12TH INTERNATIONAL CONGRESS

METAMATERIALS

27 AUGUST – 1 SEPTEMBER '18

ESPOO, FINLAND

ARTIFICIAL MATERIALS FOR NOVEL WAVE PHENOMENA

Aalto University

METAMATERIALS CONGRESS

Proceedings

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FOREWORD

It is our great pleasure to welcome you to the *12th Edition of the Metamaterials Congress*, co-organised by the *Virtual Institute for Artificial Electromagnetic Materials and Metamaterials* (METAMORPHOSE VI) and Aalto University. This Congress series spun off from a series of earlier conferences and meetings in the field of electromagnetics and electrical engineering, gathering scientists focused on artificial materials. Over the years, our community has matured and expanded evolving into a multi-disciplinary event, as it is reflected in the subtitle of the Congress, *International Congress on Artificial Materials for Novel Wave Phenomena*.

The Congress has become the reference meeting for a broad class of scientists, who look for this forum to discover the latest results in the dynamic field of metamaterials and their applications, in many fields of science and technology. We have a balanced mix of plenary, invited, contributed and poster presentations. They have all gone through a rigorous peer review process, and selected on the basis of novelty and importance. The program encompasses diverse aspects of the fundamental theory, modelling, design, applications, fabrication, and measurements.

As usual, the Congress is followed by another exciting event of the European Doctoral School on Metamaterials. This year school is devoted to a hot topic in our community, Nonreciprocal and Time-Modulated Metamaterials and Metasurfaces.

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

The success of the conference series allows METAMORPHOSE VI, a non-for-profit international association, to provide financial support to a number of participants, particularly students and scientists from developing countries, to operate the European Doctoral Programme on Metamaterials (EUPROMETA), and to deliver other services to the broad metamaterials community.

This is the last year that we serve as the General Chairs of the Metamaterials Congress: our term ends with this edition. We are very honoured to have served this scientific community and hope to have contributed to the success of this event. It has certainly been an exciting journey for us and we now wish good luck to the colleagues who will take this responsibility for the future editions.

Filiberto Bilotti
General Chair

Andrea Alù
General Co-Chair

PREFACE

On behalf of the Technical Program Committee, it is my great pleasure to outline the technical program of Metamaterials 2018 – the 12th International Congress on Engineered Material Platforms for Novel Wave Phenomena.

After over a decade since its first edition, the Congress has established itself as one of the premiere international forums on metamaterials, gradually transcending the original boundaries of microwaves and optics, so as to encompass the inherently inter/multi-disciplinary character of the discipline. This is reflected by the new Congress title that was adopted since the 2017 edition, as well as by the technical program which, also in this edition, covers a wealth of different disciplines, ranging from acoustics and mechanics to quantum physics.

This year, the technical sessions are structured in four parallel tracks of oral presentations selected among 340 submissions. More specifically, the program includes (67) invited and (178) contributed oral presentations. In addition, we have scheduled an interactive poster session with 77 presentations, which provides a great opportunity for debate in a more informal and relaxed setting.

Keeping up with a great tradition of the Congress, also this year we have four plenary presentations by distinguished leading scholars, namely, Martin van Hecke, Stefano Maci, Nader Engheta, and Arno Rauschenbeutel. I urge you not to miss what promise to be four very inspiring and visionary talks.

Moreover, the program features special sessions on recent advances and trends in metasurfaces, the VISORSURF project, nanoarchitectronics, nanogap plasmonics and devices, as well as the Physical Review Journals Symposium (organized by the editors of Physical Review).

I am greatly indebted to all the individuals and institutions that contributed to molding and assembling this technical program. In particular, I express my sincere appreciation to the 71 reviewers, who cooperated by submitting their reports within a tight deadline imposed by the Congress schedule.

Vincenzo Galdi
Chair of the Technical Program Committee

I wish all of you a very pleasant and productive stay in Espoo.
Enjoy the Congress!

WELCOME MESSAGE

Tervetuloa Aalto-yliopistoon!
Welcome to Aalto University!

Aalto University was formed in 2001 from the merger of the Helsinki University of Technology, the University of Art and Design Helsinki, and the Helsinki School of Economics. The name is a tribute to Alvar Aalto, a prominent architect known for his achievements in technology, economics, and art. The university is composed of six schools with close to 17,500 students and 4,000 staff members, making it Finland's second largest university. The 12th Edition of the Metamaterials Congress will be hosted on the main campus of Aalto University located in Otaniemi, Espoo.

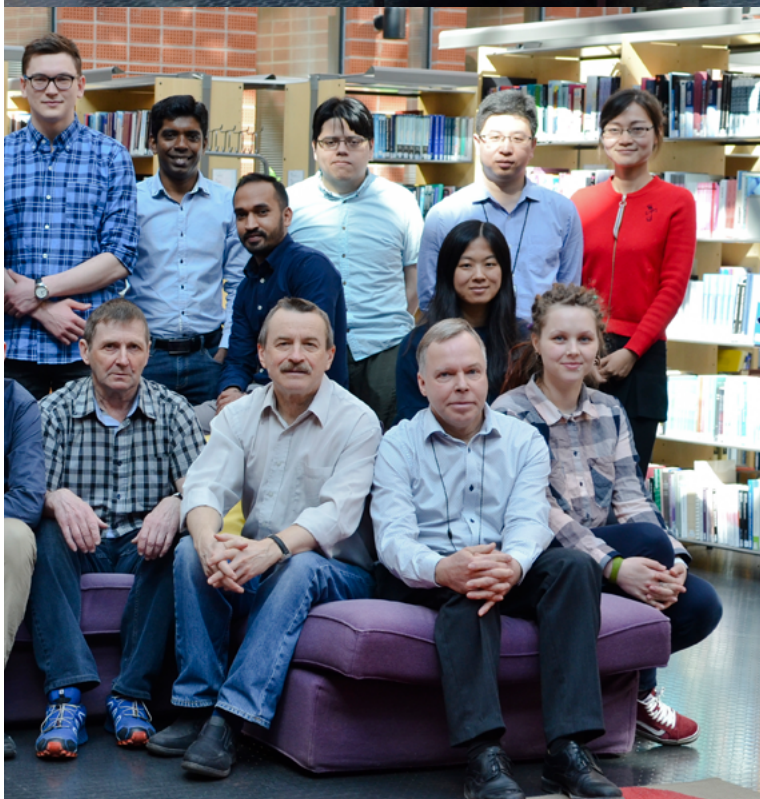
Metamaterials Congress has a close connection with Finland. The congress continues the traditions of the Workshop on Novel Microwave Materials (Bi-isotropics), organized for the first time in 1993 in Espoo. As organizers, it is an honor to celebrate the 25th anniversary of this community coming back to the place where it all started, reinforcing the presence of Finland in the metamaterials community.

This year, we celebrate the 50th anniversary of the seminal work of V. Veselago on double-negative materials. We have tried to bring back the most important milestones since the prediction of negative index materials, the origins of what we now call Metamaterials Community. We wish and hope that you will join colleagues and friends for this engaging event that includes a sample exhibition and short talks reflecting on the early history of metamaterials research.

A particular character of this edition is the emphasis on the environmental protection. Together with the METAMORPHOSE VI, we have carried out several actions for reducing the consumption of plastics and paper. To contribute to this mission, we have cast aside the distribution of the proceedings on USB sticks or any other physical device. As an alternative option, in this edition, the proceedings can be downloaded from the conference webpage. We hope that these actions will contribute to the development of a more sustainable society and science.

Finally, we would like to thank the Federation of Finnish Learned Societies, Espoo Council, and all the sponsors and exhibitors for their invaluable support to the conference.

Sergei Tretyakov and Ana Díaz-Rubio
Chairs of the Local Committee



PROGRAM

Monday 27 August

8:30 Registration

8:45 Opening ceremony

9:00 Plenary Session I

10:00 Coffee

10:30

A1	B1	D1	E1
Time-varying metamaterials	Acoustic metasurfaces	Plasmonics I	Theory and modelling I

12:30 Lunch

14:00

A2	B2	D2	E2
Exotic effects and properties I	Acoustic metamaterials I	Plasmonics II	Active/non-Hermitian systems I

15:30 Coffee

16:00

A3	B3	D3	E3
Applications of microwave and THz metamaterials	Elastic metamaterials	Quantum effects	Sensing and imaging

18:00

18:30 Espoo City Reception

21:00

Tuesday 28 August

Plenary Session II

Coffee

A4	B4	D4	E4
Ss: Recent advances and trends in metasurfaces I	Tunable/programmable metamaterials	Novel effects enabled by optical metamaterials	Theory and modeling II

Lunch + *Workshop: Simulation of Metamaterials with COMSOL*

A5	B5	D5	E5
Ss: Recent advances and trends in metasurfaces II	Acoustic metamaterials II	Plasmonics III	Magnetic-resonance-imaging applications

Coffee

A6	B6	D6	E6
Exotic effects and properties II	Mechanical and acoustic metamaterials	Graphene	Antenna applications

Social event: Excursion to Nuuksio

21:30

Wednesday 29 August

9:00 Plenary Session III

10:00 Coffee

10:30

A7	B7	D7	E7
Ss: Physical Review Journals Symposium	Nonlinear metamaterials I	Nanoparticles and nanoantennas	Design and modeling

12:30 Lunch

14:00

A8	B8	D8	E8
Topological effects I	Design of mechanical metamaterials	Ss: VISORSURF project	Active/non-Hermitian systems II

15:30 Coffee + POSTER SESSION

16:00

17:30 Exhibition + Anniversary Event

20:00 Gala Dinner

22:30

Thursday 30 August

9:00 Plenary session IV

10:00 Coffee + *Meet-and-greet the Physical Review Editors*

10:30

A9	B9	D9	E9
Ss: Nanoarchitectronics	Nonlinear metamaterials II	Metasurfaces I	Light control through metamaterials

12:30 Lunch

14:00

A10	B10	D10	E10
Topological effects II	Advanced optical materials	Applications to energy, sensing and optical trapping	Scattering control and cloaking

15:30 Coffee + *Meet-and-greet the Physical Review Editors*

16:00

A11	B11	D11	E11
Ss: Nanogap plasmonics and devices	Nonreciprocal metamaterials	Metasurfaces II	Theory and modeling III

Closing Ceremony

MONDAY

8:30 Registration

8:45 Opening ceremony
Hall: Aalto

9:00 Plenary session I

10:00 Coffee

	Aalto Hall	Hall B	Hall D	Hall E
10:30	A1	B1	D1	E1
	Time-varying meta-materials	*Acoustic metasurfaces*	*Plasmonics I*	*Theory and modeling I*
12:30	Lunch			
14:00	A2	B2	D2	E2
	Exotic effects and properties I	*Acoustic meta-materials I*	*Plasmonics II*	*Active/non-Hermitian systems I*
15:30	Coffee			
16:00	A3	B3	D3	E3
	Application of microwave and THz meta-materials	*Elastic meta-materials*	*Quantum effects*	*Sensing and imaging*

18:30 Espoo City Reception
21:00

Plenary session I

Hall: Aalto **Chair:** Sergei Tretyakov

9:00 Complex Mechanical Metamaterials
Martin van Hecke
Leiden University & Amolf, Netherlands

Mechanical metamaterials exploit motion, deformations, stresses and mechanical energy. Originally, the field focused on achieving unusual (zero or negative) values for familiar mechanical parameters, such as density, Poisson's ratio or compressibility. More recently, complex metamaterials that leverage the strong nonlinearities intrinsic in mechanics have emerged. Here, I discuss current and future strategies to implement spatial and temporal complexity into mechanical metamaterials.

10:30 Time-Variable and Nonlinear Metasurfaces: From Nanosecond Pulse Shaping to Photon Acceleration (Invited)

Gennady Shvets [Cornell University, USA]

Injection and generation of free carriers in high-Q metasurfaces can be used to tune its response, as well as manipulate the frequency of the photons trapped inside the photonic structure. The effect is particularly dramatic in the mid-infrared part of the spectrum because of the scaling of the refractive index correction with the wavelength. In this talk, I will describe two platforms for using free carriers to manipulate optical pulses. One approach can be classified as passive: free carriers are injected into graphene on a nanosecond time scale, resulting in reshaping the amplitude, phase, and polarization state of a nanosecond laser pulse interacting with a graphene-integrated plasmonic metasurface. The second, active non-perturbative approach, can be understood as photon acceleration, i.e. the extreme modification of the spectrum of a femtosecond laser pulse interacting with a semiconductor metasurface whose resonant frequency is rapidly evolving due to the generation of electrons and holes. Applications of photon acceleration to tunable harmonics generation, non-reciprocal light propagation will be described. We will demonstrate that photon acceleration is the mechanism for enhancing nonlinear interactions without sacrificing the bandwidth.

11:00 Time-Modulated Structures for Energy Accumulation (Invited)

Sergei Tretyakov, Mohammad Sajjad Mirmoosa, Grigorii Ptitsyn, and Viktar Asadchy [Aalto University, Finland]

Accumulation of electromagnetic field energy in lossless objects (resonators, metasurfaces, and reactive circuit elements) is limited by the amplitude of time-harmonic external sources. In the steady-state regime, all incident power is fully re-radiated (reflected), and the stored energy does not increase in time, although the external source continuously supplies energy. Here, we show that lossless objects can continuously accumulate unlimited energy if their properties are made time-varying. Here we consider the simplest example of a reactive load of a transmission line and analytically derive the required time dependence of the load reactance for unlimited energy accumulation. We also prove that properly designing time-varying resonant circuits, one can arbitrarily engineer the time dependence of the current in the circuit fed by a given time-harmonic source. Finally, we discuss how this stored energy can be released in form of a time-compressed pulse.

11:30 Recent Advances in Theory, Concepts, and Applications of Space-Time Modulated Media

Sajjad Taravati and Ahmed A. Kishk [Concordia University, Canada]

We report on our latest results concerning the theory, concepts, and applications of space-time modulated media. This includes a collection of theoretical, numerical and experimental demonstration of new classes of space-time varying structures and their unique functionalities.

11:45 Space-time-varying Field-Processing Metasurfaces

Nima Chamanara, Yousef Vahabzadeh, and Christophe Caloz [Polytechnique Montreal, Canada]

This paper leverages space-time variation to design metasurfaces that perform precise spatio-temporal transformations on incident electromagnetic pulses. We demonstrate how to synthesize and model space-time varying metasurfaces capable of performing transformations such as time reversal, pulse shaping, perfect pulse refraction, and mathematical derivation.

12:00 Non-Reciprocal Wave Propagation in Dynamic Materials: Homogenization, Scattering and Adiabatic Regimes

Guoliang Huang and Hussein Nassar [University of Missouri, USA]

Salient features of non-reciprocal wave propagation in dynamic materials, i.e., materials whose properties depend on time at a rate comparable to the frequency of waves propagating within, are examined in three distinct regimes. In the homogenization regime, the dynamic material is shown to exhibit a stress-velocity coupling characteristic of Willis materials. This coupling leads to a left-right bias in propagation speeds whereby waves going left/right travel faster than similar waves traveling in the opposite direction. In the scattering regime, Bragg theory is adopted and modified to account for frequency-shifting effects. Accordingly, Bragg reflection will only occur in specific directions thus leading to the emergence of one-way bandgaps. Last, in the adiabatic regime, one-way bandgaps are characterized through a topological invariant, a Chern number, proven to be quantized and accordingly robust. A connection between one-way bandgaps and the existence of one-way edge states is established in the context of a bulkedge correspondence principal.

12:15 Advanced Wave Manipulation of Space-Time Modulated Media Under Oblique Incidence

Sajjad Taravati and Ahmed A. Kishk [Concordia University, Canada]

We present a theoretical and numerical framework for the wave spectrum manipulation and control of electromagnetic waves using time-periodic space-time modulated slabs. We show that such slabs provide peculiar and unique control over electromagnetic fields as well as wave spectrum alteration. Interesting features include new frequency generation, unidirectional wave manipulation, and space-scanning.

B1 Acoustic metasurfaces

Hall: B **Chairs:** Ana Díaz-Rubio and Steven Cummer

10:30 Wavefield Shaping for Complex Acoustic Sound (Invited)

Guancong Ma [Hong Kong Baptist University, Hong Kong]

Wavefront shaping with spatial light modulators is a recent breakthrough in light propagation in diffusive medium. Here, for the first time, we apply this concept to acoustic waves. To do so, we have designed and built the first binary-phased spatial sound modulator (SSM), which is essentially a reconfigurable acoustic metasurface. The metasurface consists of unit cells with two states controllable through programmed electronics. We demonstrate the novel capability of controlling and re-shaping complex sound field with proof-of-principle experiments in complex reverberating environments.

11:00 Acoustic Metasurfaces (Invited)

Steven Cummer, Yangbo Xie, Chen Shen, Junfei Li, and Zhetao Jia [Duke University, USA]

Acoustic metasurfaces enable the manipulation of sound waves with structures of subwavelength thickness We will describe our research in this area over the past several years, and also describe a new approach for the design and implementation of metasurfaces for perfect wavefront transformation.

11:30 Bianisotropic Acoustic Metasurface for Highly Efficient Wavefront Transformation

Junfei Li, Chen Shen, Ana Díaz-Rubio, Sergei Tretyakov, and Steven Cummer [Duke University, USA, and Aalto University, Finland]

A fundamental limit for GSL-based metasurfaces is their power efficiency, especially at large deflection angles. Here we designed and fabricated the bi-anisotropic cells for wavefront transformation acoustic metasurface that overcomes this limit, allowing us to steer the power flow without parasitic scattering. Our discretized design is verified numerically and experimentally.

11:45 High-efficient Acoustic Anomalous Reflector Based on Power-flow Conformal Metamirror

Ana Díaz-Rubio, Junfei Li, Chen Shen, Steven Cummer, and Sergei Tretyakov [Aalto University, Finland, and Duke University, USA]

In the last years, metasurfaces have attracted much attention due to the capability of tailoring the response in a sub-wavelength scale and their compact implementations. In the particular case of reflective metasurfaces, also called metamirrors, anomalous reflection is a fundamental transformation between two plane waves propagating in different directions. The analysis of this scenario is important for evaluating the potential use of engineered surfaces for more complex functionalities, such as lenses or holograms. Despite the apparent simplicity of this problem, current designs suffer from low efficiency or high complexity. In this paper, we present the analysis and design of an acoustic anomalous reflector device based on power-flow conformal metamirrors. The proposal is experimentally verified showing good agreement with the theoretical predictions.

12:00 Vortex-Sound Diffusers using Spiral Metasurfaces

Noé Jiménez, Vicent Romero-García, and Jean-Philippe Groby [Universitat Politècnica de València, Spain, and Université du Mans, France]

Metamaterials allow the accurate control of the acoustic scattering using subwavelength thickness panels. In this work, we report the scattering of spiral-shaped metasurfaces with practical application to sound diffusers. We analytically, numerically and experimentally show that bipolar spiral-shaped metasurfaces produce broadband non-specular reflection. We observe that the reflected energy can be scattered at higher diffraction orders and, due to the spiral geometry, the phase of the scattering field rotates producing a vortex in the near field. Thus, the specular component at normal incidence vanish. This produces a perfect correlation-scattering coefficient when comparing to a rigid flat reflector of same dimensions. In particular, the scattering of an Archimedes spiral metasurface is presented. We show that the scattering pattern corresponds to a high-order Bessel beam. The use of binary locally reacting surfaces with chiral geometry produce non-specular reflected patterns, allowing the use of these structures use as sound diffusers.

12:15 Broadband Diffusion of Acoustic Waves Via A 1-bit Coding Metasurface

Wenkang Cao, Liting Wu, Gangyong Song, and Qiang Cheng [Southeast University, China]

The acoustic diffusers play key roles in noise control and ultrasound imaging. Here, we propose a new approach to design broadband acoustic diffusers with 1-bit acoustic coding metasurfaces, which are composed of two basic unit cells with out-of-phase responses. We show that the 1-bit acoustic coding metasurfaces are able to diffuse the acoustic waves at will by optimizing the coding sequences, giving rise to ultralow backscattering as desired.

D1 Plasmonics I

Hall: Hall D **Chairs:** Evgenii Narimanov and Katja Höflich

10:30 Hyperbolic Modes of a Single Metal-Dielectric Interface

Evgenii Narimanov [Purdue University, USA]

Subwavelength light confinements at surface plasmon resonance is fundamentally limited by the inherent mobility of free electrons. We report that this non-locality of the electromagnetic response of free charge carriers also results in the formation of a hyperbolic layer near the metal-dielectric interface. While the resulting ``hyperbolic blockade" leads to the suppression of the conventional plasmon resonance, the hyperbolic layer also supports an entirely new class of surface waves, that offer longer propagation distance and stronger field confinement. Furthermore, these "hyper-plasmons" are not limited to the proximity of the plasmon resonance, which extends the operational bandwidth of plasmonic devices.

10:45 Light Scattering by Disordered Assemblies of Plasmonic Nanonantennas

Eslam El Shamy, Patrick Bouchon, Julien Jaeck, and Riad Haïdar [ONERA and Ecole Polytechnique, France]

Optical nanoantennas are widely used to build absorbing metasurfaces with applications in photodetection, solar cells and biology. Most of the time, the nanoantennas are assembled as a periodic distribution, but there have been various works where disordered ar- rays are used, either to get rid of diffraction orders or due to a fabrication process that prevents any determined distribution. Here, we investigate both theoretically and experimentally, the unavoidable scattering introduced by such disorder and we show how this scattering can be manipulated from 0 to 50 % of the incoming light.

11:00 Strong Coupling and Non-reciprocity in the Dynamics of a V-Atom Placed Near an Anisotropic Metasurface

Danil Kornovan, Mihail Petrov, and Ivan Iorsh [ITMO University, Russia, and Aalto University, Finland]

In this work, we focus on studying the temporal dynamics of a V-type quantum emitter with two excited states, which allows observing an interplay between different spontaneous emission channels. We show that the presence of an anisotropic metasurface enables an interaction between the two active transitions and makes it possible to achieve a strong coupling regime. We also show that if the rotation plane of the transition dipole moments is arbitrarily oriented with respect to the metasurface interface, it is possible to observe a non-reciprocal behavior.

11:15 The Resonant Behavior of a Single Plasmonic Helix

Katja Höflich, Enno Hansjürgen, Thorsten Feichtner, Caspar Haverkamp, Heiko Kollmann, Christoph Lienau, and Martin Silies [Helmholtz-Zentrum Berlin für Materialien und Energie, Carl von Ossietzky University Oldenburg, and University of Würzburg,Germany]

Single silver helices with strongly resonant features in the visible range are investigated. They show a strong circular dichroism with resonant features in good agreement with full field modeling. The mechanism of excitation is elucidated using a simple geometric model and analytical considerations.

