing the NEGF method
Mansoureh Maadani, Mohammad Hossein Sheikhi, Reza Sabbaghi

Exceptional electronic and mechanical properties together with nanoscale diameter make carbon nanotube promising candidate for various components. To explore the physics of carbon nanotube solar cell self – consistent quantum mechanical simulations have been performed. Both the electron-photon and electron-phonon interactions in CNT-SCs have been analyzed numerically, employing the non-equilibrium Green's function formalism.

08:30 - 10:30 ***Rubis***

10E: Bottom-up approach towards metamaterials and plasmonics V

Organized by: Dorota Pawlak

Chaired by: Rosa Merino

08:30 : Invited talk
A new way of reducing plasmonic losses
V. A. Fedotov, J. Y. Ou, N. I. Zheludev

We report on a novel way of reducing plasmonic losses in noble metals commonly used in the fabrication of photonic metamaterials and plasmonic nanostructures

08:50 : Optical Spectroscopy, Cathodoluminescence, and Electron Energy Loss Spectroscopy on Metal Nanoparticles
V. Myrosnychenko, F. J. García de Abajo, G. Boudarham, J. Nelayah, O. Stéphan, M. Kociak, C. Colliex, G. Adamo, K. MacDonald, N. I. Zheludev, J. Rodríguez-Fernandez, E. Carbó-Argibay, L. M. Liz-Marzán

We review the use of optical spectroscopy, electron-induced radiation emission (cathodoluminescence), and electron energy-loss spectroscopy to study localized surface plasmon excitations in sub-wavelength noble-metal nanoparticles prepared via lithography or colloidal chemistry. These techniques provide information about plasmon excitations by recording different physical processes, specifically, light scattering exerted by the particles on externally incoming light, radiation emission produced by interaction with an electron beam, and energy loss suffered by those electrons. We provide a theoretical description of a study of the spectral features and spatially resolved maps of nanoparticle plasmon modes at the single-particle level by using these techniques. Numerical modeling is carried out for each set of experimental measurements in order to interpret the results.

09:10 : DNA origami for assembly of artificial plasmonic molecules with tailored optical response
Anton Kuzyk, Robert Schreiber, Zhiyuan Fan, Günther Pardatscher, Eva-Maria Roller, Alexander Högele, Friedrich Simmel, Alexander Govorov, Tim Liedl

Top-down fabrication of plasmonic materials with designed optical response in the visible spectral range by conventional lithographic methods has remained challenging due to limited spatial resolution, the complexity of scaling, and the difficulty to generate three-dimensional architectures. Bottom-up molecular self-assembly provides an alternative route to create nanomaterials which is not restricted by the above limitations. Here, we demonstrate how the DNA origami method can be used to produce plasmonic materials with tailored optical response at visible wavelengths.

09:30 : Invited talk
Physical properties of ruthenium oxide eutectic composites and their connection with the microstructure
Rosalba Fittipaldi, Veronica Granata, Mario Cuoco, Antonio Vecchione

The mechanisms and the fundamental interactions controlling the formation and the competition of different phenomena driven by the electronic correlations, dimensionality and relativistic effects in transition metal oxides are a remarkable topic in condensed matter physics. The study of the correlation between the physical properties and microstructure of the eutectic ruthenates oxides is important to shed light on this issue. Such materials allow the possibility of merging together, in a single composite crystal, individual constituents with unconventional superconducting and magnetic behaviors. They represent a relevant example in the design of new layered compounds offering heterostructures with ad hoc functionalities valuable for novel potential applications.

09:50 : Invited talk
LiF – Rare Earth Fluoride Systems — Potential Novel Polaritonic Materials: Material Preparation and Phase Diagram Studies
Detlef Klimm, Ivanildo dos Santos, Gerson de Godoy Nakamura, Maria Acosta, Rosa Merino

Most systems consisting of LiF and REF3 (RE: rare earth) possess a eutectic between LiF and an intermediate compound RELiF4. This eutectic shows upon crystallization ordering that could be useful for its application as metamaterial. Aspects of material preparation, phase diagram studies, and the growth of self-organized eutectic structures are reported.

10:10 : Invited talk
Towards a new class of metamaterials: Multi-scale phase-field modeling of eutectic self-organization
Laszlo Granasy, Gyula Toth, Gyorgy Tegze, Tamas Pusztai

To assist the designing of eutectic microstructures for metamaterial applications, we have developed a multi-scale chain of phase-field type models, which bridge time and length scales ranging from nanoseconds to minutes and from nanometers to millimeters, respectively. We present examples that demonstrate the abilities of the individual models.

08:30 - 10:30 ***Saphir***

10F: Plasmonic antennas and lenses III

Organized by: Tahsin Akalin

Chaired by: Tahsin Akalin

08:30 : Invited talk
THz Metamaterials and Plasmonics
Willie Padilla, Wenchen Chen, Tahsin Akalin

We investigate the use of metamaterial resonators as elements that enable control of surface electromagnetic waves. Plasmons propagate on a planar Goubau line (PGL), launched with a coplanar waveguide coupler. Metamaterial elements are designed to only absorb energy of the propagating mode and yield narrow-band resonances with relatively high quality factors.

08:50 : Invited talk
Dark plasmon modes and bright emitters
Femius Koenderink, Martin Frimmer, Toon Coenen

Making single photon sources brighter requires simultaneous control over whereto a single emitter emits, how fast it emits upon excitation, and finally also over where the pump field is strongest. We present near-field and far-field experiments to independently quantify all these figures of merits in plasmon antennas that are oligomers of coupled elements. We explain how collective dark modes actually give rise to brighter emission.

09:10 : Invited talk
Terahertz Plasmonic Antennas
Tahsin Akalin

For many applications, the recently developped THz sources like the QCLs require a beamshaping of the generated THz power. After a brief review on the different approaches, THz plasmonic arrays will be presented.

09:30 : Invited talk
Plasmonic lenses and metasurfaces
Alexander Kildishev, Satoshi Ishii, Xingjie Ni, Naresh Emani, Vladimir Drachev, Alexandra Boltasseva, Vladimir Shalaev

We review our recent progress in developing various types of planar nanoslit lenses, milled in metal films. We show the LC-tunable plasmonic slit lenses, which could be used as tunable elements of diffractive optical devices. Then, combining a loss-compensated hyperbolic metamaterial slab with the diffraction pattern produced by a double-slit gold mask, we show with our numerical simulations that the light confinement peak, which approaches 1/17th of a free-space wavelength of 716 nm, can be obtained, and present the experimental demonstration of the subwavelength diffraction pattern, hence, confirming the predictions of our numerical modeling. Finally, we experimentally demonstrate even more extreme control over the phase of transmitted or reflected light using a 2D array of optical nanoantennas, achieving both negative refraction and reflection in the near-IR range.

09:50 : Invited talk
Transformation optics of three-dimensional plasmonic nanoparticles
Antonio Fernandez-Dominguez, Y. Luo, S. A. Maier, J. B. Pendry

A general three-dimensional transformation optics approach is presented that yields analytical expressions for the relevant electromagnetic magnitudes in plasmonic phenomena at singular geometries. Specifically, this powerful theoretical tool enables us to reveal the broadband response and superfocusing capabilities of touching nanospheres and dielectric loaded crescent shaped nanoparticles. In this contribution, an elegant and complete physical description of the optical properties of these two plasmonic geometries will be provided.

10:10 : Invited talk
Light Propagation with Phase Discontinuities: Generalized Laws of Reflection and Refraction.
Z. Gaburro

The shaping of the wavefront of light with optical components such as lenses and prisms, as well as diffractive elements, such as gratings and holograms, relies on gradual phase changes accumulated along the optical path. This approach is generalized in transformation optics, which uses metamaterials to bend light in unusual ways, achieving such phenomena as negative refraction, subwavelength-focusing, and cloaking.