11:30 "Plasmonics" in Free Space and the Far-Field Metamaterial Superlens (Invited)

Nikolay Zheludev, Guanghui Yuan, and Edward Rogers [University of Southampton, UK, and NTU Singapore, Singapore]

We report experimental realisation of a radically new type of metamaterial "super-lens" capable of creating superoscillatory foci of arbitrary shape and size. Using integrated metamaterial interferometry that allows mapping of fields with resolution ~1/100 wavelength, we reveal the analogy between plasmonic nano-focusing of evanescent waves and superoscillatory nano-focusing of free-space waves.

12:00 Plasmonic Enhancement and Manipulation of Optical Nonlinearity in Monolayer WS2

Jinwei Shi [Beijing Normal University, China]

Two-dimensional transition metal dichalcogenides have giant second order nonlinearity. However, the sub-nanometer thickness of monolayer limits the conversion efficiency. Here, we experimentally show that the second-harmonic generation of WS2 can be enhanced by integrating it on a plasmonic metasurface. The direct enhancement factor of 400 can be realized due to the strong field confinement of the plasmonic dark mode. Meanwhile, the polarization dependence of SHG can also be controlled by the plasmonic mode.

12:15 Fiber-Tip Coupling of Bloch Surface Waves

Michele Scaravilli, Alberto Micco, Giuseppe Castaldi, Giuseppe Coppola, Mariano Gioffrè, Mario Iodice, Vera La Ferrara, Vincenzo Galdi, and Andrea Cusano [University of Sannio, CNR-IMM, and ENEA, Italy]

We experimentally demonstrate the excitation of Bloch surface waves on the tip of single-mode optical fibers via a grating-coupled mechanism. In spite of unavoidable fabrication-related tolerances, we evaluate sensing performances in line with state-of-the-art plasmonic benchmarks, paving the way for the development of advanced 'all-dielectric' lab-on-fiber optrodes.

E1 Theory and modeling I

Hall: E **Chairs:** Fabrice Pardo and Christian Kern

10:30 Light-Based Analog Computing Using a Single Array of Polarizable Particles

Younes Ra'di and Andrea Alù [The University of Texas at Austin, USA]

Light-based signal processing in the spatial domain enables parallel computation, resulting in faster operations in comparison to digital-based systems. We propose a basic platform to realize spatial differentiation and integration of the impinging wavefront using a basic array of electric/magnetic dipoles. We also leverage bianisotropic inclusions to realize odd operations on the impinging wavefront. Our results show that a single array of polarizable particles enables sufficient degrees of freedom to realize optical analog computing using metasurfaces.

10:45 Electromagnetic Field on the Space-Time Map

Marina Yakovleva, Jean-Luc Pelouard, and Fabrice Pardo [Université Paris-Sud and Université Paris-Saclay, France]

Differential forms in their application to electromagnetism are unique visualization tools and elegant way to describe electromagnetic fields. On examples of graphical representations of space-time maps of electric and magnetic fluxes, we will show they contain all the information about electromagnetic fields.

11:00 Mode Hopping in 1D Arrays of Resonant PEC Thin Wires Over an Interface Between Two Dielectric Media

Victor Zalipaev, Sergey Kosulnikov, Stas Glybovski, Alena Schelokova, Alexey Slobozhanyuk, and Pavel Belov [ITMO University, Russia]

Guided localized electromagnetic waves propagating along 1D arrays of thin metallic parallel wires, finite and infinite, are studied. The array of thin PEC wires is embedded in the upper dielectric half-space close to the interface separating two dielectric media with different permittivities. In the first part of the work we study dependence of resonance frequencies of localized modes excited by a finite array of parallel thin wires illuminated by normally incident plane electromagnetic wave with respect to the array height over the interface. Due to the symmetry only two main modes are excited. It is important that when the height of the array becomes sufficiently small the order of the resonance modes changes. We apply numerical analysis based on the Pocklington system of integral equations to compute resonance frequencies and construct excited localized modes above the array. We also compare our results against computations obtained by means of another independent numerical model.

11:15 Spin-wave Localization with Quasi-periodic Magnonic Metamaterials

Kazuzyuki Nakayama, Satoshi Tomita, Ren Kawasaki, Kenji Kasahara, Nobuyoshi Hosoito, Hisao Yanagiand, and Takashi Manago [Fukuoka University and Nara Institute of Science and Technology, Japan]

We study the emergence of localized mode in magnonic metamaterials with quasi-periodic structure. The magnonic metamaterials consist of jointed quasi-periodic grating made of metallic ferromagnetic material. A micromagnetic simulation was demonstrated that localized spin-wave advents at the vicinity of jointed interface.

11:30 TE-wave Propagation in a Graded Waveguide Structure

Mariana Dalarsson and Sven Nordebo [Linnaeus University, Sweden]

We investigate TE-wave propagation in a hollow waveguide with a graded dielectric barrier. We obtain exact analytical results for the electric field components, as well as the exact analytical results for the reflection and transmission coefficients valid for waveguides of arbitrary cross sectional shapes.

11:45 Embedding Fields Into Invisible Metasurface-Bound Volumes

Francisco Cuesta, Viktar Asadchy, Mohammad Sajjad Mirmoosa, Xin Ma, and Sergei Tretyakov [Aalto University, Finland, and Northwestern Polytechnical University, China]

Embedded eigenstates are exotic optical modes which are decoupled from radiating waves, and whose quality factor and lifetime can be unlimited. Here we consider these states as a limit of a more general scenario where one can control the fields inside metasurface-bound cavities which do not produce any scattering fields. We show that for a specific illumination direction it is possible to engineer the fields inside (for example, make them very large or very small) while the system remains perfectly invisible. This study is relevant to such applications as low-observable sensors, electromagnetic cloaking, and non-linear devices.

12:00 Hall Effect Metamaterials (Invited)

Christian Kern, Muamer Kadic, Martin Wegener, and Graeme Milton [Karlsruher Institut für Technologie, Germany, Institut FEMTO-ST, France, and University of Utah, USA]

We review the emerging field of Hall effect metamaterials and present a coherent homogenization theory for deriving the effective parameters. Furthermore, we present two new structures showing a sign reversal of the effective Hall coefficient, which are conceptually distinct from the previously introduced chainmail-inspired metamaterials.

A2 Exotic effects and properties I

Hall: Aalto **Chairs:** Mario Silveirinha and Humeyra Caglayan

14:00 20 New Varieties: Unexplored Constitutive Relations and Axions

Jonathan Gratus, Paul Kinsler, and Martin McCall [Lancaster University and the Cockcroft Institute and Imperial College London, UK]

We eliminate the excitation fields (D,H) by combining the corresponding Maxwell's equations with the constitutive relations. For a homogeneous, non-dispersive, local medium, this gives rise to 20 new parameters. Four are axionic and 16 relate differentials of (E,B) to the charge and current in non-standard ways.

14:15 Real Sources in Complex Spaces

Hayrettin Odabasi and Fernando Teixeira [Eskisehir Osmangazi University, Turkey and The Ohio State University, USA]

We utilize complex transformation optics (CTO) to mimic complex source point (CSP) fields. It is shown that the CSP fields can be exactly reproduced via planar metama-terial slabs associated with the proper complex coordinate transformations. CTO extends the real-valued coordinate transformations to complex-valued coordinate transformations. Of conventional TO, one can also control the amplitude of the fields in addition to their phase paths. In the present paper, we demonstrate that CSP fields can be produced through appropriate material tensors prescribed by the corresponding complex coordinate transformations.

14:30 Enhancement of Circular Dichroism in Epsilon-Near-Zero Chiral Hyperbolic Media

Igor Nefedov, Egor Gurvitz, Alexander Shalin, and Pavel Ginzburg [Aalto University, Finland, ITMO University, Russia, and Tel Aviv University, Israel]

We are presenting a theoretical study of light transmission through a slab of hyperbolic metamaterial made of gold rods, with chiral inclusions, thus possessing both hyperbolic and chiral properties. We have shown that circular dichroism can be strongly enhanced in epsilon-near-zero regime, when the diagonal component of the permittivity tensor corresponding to the normal to interface coordinate tends to zero. The necessary condition of the enhancement is a non-zero light incidence angle. This effect results from a considerable wavelength shortening in normal direction that increases the interaction between light and matter.

14:45 Lateral Optical Forces On Linearly-Polarized Emitters Near A Reciprocal Substrate

Hafssaa Latioui and Mario Silveirinha [University of Lisbon, Portugal]

We investigate optical forces on dipole-type emitters near a reciprocal translation-invariant substrate. Surprisingly, we find that for linearly-polarized electric dipoles the lateral force vanishes, independent of the substrate anisotropy or chirality. We identify a novel opportunity to have recoil forces with a superposition of two collinear electric and magnetic dipoles.

15:00 Moving Beyond the Point-Like Scatterer - The Dramatic Effects of Subwavelength Coupling on Micro-Doppler Signatures

Dmitry Filonov, Vitali Kozlov, and Pavel Ginzburg [Tel Aviv University, Israel]

Micro-Doppler signatures carry information on the internal motion of an electromagnetic scatterer. While standard approaches, developed for radar analysis of targets, consider rotary motion in a phenomenological fashion, detailed electromagnetic analysis enables to extract much more information regarding a motion of an object. In this report, we present a novel analysis method that allows the extraction and analysis of micro-Doppler signatures from strongly coupled subwavelength objects. This technique can allow new types of signal processing that extend the current capabilities of standard micro-Doppler methods, which were designed for large and weakly coupled objects. Such standard methods often require expensive high-frequency equipment in order to properly extract the signal, which restricts their applicability in daily use applications. Our method enables relaxing those constraints. As an example of the usefulness of the new technique, we analyze the case of a double-rotor helicopter illuminated by a low-frequency continuous wave and show how its signature can be used to estimate the angle between the rotors. New types of experiments, supported with comprehensive electromagnetic analysis will be presented.

15:15 Cancelling Magnetic Sources at a Distance with Negative Permeability

Rosa Mach-Batlle, Carles Navau, and Alvaro Sánchez [Universitat Autonoma de Barcelona, Spain]

The control of magnetic fields, traditionally done by using magnetic materials, has recently been enriched with the development of magnetic metamaterials. However, all magnetic materials and metamaterials have positive permeability values. Here we show how the consideration of negative permeability in magnetostatics yields a new set of possibilities for controlling static magnetic fields. They include intriguing possibilities such as the cancellation at a distance of the field created by a magnet.

B2 Acoustic metamaterials I

Hall: B **Chairs:** Guancong Ma and Vincent Pagneux

14:00 Coherent Perfect Absorption with Bubble Metascreens

Maxime Lanoy, Reine-Marie Guillermic, Anatoliy Strybulevych, and John H. Page [University of Manitoba, Canada]

The particularly efficient and low frequency Minnaert resonances of air bubbles in fluids or soft solids make them excellent candidates for the realization of acoustic metamaterials. Here, we study the transmission of a plane wave through a single meta-layer consisting of periodic arrangement of air bubbles trapped in a viscoelastic matrix and show how a perfect coherent absorber can be realized.

14:15 Interferometric Control of Absorption in a 3-port Acoustic Network

Olivier Richoux, Vassos Achilleos, Georgios Theocharis, and Ioannis Brouzos [University of Le Mans, France, and University of Athens, Greece]

An acoustic 3-port network is studied both theoretically and experimentally and CPA is found using asymmetric and symmetric inputs. We further study the sensitivity of CPA and propose optimized structures presenting CPA and CPT at the same frequency by tuning only phase and/or amplitude change of the input.

14:30 Measurement of Monopole and Dipole Scattering in Acoustic Meta-Atoms

Joshua Jordaan and David Powell [Australian National University and University of New South Wales, Australia]

A technique is presented to experimentally determine the monopole and dipole scattering coefficients in two-dimensional acoustic meta-atoms. The technique is calibrated against the known solution for scattering from a hard cylinder. It is then applied to space-coiling type structures, which support resonances of different multipolar order. It is shown that good quality results can be achieved for geometries having wider channels and thicker walls. Performance with narrower channels and thinner walls is poorer, which we attribute to thermo-viscous effects or excitation of elastic vibrations within the structure.

14:45 Manipulating Acoustic Waves Radiation Direction Using Liner Surface Modes

Maaz Farooqui, Yves Auregan and Vincent Pagneux, [Laboratoire d'Acoustique de l'Universite du Maine, France]

Acoustic liners are treatments of wall with impedance boundary condition, and they can be used to generate Acoustic Surface Waves (ASWs). In this work, we show how to design the impedance treatment in order to avoid the reflection of acoustic waves at the open end of a duct (anechoic termination). Moreover, by changing the liner geometry at the end of the duct, it is possible to control the acoustic wave radiation pattern. This work can have interesting applications for directional acoustic propagation.

15:00 Demonstration of Steering Acoustic Waves by Generalized Eaton Lens

Dongwoo Lee, Choonlae Cho, Namkyoo Park, and Junsuk Rho [Pohang University of Science and Technology and Seoul National University, South Korea]

We demonstrate the generalized Eaton lens in the acoustic regime by using the S-parameter retrieval method to obtain effective properties. The proposed design composed of cylindrical PMMA rods corresponding the required effective indices can steer acoustic waves at arbitrary refraction angles up to 45° in a broad range of frequency.

15:15 Radiation Characteristics of Acoustic Luneburg Lens Consisted of FCOC Metamaterial

Choon Mahn Park and Sang Hun Lee [Dong-A University and Seonam University, South Korea]

Two-dimensional acoustic Luneburg lens that can easily be expanded into a three-dimensional sphere is fabricated. We investigated typical characteristics of the resulting acoustic Luneburg lens, such as its aberration-free performance and capability for antipodal focusing of the lens for the incident plane waves through experiments and simulations.

D2 Plasmonics II

Hall: D **Chairs:** Dimitrios Tzarouchis and Alexei Vinogradov

14:00 Highly Confined Surface Plasmon on Nanostructured Surface of Aluminum (Invited)

Alexei Vinogradov, Eugeni Chubchev, Igor Nechepurenko, Alexander Dorofeenko, and Alexander Lisyansky [Dukhov Research Institute of Automatics, Russia and City University of New York, USA]

We demonstrate that in the ultraviolet range, surface plasmon propagating along a periodically nanostructured aluminum surface have an exhibits the confinement length as small as 10 nm. At the same time, the propagation length of new surface plasmon-polaritons can reach dozens of its wavelengths.

14:30 Plasmon-excitonic Enhancement of the Transverse Magneto-Optical Kerr effect in the Semiconductor Magnetic Nanostructures

Olga Borovkova, Felix Spitzer, Andrey Kalish, Vladimir Belotelov, Ilya Akimov, Aleksander Poddubny, Victor Sapega, Maciej Wiater, Tomasz Wojtowicz, Grzegorz Karczewski, Anatoly Zvezdin, Dmitry Yakovlev, Leonid Litvin, Ralf Jede, and Manfred Bayer [RQC and Ioffe Institute, Russia, TU Dortmund University and Raith GmbH, Germany, and Institute of Physics, Poland]

It is reported an enhancement of the transverse magneto-optical Kerr effect (TMOKE) in the vicinity of the excitonic and hybrid plasmon-exciton modes. Such modes are excited in quantum well in the bare diluted semiconductor thin films and in the plasmonic semiconductor nanostructures. Two-order enhancement of the TMOKE is observed in bare semiconductor films in the spectral region of the excitonic resonances. In plasmonic semiconductor nanostructures with quantum wells we also observe the hybridization of the TMOKE spectrum due to excitation of plasmon-exciton modes.

14:45 Surface Plasmon Resonances in the Diffracted Magneto-Optical Effects

Rafael Cichelero, Mikko Kataja, and Gervasi Herranz [Institut de Ciencia de Materials de Barcelona, Spain]

We study how magnetic manipulation of surface plasmon polaritons (SPPs) can influence the diffraction properties of metallic diffraction gratings. Experimental measurements unveil non-reciprocal diffraction pattern due to the ability of transverse magnetic fields to modify the SPP excitation condition.

15:00 Plasmonic Eigenmodes on Regular Nano-Polyhedra: Case Study of Electrostatic and Dynamic Resonant Effects on Rounded Superquadric Solids

Dimitrios Tzarouchis, Pasi Ylä-Oijala, and Ari Sihvola [University of Pennsylvania, Finland, and Aalto University, Finland]

The use of the theory of characteristic modes for the study of plasmonic eigenstates of rounded hexahedral and octahedral nanoscatterers is proposed and presented. After a brief study of electrostatic modes in a hexahedral structure follows the corresponding characteristic mode analysis. The analysis reveals the existence, for the first time, of highly symmetric dark modes on the surface of a rounded cube, enhancing our views on the triggered scattering mechanisms for single nanoparticles.

15:15 A Galvanically Replaced Composite Nanocrystal Based Metamaterials for Plasmonic Applications

Soo-Jung Kim, Mingi Seong, Heon Lee, SoongJu Oh, and Sung-Hoon Hong [Korea University and ETRI, South Korea]

We demonstrate the simple fabrication way of the tunable, thermally and chemically stable plasmonic metamaterials using nanoimprinting and galvanic replacement process. By galvanic replacement process, the Ag-Pt (or Ag-Au, Ag-Pd) composite metamaterials were fabricated and the optical plasmonic resonances were controlled for various applications.

E2 Active/non-Hermitian systems I

Hall: E **Chairs:** Flynn Castles and Silvio Hrabar

14:00 Active Metamaterials with Negative Static Dielectric Susceptibility

Flynn Castles and Patrick Grant [Queen Mary University of London and University of Oxford, UK]

We argue that, contrary to well-established theory and experiment for passive materials, active materials may exhibit negative static dielectric susceptibility: the electric analogue of diamagnetism. We fabricate and experimentally verify active structures with tunable and negative effective dielectric susceptibility for static electric fields.

14:15 Analysis of Metamaterial-inspired N-type Non-Foster Oscillator

Silvio Hrabar, Leo Vincelj, and Igor Krois [University of Zagreb, Croatia]

Recently introduced non-Foster antenna-transmitter could be viewed as an extension of familiar concept of one-port negative-resistance oscillator. Here, we report preliminary numerical and experimental results of applying this formalism to the design of N-type non-Foster oscillator that may be used in future active self-oscillating metasurfaces.

14:30 Non-linearity Enhances Versatility of Non-Foster Metamaterials and Metasurfaces (Invited)

Silvio Hrabar [University of Zagreb, Croatia]

Classical applications of non-Foster elements presume their linearity. Here, we show that the voltage-conversion and the current-conversion negative impedance converters show different behavior in non-liner regime. It is followed by different power-dependent properties of generated reactance/susceptance. This effect may be used in self-oscillating and self-mixing metasurfaces and in power-tunable metamaterials/metasurfaces.

15:00 Constant Pressure Sound Waves in Non-Hermitian Disordered Metamaterials (Invited)

Etienne Rivet, Andre Brandstötter, Konstantinos G. Makris, Hervé Lissek, Stefan Rotter, and Romain Fleury [Swiss Federal Institute of Technology in Lausanne, Switzerland, Vienna University of Technology, Austria, and University of Crete, Greece]

In theory, waves with constant amplitude can be perfectly transmitted through a disordered medium by adding a properly designed distribution of gain and loss. We present the theory and the first experimental proof of this concept in a one-dimensional acoustic metamaterial.

A3 Application of microwave and THz metamaterials

Hall: Aalto **Chairs:** Geoffroy Lerosey and Michal Cifra

16:00 Reduction of the Beam-Coupling Impedance in Accelerating Structures Using Metamaterial-Based Absorbers

Maria Rosaria Masullo, Vittorio Giorgio Vaccaro, Roberto Losito, Alessandro Masi, Nassim Chikhi, Can Koral, Gian Paolo Papari, Anna Pugliese, Antonello Andreone [Istituto Nazionale di Fisica Nucleare and University of Naples "Federico II", Italy, and CERN, Switzerland]

Resistive-wall impedance constitutes a significant percentage of the total beam-coupling impedance budget of an accelerator. Under extreme conditions, like large power handling and ultra-high vacuum, metamaterial-based absorbers can represent a valid alternative to other approaches for impedance mitigation in specific accelerator components, like resonant (parasitic) cavities or collimators operating along the beam line. We design sub-wavelength 2D metallic resonant structures based on split rings or on 3D hyperbolic tapered waveguide arrays that can be employed as mode dampers in accelerating structures. A number of prototypes are fabricated and then measured in a "test model" pillbox cavity.

16:15 Microwave Bandgap Structure for Detecting Changes in Dynamics of Water Molecules

Michal Cifra, Daniel Havelka, Ondrej Krivosudský, and Jiří Průša [Institute of Photonics and Electronics, Czechia]

We designed a sensing defected bandgap microwave structure based on periodically modulated coplanar waveguide with a sharp resonance at around 40 GHz due to defect in periodicity. In simulation, we demonstrated that the resonance peak is sensitive to changes of water relaxation time which can occur due to biomolecule presence.

16:30 Wavefront Shaping in the Microwave Domain Using Tunable Metasurfaces: Concept and Applications (Invited)

Geoffroy Lerosey, Philipp Del Hougne, Fabrice Lemoult, and Mathias Fink [Greenerwave and Institut Langevin, France]

In this talk we will show that the concept of wavefront shaping, originally proposed in optics, can be transposed to the lower frequency domain of microwaves, using electronically controllable metasurfaces. We will provide a physical background of wavefront shaping of microwaves in reverberant media and provide several examples of applications, from enhanced and greener wireless communications to smart cavities.

17:00 Highly Efficient Multichannel Reflection With Metagratings

Vladislav Popov, Fabrice Boust, and Shah Nawaz Burokur [Université Paris-Saclay, ONERA, and Université Paris Nanterre, France]

In this study, metagratings are used to gain total control over waves diffracted in the far-field. A 1D periodic array of N polarization electric line currents per super cell placed on a grounded dielectric substrate and excited by an incident plane wave is considered. To validate the developed theoretical approach wide-banded anomalous and multichannel reflections are demonstrated with 3D full-wave simulations at 10 GHz.

17:15 Could Wi-Fi Waves Bouncing Around Inside an Indoor Room Perform Analog Computation?

Philipp del Hougne and Geoffroy Lerosey [Institut Langevin and Greenerwave, France]

We introduce the idea that – subject to appropriate wavefront shaping – any disordered medium can serve as analog computation unit acting on impinging waves. We demonstrate the ease of implementation with an experiment emulating Wi-Fi waves in indoor environments. Using home-made tunable metasurfaces to shape the wave field, we perform a 4x4 complex-valued operation.