08:30 - 10:30 ***Jade***

10G: Advances in Metamaterials and Plasmonics IV

Organized by: Lei Zhou and Jiaming Hao

Chaired by: Andrei Lavrinenko and Cheng-Wei Qiu

08:30 : Invited talk
Terahertz plasmonic metamaterial waveguides and devices
Xiaopeng Shen, Tie Jun Cui

Surface plasmon polaritons (SPPs) have attracted great attentions owing to their ability to spatially confine electromagnetic waves on metal surfaces beyond the diffraction limit. However, most metals support well-confined SPPs only at the optical and near-infrared frequencies. In the far-infrared, terahertz and microwave regime, metals behaves like a perfect electric conductor (PEC), and hence the natural SPPs cannot be excited on the metal surfaces. The emerging concept of spoof SPPs addresses the challenge of manipulating electromagnetic waves at lower frequencies. Spoof SPPs, or designer SPPs, are sustained by periodically corrugated metal surfaces, which may be one-dimensional groove, two-dimensional holes periodically into a PEC surface, or three-dimensional (3D) periodically corrugated metal wires. They are all 3D structures. In this presentation, we show that the spoof SPPs can be sustained by planar structured metal surfaces in the terahertz frequency, with low propagation loss and bending loss. The proposed structure will be detailed and several terahertz plasmonic metamaterial devices are designed. This new type of plasmonic metamaterial that support spoof SPPs on a plane is a proposing candidate for integrated plasmonic circuits.

08:50 : Invited talk
Nano-Plasmonics: Material Models and Computational Methods
Kurt Busch

An overview of the recent progress in applying the Discontinuous Galerkin Finite-Element Time-Domain approach to nano-plasmonic systems including the development of advanced material models is provided.

09:10 : Invited talk
Effect of surface waves on light transmission through subwavelength apertures and on field enhancement in nanocavities
Haitao Liu, Zhiwen Zeng, Philippe Lalanne

Through developing intuitive models that explicitly incorporate the launching and scattering of surface waves on nano-patterned metallic surfaces, we show the effect of different surface waves on light transmission through subwavelength apertures and on field enhancement in nanocavities. Taking the geometry of a hole array and of a T-shaped groove, we show that classical surface plasmon polariton (SPP) together with another quasi-cylindrical wave (CW) will give the full contribution. Our results are helpful for clarifying the physics of nano-patterned metallic surfaces and thus provide design recipes for relevant devices.

09:30 : Invited talk
Gain-assisted extraordinary optical transmission through periodic arrays of subwavelength apertures
Roberto Marani, Antonella D'Orazio, Vincenzo Petruzzelli, Sergio Rodrigo, Luis Martin-Moreno, Francisco J. Garcia-Vidal, Jorge Bravo-Abad

We present a theoretical analysis of extraordinary optical transmission phenomena in periodic arrays of subwavelength apertures incorporating optically-pumped gain media. We show that, as a consequence of the strong spatial hole-burning effects displayed by the considered structures, three separate regimes of operation arise: the system can behave as an absorber, an optical amplifier or a laser, depending on the value of the pump intensity.

09:50 : Dispersion relation of surface plasmon polaritons in metallic nanostructures: Eigenmode analysis approach
Shulin Sun, Hung-Ting Chen, Wei-Jin Zheng, Guang-Yu Guo

We employ the eigenmode analysis approach based on finite element method to calculate the dispersion relation of the surface plasmon modes in metallic nanostructures. Firstly, benchmark results are demonstrated in metal/dielectric interface, metallic film and single nanowire. Then we focus on the metallic bi-nanowire system which has been proposed as a robust surface plasmon waveguide. We calculated the field patters, charge distributions and dispersion relations of all the surface plasmon modes existed in such system and found some interesting coupling effects. This approach can be also applied to two-dimensional (2D) or three dimensional (3D), dispersive, anisotropic, and complex shaped systems.

10:10 : Binary Programming Techniques for Linear Metamaterial Design Optimization
Joel Saa-Seoane, Ngoc Cuong Nguyen, Jaime Peraire

The design of metamaterials is nowadays an intense field of research. However, most of the metamaterials described in the literature arise from physical intuition, often, assuming infinite periodicity. There is therefore a need for a tool capable of providing patterns and designs involving two materials, combined cleverly in a pixel-by-pixel finite way, such that we wind up obtaining some effective metamaterial properties. All in all, binary programming techniques need to be considered, in contrast to classic gradient optimization algorithms, which often provide continuous solutions. Nevertheless, the computational complexity of discrete optimization problems is usually NP and thus intractable. In this document, we will present a reduced basis optimization approach involving a generalized binary gradient. Solutions will thus be always binary and, although they might not be global optima, they will be obtained efficiently.