17:30 Power Vortices in Wire-Medium Endoscopes (Invited)

Constantin Simovski, Dmitro Vovchuk, and Sergei Kosulnikov [Aalto University, Finland, University of Chernivtsi, Ukraine, and University ITMO, Russia]

In this paper we show that for a multiwire endoscope the concept of bending losses is not relevant. An array of metal wires makes the frequency-averaged power transmittance of the endoscope robust to the bends, however, the frequency dispersion of the power loss factor is strongly oscillating. These oscillations are related to power vortexes in the endoscope which drastically increase the radiation loss. This issue is critical for the future of wire-medium endoscopes

B3 Elastic metamaterials

Hall: B **Chairs:** Corentin Coulais and Jensen Li

16:00 Engineering Elastic Wave Propagation Using Metasurface Approach (Invited)

Jensen Li and Yongquan Liu [Hong Kong University of Science and Technology, Hong Kong, and University of Birmingham, UK]

We introduce our recent approaches to manipulate elastic waves based on metasurfaces. By using both non-resonating and resonating structures, flexible amplitude or phase of transmission and reflection can be obtained. Symmetry breaking and Fabry-Pérot resonance on the structures are further applied to obtain asymmetric reflection of elastic waves.

16:30 An Elastic Metasurface with Real-Time Programmed Wave Control (Extended)

Guoliang Huang and Yangyang Chen [University of Missouri, USA]

Here, we introduce a programmable elastic metasurface for the first time with self-sensing-and-actuating units, allowing to adapt and reprogram its wave control functionalities in real time.

17:00 Experimental Observation of Elastic Edge Waves in Mechanical Granular Graphene

Li-Yang Zheng [Laboratoire d'Acoustique de l'Université du Mans, France]

We theoretical and experimental study the wave dynamics in a two-dimensional magneto-granular graphene. The measured dispersion curves and evidence of Dirac cone are presented. In addition, the experimental observation of edge wave propagation in the granular graphene is demonstrated.

17:15 Negative Reflection and Refraction of Guided Elastic Waves

François Legrand, Benoit Gérardin, Jérôme Laurent, Claire Prada, and Alexandre Aubry [Institut Langevin, France]

We report on the experimental implementation of negative refraction phenomena with guided elastic waves. On the one hand, we explore the analogy between negative reflection and phase conjugation for the control of waves in random scattering and chaotic media. On the other hand, we implement the concept of complementary media and the ability to cancel the propagation of waves by adjoining two mirror regions of opposite refractive indices. To that aim, a semi-analytical model and FDTD numerical simulations have been developed to optimize and design these acoustic devices. Wave propagation through the designed elastic plates is experimentally investigated by means of laser interferometry.

17:30 Asymmetric Elastic Wave Propagation in Spatiotemporal Granular Phononic Crystal

Florian Allein, Samuel P. Wallen, Georgios Theocharis, and Nicholas Boechler [Le Mans Université, France, and The University of Texas at Austin and University of California, USA]

We present a granular-based acoustic device to control elastic wave propagation that takes advantage of the translational and rotational degrees of freedom in the device. Asymmetric wave propagation is investigated via spatiotemporal modulation of stiffnesses. The presence of directional band gaps, directional wave conversion, and directional wave reflection/transmission is shown.

17:45 Inertial Amplification Induced Phononic Band Gaps in a Chiral Elastic Metamaterial

Cetin Yilmaz [Bogazici University, Turkey]

A helical structure with periodic disks is investigated. By varying the helix angle of the links that connect the disks, dispersion diagram of this chiral structure is altered. Both Bragg scattering and inertial amplification induced gaps are generated. Compact analytical formulations are derived for the band gap starting frequency and the notch frequency due to inertial coupling within the structure.

D3 Quantum effects

Hall: D **Chairs:** Iñigo Liberal and Xiangdong Zhang

16:00 Quantum Metamaterials with Extreme Nonlinearities (Invited)

Zhaowei Liu [University of California, USA]

With the size of metal films entering into the nanoscale, the impact of quantum size effect becomes significantly important. Here we demonstrate a giant optical Kerr susceptibility in sub-3nm gold films, which is 4 order-of-magnitude higher than the intrinsic value of bulk gold, opening new doors for metamaterials with extreme nonlinearities.

16:30 Controlling Photon Statistics with Arrays of Quantum Emitters (Extended)

Iñigo Liberal, Iñigo Ederra, and Richard W. Ziolkowski [Public University of Navarre, Spain, and University of Arizona, USA]

We introduce the concept of quantum antenna arrays, i.e., ensembles of quantum emitters that enable control over photon statistics of any order by designing the geometry of the array. To this end, we generalize conventional antenna array theory by introducing an array factor of order L, which describes the impact of the array geometry in angular photon statistics of order L. As an example, we examine the emission properties of a linear vertical array, and we discuss its application as a source of directionally entangled photon bunches.

17:00 Metamaterial Chips: Implementing Quantum Algorithm

Xiangdong Zhang, Weixuan Zhang, Kaiyang Cheng, Chao Wu, Yi Wang, and Hongqiang Li [Beijing Institute of Technology and Tongji University, China]

We report recent researches on a new class of metamaterial chips to perform wave-based quantum algorithms. The metamaterial chips have been fabricated by using 3D printing technique. Quantum searching algorithm and Deutsch–Jozsa algorithm have been demonstrated experimentally by using our metamaterial chips. Such metamaterial-based quantum algorithm simulators may lead to remarkable achievements in wave-based signal processors.

17:15 2D Semi-Analytical Model for Optimizing the Radiation Emission of Quantum Emitters Embedded in a Bounded Nano-Patterned Hyperbolic Metamaterial

Achiles Fontana da Mota, Augusto Martins, Vinicius Marrara Pepino, Emiliano Rezende Martins, John Weiner, Fernando Lisboa Teixeira, and Ben-Hur Viana Borges [University of São Paulo, Brazil and Ohio State University, USA]

We propose a two dimensional (2D) semi-analytical method to calculate the radiated power and Purcell factor of a quantum emitter (QE) embedded in a medium bounded between a nano-patterned structure and a homogeneous dielectric. We apply our 2D model to optimize a nano-patterned hyperbolic metamaterial (HMM) to increase the QE's quantum efficiency while preserving a high Purcell factor. The low computational cost of this method makes it quite attractive for quantum efficiency optimization, providing initial physical and/or geometrical parameters to be fine-tuned with three-dimension (3D) full-wave techniques such as FDTD.

17:30 Optical Properties of Core-Shell Systems with Sub-Nanometer Plasmonic Gaps: A Quantum Hydrodynamic Theory Approach

Muhammad Khalid, Fabio Della Sala, and Cristian Ciraci [Istituto Italiano di Tecnologia and Institute for Microelectronics and Microsystems-CNR, Italy]

Plasmonic response of the metallic structure characterized by sub-nanometer dielectric gaps can be strongly effected by nonlocal or quantum effects. In this paper, we investigate these effects in spherical nanomatryoshka structures with sub-nanometer core-shell separation. We use the state-of-the-art quantum hydrodynamic theory to study both near-field and far-field optical properties of these systems. We find that the results obtained using the QHT method are in a very good agreement with those of time-dependent density functional theory.

17:45 Coherent Perfect Absorption and Switching in a Fiberized Quantum Network with Plasmonic Metadevice

*Anton Vetlugin, Ruixiang Guo, Angelos Xomalis, Salih Yanikgonul, Giorgio Adamo, Cesare Soci, and Nikolay Zheludev [Nanyang Technological University and Data Storage Institute A*STAR, Singapore, and University of Southampton, UK]*

In this report, we provide the first demonstration of a fully fiberized quantum network with a fiber-integrated metamaterial as a dissipative switching element. Using the phenomenon of coherent absorption in plasmonic metamaterials we achieve high-contrast control of the single photon absorption probability and demonstrate switching application.

E3 Sensing and imaging

Hall: E **Chairs:** Giuseppe Strangi and Alexander V. Kildishev

16:00 Coherent Electron Transport in Metamaterials of Integrated Semiconductor Quantum Dots and Biomolecules for Medical Imaging Applications

Bakhysh Bairamov, Vadimir Toporov, Farid Bayramov, Oleg Chakchir, Harry Lipsanen, Ilkka Tittonen, and Mack Kira [Ioffe Institute and St.Petersburg National Research Academic University RAS, Russia, Aalto University, Finland, and University of Michigan, USA]

The fundamental research of many-body interactions and coherent transport of single particle elementary excitations exploiting strong-light matter interactions in artificial molecular metamaterials of nc-Si/SiO2 quantum dots as well as their functionalization by biomolecules will be considered.

16:15 Terahertz and Infrared Imaging of Absorption in Disordered Metasurfaces

Nicolas Fernez, Ludovic Burgnies, Guillaume Ducournau, and Eric Lheurette [Université de Lille and Université du Littoral Côte d'Opale, France]

We performed terahertz imaging of absorption parameter in positional disordered metasurfaces as a function of frequency. This experimental characterization highlights the influence of array density in absorption level and bandwidth. In addition, infrared imaging of these metasurfaces under large signal excitation is used to analyze the role of extended modes in the absorption mechanism.

16:30 High Temperature Sensing with Refractory Plasmonic Metasurfaces (Invited)

Urcan Guler, Krishnakali Chaudhuri, Shaimaa Azzam, Harsha Reddy, Vladimir Shalaev, Alexandra Boltasseva, and Alexander Kildishev [Purdue University, USA]

We utilize refractory plasmonic material titanium nitride to experimentally demonstrate metasurface-based remote optical sensing of high temperatures in harsh environmental conditions. Temperature-dependent optical constants give rise to a change in reflectance with varying temperatures.

17:00 Extreme Optics of Hyperbolic Dispersion: Plasmons at the Bio-Photonic Interface (Invited)

Giuseppe Strangi, Sreekanth K.V., Mohamed ElKabbash, and Michael Hinczewski [Case Western Reserve Univeristy, USA]

In recent years, significant efforts have been made to design and fabricate functional nanomaterials for biomedical applications. These research activities unlocked a complete new research field known as nano-biophotonics. Extreme optics of artificial materials characterized by hyperbolic dispersion allowed to access new physical effects and mechanisms. The unbound isofrequency surface of hyperbolic metamaterials opened the way for virtual infinite photonic density of states and ultrahigh confinement of electromagnetic fields in multilayered nanostructures which led to perfect absorption and unparalleled sensing properties. Optical sensor technology based on plasmonic metamaterials offers significant opportunities in the field of clinical diagnostics, particularly for the detection of lower-molecular-weight (<500 Da) biomolecules in highly diluted solutions. Research activities based on new advanced designs of hyperbolic dispersion metamaterials for perfect absorption and super-collimation will be discussed.

17:30 Detection of Small Magnetic Fields via Magneto-optical Intensity Effect in Metal-dielectric Heterostructures

Andrey Kalish, Grigory Knyazev, Pavel Kapralov, Nikolay Gusev, Petr Vetoshko, Anatoly Zvezdin, and Vladimir Belotelov [Russian Quantum Center, Russia]

A new method for detection of weak magnetic fields using the longitudinal magnetophotonic intensity effect in periodic metal-dielectric heterostructures is proposed. Experimental demonstration of the method allowed to achieve sensitivity of about 1 nT in the spectral band of 60 kHz. A theoretical estimate of the sensitivity limit is given.

17:45 Measuring Glucose Content in Aqueous Solutions by means of Split Ring Resonator (SRR) Loaded Transmission Lines

Paris Velez, Jonathan Muñoz, Javier Mata-Contreras, David Dubuc, Katia Grenier, and Ferran Martín [Universitat Autonoma de Barcelona and Universidad de Málaga, Spain, and Laboratory of Analysis and Architecture of Systems, France]

In this paper, a pair of uncoupled microstrip lines each one loaded with a split ring resonator (SRR) in a symmetric configuration is useful to measure the solute content in very diluted solutions. The principle of operation of this microwave sensor is symmetry disruption, achieved by loading both resonators with different aqueous solutions.

TUESDAY

9:00 **Plenary session II**

10:00 **Coffee**

	Aalto Hall	Hall B	Hall D	Hall E
10:30	**A4**	**B4**	**D4**	**E4**
	Special session: Recent advances and trends in meta-surfaces I	*Tunable / programmable metamaterials*	*Novel effects enabled by optical meta-materials*	*Theory and modelling II*

12:30 **Lunch**
Workshop: Simulation of Metamaterials with COMSOL

14:00	**A5**	**B5**	**D5**	**E5**
	Special session: Recent advances and trends in meta-surfaces II	*Acoustic meta-materials II*	*Plasmonics III*	*Magnetic-resonance-imaging applications*

15:30 **Coffee**

16:00	**A6**	**B6**	**D6**	**E6**
	Exotic effects and properties II	*Mechanical and acoustic meta-materials*	*Graphene*	*Antenna applications*

17:40 **Social event: Excursion to Nuuksio**
21:30

Plenary session II

Hall: Aalto **Chair:** Vincenzo Galdi

9:00 Metasurface Antenna Design
Stefano Maci
University of Siena , Italy

A review of recent achievements obtained in Metasurface Antennas design is presented. These antennas are based on a transformation between a cylindrical surface-wave (SW) and a leaky-wave (LW) through interaction with a periodically modulated MTS. The latter is realized by using sub-wavelength patches of different dimensions printed on a grounded slab or by metal pins on stepped metallic ground. A general design process is described, followed by a description of the main challenges and open problems in practical implementation.

A4 Special session:
Recent advances and trends in metasurfaces I

Hall: Aalto **Chairs:** David Smith and Stefano Maci
Organizers: David Smith and Stefano Maci

10:30 Electrically Tunable Metasurfaces (Invited)
Ali Forouzmand, Mohammad Mahdi Salary, and Hossein Mosallaei [Northeastern University, USA]

Several novel methodologies and design principles are proposed to realize tunable multifunctional and multispectral metasurfaces which operate based on gate-tunable biasing and integration of indium-tin-oxide into plasmonic and all-dielectric nanostructures offering large phase modulation. Moreover, the potential of time-modulation for achieving wide operating bandwidth and full phase-agility is investigated.

11:00 Line Waves and Unidirectional Propagation on Metasurfaces (Invited)
Daniel Sievenpiper and Dia'aaldin Bisharat [University of California San Diego, USA]

We have developed a new kind of waveguide in which the modes consist of the interface states between two complementary impedance surfaces. It is analogous to two-dimensional surface waves, which are bound to the planar interface between two media, but in this case the waves are bound to the one-dimensional line interface between two sheets. They have several important properties, including a field singularity, and unidirectional propagation of two orthogonal modes, such that the polarization is locked to the propagation direction. We will examine how they are realized using metasurfaces, and their relationship to other media such as photonic topological insulators and chiral materials.

11:30 Engineering Diffraction With Analytically Designed Metagratings (Invited)
Oshri Rabinovich and Ariel Epstein [Technion - Israel Institue of Technology, Israel]

We report analytical methodologies for synthesis of planar devices for perfect beam deflection, based on periodic arrays of printed capacitors (meta-atoms). These so called metagratings (MGs) were shown to facilitate efficient anomalous reflection by tuning the capacitor width and position such that the spurious (specular) reflection is cancelled, and all of the incoming power is coupled to the desirable (first-order) Floquet-Bloch mode. In this talk we present two advancements with respect to previous work. First, we incorporate a supporting substrate into the analytical model, allowing rigorous design of realistic printed-circuit-board (PCB) MGs for perfect anomalous reflection. Second, we extend the MG concept to include multiple meta-atoms per period, enabling control of multiple diffraction modes, implementing perfect anomalous refraction. Importantly, both physical designs, verified via full-wave simulations, are obtained without any optimization in commercial solvers, demonstrating the efficiency and reliability of the proposed schemes for developing advanced diffraction engineering surfaces.

12:00 From Cascaded Metasurfaces to Compound Metaoptics (Invited)
Anthony Grbic, Zhanni Wu, Brian O. Raeker, and Amin Ranjbar [University of Michigan, USA]

This paper summarizes recent advances and ongoing work by the authors in the area of metamaterial surfaces. Specifically, cascaded metasurfaces are described that consist of multiple subwavelength patterned sheets and can exhibit electric, magnetic, and magnetoelectric properties.

B4 Tunable /programmable metamaterials

Hall: B **Chairs:** Anastasiia Krushynska and Xiang Wan

10:30 Tunable Extraordinary Sound Transmission by a Metasurface Based on Acoustic Mie-Resonator Dimers

Jin Zhang, Ying Cheng, Desheng Ding, and Xiaojun Liu [Nanjing University and Southeast University, China]

The effective impedance modulation of artificial acoustic metamaterials is crucial in application scenarios. Here, a Mie-resonator dimer is proposed as a tunable mutual inductive coupled unit to drive a mismatched to matched impedance transition, which can achieve a wide impedance modulation range.

10:45 Tunable Extremely Wide Low-frequency Band Gaps in Accordion-like Metamaterials

Anastasiia O. Krushynska, Ada Amendola, Federico Bosia, Chiara Daraio, Nicola M. Pugno, and Fernando Fraternali [University of Trento, University of Salerno, and University of Torino, Italy, and California Institute of Technology, USA]

To achieve wave control at broad-band ultra-low frequencies, we design "accordion-like" meta-structures by periodically alternating tensegrity prisms with solid disks. The structures are characterized by extremely wide band gaps, which can be tuned by varying the level of prestress in the constituent elements. They provide valid alternatives to other metamaterials with low-frequency performance, the functionality of which relies on a locally resonant mechanism, by overcoming an inherent limit of narrow operating frequency ranges and demonstrating the resilience to variations in geometric and material parameters.

11:00 Tunable Perfect Anomalous Reflection in Metasurfaces with Capacitive Lumped Elements

Odysseas Tsilipakos, Fu Liu, Alexandros Pitilakis, Anna Tasolamprou, Do-Hoon Kwon, Mohammad Mirmoosa, Nikolaos Kantartzis, Eleftherios Economou, Maria Kafesaki, Costas Soukoulis, and Sergei Tretyakov [Foundation for Research and Technology Hellas, Greece, Aalto University, Finland, and University of Massachusetts Amherst and Iowa State University, USA]

We demonstrate tunable perfect anomalous reflection with metasurfaces incorporating lumped elements. Properly tuning the capacitance of each element allows for tilting the reflected wavefront. The performance is thoroughly assessed for both TE and TM polarization and for reflection to the first and second diffraction order.

11:15 Electrically Tunable Solid-State Terahertz Metamaterial Absorbers

Dimitrios Zografopoulos, Goran Isic, Borislav Vasic, Antonio Ferraro, Giorgos Sinatkas, Emmanouil Kriezis, Radoš Gajić, and Romeo Beccherelli [Istituto per la Microelettronica e Microsistemi, Italy, University of Belgrade, Serbia, and Aristotle University of Thessaloniki, Greece]

Electrically tunable terahertz metamaterial absorbers are designed, based on critically coupled resonant cavities filled with n-doped GaAs. By reverse biasing a Schottky junction at the top GaAs/metal interface, the GaAs complex permittivity is tuned, achieving amplitude modulation of the reflected wave with low insertion losses and theoretically infinite extinction ratio.

11:30 Dynamic Steganographic Crypto-metaprints

Jaehyuck Jang, Heonyeong Jeong, and Junsuk Rho [Pohang University of Science and Technology, South Korea]

Meta-structural colours demand broad and dynamic/tunable colours for the next step toward real life applications. We used Kerker's conditions to design broad and dynamic meta-structural colours with near-zero-loss dielectric material. The colours are modulated by changing unit nanocuboid structures and incident polarization state; this process enables highly-secure steganographic crypto-metaprints.

11:45 Direct Transmission of Near-field Images Using Binary Programmable Metasurface

Xiang Wan and Tie Jun Cui [Southeast University, China]

A binary programmable metasurface is designed to generate arbitrary images in the near-field region. By adequately changing the coding sequences of the metasurface, these images can be detected by a single fixed probe, hence realizing direct transmission of near-field images.

12:00 Emerging Materials for Tailorable Nanophotonic Devices (Invited)

Zhuoxian Wang, Deesha Shah, Krishnakali Chaudhuri, Alessandra Catellani, Mohamed Alhabeb, Harsha Reddy, Xiangang Meng, Shaimaa Azzam, Nathaniel Kinsey, Alexander Kildishev, Young Kim, Vladimir Shalaev, Arrigo Calzolari, Yury Gogotsi, and Alexandra Boltasseva [Purdue University, Drexel University, and Virginia Commonwealth University, USA, and Instituto Nanoscience, Italy]

We report on two classes of emerging materials, ultra-thin TiN and MXenes, as a potential material platform for plasmonic metamaterials. Due to their increased sensitivity to structural and compositional parameters, both ultra-thin TiN and MXenese are promising candidates for tailorable nanophotonic devices.

D4 Novel effects enabled by optical metamaterials

Hall: D **Chairs:** Alessio Monti and Kyoungsik Kim

10:30 Resonant Scattering of Ultrashort Laser Pulses: New Effects (Invited)

Michael Tribelsky [Lomonosov Moscow State University, Russia]

A survey of the recent results of the author in the unsteady high-Q resonant scattering of ultrashort laser pulses by nanoparticles is presented. It is shown that the unsteadiness of the scattering process may result in qualitative changes of the phenomenon both in the near field and in far field wave zones. The most attention is paid to the dynamics of the nonradiating anapole modes and dynamical Fano resonances, which are discussed in detail. Simple, analytically tractable models are proposed to describe the transient processes. Their comparison with the results of the direct numerical integration of the complete set of the Maxwell equations shows that the models exhibit high accuracy in the quantitative description of the phenomenon.

11:00 Elasto-Optic Metamaterials For Large-Scale Optical Devices (Invited)

Kyoungsik Kim, Dongheok Shin, and Changwook Kim [Yonsei University, South Korea]

By mechanically compressing the transparent nanoporous silica aerogels, we realize gradient index optical components and devices which have inhomogeneous refractive index distribution in the visible wavelength region. A Luneburg lens and a transformation optics wave bender are experimentally demonstrated.

11:30 Spontaneous Emission from Embedded Quantum Dots Enhanced by Mie Resonances

Mihail Petrov [ITMO University, Russia]

Resonant silicon nanostructures possessing magnetic and electric Mie resonances became of strong interest for nanophotonics. Previously, the light emission stimulated with Mie modes was considered from the quantum sources placed outside the resonators such as colloid quantum dots. In this work we, for the first time, demonstrate that the emission enhancement from Ge(Si) quantum dots embedded inside the nanoresonators. We observe reshaping of the emission spectrum and demonstrate that it can be controlled through the mode engineering in silicon nanoresonators oligomer structures.

11:45 Tailoring Optical Reflections Through Lattices of High-Index Dielectric Nanoparticles

Alessio Monti, Andrea Alù, Alessandro Toscano, and Filiberto Bilotti [Roma Tre University, Italy, and CUNY Advanced Science Research Center, USA]

Due to their low losses and exotic response at optical frequencies, high-index dielectric nanoparticles are a promising candidate for many relevant nanophotonics applications. In this contribution, we investigate the use of arrays of dielectric nanoparticles for tailoring optical reflections. Two different categories of devices are considered: (i) ultra-thin all-reflection coatings and (ii) highly-efficient non-gradient anomalous reflectors. Through both theoretical arguments and full-wave simulations, it is proven that dielectric nanoparticles allow achieving high performances in both the scenarios enabling, thus, new degrees of freedom in the manipulation of optical reflections.

12:00 On the Integration and Characterization of Chainmail-Like Hall-Effect Metamaterials

Christian Kern, Muamer Kadic, and Martin Wegener [Karlsruher Institut für Technologie, Germany, and Institut FEMTO-ST, France]

We realize metamaterial Hall bars that are connected to printed circuit boards in a permanent manner. This brings this class of metamaterials closer to possible applications and facilitates our study of the isotropy of the sign reversal for cubic chainmail-like metamaterial unit cells.

12:15 Towards a Physically Sound D-dot Transmission-Line Theory Model

Boris Okorn, Jordi Sancho-Parramon, and Silvio Hrabar [Ruđer Bošković Institute and University of Zagreb, Croatia]

Recently, a novel paradigm of metatronics has been introduced. It offers optical nano-circuitry similar to RF electronics but based on manipulation of displacement current flow. A main conductor in metatronics is the D-dot wire structure. Here we introduce the idea of a D-dot transmission line that can be modelled using standard circuit theory.

E4 Theory and modelling II

Hall: E **Chairs:** Ari Sihvola and Constantinos Valagiannopoulos

10:30 Theory of Dual-Tunable Thin-Film Multiferroic Heterostructures with a Coplanar Transmission Line

Aleksei Nikitin, Alexey Ustinov, Andrey Nikitin, Erkki Lähderanta, and Boris Kalinikos [St. Petersburg Electrotechnical University, Russia, and Lappeenranta University of Technology, Finland]

A theory of spin-electromagnetic wave (SEW) spectrum has been developed for a thin-film ferrite-ferroelectric structure based on a coplanar transmission line. The dispersion relation was derived through analytical solution of the full set of Maxwell`s equations utilizing a method of approximate boundary conditions. The distinctive features of the investigated structures are the thin-film planar topology and dual tunability of the SEW spectrum.

10:45 Analysis Of Scatterers With Discontinuous Impedance Boundary Condition Using Surface-Integral-Equation Method

Beibei Kong, Pasi Ylä-Oijala, Maria Denise Astorino, Henrik Wallen, and Ari Sihvola [Aalto University, Finland, and "La Sapienza" University of Rome, Italy]

This contribution presents a surface-integral-equation-based computational method to analyze scattering by objects with strongly discontinuous surface impedance parameters. As an example of the application of the method, the response of a PEC-PMC sphere is analyzed, revealing unexpected and strongly anisotropic scattering behavior.

11:00 Universal Expression for Poynting Vector Applicable for Evanescent Waves: Inherent Output from the Method of Single Expression

Tamara Knyazyan, Hovik Baghdasaryan, Tamara Hovhannisyan and Marian Marciniak [National Polytechnic University of Armenia, Armenia, and National Institute of Telecommunications, Poland]

An alternative expression for Poynting vector valid for evanescent waves is presented in the method of single expression (MSE). The boundary problem solution by the MSE permits to observe spatial distributions for electric, magnetic field amplitudes and Poynting vector. The suggested Poynting vector is in agreement with the traditional one.

11:15 Theory of Characteristic Modes for Impedance Bodies

Pasi Ylä-Oijala, Henrik Wallen, Bei-Bei Kong, Seppo Järvenpää [Aalto University, Finland]

The theory of characteristic modes, formulated with surface integral operators, is presented for closed objects with isotropic and position dependent surface impedances. The proposed method allows excitation-independent analysis of fundamental electromagnetic scattering properties of arbitrarily shaped impedance bodies.

11:30 Discontinuous Transformation Optics For Surface Phenomena

Lieve Lambrechts, Vincent Ginis, Jan Danckaert, and Philippe Tassin [Vrije Universiteit Brussel, Belgium, Harvard University, USA, and Chalmers University of Technology, Sweden]

We introduce an innovative way of using discontinuous coordinate tranformations to extend the geometrical formalism of transformation optics beyond the manipulation of light ray trajectories inside bulk media. Specifically, we demonstrate how discontinuous transformation optics can be used to design electromagnetic surface phenomena at the interface of man-made materials. As a first application of our approach, we show how the Goos-Hänchen effect can be understood and tailored from a geometrical point of view. In addition, we propose a similar approach for transition radiation.

11:45 50 Years of Negative Refraction (Invited)

Victor Georgievich Veselago [Institute of General Physics, Russian Academy of Sciences, Russia]

12:00 Retrieving Regular Photonic Structures Though Global Optimization

Antoine Moreau, Mamadou Aliou Barry, Vincent Berthier, Marie-Claire Cambourieux, Rémi Pollès, Olivier Teytaud, Emmanuel Centeno, Bodo Wilts, and Nicolas Biais [Université Clermont Auvergne and INRIA, France, Fribourg University, Switzerland, and Brooklyn College, USA]

Optimization tools are increasingly used, for instance for the design of metamaterials analog computers. Yet they have not so far been able to produce designs as regular as in nature or in technology like photonic crystals or metamaterials. Here we show that it is possible, using state of the art global optimization techniques, to obtain periodic or regular structures. Some algorithms seem particularly suited for the difficult problems that can be found in photonics. They can even be used to produce counter-intuitive but very efficient strutures for problems like light absorption in solar cells.

12:15 Optimized Operation of Photonic Devices With Use of Ordinary Bulk Materials

Constantinos Valagiannopoulos [Nazarbayev University, Kazakhstan]

Structural boundaries, materials and feeding sources are the three fundamental segments defining photonic devices. Since excitation is usually dictated by the application and there are infinite ways to select the spatial configuration of the component, an optimization with respect to the used media is both doable and useful. We provide several combinations of elements and compounds making high-performing electromagnetic devices in terms of absorption, scattering and unusual refraction with simple structures like bilayers, two- and three- dimensional core-shell particles or binary metasurfaces. Such large sets of potential candidates for the employed media can be deployed by experimentalists after applying a secondary sweep by imposing additional constraints concerning ease of fabrication.

A5 Special session: Recent advances and trends in metasurfaces II

Hall: Aalto **Chair:** David Smith and Stefano Maci

Organizers: David Smith and Stefano Maci

14:00 Singular Metasurfaces (Invited)

John Pendry [Imperial College London, UK]

Plasmonic systems are dominated by their surface structure which couples external radiation to the surface plasmons. I shall show how metasurfaces can be derived by a series of conformal transformations from a flat surface, enabling comprehensive analysis. when these transformations are singular reflection spectra change dramatically. Non singular surfaces as in a conventional grating show absorption of a single colour dictated by the angle of incidence and the plasmon frequency. On the other hand singular surfaces have a broad band absorption spectrum and appear to be black. An instance of this is colloidal silver where the touching nanospheres create singularities. Unlike conventional gratings singular structures are characterised by three wave vectors not two: the third wave vector hidden, or 'compacted' in the singularity

14:30 Recent Advances in Huygens' Metasurfaces (Invited)

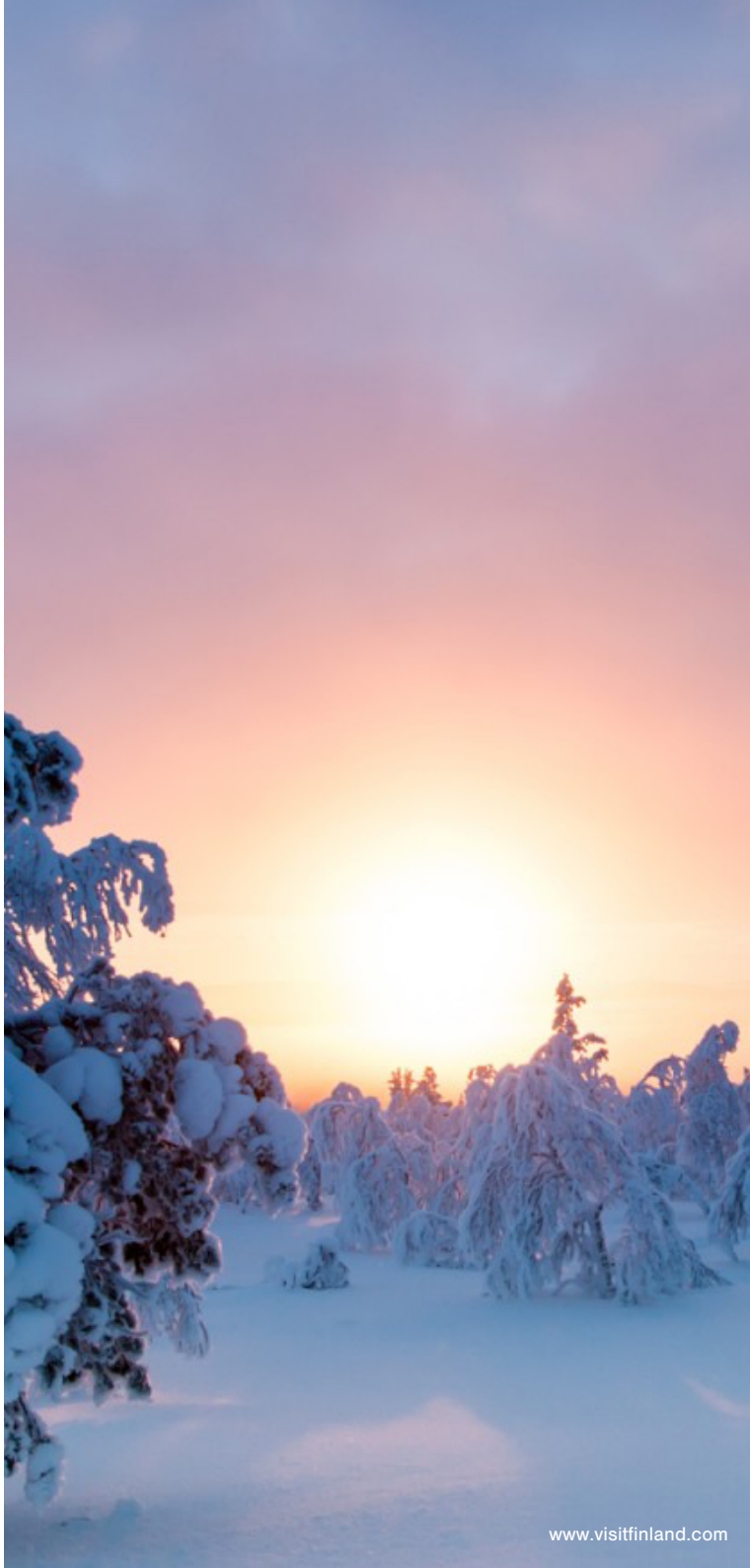
George Eleftheriades, Michael Chen, Ayman Dorrah, and Gleb Egorov [University of Toronto, Canada]

In this paper, recent advances in Huygens' metasurfaces are described. These include novel broadband and bi-anisotropic unit cells, as well as beam expansion for antenna directivity enhancement using phase-changing metasurfaces.

15:00 Multiscale Modeling of Electrically Large Waveguide-Fed Metasurface Apertures using a Coupled Dipole Approach (Invited)

David Smith, Laura Pulido-Mancera, Patrick Bowen, and Nathan Kundtz [Duke University and Kymeta Corporation, USA]

Waveguide-fed metasurface apertures have seen intense development and widespread commercialization across a rising number of applications. The metasurface architecture inherently lends itself to an alternative, highly efficient, hybrid simulation approach. We summarize the waveguide-fed metasurface architecture, compare it with other aperture concepts and introduce the dipole and coupled-dipole model modeling platform. We find excellent agreement between full-wave simulations and the coupled-dipole approach in the cases examined.



B5 Acoustic metamaterials II

Hall: B **Chairs:** Olivier Mondain Monval and Romain Fleury

14:00 Soft Porous Metamaterials for Acoustics

Raj Kumar, Yabin Jin, Olivier Poncelet, Thomas Brunet, Artem Kovalenko, and Olivier Mondain Monval [University of Bordeaux, France]

We present a new method to prepare soft porous materials with fully tunable values of the acoustic refraction index. The index value depends on the sample porosity and mechanical properties through a very simple model expression. Our study paves the way to the realization of gradient index materials and metasurfaces allowing for new directional, focusing or attenuating properties.

14:15 Doubly Negative Bubbly Metamaterials

Maxime Lanoy, John H. Page, Geoffroy Lerosey, Fabrice Lemoult, Valentin Leroy, and Arnaud Tourin [University of Manitoba, Canada, and Institut Langevin and Université Paris Diderot, France]

Thanks to their particularly efficient, low frequency Minnaert resonance, air bubbles are known to be excellent candidates for the realization of acoustic metamaterials. Here, we demonstrate that the introduction of pair-wise spatial correlations between the bubbles can result in double negativity. This can occur when the bubble pairs are arranged either in random or periodic configurations. Predictions for both types of structure will be presented and the influence of dissipation on the doubly negative behaviour discussed

14:30 Nonlinear Elastic Metasurface Design Achieving Acoustic Wave Scattering Control

Xinxin Guo, Vitalyi E. Gusev, Katia Bertoldi, and Vincent Tournat [Le Mans Université, France, and Harvard University, USA]

The acoustic wave scattering properties of a nonlinear elastic metasurface, through different metasurface designs, derived from resonant nonlinear elastic elements, are theoretically and numerically studied. The results indicate the possibility of converting, during the reflection/transmission process, most of the fundamental incoming wave energy into the second harmonic wave.

14:45 Envelope Solitons in 1D Acoustic Metamaterials

Jiangyi Zhang, Vicente Romero-García, Georgios Theocharis, Olivier Richoux, Vassos Achilleos, and Dimitrios J. Frantzeskakis [Université du Maine, France, and National and Kapodistrian University of Athens, Greece]

In this work, we study analytically and numerically envelope (bright, gap, black and gray) solitons in one-dimensional weakly lossy nonlinear acoustic metamaterials with effective negative material characteristics (effective negative mass density or bulk modulus). Our numerical and analytical results are found to be in good agreement.

15:00 Acoustic Metamaterials Crystal for Passive Parity-Time-Symmetric Modulation

Tuo Liu and Jie Zhu [The Hong Kong Polytechnic University, Hong Kong]

The exploration of parity-time (PT) symmetry with classical wave systems has enabled many counter-intuitive ways of wave manipulation and innovative applications, yet is still a great challenge for sound waves due to the lack of acoustic gain medium in nature. Here we report the realization of an acoustic metamaterials crystal that respects passive PT symmetry, by interleaving groove- and holey-structured metamaterials to offer intrinsic PT-symmetric potential without any active element. At the exceptional point where a transition from the unbroken to broken PT symmetry phase happens, unidirectional sound reflectionless effect is numerically achieved. Our demonstration provides a feasible path to the investigation of PT symmetry in acoustic wave system with practical structures free of gain medium.

15:15 Mechanism of Sound Detection in Human Hearing System Based on Extraordinary Acoustic Transmission

Yasushi Horii, Wenjia Hong, Airi Tamaki, and Toshiaki Kitamura [Kansai University, Japan]

This paper proposes a new sound detection theory of human hearing system based on extraordinary acoustic transmission. From engineering point of view, resonance on enlarged hair cell models are demonstrated theoretically. This new idea can be applied to super-compact hair cells to account for mechanism of human hearing system.

D5 Plasmonics III

Hall: D **Chair:** Filipa Rodrigues and Viktor Podolskiy

14:00 Wideband Filters Based On Spoof Localized Surface Plasmon Resonators

Xuanru Zhang, Zuqi Fang, Di Bao, and Tie Jun Cui [Southeast University, China]

Spoof localized surface plasmon (SLSP) resonators with underlayer ground plane are investigated under monopole antenna excitation. Wideband bandpass SLSP filters are validated. The SLSP filters exhibit wide passbands in compact sizes and balanced shapes, while holding satisfactory spurious rejection bands and group delays.

14:15 Extraordinary Optical Transmission via Hybridization of Core-cavity Plasmon Modes

Bilge Can Yildiz, Alireza Rahimi Rashed, and Humeyra Caglayan [Atilim University, Turkey, and Tampere University of Technology, Finland]

We demonstrate that extraordinary optical transmission through a periodic hole array of gold nanostructure is considerably enhanced when there are gold nano-cores inside these holes. We explain this phenomenon by hybridization of surface plasmon polariton (SPP) and localized surface plasmon (LSP) modes excited on the nano-holes and the nano-cores, respectively, at different wavelengths, giving rise to the transfer of more energy to the transmitted light, compared to the case where only the SPP modes are excited.

14:30 Metallic Nanoparticle-Array Lasers with Ultrafast Modulation Speeds and Highly Directional Beam

Konstantinos Daskalakis, Aaro Väkeväinen, Jani-Petri Martikainen, Tommi Hakala, and Päivi Törmä [Aalto University, Finland]

In this paper, we demonstrate an organic dye nanolaser that exhibits ultrafast modulation speed and high beam directionality. The studied nanolaser consists of arrays of cylindrical gold nanoparticles with a diameter of 100 nm and a height of 30 nm, arranged in a square lattice. The periodicity is varied between 550 – 590 nm. To probe the lasing properties, IR-140 dye (5,5′-dichloro-11-diphenylamine-3,3′-diethyl-10,12-ethylene-thiatricarbocyanine-perchlorate), in low concentration solutions is deposited on the sample. In this configuration, the sample exhibit lasing at room temperature at infrared wavelength (~ 880 nm).

14:45 Fabrication, Characterization and Applications of a Gradient Refractive Index Plasmonic Metamaterial

R. Margoth Córdova-Castro, Brian Wells, Alexey V. Krasavin, Mazhar E. Nasir, Wayne Dickson, Victor A. Podolskiy, and Anatoly V. Zayats [King's College London, UK, University of Hartford and University of Massachusetts, USA]

We investigate the engineered optical properties in a plasmonic nanocone metamaterial, fabricated via a manufacturing process which allow very high density of hot spot over a large area. Such anisotropic metamaterial behaves as a transitional metamaterial with gradient of a refractive index across its thickness.

15:00 Resonant Graded-Index Plasmonic Nanoscatterers: Enabling Unusual Light-Matter Interactions

Dimitrios Tzarouchis, Nader Engheta, and Ari Sihvola [Aalto University, Finland, and University of Pennsylvania, USA]

Light scattering by a subwavelength sphere exhibiting a radially inhomogeneous permittivity profile is considered here. A generalization of the polarizability for radially inhomogeneous sphere is given in terms of a so-called inhomogeneity factor. The special case of an inhomogeneous Drude profile unveils a series of scattering peculiarities, motivating further discussion for the implementation of spheres with graded-index plasmonic profiles.

15:15 Lasing in Dark and Bright Modes of Plasmonic Nanoarrays

Tommi Hakala, Heikki Rekola, Aaro Vakevainen, Jani-Petri Martikainen, Marek Necada, Antti Moilanen, and Paivi Torma [Aalto University, Finland]

We show lasing at the visible wavelengths in both bright and dark modes of the plasmonic nanoparticle array.

E5 Magnetic-resonance-imaging applications

Hall: E **Chairs:** Stefan Enoch and Pavel Belov

14:00 MetaMaterials for Ultra-high Field MRI. M-Cube Project: Objectives and Some Results (Invited)

Redha Abdeddaim and Stefan Enoch [Aix-Marseille Université and Institut Fresnel, France]

We will present the main challenges in the development of routine clinical use of ultra-high field MRI and opportunities for metamaterials for ultra-high field MRI. Then results obtained by the M-Cube project consortium will be presented.

14:30 Tunability Methods for Magnetic Resonance Imaging Applications of Metasurfaces (Invited)

Alena Schelokova, Ekaterina Brui, Stanislav Glybovskiy, Alexey Slobozhanyuk, Irina Melchakova, and Pavel Belov [ITMO University, Russia]

In this work, we propose and discuss methods of tuning eigenmode resonance frequencies of wire metasurfaces. Fine tuning of metasurface properties is essential for maximizing its coupling with transmitting and receiving radiofrequency (RF) coils of a magnetic resonance imaging (MRI) system. We have studied numerically and experimentally two designs of metasurfaces with different tunability mechanisms. The first design is a hybrid structure based on periodic wires with extremities penetrating high-permittivity dielectric volumes, where tunability achieved by changing properties of the dielectric parts. The second metasurface is formed by an array of capacitively loaded telescopic wires that permit to adjust the eigenmode resonance frequencies by mechanical expansion of the wires. Both metasurfaces demonstrated the spectacular capability to locally enhance the magnetic field of an external RF coil being precisely tuned to the Larmor frequency of a clinical MRI scanner.

15:00 A Single Unit Cell Metasurface for Magnetic Resonance Imaging Applications

Tingzhao Yang, Kenneth Ford, Madhwesha Rao, and James Wild [University of Sheffield, UK]

This paper describes a method for designing a non-periodic metasurface for use in 1.5T magnetic resonance imaging applications. The use of an inter-digitated capacitive surface combined with a circular radio frequency transceiver coil is shown to improve the magnetic flux density whilst being compact in cross section and thickness. By using a single unit cell structure the magnetic flux density, which is proportional to signal to noise ratio (SNR), was improved by a maximum of 120%. The single unit cell design also offers a more uniform magnetic flux density distribution when compared to periodic metamaterial approaches.

15:15 Investigation of Metasurface Eigenmode Impact on Receive Sensitivity Enhancement of MRI Machine

Egor Kretov, Alena Shchelokova, and Alexey Slobozhanyuk [ITMO University, Russia]

Magnetic resonance image quality directly depends on the signal-to-noise ratio provided by the receive coil. It was recently shown that wire metasurface can enhance the signal-to-noise ratio of the commercial scanner due to the spatial redistribution of the radiofrequency electromagnetic field through the resonant excitation of a wire metasurface eigenmode. In this work, we experimentally investigate the impact of this eigenmode on receive sensitivity enhancement of the 1.5 T birdcage coil. We proof that due to the certain spatial profile of the metasurface eigenmode, signal-to-noise ratio enhancement directly depends on the position and dimensions of the studied object on the metasurface.