08:30 - 10:30 ***Grenat***

10H: Plasmonics and nanophotonics for sensing, imaging, and spectroscopy III

Organized by: Sang-Hyun Oh and Alexandre Brolo

Chaired by: Sang-Hyun Oh and Alexandre Brolo

08:30 : Invited talk
Material-selective surface chemistries for nanoplasmonic hot spots and flow through sensing
Fredrik Hook

The sensitivity of surface-based sensors designed to probe biomolecular interactions can be defined as the lowest number of simultaneous biomolecular binding reactions required to yield a detectable signal. Since the interactions between the probes (e.g. antibodies, glycolipids, membrane-protein receptors etc) utilized to specifically bind suspended target molecules (e.g. antigens, drug compounds etc) are reversible, the limit of detection - i.e. the lowest concentration that can be detected - is determined by the affinity of the interaction. Single-molecule sensitivity represents the ultimate sensitivity limit, which would in principle enable utterly low affinity interactions to be unambiguously measured. However, in order for single-molecule assays to yield sufficient statistics within reasonable time scale, it is important that multiple single molecular binding events can be probed simultaneously. I will present a new means to utilize material-selective surface modifications to direct the bimolecular reactions to occur exclusively in the hot spot between pairs of nanoscale gold discs. The results will be discussed based on the signal enhancement provided and what additional steps that are required to make full use of the single-molecule sensitivity that is now within reach. I will also discuss how the positioning of nanoplasmonic elements in pores than span thin SiN membrane may help overcoming the diffusion limits that often hamper binding kinetics analysis in label-free sensing assays.

08:50 : Invited talk
Engineered metallic nanoholes and nanogaps for biosensing and spectroscopy
Sang-Hyun Oh

Following the discovery of extraordinary optical transmission, metallic films perforated with subwavelength nanoholes have been the focus of intense research, in particular toward applications in sensing, imaging, and spectroscopy. Here we employ holographic lithography, nano-imprint lithography, and template stripping to demonstrate inexpensive, reproducible, and high-throughput fabrication of nanohole arrays in gold and silver films for protein biosensing applications. The resulting nanohole arrays, patterned over centimeter-sized areas, exhibit homogeneous optical properties with sharp and intense plasmon peaks. We describe techniques for surface modification and integration with microfluidics to utilize these nanostructured films for biosensing in an aqueous environment. We will also describe a high-throughput fabrication technique that utilizes nanosphere lithography to form ultra-thin nanogap arrays over a large area for surface-enhanced Raman spectroscopy (SERS). These engineered plasmonic substrates are used for real-time protein biosensing as well as SERS biosensing of various analytes in a label-free manner.

09:10 : Invited talk
Plasmonic antenna-based near-field probes for nanoscale imaging and spectroscopy
James Schuck

By enabling the exploration of physical parameter spaces that are nearly impossible to access any other way, the efficient conversion between photonic and nano-plasmonic modes is of high interest for applications ranging from nano-optical imaging and sensing to information science. In this talk, I will describe our efforts in creating novel near-field probes that exploit the light-coupling and field enhancement properties of plasmonic optical antennas. Because of their advantages over current technologies, we have successfully used them to characterize different nanostructures via hyperspectral Raman and PL imaging (collecting full spectra at each pixel in the image). I will then discuss our next generation photonic/plasmonic hybrid near-field scanning optical microscopy (NSOM) probe called the campanile tip, which demonstrates a superior combination of field coupling, spectral bandwidth, enhancement, and resolution capabilities. Based on extensive simulations of various optical transformer geometries, these campanile tips effectively combine the beneficial properties of photonic waveguides, plasmonic waveguides and plasmonic optical antennas. Mode coupling and adiabatic compression occurs over a broad bandwidth without sacrificing the field strength or throughput often associated with resonant structures. This is crucial for many optical spectroscopy techniques ranging from Raman and IR spectroscopy to white-light nano-ellipsometry to ultrafast pump-probe studies.

09:10 : Invited talk
Terahertz nano antennas with subskin depth physics
DaiSik Kim

We will discuss infinitely long and finite nano antenas designed to operate in the terahertz frequency regime. Giant field enhancement will be discussed for the slit widths smaller than the metallic skin depth at terahertz frequencies. Phase transition metamaterial using VO2 in combination with terahertz antennas will also be presented.

Coffee Break and Exhibit Inspection

10:30 - 11:00

11:00 - 12:00 ***Thévenin***

11A: Plasmonics and nanophotonics X

Chaired by: Pavel Belov

11:00 : Surface Plasmon Interaction with a Waveguide
Ramon Munguia-Arvayo, Jorge Gaspar-Armenta, Raul Garcia-Llamas

The influence of an infinite set of waveguides on the evanescent field of a surface plasmon excited at attenuated total reflection by a Gaussian beam is studied theoretically. The set of waveguides is treated as a periodic inhomogeneous medium, with period a. Numerical results are presented for the case when a is greater than l, the wavelength used to excite the surface plasmon. This case leads to the simulation of Scanning Tunnel Optical Microscopy in 2D geometry.

11:20 : Plasmon-induced spatial hysteresis and modulational instability in arrays of nonlinear metallic nanoparticles
Roman Noskov, Pavel Belov, Yuri Kivshar

We consider spatial hysteresis and modulational instability in arrays of nonlinear metallic nanoparticles. We show that such plasmonic systems are characterized by a bistable response, and they can support the propagationof dissipative switching waves (or plasmonic kinks) connecting the states with different polarization. We demonstrate that modulational instability, also inherent in our system, can lead to the formationof regular periodic or quasi-periodic modulations of the polarization. We reveal that arrays of metallic nanoparticle scan support nonlinear localized modes of two different types – plasmon-solitons and plasmon-oscillons. They both possess deeply subwavelength size. However, the profile of plasmon solitons is stationary whereas plasmon-oscillons has the oscillating profile which can stand at rest or slowly drift along the chain.

11:40 : Electromagnetic field radiated by Nanoemitters in Graphene
L. Martin-Moreno, A. Nikitin, P. A. Huidobro, F. Guinea, F. J. Garcia-Vidal

Graphene has attracted recently a great deal of attention due to its amazing electronic properties. Remarkably, even one-atom-thick graphene can bind electromagnetic modes (surface plasmon polaritons), despite being almost transparent. This brings to the fore the possibility of using graphene for many of the functionalities sought within the field of plasmonics, with the advantage that graphene the carrier concentration in graphene can be modulated by external gates. In the first part of this talk we will analyze the spacial distribution of the electromagnetic field radiated by a nanoemitter in graphene, as a function of frequency and doping concentration. We will show the appearance of different regimes in the field dependence on distance to the source. In the second part, we will use this information to analyze the super radiance of two emitters mediated by graphene surface plasmons.

11:00 - 12:20 ***B310***

11B: Structured and disordered media II

Chaired by: Stefan Linden

11:00 : Two dimensional disordered optical modes for highly efficient photon absorption
Matteo Burresi

We present a novel nanophotonic strategy to greatly augment the absorption of thin-film materials over a large range of wavelength. The absorption enhancement is polarization insensitive and highly efficient at all incident angles. The introduction of a properly engineered 2D random structure gives rise to guided disordered modes in the absorbing material, which traps light impinging from the third direction thus enhancing the absorption. This photonic architecture can be used to increase the absorption efficiency of third-generation solar cell.

11:20 : Active control of the emission of a random laser
Nicolas Bachelard, Jonathan Andreasen, Sylvain Gigan, Patrick Sebbah

The lasing emission spectrum of a random laser is both unpredictable and very sensitive to fluctuation of pump excitation. We demonstrate that its spectrum can be controlled and any mode can be selected by adjusting iteratively the pump profile. This control is tested numerically in the case of a one-dimensional random laser and adapted to an actual experiment.