A6 Exotic effects and properties II

Hall: Aalto **Chairs:** Davide Ramaccia and Carsten Rockstuhl

16:00 Contribution to the Theory of THz Laser Based on Asymmetrical Hyperbolic Media

Olga Kozina, Leonid Melnikov, and Igor Nefedov [Kotel'nikov Institute of Radio-Engineering and Electronics and Yuri Gagarin State Technical University of Saratov, Russia, and Aalto University, Finland]

Theory of a nonlinear wave propagation in a complex cavity which contains the graphene-based asymmetric hyperbolic metamaterial is suggested. The THz gain saturation in an active medium slab is taken into account.

16:15 Disorder-Induced Phase Transition in Dielectric Metasurfaces

Aso Rahimzadegan, Dennis Arslan, Stefan Fasold, Matthias Falkner, Thomas Pertsch, Isabelle Staude, and Carsten Rockstuhl [Karlsruhe Institute of Technology and Friedrich Schiller University Jena, Germany]

The complex behaviour of light in disordered materials has some intriguing features, which motivates its exploration. Here, we study a disorder induced phase transition in a dielectric Huygens' metasurfaces made from silicon nano-disks supporting electric and magnetic resonances. Depending on the disorder, the phase of the transmitted field undergoes a phase transition from normal to anomalous dispersion above a critical threshold. The threshold also depends on the detuning among the electric and magnetic resonance. For detuning in excess, a third phase emerges where both resonances appear isolated. The effect can nicely be explored while considering a Lorentzian resonance profile for the disks but is also revealed in full-wave simulations and in experiments. Uncovering this novel phenomenon is an important milestone in the growing fields of both, metamaterials and disordered photonics.

16:30 Metasurface-Based Doppler Cloaks: Time-Varying Metasurface Profile to Achieve Perfect Frequency Mixing (Extended)

Davide Ramaccia, Dimitrios Sounas, Andrea Alù, Alessandro Toscano, and Filiberto Bilotti [RomaTre University, Italy, and University of Texas at Austin, USA]

Doppler cloaks are spatiotemporally modulated metamaterial covers to be placed in front or wrapped around a moving object to restore locally the source illumination frequency, as if it were not in motion. Although the cloak effectively compensates such a frequency shift, the required thickness of the metamaterial is in the order of dozens of wavelengths of the incident signal for ensuring a complete energy transfer from the Doppler shifted to the original source frequency. In this contribution, we present a bi-dimensional version of the Doppler cloak, realized by a time-varying metasurface with proper time-dependent transmission coefficient. The temporal profile of the transmission coefficient is defined for achieving the same frequency mixing behavior of bulk Doppler cloaks. The operation is verified by a full-wave FDTD numerical simulation in case of normal incidence.

17:00 Independent Manipulation of Amplitude and Phase of Light based on the de Broglie-Bohm Viewpoint (Invited)

Sunkyu Yu, Xianji Piao, and Namkyoo Park [Seoul National University, South Korea]

In this talk, we introduce the concept of "Bohmian photonics" for the design of optical structures, to achieve the independent manipulation of amplitude and phase of light. As representative examples, the design strategies of phase-conserved energy confinement and annihilation, and constant-intensity waves are discussed.

B6 Mechanical and acoustic metamaterials

Hall: B **Chairs:** Bogdan Ungureanu and Aurélien Merkel

16:00 Some Challenges Regarding Cloaking And Earthquake Protection

Sebastien Guenneau, Stephane Brule, Stefan Enoch, Andre Diatta, Younes Achaoui, Bogdan Ungureanu, Harsha Hutridurga, and Richard Craster [Institut Fresnel, France, and Imperial College London, UK]

Building upon analogies with cloaking of elastic waves in plates, a large scale experiment has demonstrated unprecedented control of surface seismic waves in structured soils. Here, we would like to review recent research advances and remaining challenges in the theory and applications of seismic metamaterials for cloaking and earthquake protection. We recall some results on transformation elastodynamics and introduce mathematical theory of near cloaking for elastic equations. The former is a natural framework for scattering problems in unbounded domains, while the latter addresses boundary measurements in bounded domains. These two fields of investigation bring complementary information on cloaking efficiency. Intimate links between cloaking and wave protection will be also discussed.

16:15 Sound Propagation in a One-Dimensional PT Symmetric Sonic Crystal

María Rosendo López, Aurélien Merkel, and Johan Christensen [Universidad Carlos III de Madrid, Spain]

Parity-Time (PT) symmetric structures based on balanced distributions of gain and loss have attracted significant attention in acoustics metamaterials researches since they allow one to sculpture the flow of sound waves in complete new ways. We compute Bloch states in periodic fluidic stacks into which a spatially variation of gain and loss components are distributed. The complex acoustic band diagram exhibit modes coalescence, various exceptional points beyond which acoustic Bloch states are allowed to either amplify or attenuate sound within the PT broken phase.

16:30 Platonic Quasicrystal for Flatlens Focusing of Flexural Waves

Kun Tang, Sebastien Guenneau, and Patrick Sebbah [Bar-Ilan University, Israel, and Aix-Marseille University, France]

Negative refraction and flat lens focusing of elastic waves has been recently demonstrated experimentally, though restricted to periodic structures where dispersion relations are readily available for prediction and design of superlenses. This is not possible anymore when considering quasiperiodic structures. Here we demonstrate quasicrystal platonic superlensing of elastic waves in perforated metallic thin plates, opening new possibilities for applications of quasiperiodic structures in elastic waves.

16:45 Design of a Chiral Elastic Structure Supporting Interfacial Waveforms

Michael Nieves, Marta Garau, Giorgio Carta, Ian Jones, Natasha Movchan, and Alexander Movchan [University of Liverpool, Keele University, and Liverpool John Moores University, UK, and University of Cagliari, Italy]

An infinite heterogeneous elastic triangular lattice connected to a non-uniform array of gyroscopic spinners is considered. An algorithm is described for generating interfacial waves that propagate along the boundaries of subdomains containing inhomogeneities in the spinner array. The interfacial waveforms have preferential directions that can be controlled through adjusting the frequency of excitation or the arrangement of the spinners.The RT-CB was recently translated to Fortran 90/95 and the code will be publicly available.

17:00 The Anisotropy of Layered Bathymetries for Water Waves

Agnès Maurel, Jean-Jacques Marigo, Pablo Cobelli, Philippe Petitjeans, and Vincent Pagneux [Intitute Langevin, PMMH/ESPCI, LMS/Ecole Polytechnique, and Université du Mans, France, and Universidad Buenos Aires and IFIBA, Argentina]

Experimental and theoretical results show that layered bathymetries for water waves allow to obtain effective medium with significant anisotropy. The theory is based on the homogenization technique applied to the three-dimensional water wave problem. It agrees very well with experimental measurements.

17:15 Symmetry Induced Broadband Transmission Enhancement Through Opaque Barriers Coated by Opaque Disordered Slabs

Elie Chéron, Simon Félix, and Vincent Pagneux [Université du Mans, France]

We show in multimodal quasi-1D waveguides that constructive interference effects caused by the addition of two symmetrical disordered slabs provide a significant and broadband increase of transmission through opaque barriers. Numerical simulations and a model are presented in order to tune and optimize this gain in transmission.

D6 Graphene

Hall: D **Chairs:** Mona Jarrahi and Hossein Mosallaei

16:00 Gold-Patched Graphene Nano-Stripes for Photodetection with Unprecedented Functionalities (Invited)

Mona Jarrahi, Semih Cakmakyapan, and Ping Keng Lu [University of California Los Angeles, USA]

We present engineered photoconductive nanostructures based on gold-patched graphene nano-stripes, which enable simultaneous broadband and ultrafast photodetection with high responsivity. These nanostructures merge the advantages of broadband optical absorption, ultrafast photocarrier transport, and carrier multiplication in graphene nano-stripes with the ultrafast transport of photocarriers to the gold patches before recombination. Through this approach, high-responsivity operation is achieved without the use of bandwidth- and speed-limiting quantum dots, defect states, or tunneling barriers.

16:30 Enhanced Tunability of Metasurfaces with Graphene

Humeyra Caglayan, Mohsin Habib, Ekmel Ozbay, Alireza Rahimi Rashed [Tampere University of Technology, Finland, and Bilkent University, Turkey]

We present graphene-gold metasurfaces to enhance light-graphene interaction in the MIR region and additionally, we demonstrate a new class of electrically controlled active metadevices working in microwave frequencies. The results show that electrical gating of graphene allows actively tuning the resonance wavelength.

16:45 Electromagnetic Crystalline Metamaterial With Subwavelength Dirac Cones

Simon Yves, Fabrice Lemoult, Thomas Berthelot, Mathias Fink, Geoffroy Lerosey [Institut Langevin, CEA Saclay, and KELENN Technology , France]

Graphene, a honeycomb lattice of carbon atoms ruled by tight-binding interactions, exhibits extraordinary electronic properties, due to Dirac cones within its band structure. We present an experimental electromagnetic analog of graphene obtained with crystalline metamaterials made of simple copper wires and we demonstrate the presence of subwavelength Dirac cones.

17:00 Singular Graphene Metasurfaces

Emanuele Galiffi, Paloma Huidobro, and John Pendry [Imperial College, UK]

The dynamic tunability of graphene enables the engineering of metasurfaces such as conductivity gratings, which couple incident radiation to surface plasmons. Here we discuss singular graphene metagratings, whose conductivity is strongly suppressed. These surfaces are found to exhibit remarkably broadband THz response, thus functioning as efficient broadband absorbers. By analytically characterising their response via transformation optics, we provide an intuitive understanding of the interaction of light with these surprisingly exotic metastructures.

17:15 Graphene-Based Tunable Metasurface for All-Angle Perfect Absorption

Xuchen Wang and Sergei Tretyakov [Aalto University, Finland]

Motivated by the idea of "smart" metasurfaces, we will demonstrate a graphene-based tunable absorber in which perfect absorption can be achieved for all angles of incidence, only by tuning the Fermi level of graphene. We place an unpatterned graphene sheet on a mushroom-type high impedance surface whose resonant frequency is stable for all incident angles. For TM-polarization, perfect absorption can be realized from normal to grazing incidence at the same frequency when modulating the Fermi level of graphene from 0.18 eV to 1 eV.

E6 Antenna applications

Hall: E **Chairs:** Mirko Barbuto and Richard Ziolkowski

16:00 Design of a Patch Antenna with a Sector Radiation Pattern by Exploiting Topological Properties of Vortex Fields

Mirko Barbuto, Mohammad-Ali Miri, Andrea Alù, Filiberto Bilotti, and Alessandro Toscano [Niccolò Cusano University and Roma Tre University, Italy, and University of Texas at Austin, USA]

Topological properties of vortex fields have witnessed an increasing attention due to a wide spread of possible applications at both microwave and optical frequencies. In particular, we have recently shown that composite vortices, i.e. superposition of vortex fields with different topological charges, can be exploited to manipulate the radiation pattern of a microwave patch antenna. In this contribution, we further explore the generation and manipulation of composite vortices in order to design a single patch antenna that exhibits a sector radiation pattern and emulates the radiation properties of a dipole placed at a quarter of wavelength from a reflector.

16:15 Fully-metallic, Low-dispersive, Leaky-wave Fed Lens Antenna for 60 GHz Base Station Applications

Oskar Dahlberg, Elena Pucci, Lei Wang, and Oscar Quevedo-Teruel [KTH Royal Institute of Technology and Ericsson AB, Systems & Technology, Sweden, Hamburg University of Technology, Germany]

The guiding structure commonly employed in leaky-wave antennas is dispersive, resulting in beam-steering with frequency. This behavior reduces operational bandwidth in point-to-point communication applications. In this work, we present an approach that aims at increasing the operational bandwidth of leaky-wave antennas by the employment of a metasurface lens.

16:30 Metamaterial-inspired Compact Directive Antenna Systems (Invited)

Richard W. Ziolkowski [University of Technology Sydney, Australia]

Huygens dipole and multipole antennas are briefly reviewed. These electrically small systems provide enhanced directivity, a feature highly desired for current and future wireless platforms. The design, simulation, fabrication, and measurement results for the Huygens dipole antennas are discussed. The Huygens multipole antenna concepts are described. These brief examinations will be greatly expanded upon during my presentation.

17:00 Multiple Scattering Enabled Superdirectivity from a Subwavelength Ensemble of Resonators

Samuel Métais, Fabrice Lemoult, and Geoffroy Lerosey [Institut Langevin, France]

Locally resonant metamaterial allow great control on the near field of incoming waves. Here we harness multiple scattering around a single source in a finite size array of subwavelength resonators of optimized size, in order to achieve control over the farfield emission, reaching superdirectivity in the microwave domain.results obtained with the proposed method are compared with the full wave Contour-FFT (CFFT) based MoM simulation of a MTS implemented with sub-wavelength printed patches.

17:15 Analysis of Elliptical Aperture Metasurface Antennas

Modeste Bodehou, Simon Hubert, Husnain Ali Kayani, Christophe Craeye, and Isabelle Huynen [Université catholique de Louvain, Belgium]

A Method of Moments (MoM) based analysis is presented for elliptical aperture metasurface (MTS) antennas. The MTS is represented as a sheet transition impedance boundary condition incorporated in a transmission line which accounts for the substrate interaction with the patches layer. The algorithm uses the Fourier-Bessel basis functions (FBBFs) and is inspired from the circular domain analysis. The computation time is then comparable to that of an equivalent size circular aperture MTS. Numerical results obtained with the proposed method are compared with the full wave Contour-FFT (CFFT) based MoM simulation of a MTS implemented with sub-wavelength printed patches.

WEDNESDAY

9:00 Plenary session III

10:00 Coffee

	Aalto Hall	Hall B	Hall D	Hall E
10:30	A7	B7	D7	E7
	Special session: Physical Review Journals Symposium	*Nonlinear meta-materials I*	*Nano-particles and nanoantenas*	*Design and modeling*
12:30	Lunch			
14:00	A8	B8	D8	E8
	Topological effects I	*Design of mechanical meta-materials*	*Special session: VISORSURF project*	*Active/non-Hermitian systems II*

15:30 Coffee and Poster Session

17:30 Anniversary Event

20:00 Gala Dinner
22:30

Plenary session III

Hall: Aalto **Chair:** Filiberto Bilotti

9:00 Metamaterials for Informatics
Nader Engheta
University of Pennsylvania, USA

We explore how metastructures can be designed to perform analog computing and to solve integral equations using wave interaction in such structures. We consider two platforms for this purpose: (1) inhomogeneous metamaterials, and (2) collection of Mach-Zehnder interferometers (MZIs). We show how wave-matter interaction can be a tool to do “photonic mathematics” and information processing with metamaterials.

A7 Special session: Physical Review Journals Symposium

Hall: Aalto **Chairs:** Thomas Pattard, Ling Miao, Julie Kim-Zajonz, Manolis Antonoyiannakis, and Mu Wang

Organizers: Thomas Pattard, Ling Miao, Julie Kim-Zajonz, Manolis Antonoyiannakis, and Mu Wang

10:30 Local Densities of States in Photonic Systems with Loss and Material Dispersion (Invited)

Christian Wolff, Kurt Busch, and N. Asger Mortensen [University of Southern Denmark, Denmark, and Max-Born-Institut Berlin and Humboldt-Universitaet zu Berlin, Germany]

We report on our recent progress in developing expressions for the complex bandstructure derivative and the density of transverse optical states (tDOS) using an adjoint mode formalism. We illustrate the usefulness by discussing the analytically solvable problem of a lossless dielectric band gap material perturbed by one sharp Lorentzian material resonance.

11:00 Programmable Metastructures: Rainbow Trapping and Anisotropy Correction (Invited)

Stefano Gonella, Paolo Celli, and Weiting Zhang [University of Minnesota and California Institute of Technology, USA]

In this work, we explore the opportunities for tunable wave manipulation in metastructures endowed with programmable mechanical characteristics. Programmability is here obtained through electromechanical control. Specifically piezoelectric shunts are intelligently distributed in the mechanical domain and used to convert certain elastic elements into electromechanical resonators. By taking advantage of tunable components in the electric circuits that are shunted to the piezo patches we can semi-actively modify the resonant frequencies of the resonators, thus tuning the response of the entire metastructure to specific frequencies of interest. The approach is first tested in the context of metamaterial waveguides. The waveguides are shown to work as tunable rainbow traps capable of variable and broadband mechanical filtering and as programmable mechanical signal jammers. The same concept is then extended to lattice structures, in which waves propagate with highly directional and frequency-selective spatial patterns. Tunability via piezo shunting is here exploited to induce a programmable correction of the intrinsic anisotropy of the lattices. A purely mechanical version of the same paradigm is also presented, relying on telescopic slender structures to realize forests of tunable resonators on the surface of thin vibrating sheets.

11:30 Engineering Dissipation in Photonic and Phononic Systems for Non-Reciprocal Quantum Interactions (Invited)

Aashish Clerk [University of Chicago, USA]

The last few years have seen an ever-growing amount of interest in non-reciprocal photonic systems where the directionality results from driving the system, and not from the use of magnetic or magneto-optic materials. The motivation here ranges from new design principles for photonic devices, to the realization of novel kinds of correlated photonic physics. In this talk, I'll give an overview of recent work in my group exploring how engineered dissipation can be used to make almost any kind of interaction between two subsystems non-reciprocal (i.e. unidirectional). This provides a unified approach for discussing synthetic non-reciprocity in a range of different systems, and also a powerful means to design new kinds of non-reciprocal systems (both classical and quantum). I will touch on connections to quantum-limited amplification, quantum state preparation and measurement-based quantum feed-forward protocols, and also discuss recent implementations of our ideas in quantum optomechanics.

12:00 Metasurface Polarization Optics: Independent Phase Control of Arbitrary Orthogonal States of Polarization (Invited)

Federico Capasso [Harvard University, USA]

B7 Nonlinear metamaterials I

Hall: B **Chairs:** Natalia Litchinitser and Alex Schuchinsky

10:30 Metallic Nanoarc Antennas – Plasmonics Building Blocks for Non-Linear Optical Metamaterials

Kunyi Zhang, Ekaterina Poutrina, Augustine Urbas, and Oded Rabin [University of Maryland, UES Inc., and Air Force Research Laboratory, USA]

The linear and non-linear optical properties of metallic nanoarcs were investigated. The resonance frequencies in the NIR spectrum were correlated to geometric and materials parameters, primarily the nanoarc length and the permittivity of the substrate. Metamaterials consisting of arrays of arcs were designed to display enhanced Second Harmonic Generation at a predictable frequency. The enhancement is achieved through a double-resonance matching condition between the incident and emitted light and two plasmon resonances of individual nanoarcs. Larger nanoarc central angles lead to higher linear extinction cross-section at the second longitudinal mode resonance and larger second harmonic generation signal. The metamaterial consist of common, low-cost materials with no intrinsic second-order susceptibility.

10:45 Gap Solitons in Double-Lorentz Nonlinear Metamaterials

Polykarpos Porfyrakis, Nikolaos Tsitsas, and Dimitri Frantzeskakis [Aristotle University of Thessaloniki and University of Athens, Greece]

A nonlinear metamaterial, characterized by a double-Lorentz model of its frequency-dependent linear effective permittivity and permeability, is considered. The formation of gap solitons in the two frequency band gaps of this metamaterial is investigated analytically.

11:00 Ultrafast Polarisation Control with Metamaterials (Invited)

Anatoly Zayats [King's College London, UK]

Plasmonic and dielectric metamaterials allow designing not only linear but also nonlinear optical response, such as Kerr-nonlinearity and harmonic generation. We will discuss applications of anisotropic plasmonic metamaterials and metasurfaces in active control of polarisation state of transmitted and reflected light on ultrafast timescales.

11:30 Light-Matter Interactions in Engineered Nonlinear Photonic Media (Invited)

Natalia Litchinitser, Jingbo Sun, Wiktor Walasik, Mikhail Shalaev, Yun Xu, Jesse Frantz, Jason Myers, Robel Bekele, Jasbinder Sanghera, and Alexander Tsukernik [University at Buffalo, The State University of New York, and US Naval Research Laboratory, USA, and University of Toronto, Canada]

Recent progress in the development of artificial materials, or metamaterials, with fundamentally new physical properties opens new opportunities for tailoring the properties of nanostructures and of light beam themselves. In the first part of this talk, we discuss the experimental demonstration of the evolution of the orbital angular momentum (OAM) carrying beams propagating in engineered, all-dielectric nano-colloidal suspensions with negative polarizability and saturable nonlinearity. Due to the high power of the incident beam, the modulation instability leads to an exponential growth of weak perturbations and thus splits the original OAM beam into a necklace beam consisting of several bright spots. The number of observed bright spots is intrinsically determined by the topological charge of the incident beam and agrees well with the predictions of the linear stability analysis and numerical simulations. In the second part of this talk, we discuss the design and experimental demonstration of a chalcogenide glass based metasurface enabling all-optical switching of a Hermite-Gaussian beam to an OAM beam depending on the intensity of the incoming light beam. Such nonlinear metasurface was designed using the analysis of guided resonances in photonic crystal and fabricated using standard electron beam lithography technique.

12:00 Losses and Nonlinear Distortion of Wave Packets due to Conductor Surface Roughness

Alex Schuchinsky [University of Liverpool, UK]

Surface roughness and texture of printed conductors increase dissipative losses and enhance the effect of electro-thermal nonlinearity. Although this nonlinearity is weak it can significantly distort the wave packets and modulated signals. In this work, the effects of conductor losses on integrity of multifrequency wave packets is explored and elucidated.

12:15 Nonlinear Quasi-Phase Matching with metasurfaces

Sébastien Héron, Bernhard Reineke, Stéphane Vézian, Thomas Zentgraf, Benjamin Damilano, and Patrice Genevet [CNRS - CRHEA, France, and University of Paderborn, Germany]

Quasi-Phase Matching is an optical process needed to build up nonlinear signal from strong pump intensity and is generally obtained through periodical inversion of coherence domains of the crystal. We show that this effect can be artificially monitored through inserting metasurfaces along the optical path of the light in a waveguide allowing continuous increase of the nonlinear signal.

D7 Nanoparticles and nanoantenas

Hall: D **Chairs:** Carlo Forestiere and Francisco Rodríguez-Fortuño

10:30 On the Nanoparticle Resonances in the Full-Retarded Regime

Carlo Forestiere, Giovanni Miano, Mariano Pascale, and Roberto Tricarico [University of Naples Federico II, Italy]

A spectral technique is applied to evaluate the resonance frequencies of the full retarded scattering from spherical nanoparticles. This approach allows one to identify the modes that are responsible of both the peaks and the asymmetric lineshapes of the scattered power spectra. The resonances properties of dielectric and metal spheres are discussed.

10:45 Design of Particles Permittivity for Electromagnetic Scattering through Material Independent Modes

Carlo Forestiere, Giovanni Miano, Mariano Pascale, and Roberto Tricarico [University of Naples Federico II, Italy]

We represent the electromagnetic field scattered by an homogeneous object in terms of a set of modes independent of its permittivity. In this basis the expansion coefficients of the scattered field are a rational function of the permittivity of the scatterer. We show how, exploiting this very simple functional dependence, we are able to greatly simplify the design of the permittivity of an object to pursue a prescribed tailoring of the scattered field.

11:00 Resonances in Impedance-Boundary Scatterers

Ari Sihvola, Dimitrios Tzarouchis, Pasi Ylä-Oijala, Henrik Wallén, and Beibei Kong [Aalto University, Finland]

This presentation focuses on the electromagnetic scattering characteristics of spheres with surface defined by the impedance boundary condition. The results include resonances that are very strong and sharp for small subwavelength particles, and analogous to the localized surface plasmons.

11:15 Eccentric Metallo-Dielectric Core-Shell Nanoparticles For Switching And Guiding Purposes

Angela I. Barreda, Yael Gutierrez, Juan M Sanz, Francisco Gonzalez, and Fernando Moreno [University of Cantabria and Textil Santanderina, Spain]

We demonstrate the possibility of using isolated eccentric metallo-dielectric core-shell nanoparticles for redirecting the incident radiation into some specific directions eventually different from the forward and backward ones. In particular, we show their utility for building operational switching devices

11:30 Dual Scatterers: Design and Applications (Invited)

Carsten Rockstuhl, Ivan Fernandez-Corbaton, Aso Rahimzadegan, Florian Graf, and Mohamed Ismail Abdelrahman [Karlsruhe Institute of Technology, Germany]

Dual scatterers attracted quite a lot of research attention thanks to their ability to preserve the helicity of the incident light and to suppress backscattering. This might find use in the design of, e.g., highly efficient meta-surfaces. However, dual scatterers are frequently discussed while assuming them to be dipolar. Here, we overview our recent efforts to identify dual scatterers that are dual beyond the dipolar assumption.

12:00 Near-field Directionality Beyond Circularly Polarized Dipoles: the Janus Source (Invited)

Michela F. Picardi, Lei Wei, Jack J. Kingsley-Smith, Anatoly V. Zayats, and Francisco J. Rodríguez-Fortuño [King's College London, UK]

Near-field directionality of circularly polarized dipoles has opened the way to the design of novel devices such as integrated nano-polarimeters, polarization-based nano-routers, and non-reciprocal optical devices. Here we extend the directionality of dipolar near-fields, uncovering novel directional sources beyond the circularly polarized emitter. These sources exhibit distinct symmetries and behaviors

E7 Design and modeling

Hall: E **Chairs:** Baile Zhang and Wenjie Chen

10:30 Surface-Wave Photonic Crystals (Invited)

Baile Zhang [Nanyang Technological University, Singapore]

Photonic crystals generally lack subwavelength features, while surface plasmons or spoof surface plasmons possess spatial scales typically much smaller than the wavelength. Here we show that many device concepts in photonic crystals can be transferred and applied directly to the manipulation of surface waves at the subwavelength scale.

11:00 Metamaterials with Index Ellipsoids at Arbitrary k-points (Invited)

Wenjie Chen, Bo Hou, Zhao-Qing Zhang, John B. Pendry, and C. T. Chan [Hong Kong University of Science and Technology and Soochow University, China, and Imperial College, UK]

Ordinary materials have their index ellipsoids centered at k = 0. We propose a new type of metamaterial possessing multiple index ellipsoids centered at arbitrary nonzero k-points. Their locations in momentum space are determined by the connectivity of a set of interpenetrating metallic scaffolds. Such system is a new class of metamaterial whose properties arise from global connectivity and hence can have broadband functionality in applications such as negative refraction, orientation-dependent coupling effect and cavity without walls; and they are fundamentally different from ordinary resonant metamaterials which are inherently bandwidth limited. We performed microwave experiments to confirm our findings.

11:30 A Complete Circuit Model for Two Coils inside a Dissipative Medium

Son Chu, Christopher J. Stevens, Ekaterina Shamonina [University of Oxford, UK]

Mutually coupled inductors are a vital part of many metamaterials system as well as near field communication and wireless power transfer technologies. A conducting, dissipative medium in proximity to two inductors can have a significant impact on their near fields and hence their mutual coupling. Eddy currents in the medium are responsible for the change in mutual and self-inductance. In this paper, we develop a complete circuit model of two coils inside a conductive environment, where the lossy Kirchhoff's coefficients due to the eddy currents are derived from the field solutions.

11:45 Interplay between Chirality and Magnetism in Microwave Metamaterials

Satoshi Tomita, Hiroyuki Kurosawa, Kei Sawada, and Tetsuya Ueda [Nara Institute of Science and Technology, National Institute of Information and Communications Technology, RIKEN SPring-8 Center, and Kyoto Institute of Technology, Japan]

This paper introduces interplay between chirality and magnetism in microwave metamaterials with simultaneous space-inversion and time-reversal and symmetry breaking. Experimental and numerical studies show the emergence of enhanced and giant magnetochiral effects by combining chiral and magnetic resonances in the metamolecule. This work paves a way toward the realization of a one-way mirror and synthetic gauge fields for electromagnetic waves.

12:00 Optimization of Meta-atoms for 3D Printed Metamaterial Structures

Andrea Vallecchi, Son Chu, Ekaterina Shamonina, and Christopher J. Stevens [University of Oxford, UK]

Additive manufacturing by fused deposition modelling (FDM) now offers some useful performance for functional materials including conductors. Whilst this technology enables the creation of truly three-dimensional (3D) composite structures its accuracy and resolution are not yet so refined as those of 2D fabrication methods. Moreover, dielectric and metallic filaments used in FDM have complex material properties that depend on print parameters and usually exhibit higher losses than RF substrates and bulk conductors. In this work we investigate by simulations and experiments several magnetic meta-atom variants with a view to developing optimal designs for the successful production of metamaterials at microwaves with FDM techniques. Conductor thickness is shown to be a useful new design parameter to reach the desired degree of miniaturization and resonance quality factor of the meta-atoms at low print resolution.

12:15 Optically Transparent Metasurfaces for Controlling Microwave Scattering and Absorption

Ke Chen, Tianshu Li, and Yijun Feng [Nanjing University, China]

Conventional microwave metasurfaces are usually composed of copper/dielectric inclusions which are opaque in visible frequencies. Here, metasurfaces with optical transparency is proposed to control either the backward scattering or the absorption in microwave region. We have designed a flexible coding metasurface for reducing the backward scattering with at least 10 dB from 7.8 to 15 GHz. By using lossy optically transparent film, we have also optimized a broadband microwave absorber with subwavelength thickness. These proposals offer new opportunities for manipulating the microwave scattering and absorption with simultaneously high optical transparency, which may provide benefits in real-world uses, for example, window and solar panel applications.

A8 Topological effects I

Hall: Aalto **Chair:** Gennady Shvets and Dimitrios Sounas

14:00 Chern Topological Index as a "Quantum" of the Fluctuation-Induced Light-Angular Momentum (Invited)

Mario Silveirinha [University of Lisbon, Portugal]

Topological phases of nonreciprocal photonic platforms are usually characterized by the Chern number. Different from condensed-matter systems, so far no physical meaning has been attributed to the photonic Chern number. Here, it is shown that the photonic Chern number is the quantum of the thermal or quantum fluctuation-induced light-angular momentum in a closed photonic insulator cavity.

14:30 Exploration of Edge Modes Formed in Periodic Hexagonal Metasurfaces With Glide Symmetry

Julia D. de Pineda, Gareth P. Ward, Alastair P. Hibbins, and J. Roy Sambles [University of Exeter, UK]

We study the edge modes supported by a bilayer metasurface formed by two arrays of circular metallic patches with a finite width. The circular patches are arrangend in an identical hexagonal array in each layer. It was found that depending on the way the second layer is placed with respect to the first one, there exists an edge mode at frequencies that lie inside the stopband of the structure.

14:45 Active Topological Plasmons in Graphene: The Meta-Gate Approach

Minwoo Jung, Zhiyuan Fan , and Gennady Shvets [Cornell University, USA]

A valley plasmonic crystal for graphene surface plasmons (GSPs) will be described. It will be shown that a designer metagate, placed within a few nanometers from graphene, can be used to impose a triangular periodic Fermi energy landscape on the latter. For specific metagate geometries and bias voltages, the combined metagate-graphene structure is shown to produce sufficiently strong Bragg scattering of GSPs to produce complete propagation bandgaps, and to impart the GSPs with nontrivial valley-linked topological properties. Valley-selective kink states supported by a domain wall between differently patterned metagates are shown to propagate without reflections along sharply curved interfaces owing to suppressed inter-valley scattering. Our approach paves the way for non-magnetic dynamically reconfigurable topological nanophotonic devices.

15:00 Piezoelectric Topological Insulators for Acoustic Waves

Dimitrios Sounas and Andrea Alu [City University of New York, USA]

We present topological insulators for surface acoustic waves on piezoelectric materials. Our structures are based on honeycomb lattices of different types of acoustic domains and derive their nontrivial topology by breaking the symmetry of the lattice hexagonal unit cells. Our results can have applications in compact signal processing integrated devices at microwave frequencies based on surface acoustic waves.

15:15 Experimental Demonstration of an Acoustic Anomalous Floquet Topological Insulator in Waveguide Network

Qi Wei, Da-Jian Wu, Ying Cheng, Zheng Xu, and Xiao-Jun Liu [Nanjing University, Nanjing Normal University, and Tongji University, China]

We experimentally demonstrate an acoustic anomalous Floquet topological insulator in a waveguide network. The gapless edge states can be found in the band gap when the waveguides are strongly coupled. The scheme features simple structure and high-energy throughput, leading to efficient and robust topologically protected sound propagation along the boundary.

B8 Design of mechanical metamaterials

Hall: B **Chairs:** Giorgio Carta and Martin Wegener

14:00 Recent Progress on 3D Mechanical Metamaterials (Invited)

Jingyuan Qu, Tobias Frenzel, Muamer Kadic, and Martin Wegener [Karlsruhe Institute of Technology, Germany]

We present our recent theoretical and experimental progress on microstructured 3D mechanical metamaterials. This includes drastically simplified architectures leading to a negative effective volume compressibility and mechanical activity in 3D chiral micropolar metamaterials.

14:30 Physical Model of a Chiral Flexural Waveguide

Giorgio Carta, Michael Nieves, Ian Jones, Natasha Movchan, and Alexander Movchan [Liverpool John Moores University, Keele University, and University of Liverpool, UK]

We present a novel physical model of a gyrobeam, a chiral structural element where flexural and rotational motions are coupled. In the literature, the gyrobeam is described as a mathematical object possessing a continuous distribution of stored angular momentum. In this paper, we show that gyrobeams can be realised by connecting gyroscopes to Euler-Bernoulli beams; in addition, we provide a physical interpretation of the gyricity parameter of a gyrobeam.

14:45 Manipulation of Vector Elastic Solitons by Flexible Mechanical Metamaterials

Bolei Deng, Pai Wang, Qi He, Vincent Tourinat, and Katia Bertoldi [Harvard University, USA, Tsinghua University, China, and Le Mans Université, France]

We report the design and analysis of nonlinear mechanical metamaterials whose structure and properties can be controlled in multiple ways, and which support the propagation of nonlinear elastic waves. We particularly focus on auxetic rotating squares structures, made of rigid masses connected by flexible elastic hinges, the latter playing the roles of longitudinal, shear and bending springs. Through theoretical and numerical modeling as well as experiments, we study the propagation of vector elastic solitons in a quasi one-dimensional configuration, and show that the actual nonlinearity of the system can be controlled. The interactions of vector elastic solitons with controlled defects is analyzed and reveal means of manipulating their reflexion and transmission properties, which are found dependent on their amplitude, i.e. nonlinear. Possible use of the observed effects will be discussed.

15:00 Non-reciprocity in Mechanical Metamaterials

Corentin Coulais [University of Amsterdam, Netherlands]

We introduce mechanical metamaterials with suitably designed architectures and active-feedback that exhibit non-reciprocity, namely they transmit motion differently depending on the direction of the input forcing

15:15 Non-commuting Metamaterials: A New Paradigm Towards Reprogrammability?

Matthieu Labousse and Martin van Hecke [Laboratoire Gulliver, ESPCI Paris, CNRS & PSL University, France, and AMOLF & Leiden University, The Netherlands]

The development of mechanical metamaterials rapidly grows and explores multiple strategies to design functional materials. Essentially a function relies on a internal structural property, so that a radical change of function often requires redesigning a new structure from scratch. Pre-encoding several functions in one single structure is a corner stone towards designing truly reprogrammable mechanical metamaterials. In this talk I will discuss a new strategy we have investigated. We construct a metamaterial by assembling non-commuting unit cells. Each unit can be actuated by two external inputs, say A and B such that actuating A then B is different than B then A. We propose a rationale design to encode this non-commuting property. Finally by assembling multiple unit cells we obtain what we call a non-commuting material and I will present some of its emerging properties.

D8 Special session: VISORSURF project

Hall: D **Chairs:** Sergei Tretyakov and Maria Kafesaki
Organizers: Sergei Tretyakov and Maria Kafesaki

14:00 Software-Defined Metasurface Paradigm: Concept, Challenges, and Prospects (Invited)
Alexandros Pitilakis, Anna C. Tasolamprou, Christos Liaskos, Fu Liu, Odysseas Tsilipakos, Xuchen Wang, Mohammad Sajjad Mirmoosa, Kypros Kossifos, Julius Georgiou, Andreas Pitsilides, Nikolaos V. Kantartzis, Sotiris Ioannidis, Eleftherios N. Economou, Maria Kafesaki, Sergei A. Tretyakov, and Costas M. Soukoulis [Foundation for Research and Technology Hellas, Greece, Aalto University, Finland, and University of Cyprus, Cyprus]
HyperSurfaces (HSFs) are thin-layered metamaterials whose electromagnetic behavior is defined programmatically. HSFs merge metasurfaces with networks of miniaturized electronic controllers in an integrated scalable hardware platform, so that programmatic commands expressing the desired end-functionality effectively reconfigure the metasurface. We present the HSF paradigm and highlight its challenges and prospects.

14:30 Electromagnetic Aspects of Practical Approaches to Realization of Intelligent Metasurfaces (Invited)
Fu Liu, Odysseas Tsilipakos, Xuchen Wang, Alexandros Pitilakis, Anna Tasolamprou, Mohammad Mirmoosa, Do-Hoon Kwon, Kypros Kossifos, Julio Georgiou, Maria Kafesaki, Costas Soukoulis, and Sergei Tretyakov [Aalto University, Finland, Foundation for Research and Technology Hellas, Greece, University of Massachusetts Amherst, USA, University of Cyprus, Cyprus]
We thoroughly investigate the electromagnetic response of intelligent metasurfaces. We study two distinct designs, a switch-fabric-based design for GHz frequencies and a graphene-based approach for THz band, and discuss the respective practical design considerations. The performance for tunable perfect absorption applications is assessed in both cases.

15:00 Information Metamaterials: Real-Time Information Processing Systems (Invited)
Tie Jun Cui [Southeast University, China]
The concept of coding metamaterials or metasurfaces has been proposed, in which metamaterials are characterized by 1-bit digital coding particles of '0' and '1' with 180° phase difference, or 2-bit digital coding particles of '00', '01', '10', and '11' with 90° phase difference, etc. It was demonstrated that the electromagnetic waves can be manipulated by changing the digital coding sequences.

E8 Active/non-Hermitian systems II

Hall: E **Chairs:** Mercedeh Khajavikhan and Filippo Capolino

14:00 Towards Experimental Implementation and the Effects of Finite-Aperture Size in Dark State Metasurface Lasers
Sotiris Droulias, Thomas Koschny, and Costas M. Soukoulis [Foundation for Research and Technology Hellas, Greece, and Ames Laboratory and Iowa State University, USA]
We propose a metamaterial laser system, which allows to separate the implementation of the resonant lasing state from radiative out-coupling. We examine the proposed laser concept in implementations that represent realistic experiments and we establish conditions for the required minimum system and aperture size.

14:15 Graphene-Based Hyperbolic Metamaterials with Non-Local Quantum Gain
Illya Tarasenko, Freddie Page, and Ortwin Hess [Imperial College London, UK]
We propose stratified graphene-dielectric structures as a route to active hyperbolic metamaterials. Employing an exact in RPA, non-local quantum conductivity model allows us to describe the graphene plasmons in the photo-inverted graphene carrier system at large wavevectors, which is of key interest for hyperbolic metamaterials. By calculating Bloch modes of these structures, we predict the possibility of mode loss compensation and amplification, as well as show the tunability of these properties.

14:30 Enhanced Sensitivity at Non-Hermitian Exceptional Points (Invited)
Mercedeh Khajavikhan, Demetrios Christodoulides, and Hossein Hodaei [University of Central Florida, USA]
Enhanced sensitivity is demonstrated in PT-symmetric coupled micro-resonator arrangements biased at an exceptional point. The spectral response of such a system is shown to follow a nth root dependence on externally introduced perturbations.

15:00 General Conditions to Realize Exceptional Points of Degeneracy and Applications (Invited)
Mohamed Nada, Tarek Mealy, Farshad Yazdi, Ahmed Abdelshafy, Alexander Figotin, and Filippo Capolino [University of California, Irvine, USA]
We explore the emergence of exceptional points of degeneracy (EPDs) that denote a coalescence of multiple eigenmodes in coupled-mode structures. We establish the general conditions that lead to observing EPDs of different orders in various coupled systems, either uniform (non-periodic) or periodic. EPDs can be found in lossless systems as well as in systems with gain-loss balance. Also, we provide examples of potential applications of structures with EPDs that help improve the performance of devices, like sensors, oscillators, etc., at microwave and optical frequencies.

PS: Poster Session

Chairs: Igor Nefedov and Tommaso Isernia

15:00

Metamaterials-based antennas

1. Recent Developments in the Design of Waveform-Selective Mantle Cloaks for Antenna Applications
Stefano Vellucci, Alessio Monti, Mirko Barbuto, Alessandro Toscano, and Filiberto Bilotti ["Roma Tre" University and Niccolò Cusano University, Italy]

2. Optimized Metamaterial Loaded Square Fractal Antenna for Gain and Bandwidth Enhancement
Suganthi Sellakkutti [CHRIST (Deemed to be University), India]

3. Planar Directivity of a Dipole Array
Jiaruo Yan, Ekaterina Shamonina, and Christopher Stevens [University of Oxford, UK]

4. Improvement of Low Profile Dipole Antenna Parameters with EBG-Mushroom Structure in X Band for Microwave Imaging
Emin Unal, Fatih Alkurt, Olcay Altintas, Mehmet Bakir, and Muharrem Karaaslan [Iskenderun Technical University and Bozok University, Turkey]

5. Mutual-Coupling Reduction in Metamaterial SIW Slotted Antenna Arrays Using Metal Fence Isolators for SAR and MIMO Applications
Mohammad Alibakhshikenari, Bal S. Virdee, Chan H. See, Raed Abd-Alhameed, Marjan Marbouti, Francisco Falcone, and Ernesto Limiti [University of Rome "Tor Vergata", Italy, Universidad Pública de Navarra, Spain, University of Helsinki, Finland, and University of Bradford, University of Bolton, and London Metropolitan University, UK]

6. Practical Isotropy and Anisotropy of 3-D Printed Artificial Foam-Like Dielectrics with Antenna Applications
Plamen Dankov, Valda Levcheva , and Mario Iliev [Sofia University, Bulgaria]

7. Decoupling of Two Closely Located Dipoles Using Metasurfaces of Resonant Dipoles and Split-Loop Resonators
Masoud Sharifian Mazraeh Mollaei, A. Hurshkainen, S. Kurdjumov, S. Glybovski, and C. Simovski [Aalto University, Finland, and ITMO University, Russia]

8. Effective Source of Runaway Electrons for Low-Dose Industrial Radiography
Vasily Kozhevnikov, Andrey Kozyrev, Natalia Semeniuk, Aleksandr Kokovin, and Viktoriia Goliak [Institute of High Current Electronics and Tomsk State University, Russia]

9. Compact Broadband Dipole Antenna with Split Ring Resonators
Ikmo Park, Kam Eucharist Kedze, and Heesu Wang [Ajou University, South Korea]

10. Two Elements MIMO Antenna with Asymmetric Coplanar Strip Metamaterial Configuration and EBG Hybrid Isolation
Mahmoud Abdalla, Donya Nazif, and Aya Ali [Military Technical College and October University for Modern Sciences and Arts, Egypt]

Microwave and THz applications

11. A Compact Band Stop Filter with Sharp Stopband Response using D-CRLH Configuration
Mahmoud Abdalla, Yasmine Hammad, and Ahmed Daw [Military Technical College and October University for Modern Sciences and Arts, Egypt]

12. Engineering of Metamaterials Based Cut-band to Bandpass Filters
Frederique Gadot, Benoit Belier, Michel Piat, and Faouzi Boussaha [Université Paris Nanterre, Université Paris Saclay, Université Paris Diderot, and Observatoire de Paris, France]

13. A Linear-To-Circular Polarization Converter With Broadband Transparency Based On Huygens' Metasurface
Andrey Sayanskiy, Stanislav Glybovski, and Juan Domingo Baena [ITMO University, Russia, and Universidad Nacional de Colombia, Colombia]

14. Contact-less Measurement by Using Glide-symmetric Holes on Flanges
Mahsa Ebrahimpouri and Oscar Quevedo-Teruel [KTH Royal Institute of Technology, Sweden]

15. Chiral Metamaterial Based Microfluidic Sensor
Mehmet Bakir, Muharrem Karaaslan,Faruk Karadag, Şekip Dalgac, Fatih Özkan Alkurt, Mehmet Bagmanci, and Olcay Altintas [Bozok University, İskenderun Technical University, Çukurova University, Turkey]

16. Metamaterial-based Sensor for Measurements of physical Quantities and Parameters of technological Processes
Andrey Yelizarov, Alexander Kukharenko, and Andrey Skuridin [Moscow Institute of Electronics and Mathematics, NRU Higher School of Economics, and ARM Expertise Dept. JSC «Sberbank-Service», Russia]

17. Superdirective Radiation of Helical Trimers
Pavel Petrov, Gareth Ward, Roy Sambles, Alastair Hibbins [University of Exeter, UK]

18. High-Performance and Label-Free THz Biosensing from Metamaterial
Biao-Bing Jin, C.H. Zhang, J.B. Wu, J. Chen, and P.H. Wu [Nanjing University, China]