11:40 : Strategy for broadening antireflection spectrum: quarter-wavelength AR nanoislands on Si nanoconical-frustum
Kyoungsik Kim, Haesung Park, Dongheok Shin

The quarter wavelength (l/4) antireflection (AR) coating and biomimetic moths eye structure are most commonly adopted individual strategy for reducing Fresnel reflection from interface between two different mediums. Based on nanosphere lithography and single-step deep reactive ion etching, we demonstrate new strategy for broadband antireflection enhancement including near-UV region without fabricating sub-300nm features. This is first extension method which can suppress the reflection losses at the wavelength region where is smaller than the lattice constant of biomimetic moths eye structure. Experimental absolute hemispherical measurement shows that the average reflectance in the range of 300nm

to 400nm is reduced from 20.4% to 9.3% with 500nm lattice constant of AR nanostructure.

12:00 : Random laser in totally disordered 2D GaAs/AlGaAs heterostructures
Antoine Monmayrant, Olivier Gauthier-Lafaye, Sophie Bonnefont, Kiran Bhakta, Christian Vanneste, Françoise Lozes-Dupuy

We demonstrate random lasing emission in a AlGaAs suspended membrane randomly perforated with subwavelenth circular holes. Spectrally-resolved imaging of the lasing emission allows identifying lasing modes in the diffusive regime.

11:00 - 12:40 ***B312***

11C: Periodic structures and extraordinary transmission

Chaired by: Anne Claire Lepage

11:00 : Enhancing the transmission of higher order plasmon modes through periodic hole array with paired apertures as the basis
Yu-Cheng Chen, Yi-Tsung Chang, Hung-Hsing Chen, Chih-Wei Yu, Shao-Yu Huang, Si-Chen Lee

The transmission of higher order surface plasmon (SP) modes can be enhanced through periodic holes array with paired apertures as the basis. The whole shape of the basis pair can be identical circle, square and triangle, etc. It is demonstrated that the concept of structure factor in constructing the reciprocal lattice of a crystal in solid state physics can be adopted to explain the observed intensity of the higher order modes. It is found that the separation between the paired holes is the key factor to determine the strength of the higher order surface plasmon modes. Here we demonstrate this new concept of enhanced higher order SP modes both experimentally and theoretically.

11:20 : Extraordinary transmission of three-dimensional crescent-like holes array
Chongjun Jin, Yang Shen

We developed a method to fabricate a periodic array of three-dimensional crescent-like holes (3DCLH) via an inverted hemispherical colloidal lithography. It is found that there exists an extraordinary optical transmission (EOT) in this non-planar perforated periodic array of 3DCLH which is caused by an asymmetric localized surface plasmon resonance. It is also found that the EOT peak is consistent with the change of incident angles. This structure might be useful for the optical sensing and optical integrated circuits.

11:40 : Dual-band Artificial Magnetic Conductor
Julien Sarrazin, Anne Claire Lepage, Xavier Begaud

A dual-band Artificial Magnetic Conductor (AMC) is presented in this paper. The proposed metasurface is based on a spiral geometry in which an additional resonance has been introduced thanks to a physical understanding of the structures behavior. Thus, electric field from that surface is reflected in phase at two different frequencies which can be set independently.

12:00 : Novel uniplanar flexible Artificial Magnetic Conductor
Maria Elena de Cos, Fernando Las-Heras

A novel flexible uniplanar Artificial Magnetic Conductor (AMC) design is presented. A prototype is manufactured and characterized under flat and bent conditions in anechoic chamber. The designed prototype shows broad AMC operation bandwidth, polarization angle independency and high angular stability margin when operating under oblique incidence

12:20 : Low Profile Antenna Radiation Enhancement with Novel EBG Structures
Muharrem Karaaslan

We design, characterize and fabricate electromagnetic band gap structure (EBG) composed of three different scale planar rectangular mushrooms for low profile antenna applications. Proof of principle demonstration of surface wave minimization is realized between three different bands depending on mushroom numbers in one unit cell and low profile antenna radiation pattern enhancement is observed by monitoring transmission changes of surface waves using both

two different numerical methods and measurements. Three different scale rectangular mushrooms show significantly better performance and wider EBG than many other EBG systems for improved antenna applications such as bowtie and logarithmically periodic antennas.

11:00 - 12:00 ***Emeraude***

11D: Analytical and numerical modelling of complex materials and structures II

Chaired by: Arcady Zhukov

11:00 : A Microwave Engineering Perspective of the Superlens
Ravi Hegde, Yew Li Hor, Wolfgang Hoefer

Super-resolution imaging involves the interaction of electromagnetic waves with objects that have dimensions similar to, or smaller than the wavelength. That is precisely the hallmark of microwave technology. It suggests that microwave concepts and design approaches may be helpful not only in the description and modeling of the superlens behavior, but can provide useful tools for designing and realizing the superlens, notably the metamaterial itself. In this paper we present some interesting results and insights yielded by the microwave perspective, including waveguide, circuit and filter representations of the superlens.

11:20 : The relative impedance of waveguiding structures
Thomas Kaiser, Shakeeb Bin Hasan, Thomas Paul, Thomas Pertsch, Carsten Rockstuhl

The concept of an impedance is a valuable means to access how light couples among adjacent half-spaces. Being a quantity linked to the eigenmodes of a medium, it is well established for plane waves in free space but a unique definition for modes propagating in more complicated nanostructured media is a challenging task. We show here that the introduction of absolute impedance is usually not possible since its definition crucially depends on a referential mode. We lift this problem by introducing a relative impedance that only requires the fields of the fundamental modes in each medium. At the example of nanostructured metallic waveguides, we outline the concept and provide evidence for its applicability to predict the reflection among different waveguides in a simple way. It therefore constitutes a valuable design tool for sophisticated waveguiding structures for many applications.

11:40 : Modeling of the crystal structure growth process of GaAs
Klara Iskakova

The current industry needs for new results require current capabilities of computer technology can solve problems on a whole new level. This article briefly describes the algorithms for obtaining the structures and the appearance of discontinuities in the growth of crystals.

11:00 - 12:00 ***Rubis***

11E: Technologies and applications III

Chaired by: Eric Akmansoy

11:00 : Efficient high-harmonic generation in a mixture of a noble gas and metal nanoparticles and on rough metal surfaces
Joachim Herrmann, Anton Husakou, Kwang-Hyon Kim

We investigate low-intensity high-harmonic generation enabled by the plasmonic electric field enhancement in a mixture of a noble gas with metal nanoparticles and near random rough surfaces. HHG efficiencies up to $10^{(}-6)$ are predicted.

11:20 : Proposal and Analysis of Artificial Dielectric Lens with Metallic Corrugated Structures for Terahertz Wave Band
Takuya Konno, Takahiro Suzuki, Jhon Young, Mikio Saigusa, Keisuke Takano, Hideaki Kitahara, Masanori Hangyo, Takehito Suzuki

Optical devices for the terahertz wave band are being developed now and require better designs. This paper proposes an artificial dielectric lens with metallic corrugated structures for the terahertz wave band. A periodic analysis model extracted from the full model by assuming periodicity confirms the phase delay, which produces the focusing effect. Full model analysis also confirms the focusing effect. The full model analysis also confirms that the focusing length is longer with the wider spacing of corrugated baffles, the wider metallic groove width, and the shallower groove depth. The lens shape without grooves does not produce the focusing effect. The results of the full model analysis are qualitatively consistent with those of the periodic model ones. This implies that the design for an exact size lens is possible by using the periodic model.

11:**40 : New equipment for SHF electric field visualization**
I. Karpov, E. D. Shoo, M. R. Trunin

We have developed a pioneering experimental equipment for investigation of the properties and measurement of characteristics of SHF metamaterials. The equipment enables in polar coordinate control of the characteristics of the electromagnetic flow in the SFH range in the vicinity of the metamaterial item, that allows reproducing the pattern of its surrounding electromagnetic SHF field.

11:00 - 12:20 ***Saphir***

11F: Computational techniques for photonic crystals

Organized by: Robert C. Gauthier

Chaired by: Robert C. Gauthier

11:**00 : Asymmetric transmission without breaking time reversal symmetry: anomalous diffraction vs polarization conversion**
Andriy Serebryannikov

Two mechanisms of reciprocal but strongly asymmetric transmission are compared in the framework of the multichannel/multiport theory. The corresponding performances are based on either photonic crystals or (quasi)planar chiral arrays that are made of linear isotropic materials. Realizable transmission regimes, conditions of existence, and peculiarities of design are discussed.