19. Phase Advance in a Textile Metamaterial Operating in Sub-Millimeter Band
Ludovic Burgnies, Camille Huppé, Guillaume Ducournau, Cédric Cochrane, François Rault, Vladan Koncar, and Eric Lheurette [Institute of Electronics, Microelectronics and Nanotechnology and Génie et Matériaux Textiles Laboratory, France]

20. Diffuse THz Scattering via Coding Metasurfaces
Can Koral, Gianpaolo Papari, Antonello Andreone, Massimo Moccia, Giuseppe Castaldi, Vincenzo Galdi, Shuo Liu, and Rui Yuan Wu, and Tie Jun Cui [University of Naples "Federico II" and University of Sannio, Italy, and Southeast University, China]

21. Numerical Study of Fabry-Pérot Resonance Based Metamaterials for Subwavelength Imaging
Md Anazan-uz-Zaman and Shin Hur [Korea Institute of Machinery and Materials, University of Science and Technology, Republic of Korea]

Optical applications

22. Light Manipulation at Compact Scale via all-Dielectric Metasurfaces
Muhammad Qasim Mehmood [Information Technology University of the Punjab, Pakistan]

23. Anti-Reflective Metasurface Coatings for Mid-Infrared Range
Zhanna Dombrovskaya and Alexander Bogolyubov [Lomonosov Moscow State University, Russia]

24. Dielectric Color Metasurface Based On Regular Hole Arrays
Mehdi Keshavarz Hedayati, Søren Raza, and Anders Kristensen [Technical University of Denmark, Optofluidics, Denmark]

25. Phase Manipulation of Constant-Intensity Waves in Disordered Optical Structures
Sunkyu Yu, Xianji Piao, Choonlae Cho, and Namkyoo Park [Seoul National University, South Korea]

26. Remote Modulated Distributed Bragg Reflectors
David Margousi, Hamed Reza Shoorian, and Zahra Amin [University of Shahre-Rey, University of Allameh Tabataba'I, and University of Torbat-e-Heydarieh, Iran]

27. The Micron-sized Periodic Structures and Silicon nanocrystals created at the Surface of the Crystal and Amorphous Silica by Resonant CO2 Laser Irradiation
Anel Mukhamedgalieva, Igor Shvedov, and Vladimir Laptev [Institute of Spectroscopy, Russian Academy of Sciences, and National Research Technological University MISIS, Russia]

28. Optical Force Control Using Phase-Gradient Metasurfaces
Karim Achouri, Hsiang C. Wang, and Olivier J. F. Martin [EPFL, Switzerland]

Tunability

29. High-Efficiency Thermal Tuning of a Terahertz Metamaterial with Liquid Crystal
Rafał Kowerdziej and Marek Olifierczuk [Military University of Technology, Poland]

30. Optical Switching Cell Based On Metamaterials and Ferrite Films
Konstantin Vytovtov, Elizaveta Barabanova, and Said Zouhdi [Astrakhan State Technical University, Russia, and Paris-Sud University, France]

31. Metasurface-Based Tunable Reflector for Independent Control of Orthogonal Polarizations
Christophe Fisne, Cédric Martel, Anne-Laure Franc, and Nathalie Raveu [The French Aerospace Laboratory and University of Toulouse, France]

32. Numerical Modeling of Tunable Nonlinear Graphene-Based Metamaterials, Metasurfaces and Metadevices for Nanophotonics
Galina Makeeva, Oleg Golovanov, and Anatoly Rinkevich [Penza State University and Institute of Metal Physics Ural Branch of Russian Academy of Science, Russia]

33. Tunable Photonics Crystal Slab Waveguide using Transparent Conductive Oxide
Vishal Vashistha and Maciej Krawczyk [Adam Mickiewicz University in Poznan, Poland]

Material characterization

34. Terahertz Conductivity of Few Layer Graphene Intercalated with Ferric Chloride under Optical Pumping
Mikhail Khodzitsky, Alexander Grebenchukov, Petr Demchenko, Anton Zaitsev, and Anna Baldycheva [ITMO University, Russia, and University of Exeter, UK]

35. Impact of Optical Pumping on Carbon Nanotubes Permittivity in THz Frequency Range
Mikhail Khodzitsky, Daniel Gomon, Ilya Anoshkin, Dmitrii Lioubtchenko, P. Demchenko [ITMO University, Russia, and Royal Institute of Technology, Sweden]

36. Rapid Characterization of Metasurface Unit Cells using Scanning Differential Heterodyne Microscopy
Rucha Deshpande, Ildar Akhmedzhanov, Dmitry Baranov, Evgeny Zolotov, and Sergey Bozhevolnyi [University of Southern Denmark, Denmark, and Russian Academy of Sciences, Russia]

37. Quantitative 3D Imaging of Metasurfaces Phase Response
Jiří Babocký, Aneta Křížová, Lenka Štrbková, Lukáš Kejík, Filip Ligmajer, Martin Hrtoň, Alexander Faßbender, Petr Dvořák, Matěj Týč, Jana Čolláková, Vlastimil Křápek, Radek Kalousek, Radim Chmelík, and Tomáš Šikola [Brno University of Technology, Czech Republic, and Rheinische Friedrich-Wilhelms Universität Bonn, Germany]

38. Tuned Thermal Conductivity of Poly (acrylic acid) by Metal Impregnation
Seung-Mo Lee, Nguyen Quy Dat, and Jae-Hyun Kim [Korea Institute of Machinery and Materials, South Korea]

Plasmonics

39. Theory of Graphene Plasmon Cavity
Xiaofei Xiao, Stefan A. Maier, and Vincenzo Giannini [Imperial College London, UK]

40. Transmission Properties of the Plasmon-Polariton Gap in One-dimensional Kerr-metamaterial Superlattices
Tiago Lobo and Solange Cavalcanti [Universidad Federal de Alagoas, Brazil]

41. Lasing at K-point in Plasmonic Honeycomb Lattice
Marek Nečada, Rui Guo, Tommi Hakala, Aaro Väkeväinen, and Päivi Törmä [Aalto University, Finland]

42. The Transverse Magneto-Optical Kerr Effect in a Plasmonic Structure with Non-Symmetric Nanoparticles
Andrey Kalish, Maxim Goguev, Alexey Kuzmichev, and Vladimir Belotelov [Lomonosov Moscow State University and Russian Quantum Center, Russia]

43. Magnetoplasmonic Heterostructure Based on Nanoparticles and Gold Gratings
Roman Komarov, Andrey Kalish, Mikhail Kozhaev, Sergey Tomilin, Anatoly Prokopov, Vladimir Berzhansky, Alexander Shaposhnikov, Andrey Karavaynikov, and Vladimir Belotelov [Russian Quantum Center, Crimean Federal University, and Lomonosov Moscow State University, Russia]

44. Numerical Simulations of Hybrid Sphere-gap-cone Dimer Nanoantenna
Sergey Makarov, Yali Sun, and Dmitry Zuev [ITMO University, Russia]

45. Magnetic Plasmon Coupling in Connecting Deep-Subwavelength Plasmonic Metamaterial Resonators
Zhen Liao, Guo Qing Luo, and Tie Jun Cui [Hangzhou Dianzi University and Southeast University, China]

46. Bose-Einstein Condensation in a Plasmonic Lattice
Tommi Hakala, Antti Moilanen, Aaro Väkeväinen, Rui Guo, Jani-Petri Martikainen, Konstantinos Daskalakis, Heikki Rekola, Aleksi Julku, and Päivi Törmä [Aalto University, Finland]

47. Babinet's Principle for Plasmonic Antennas: Complementarity and Differences
Martin Hrtoň, Vlastimil Křápek, Michal Horák, Filip Ligmajer, Andrea Konečná, Jiří Babocký, Tomáš Šamořil, Michael Stöger-Pollach, and Tomáš Šikola [Brno University of Technology, Czech Republic, Materials Physics Center of San Sebastián, Spain, and Vienna University of Technology, Austria]

48.Refractive Index Engineering With Silver Nanodisc Metasurfaces For Developing Functional Films
Hideki Yasuda, Takeharu Tani, and Masayuki Naya [Fujifilm Corporation, Japan]

49. Electromagnetic Modeling and Design of Gold Nanoantennas on a Magnetic Dielectric for Ultrafast Magnetism
Daria Sylgacheva, Mikhail Kozhaev , Alexander Chernov , Andrey Kalish, and Vladimir Belotelov [Lomonosov Moscow State University and Prokhorov General Physics Institute, Russia]

50. On the Plasmonic Resonances in a Layered Waveguide Structure
Yevhen Ivanenko, Mariana Dalarsson, Sven Nordebo, and Richard Bayford [Linnaeus University, Sweden, and Middlesex University, UK]

51. Tunable Reflection Type Plasmon Induced Transparency with Graphene
Mohsin Habib, Ekmel Ozbay, and Humeyra Caglayan [Bilkent University, Turkey, and Tampere University of Technology, Finland]

52. Reflection Spectra from SiC Substrate with Circular-Slot Antennas and Influence of Surface-Plasmon Polaritons and on Surface-Phonon Polaritons
Kenichi Kasahara, Nobuyuki Umemori, Toyonari Yaji, Nobuhiko Ozaki, Naoki Ikeda, and Yoshimasa Sugimoto [Ritsumeikan University, Wakayama University, and National Institute for Materials Science, Japan]

53. On The Optimal Plasmonic Resonances in Lossy Media
Sven Nordebo, Mariana Dalarsson, Mats Gustafsson, and Daniel Sjöberg [Lund University, Sweden]

Theory and methods

54. Electromagnetic Modeling of Finite Fragments of Metamaterials and Metasurfases based on Method of Minimal Autonomous Blocks
Yauheni Arlou, Sergei Maly, and Eugene Sinkevich [Belarusian State University of Informatics and Radioelectronics, Belarus]

55. Quasi-Static Metamaterials with Million-Times Enhanced Susceptibilities over Many Decades of Frequencies
Taeyong Chang, Yong-Hee Lee, and Jonghwa Shin [KAIST, Republic of Korea]

56. Synthesis of Metamaterials Based on the Minimal Autonomous Blocks Method and Deep Learning Technology
Sergey Maly, Alexander Dezhurko, and Hanna Arlova [Belarusian State University, Belarus]

57. Inverse Homogenization of a Quasiperiodic Composite
Elena Cherkaev, Sebastien Guenneau, and Niklas Wellander [University of Utah, USA, Aix-Marseille Universite and Institut Fresnel, France, Swedish Defence Research Agency, Sweden]

58. Selection Rules In Second Harmonic Generation Process Supported By Mie Resonances
Kristina Frizyuk and Mihail Petrov [ITMO University, Russia]

59. Surface-to-Propagating Wave Conversion Using Metasurfaces: Canonical Solution
Svetlana Tcvetkova, Stefano Maci, and Sergei Tretyakov [Aalto University, Finland, and University of Siena, Italy]

60. The Physics of Self-Complementary Metasurfaces Under Circularly Polarized Waves
Julian D. Mateus, Juan P. del Risco, Andrey Sayanskiy, Stanislav B. Glybovski, and Juan D. Baena [Universidad Nacional de Colombia, Colombia, and ITMO University, Russia]

61. Validity of homogenization for Artificial Plasmas: Straight Strips Versus Zigzag Strips
Jesús Alberto Parra Peña, Andrey Sayanskiy, Dmitry Zhirihin, Stanislav B. Glybovski, Juan Domingo Baena Doello [Universidad Nacional de Colombia, Colombia, and ITMO University, Russia]

62. Topological Interface between Anisotropic Materials for Transverse Spinning of Light Fields
Xianji Piao, Sunkyu Yu, Minpyo Lee, and Namkyoo Park [Seoul National University, South Korea]

63. Transition Conditions to Simulate Biaxial Anisotropic Thin Slab
Nezahat Gunenc Tuncel and A. Hamit Serbest [University of Cukurova, Turkey]

64. Mode Conversion of Parallel Plate Waveguide with Periodic Membranes
Takaaki Minamigaito, Toshiaki Kitamura, and Yasushi Horii [Kansai University, Japan]

65. Tunable Frequency Conversion With Coupled Time-Modulated Cavities
Galaad Altares Menendez and Bjorn Maes [University of Mons, Belgium]

66. Revisiting the Boundary Effects of Weak Nonlocality in Multilayered Dielectric Metamaterials: A Trace and Anti-trace Map Approach
Giuseppe Castaldi, Andrea Alù, and Vincenzo Galdi [University of Sannio, Italy, and University of Texas at Austin, USA]

67. A Study of Spectral Singularities in Non-Hermitian Cylindrical Core-Shell Geometries
Massimo Moccia, Giuseppe Castaldi, Andrea Alù, and Vincenzo Galdi [University of Sannio, Italy, and University of Texas at Austin, USA]

68. The Concept of Active Metasurface-based Electromagnetic Wave Cancellation
Joisp Lončar and Borna Jelačić [University of Zagreb, Croatia]

69. Negative Refraction in Plasma and Magnetic Materials
Naghi Gasimov, Faruk Karadag, Muharrem Karaaslan, and Victor Veselago [Cukurova University and Iskenderun Technical University, Turkey, and Russian Academy of Sciences, General Physics Department, Russia]

70. Storage and Retrieval of Electromagnetic Waves with Metamaterial Analog of Electromagnetically Induced Transparency
Toshihiro Nakanishi and Masao Kitano [Kyoto University, Japan]

71. Magnetic Permeability Spectra of Metamaterials Composed of Split Cut Wires Retrieved from Circuit Theory
Sung-Soo Kim, Joon-Hee Lim, and Min-Sung Kim [Chungbuk National University, South Korea]

72. Plane Wave Diffraction by a 90° Wedge Coated by Metamaterial Slabs: a Uniform Asymptotic Solution in the Case of Normal Incidence
Giovanni Riccio and Gianluca Gennarelli [University of Salerno and I.R.E.A. - C.N.R., Italy]

73. On the Dyakonov Waves Guided by the Interface with a Columnar Thin Film
Muhammad Faryad and Farhat Abbas [Lahore University of Management Sciences, Pakistan, and The University of Texas at Dallas, USA]

Acoustics

74. Perfect Absorption and Total Reflection in Space-Coiled Sub-Wavelength Channels
Anastasiia O. Krushynska, Vincent Romero-Garcia, Federico Bosia, Nicola M. Pugno, and Jean-Philippe Groby [University of Trento and University of Torino, Italy, and Universite du Mans, France]

75. A Bi-functional Metamaterial Simultaneously for acoustic Insulation and Electromagnetic Diffusion
Cheng Zhang, Wenkang Cao, and Qiang Cheng [Southeast University, China]

76. Sound Transmission Loss of Locally Resonant Metamaterial and Phononic Crystal Plates
Lucas Van Belle, Claus Claeys, Elke Deckers, and Wim Desmet [KU Leuven, Belgium]

77. High-order Modes Of Spoof Surface Acoustic Waves
Liting Wu, Wenkang Cao, Gangyong Song, Qiang Cheng, and Tiejun Cui [State Key Laboratory of Millimeter Waves, Southeast University, China]

THURSDAY

9:00 Plenary session IV

10:00 Coffee
Meet-and-greet the Physical Review Editors

	Aalto Hall	Hall B	Hall D	Hall E
10:30	**A9**	**B9**	**D9**	**E9**
	Special session: Nano-architectronics	*Nonlinear meta-materials II*	*Meta-surfaces I*	*Light control through meta-materials*

12:30 Lunch

14:00	**A10**	**B10**	**D10**	**E10**
	Topological effects II	*Advanced optical materials*	*Applications to energy, sensing, and optical trapping*	*Scattering control and cloaking*

15:30 Coffee
Meet-and-greet the Physical Review Editors

16:00	**A11**	**B11**	**D11**	**E11**
	Special session: Nanogap plasmonics and devices	*Non-reciprocal meta-materials*	*Meta-surfaces II*	*Theory and modeling III*

18:00 Closing Ceremony

18:30

Plenary session IV

Hall: Aalto **Chair:** Andrea Alù

9:00 Seeing A Single Atom Where It Is Not

Arno Rauschenbeutel, Gabrie Araneda, Stefan Walser, Yves Colombe, Daniel B. Higginbottom, Jürgen Volz, and Rainer Blatt
[Humboldt-Universität zu Berlin, Germany, and Universität Innsbruck, TU Wien, and Universität Innsbruck, Austria]

I will show that, for a perfect, aberration-free optical imaging system like an ideal optical microscope, the image of an elliptically polarized emitter does not coincide with the emitter's real position. Imaging a single atom as well as a single gold nanoparticle, we demonstrate this effect and observe wavelength-scale shifts.

A9 Special session: Nanoarchitectronics

Hall: Aalto **Chairs:** Stefano Maci and Anatoly Zayats

Organizer: Stefano Maci and Anatoly Zayats

10:30 Nanoarchitectronics (Invited)

Jouni Ahopelto, Andrea Benini, Filiberto Bilotti, Bruno Casali, Jean Chazelas, Giampiero Gerini, Yang Hao, Kai Herbertz, Stefano Maci, Andrea Massa, Luca Pierantoni, Clivia Sotomayor-Torres, Sergei Tretyakov, Charlotte Tripon-Canseliet, Yiannis Vardaxoglou, Giuseppe Vecchi, and Anatoly Zayats [VTT and Aalto University, Finland, University of Siena, RomaTre University, IDS, University of Trento, Università Politecnica delle Marche, and Polytechnic of Turin, Italy, THALES S.A., and ESPCI, France, TNO, The Netherlands, Queen Mary University, Loughborough University, and, King's College, UK, Fraunhofer FHR, Germany, and, ICN2 and ICREA, Spain]

Interdisciplinary research area at the crossroad of Nanophotonics, Electromagnetics and Nanoelectronics. It is a new technology aimed at conceiving, designing and developing reconfigurable, adaptive and cognitive structures, sensorial surfaces and functional "skins" with unique physical properties, and engineering applications in the whole electromagnetic spectrum; through assembling building blocks at nanoscale in hierarchical architectures. The conception of this new area responds to the need of unifying concepts, methodologies and technologies in Communications, Environment Sensing Systems, Safety and Security, Bio-Sensing Systems and Imaging Nanosystems, within a wide frequency range. The FET project called NTX, funded by the European Framework of Research "Horizon 2020", gathers thirteen universities, research centers and high-tech industries, belonging to eight European countries. According to the FET work-program, the major objective of "Nanoarchitectronics" is to boost the future application-driven research through the establishment of an accepted language among physicists and engineers, a shared way of thinking, a common theoretical foundation and a common strategy for the future. Therefore, the project aims at laying the foundation for an ever-increasing synergy and progress of Nanoarchitectronic

11:00 Nanoarchitectronics: the New Paradigm of Airborne Systems (Invited)

Jean Chazelas and Charlotte Tripon-Canseliet [Thales DMS and PSL/ESPCI, France]

The objective of this talk is to address the impact of the nanoarchitectronics paradigm on advanced airborne systems. It will review some applications of the nanomaterial and nanotechnology concepts to the future smart skins systems.

11:15 Metamaterials in the Time Domain (Invited)

John Pendry [Imperial College London, UK]

Conventional metamaterials rely on their spatial structure for their performance. However, it is often possible to reconfigure the internal structure and hence introduce time dependence adding the dimension of time to the possible variables. I shall present results for very simple time dependent metamaterials and make some speculations for their future deployment.

11:30 Structured Waves (Invited)

Nader Engheta [University of Pennsylvania, USA]

One of the interesting features of metamaterials and metastructures is the ability to sculpt and structure fields and waves in ways not readily achievable with conventional platforms. Such manipulation of waves by means of specialized materials has opened new venues for light-matter interaction, with particular attention to novel functionalities. Extreme light-matter interaction can be accomplished by extreme materials. We have explored a variety of "structured waves", in which some forms of extreme platforms have been utilized to tailor structured light. Some of these scenarios include (1) optical metatronics and quantum metatronics, (2) "informatic" materials for analog computing, (3) temporal and spatio-temporal metastructures, (4) near-zero-index photonic platforms, (5) one-atom-thick optical devices, (6) quantum optics with zero index, (7) photonic doping, and (8) designer metasurfaces, just to name a few. In this talk, I will give a brief overview of some of these structured wave platforms.

11:45 Metatronics Concept and its extension within the H2020 NanoArchitectronics Project: Definition and Potential Impact (Invited)

Filiberto Bilotti, Davide Ramaccia, Sergei Tretyakov, Constantin Simovski, Andrea Massa, Giacomo Oliveri, Stefano Maci, Clivia Sotomayor-Torres, Charlotte Tripon-Canseliet, Giampiero Gerini, Jouni Ahopelto, Anatoly Zayats, Giuseppe Vecchi, Davide Mencarelli, Luca Pierantoni, Bruno Casali, Thomas Bertuch, Kai Herbertz, Jean Chazelat [RomaTre University, University of Siena, Politecnico de Turin, Università Politecnica delle Marche, University of Trento, and IDS S.p.A., Italy, Aalto University and VTT, Finland, Catalan Institute of Nanoscience and Nanotechnology (ICN2), Spain, ESPCI, and Thales Research and Technology, France, TNO, Netherlands, King's College London, UK, and Fraunhofer Inst. High Frequency Physics & Radar Techniques FHR, Germany]

Metatronics (MTX) was introduced by Nader Engheta in 2007 as a new concept that unifies the fields of electronics and photonics, introducing "circuit elements" for light, in analogy with circuit elements used in electronics: capacitors, inductors, transistors, etc. Thanks to the recent advancements in metamaterial technology, the concept of MTX can be further extended, considering the current technological achievements allowing material properties to be dynamically controllable in both space and time. This would open a multitude of new applications and scientific explorations. In this contribution, we briefly review the MTX concept, present its extension within the H2020 NANOARCHITECTRONICS project, discuss about the impact that MTX will have on European technology and competitiveness, and identify the current centers of excellence in Europe.

12:00 Round Table Discussion

Anatoly Zayats, Stefano Maci, Filiberto Bilotti, Jean Chazelas, Nader Engheta, and John Pendry [King's College London and Imperial College, UK, University of Siena and Roma Tre University, Italy, THALES-SA, France, University of Pennsylvania, USA]

10:30 Less is More – Enhancing Second-harmonic Generation from Metasurfaces by Engineering Interparticle Interactions

Mikko Huttunen, Robert Czaplicki, Antti Kiviniemi, Xiaorun Zang, Timo Stolt, Ismo Vartiainen, Jeremy Butet, Markku Kuittinen, Olivier Martin, and Martti Kauranen [Tampere University of Technology and University of Eastern Finland, Finland, Nicolaus Copernicus University, Poland, and Swiss Federal Institute of Technology, Switzerland]

We demonstrate a considerable enhancement of second-harmonic generation from metasurfaces due to strong interparticle interactions. Two different arrays of V-shaped gold nanoparticles are characterized. While both arrays exhibit similar linear responses, their nonlinear responses are remarkably different. Second-harmonic emission from the optimized array is found to be over five-fold enhanced.