11:**20 : Circular-lattice photonic crystal Taper for optical waveguides**
Gilliard Malheiros-Silveira

A new taper to coupling two ridge waveguides with different width dimensions by means of a circular-lattice photonic crystal has been theoretically investigated. The studies were carried out by using a finite-difference time-domain (FDTD) method. Coupling efficiency above 65 % was obtained for waveguides whose widths were related by a factor of five.

11:**40 : Efficient Frequency-Domain Method for Analyzing Optical Bistability in Photonic Crystal Cavities**
Lijun Yuan, Ya Yan Lu

An efficient numerical method is developed for analyzing optical bistability in two-dimensional photonic crystal cavities with a Kerr nonlinearity, where the governing equation in the frequency-domain is a nonlinear Helmholtz equation. The method relies on the fact that the nonlinear effect is localized around the cavity and takes advantage of the many identical unit cells of the photonic crystal by computing the Dirichlet-to-Neumann operators of the unit cells.

12:**00 : A Fourier-Bessel Expansion Method Applied to Photonic Crystals: Theory and Accuracy**
Scott Newman, Robert Gauthier

Fourier-Bessel functions are used to expand the field and dielectric in the 2D cylindrical Maxwell's equations recasting their solutions into eigenvalue problems. The eigenvalues obtained are the localized states of the given structure with their density indicating optical band gaps. The technique is shown for both TE and TM polarizations within a triangular lattice photonic crystal. The accuracy and efficiency of the results are compared relative to finite difference techniques.

11:00 - 12:40 ***Jade***

11G: Advances in Metamaterials and Plasmonics V

Organized by: Lei Zhou and Jiaming Hao

Chaired by: Kurt Busch and Jiaming Hao

11:00 : Invited talk
Plasmonic nanoparticles for bioanalytics at the limits
Fritzsche Wolfgang, Andrea Csaki, Thomas Schneider, Janina Wirth, Frank Garwe, Ondrej Stranik

Plasmonic nanoparticles combine fascinating physical properties with the compatibility with the molecular world regarding size scale as well as chemical approaches. They allow for sensoric measurements at a nanometer lateral resolution such as in cells or even organelles but by optical tools. Moreover, beside this passive readout, also active optical manipulation of individual particles using their nanoantenna capabilities is possible at the same scale with nanometer precision. We will illustrate both sides of this impressing developments by results form our work.

11:20 : Effective Medium of Low-symmetry Metamaterials
Tianhua Feng, Jensen Li, F. Liu, Y. Li, W. Y. Tam

We have developed an extended S-parameter retrieval method to study the effective medium of low-symmetry metamaterials. Within our approach, we can extract the frequency dependent local effective medium without the appearance of anti-resonance. The full 4x4 constitutive tensor at normal incidence can be extracted to reveal magnetoelectric properties.

11:40 : Surface Plasmon - Guided Mode strong coupling
Aurore Castanié, Didier Felbacq, Brahim Guizal

It is shown that it is possible to realize a strong coupling between a surface plasmon and a guided mode in a layered structure. The dispersion relation of such a structure is obtained through the S-matrix algorithm combined with the Cauchy integral technique that allows for rigorous computations of complex poles. The strong coupling is demonstrated by the presence of an anticrossing in the dispersion diagram and simultaneously by the presence of a crossing in the loss diagram. The temporal characteristics of the different modes and the decay of the losses in the propagation of the hybridized surface plasmons are studied.

12:20 : A group theory approach to tailored electromagnetic properties of metamaterials: An inverse problem solution
I. El-Kady, Chalrles Reinke, Michael Sinclair

The problem of designing electromagnetic metamaterials is complicated by the pseudo-infinite parameter space governing such materials. We present a general solution based on group theory for the design and optimization of the electromagnetic properties of metamaterials. Using this framework, the fundamental properties of a metamaterial design, such as anisotropy or magnetic or electrical resonances, can be elucidated based on the symmetry class into which the unit cell falls. This provides a methodology for the inverse problem of design of the electromagnetic properties of a metamaterial. We also present simulations of a zia metamaterial that provides greater design flexibility for tuning the resonant properties of the device than a structure based on a simple split-ring resonator. The power of this zia element is demonstrated by creating bianisotropic, chiral, and biaxial designs using the inverse group-theory procedure outlined in this paper.