10:45 Homogenization and Scattering Analysis of Second-Order Nonlinear Metasurfaces

Karim Achouri, Gabriel D. Bernasconi, Jérémy Butet, and Olivier J. F. Martin [EPFL, Switzerland]

We present an extensive discussion on the homogenization and scattering analysis of second-order nonlinear metasurfaces. We use the generalized sheet transition conditions (GSTCs) in the frequency-domain to model the electromagnetic responses of nonlinear metasurfaces. We present the general second-harmonic scattering relations, in the undepleted pump regime approximation, and the resulting reflectionless, transmissionless and asymmetric reflection and transmission conditions. Finally, to clarify certain misconceptions, we also discuss the concept of nonreciprocal scattering in nonlinear optics.

11:00 Transient Nonlinear-Optical Response of All-Dielectric Nanostructures and Metasurfaces (Invited)

Andrey Fedyanin [Lomonosov Moscow State University, Russia]

The talk surveys the results of the experimental studies of the nonlinear-optical effects of all-dielectric nanoantennas and metasurfaces formed from Mie-resonant dielectric nanoparticles. The effects of the second- and third harmonics generation as well as ultrafast effects related to optical nonlinearities are discussed. The main material used in all-dielectric nanostructures possessing low-order magnetic-dipole resonances is silicon (crystalline and amorphous one). We also demonstrate that plenty of other semiconductors both indirect as germanium and direct as gallium arsenide can be used as a good platform for fabricating all-dielectric nanostructures having intriguing nonlinear effect upon interaction with laser electric field. Strong light localization as well as the realization of the phase matching conditions are discussed as possible mechanisms of the observed enhancement of the nonlinear-optical effects.

11:30 Structural Second Harmonic Nonlinearity in Plasmonic Metamaterials (Invited)

Viktor Podolskiy, Brian Wells, Anton Bykov, Giuseppe Marino, Mazhar Nasir, and Anatoly Zayats [U Mass Lowell and Purdue University, USA, and King's College London, UK]

We demonstrate that spectral and polarization control of second harmonic generation in plasmonic metamaterials can be engineered in terms of effective bulk second harmonic polarizability of the metamaterial composite. Our analytical results are validated via both experimental studies and numerical solutions of the Maxwell equations.

12:00 Low-Index Materials for Enhanced Optical Nonlinearities (Invited)

Clayton DeVault, Vincenzo Bruno, Stefano Vezzoli, Thomas Roger, Soham Saha, Marcello Ferrera, Matteo Clerici, Audrius Dubietis, Alexandra Boltasseva, Daniele Faccio, and Vladimir Shalaev [Purdue University, USA, Heriot-Watt University and University of Glasgow, UK, and Vilnius University, Lithuania]

Low-index materials are well suited for optical nonlinearities due to their inherent ability to enhance electric fields and satisfy phase-matching conditions. Here, we investigate the nonlinear optical properties of the low-index material, aluminum-doped zinc oxide, and demonstrate generation of time-reversed beams and plasmonic strong-coupling signatures in epsilon-near-zero films. Our results corroborate the outstanding potential of low-index materials and provide foundational support for future studies.

D9 Metasurfaces I

Hall: D **Chairs:** Nima Chamanara and Younes Ra'di

10:30 All-dielectric Mie-resonant Meta-optics (Invited)

Yuri Kivshar [Australian National University, Australia]

Recently emerged new field of all-dielectric resonant meta-optics aims at the manipulation of strong optically-induced Mie-type resonances in dielectric nanostructures and metasurfaces with high refractive index. Unique advantages of dielectric resonant nanostructures over their metallic counterparts are low dissipative losses, a wide range of multipolar interferences, and the enhancement of both electric and magnetic fields that provide competitive alternatives for plasmonic structures including optical nanoantennas, efficient biosensors, passive and active metasurfaces, and functional metadevices. This talk will summarize the most recent advances in the field of all-dielectric Mie-resonant meta-optics including active nanophotonics as well as the recently emerged directions of topological photonics and nonlinear metasurfaces.

11:00 Mie-Resonance-Enhancing Electric-Dipole Emissions on All-Dielectric Metasurfaces

Masanobu Iwanaga [National Institute for Materials Science, Japan]

We report our experimental finding on a new capability of the dielectric metasurfaces comparable to selected plasmonic metasurfaces, that is, fluorescence-enhancing performance. At some of Mie resonances in the dielectric metasurfaces, the intensity enhancement becomes approximately 1000-fold for non-enhancing silicon wafers.

11:15 Plasmonic Meta-Surfaces Dispersionless Both Temporally And Spatially

Aristeidis Karalis and John Joannopoulos [MIT, USA]

A linear passive plasmonic meta-surface platform is introduced to accomplish simultaneous cancellation of temporal and spatial dispersion to high orders for subwavelength slow light.

11:30 Metagratings for Efficient Wavefront Manipulation

Younes Ra'di and Andrea Alù [The University of Texas at Austin, USA]

Metagratings are two-dimensional periodic arrays of individual scatterers that enable highly-efficient extreme wave transformation which was impossible using conventional metasurfaces. We review our recent progress in this area and, notably, discuss metagrating designs based on asymmetric electric dipoles that are practically easier to realize compared to bianisotropic inclusions. In addition, we present the design of a tunable metagrating based on graphene strips. It will be shown that the proposed structure can provide multiple functionalities by tuning just two bias voltages. The efficiency of the proposed design is only limited by dissipation in graphene.

11:45 Metasurfaces with Interleaved Electric and Magnetic Resonances for Broadband Arbitrary Group Delay in Reflection

Odysseas Tsilipakos, Thomas Koschny, and Costas Soukoulis [Foundation for Research and Technology Hellas, Greece, and Ames Laboratory and Iowa State University, USA]

We demonstrate metasurfaces that can perfectly reflect arbitrarily broadband pulses imparting on them a prescribed group delay without distorting the pulse shape, opening new possibilities for dispersion engineering across deeply subwavelength physical scales. This is achieved by implementing multiple, properly-arranged resonances in the electric and magnetic sheet admittivities.

12:00 Self-Complementary Tessellations as Universal Design Approach for LP-to-CP Transforming Frequency Selective Surfaces

Stanislav Glybovski, Andrey Sayanskiy, Sergei Kuznetsov, Juan del Risco, Alexey Slobozhanyuk, Pavel Belov, and Juan Baena [ITMO University and Institute of Semiconductor Physics SB RAS, Novosibirsk State University, Russia, and Universidad Nacional de Colombia, Colombia]

Recently self-complimentary frequency-selective surfaces (FSSs) have been shown capable of linear-to-circular polarization transformation. In this work we numerically and experimentally prove generality of this approach showing that similar self-complimentary tessellations can be used as FSS patterns in both the microwave and the sub-millimeter wave ranges. Moreover, we simulated two Escher's tessellations as patterns of microwave FSSs to further demonstrate the polarization transform function of arbitrary self complimentary FSSs.

12:15 A Transparent, Time-Modulated Metasurface

Zhanni Wu and Anthony Grbic [The University of Michigan, USA]

A transparent, time-modulated metasurface that can perform frequency conversion in the X-band is reported. The metasurface provides high transmission amplitude and an electrically driven, time-modulated transmission phase. Depending on the time-dependent transmitted phase variation, the metasurface can either upconvert or downconvert (Doppler shift) the frequency of the incident wave, without generating an undesired image frequency.

E9 Light control through metamaterials

Hall: E **Chairs:** Owen Miller and Vassili Fedotov

10:30 Flat Optics: from Metalenses to Structured Light (Invited)

Federico Capasso [Harvard University, USA]

Arrays of optically thin, sub-wavelength spaced optical elements (metasurfaces) have major potential for wavefront shaping through local control of the phase, amplitude and polarization of light. Flat optics has emerged from this approach with the goals of replacing refractive lenses in most applications requiring aberrations' correction as well as conventional phase plates used in polarization optics and last but not least of providing a new path to the creation of structured light.

11:00 Fundamental Limits To Light-Matter Interactions (Invited)

Owen Miller [Yale University, USA]

When light interacts with nanophotonic matter, what is the strongest possible optical response? I will describe energy-conservation principles that form the foundation for general limits to light-matter interactions, offering insights into ideal approaches to plasmonics, "perfect" absorbers, near-field "blackbodies," Casimir forces, and more.

11:30 Automated Design of Photonic Crystal Demultiplexers

Boaz Blankrot and Clemens Heitzinger [Vienna University of Technology, Austria]

We describe an approach for the automated design of photonic crystals for various applications. Our approach includes gradient-based optimization for arbitrary objective functions, with the electromagnetic fields calculated by an accurate multiple-scattering approach. An example of a two-color silicon photonic crystal demultiplexer designed by our method is presented, with dozens of parameters chosen automatically in reasonable time. The optimized device exhibits strong focusing with low crosstalk for both frequencies.

11:45 Limits of Laminates in Diffusive Optics

Andreas Niemeyer, Sabine Mannherz, Frederik Mayer, and Martin Wegener [Karlsruhe Institute of Technology, Germany]

Laminates are among the most basic metamaterials. They allow for achieving anisotropy from two isotropic ingredients. Here, we study the fundamental limits of laminates for light propagation in turbid media by extensive Monte Carlo simulations. We find that large optical transmission and large effective anisotropy are not possible simultaneously.

12:00 A Fiberized Metadevice for Ultrafast All-optical Signal Processing and Picosecond Dark Pulse Generation

Odysseas Angelos Xomalis, Iosif Demirtzioglou, Yongmin Jung, Eric Plum, Cosimo Lacava, Perikilis Petropoulos, David Richardson, Nikolay Zheludev [University of Southampton, UK, and Nanyang Technological University, Singapore]

We report a fiberized metadevice for all-optical signal processing based upon coherent modulation of absorption. We demonstrate signal processing operations at data rates ranging from kbit/s up to Gbit/s, with energy consumption as low as few fJ/bit, controlled absorption and transmission of picosecond pulses and generation of 1 ps 'dark pulses'

12:15 The Study of Singular Metasurfaces with Transformation Optics

Fan Yang, John Pendry, and Paloma Huidobro [Imperial College London, UK]

The transformation optics (TO) approach is employed to study singular plasmonic metasurfaces. Being widely used in optical instruments and telescopes, it is of great significance to analytically study singular metasurfaces. This singular metasurface is transformed into an array of slabs, where the absorption by surface plasmon polaritons (SPPs) is calculated. In the metasurface frame, the absorption due to SPP is effectively modeled as a surface conductivity. Then, a flat surface model is used to calculate the reflection for the metasurface, which gives a satisfying agreement with numerical simulation.

A10 Topological effects II

Hall: Aalto **Chairs:** Namkyoo Park and Viktar Asadchy

14:00 Group Theoretical Route to Weakly and Strongly Protected Surface States in 2D and 3D Photonic Crystals

Matthias Saba, Stephan Wong, Mathew Elman, Sang Soon Oh, and Ortwin Hess [Imperial College London and Cardiff University, UK]

We introduce a group theoretical recipe towards topologically protected surface states on purely dielectric metasurfaces, and fully connected 3D photonic crystals. The predictions are verified by full wave simulations of particular designs. These can be readily realized by current direct manufacturing techniques, such as electron beam lithography and direct laser writing, respectively.

14:15 Dipole Excitation of Unidirectional Edge Modes in Dielectric Photonic Topological Insulators

Sang Soon Oh, Ben Lang, Daryl Beggs, Diana Huffaker, Matthias Saba, and Ortwin Hess [Cardiff University, University of Bristol, and Imperial College London, UK]

A unidirectional chiral edge mode in time-reversal symmetric topological insulators can be selectively excited by a circularly-polarized dipole source. By calculating the local chirality of an edge mode in dielectric photonic topological insulators, we show that the directionality is also strongly dependent on the position of the circularly-polarized dipole source.

14:30 Crystalline Metamaterials for Topological Properties at the Subwavelength Scale (Extended)

Simon Yves, Romain Fleury, Thomas Berthelot, Fabrice Lemoult, Mathias Fink, and Geoffroy Lerosey [Institut Langevin, CEA Saclay, and KELENN Technology, France, and , EPFL, Switzerland]

The concept of topological insulators has recently been transposed from condensed matter to classical wave physics such as microwaves. However, these photonic topological insulators are inherently wavelength scaled because their physics rely on Bragg interferences. Here, we show experimentally how structural deformations of an electromagnetic metamaterial, although subwavelength scaled, also induce a topological phase transition.

15:00 Efficient Coupling between a Circular Waveguide and Topologically Protected Unidirectional Helical Modes in Metallic Photonic Crystals

Gian Guido Gentili, Giuseppe Pelosi, Francesco Piccioli, and Stefano Selleri [Politecnico di Milano and University of Florence, Italy]

A circular waveguide transition is used to selectively excite unidirectional Topologically Protected Helical Edge Modes along an interface between metallic Photonic Crystals. Return losses lower then -40dB are observed for a single port excitation and quasi-unitary transmission, mediated by the Topological interface, is observed between two circular waveguide ports for the mid-band frequency.

15:15 All-Dielectric Valley Photonic Crystals: Paving the Way to Topological Nanophotonics

Jianwen Dong [School of Physics and State Key Laboratory of Optoelectronic Materials and Technologies, Sun Yat-Sen University, China]

In this talk, I will show our recent works about realization of all-dielectric valley photonic crytals from theory to experiment, not only in microwave range but also in telecommunication wavelength. These works may open up an alternative route towards the discovery of topological nanophotonics.

B10 Advanced optical materials

Hall: B **Chair:** Pavel Ginzburg and Kevin MacDonald

14:00 Magneto-optical Properties of Fibonacci-modulated Fe-Pt Multilayer Metamaterials

Satoshi Tomita, Tomomi Suwa, Patricia Riego, Andreas Berger, Nobuyoshi Hosoito, and Hisao Yanagi [Nara Institute of Science and Technology, Japan, and CIC nanoGUNE, Spain]

We investigate the magneto-optical (MO) properties of epitaxially-grown Fe-Pt periodic and quasi-periodic modulated multilayer metamaterials by means of generalized MO ellipsometry (GME) in the visible and near-infrared regions. Large Kerr rotation, ellipticity, and MO coupling parameters are obtained for the inverse-Fibonacci-modulated multilayer (IFM) metamaterials. Contrastingly, the periodic multilayers show small MO parameters although they exhibit hysteresis loops in magnetization and refractive indices in GME measurements very similar to those for IFM metamaterials.

14:15 Spherulites as Natural Birefringent Metamaterials

Roman Noskov, Hani Barhom, Ivan Shishkin, and Pavel Ginzburg [Tel Aviv University, Israel]

Spherulites are naturally available pours structures, which recently have got an enormous attention due to their capabilities to serve as extremely efficient biomedical cargoes in drug delivery applications. Owing to the natural crystal grows processes, those composites are made of collection of nanoscale birefringent crystals, which have nontrivial spatial orientations. Here we report on comprehensive analytical, numerical and experimental studies of vaterite microparticles and unravel their peculiar optical properties, which are significantly different from standard Mie solutions for a sphere. We analyze microparticle birefringence as a function of light wavelength and reveal that driven by different eigenmodes birefringence can change the sign and become equal to zero. Furthermore, strongly anisotropic optical properties of vaterites enable investigation of nontrivial optical forces. In particular, diverse types of rotation of optically trapped vaterites will be demonstrated. Flexible optomechanical manipulation together with superior load capacities of Spherulites make them attractive to drug delivery applications.

14:30 Linear and Circular Dichroism in Gyroid Optical Metamaterials

Cédric Kilchoer, James A. Dolan, Matthias Saba, Narjes Abdollahi, Karolina Korzeb, Ulrich Wiesner, Ullrich Steiner, Ilja Gunkel, and Bodo D. Wilt [Adolphe Merkle Institute, University of Fribourg, Switzerland, University of Chicago and Cornell University, USA, and Imperial College, UK]

Gyroid optical metamaterials with unit cell sizes of tens of nanometers are fabricated via electrodeposition of gold into voided polymer template. We show that reflected light from gold gyroids is strongly polarization-dependent, and sensitive to the handedness of the gyroid and the terminations of its top surface.

14:45 Top-down Fabrication of Barium Titanate Metasurfaces with Transmission Filtering in the Visible

Flavia Timpu, Marc Reig Escalé, Adrien Merkt, Lukas Lang, Mariia Timofeeva, and Rachel Grange [ETH Zürich, Switzerland]

We use thin films of barium titanate ($BaTiO_3$), a perovskite ferroelectric material, to fabricate nonlinear metasurfaces. This enables us to add the bulk nonlinearity from a noncentrosymmetric material as an additional property to the versatility and tunability of metasurfaces. We demonstrate a tunable variation of the transmittance in the 400-600 nm range by variation of the pitch and the radius of the perovskite nanostructures.

15:00 Extraordinary Properties of Chalcogenide Metamaterials (Invited)

Kevin MacDonald, Davide Piccinotti, Artemios Karvounis, Behrad Gholipoour, Jin Yao, Brian Hayden, and Nikolay Zheludev [Univesity of Southampton, UK]

Fascinating opportunities are offered by metamaterial nanostructures fabricated from materials with highly-dispersive optical properties, between those of ideally plasmonic (e.g. noble metal) and transparent dielectric media. Chalcogenide semiconductors are excellent examples – their optical properties can be engineered by controlling alloy composition and phase state to provide high and low refractive indices, plasmonic, dielectric and epsilon-near-zero characteristics at near-ultraviolet to near-infrared wavelengths. We report here on the application of chalcogenide materials to photonic metasurfaces.

D10 Applications to energy, sensing, and optical trapping

Hall: D **Chairs:** Alireza Rahimi Rashed and Mohammad Sajjad Mirmoosa

14:00 Gap-Free Super-Planckian Thermophotovoltaics

Mohammad Sajjad Mirmoosa, Svend-Age Biehs, and Constantin Simovski [Aalto University, Finland, and Oldenburg University, Germany]

The concept of a thermophotovoltaic system whose emitter is separated from the photovoltaic cell by an intermediate thick slab of gallium arsenide is introduced. Due to the engineered structure of the emitter (a multilayer structure of negative and positive-epsilon layers) together with a high refraction index and transparency of the intermediate slab, we achieve a super-Planckian and frequency-selective spectrum of radiative heat transfer which is desirable for the efficient performance of thermophotovoltaic systems. While the thermal power transported from the emitter towards the photovoltaic cell by the heat conduction is not zero anymore due to the presence of the intermediate slab, we show that it is less than the transferred radiative thermal power and it can be evacuated by a water-cooling system.

14:15 Front-Electrode Design For Efficient Near-Field ThermoPhotoVoltaics

Aristeidis Karalis and John Joannopoulos [MIT, USA]

Detailed design guidelines and optimization results are presented for front electrodes in efficient resonant near-field thin-film TPV cells, including novel near-field effects, a comparison of different transparent conducting materials and metal-grid-finger considerations.

14:30 Insights into Broadband Backscattering Suppression in Solar Cells from the Duality Point of View

Evgeniia Slivina, Aimi Abass, Ivan Fernandez-Corbaton, Derk Bätzner, and Carsten Rockstuhl [Karlsruhe Institute of Technology, Germany, and Meyer Burger Research AG, Switzerland]

Employing high index dielectric cylindrical nanoparticle arrays has been shown to provide strong broadband suppression of reflection in solar cells when their geometry is properly tailored. The physical mechanism behind this effect, however, is not well understood, with most attributing it only to the silicon wafer's higher density of states due to its index. Here, we discuss the phenomena from the stand point of duality, which is the condition where the magnetic and electric response of the system are equal. We consider an optimized electrically decoupled sub-micron cylinder array, which provides reflection below 5% in the spectral region where the solar cell is highly absorptive. We show that spectral regimes corresponding to high reflection in our optimized solar cell structure are essentially regimes where one is significantly far from the duality condition for the entire sample. We further show that anti-reflective performance of a cell can be improved even more for a system with a higher degree of symmetry.

14:45 Highly Sensitive Near-Infrared Refractive Index Sensor by Metatronic Nanocircuits

Alireza Rahimi Rashed, Basak Gudulluoglu, Hye-Won Yun, Mohsin Habib, Ismail Hakki Boyaci, Ekmel Ozbay, and Humeyra Caglayan [Tampere University of Technology, Finland, Hacettepe University and Bilkent University, Turkey, and Electronics and Telecommunication Research Institute, Republic of Korea]

In this work, we present a highly-sensitive refractive index nano-sensor based on metatronic nanocircuits operating at near-infrared spectral range. The structure is designed based on simple nanorod geometry and fabricated by nanopatterning of transparent conducting oxides. The sensing feature of these polarization dependent metatronic nanocircuits is investigated by depositing NH2 (Amine) groups via plasma polymerization technique above them. We show that the dielectric constant of Amine groups can be controlled by changing their thicknesses, as the RF power or time duration of the applied plasma polymerization process changes. The resonance wavelengths of nanocircuits shift to higher wavelength, as the dielectric constant of the deposited material increases. Our nano-sensor offers a high-sensitive performance of 1587 nm/RIU with a satisfactory figure of merit for this class of sensors.

15:00 Interaction Forces of Electric Currents and Charges in a Double DNA-like Helix and its Equilibrium

Igor Semchenko, Sergei Khakhomov, Alexei Balmakou, and Ivan Mikhalka [Francisk Skorina Gomel State University, Belarus]

The interaction of currents and charges in two helices is considered when a standing low-frequency electromagnetic wave arises in a double DNA-like helix. The mutual displacement of the two helices along their common axis is taken into account. It is shown that it leads to the simultaneous existence of force and moment of force acting on each helix and directed along their common axis. Radial components of the forces of currents and charges interaction are also considered depending on the pitch angle of the double helix.

15:15 Metamaterial Substrates for Optical Pulling Forces

A. Ivinskaya, N. Kostina, M.I. Petrov, A.A. Bogdanov, S. Sukhov, P. Ginzburg, and Alexander Shalin [ITMO University, Russia, University of Central Florida, USA, and Tel Aviv University, Israel]

The optical force acting on a nanoparticle near a planar substrate is governed by incident light and excitation of surface and volume modes of the substrate. We study system configurations leading to significant enhancement of optical forces, for example, plane wave results in pulling forces towards the source for certain types of anisotropic substrates.

E10 Scattering control and cloaking

Hall: E **Chairs:** Alvar Sanchez and Do-Hoon Kwon

14:00 Lossless Tensor Surface Invisibility Cloaks Utilizing Surface Waves

Do-Hoon Kwon [University of Massachusetts Amherst, USA]

A design technique for lossless surface invisibility cloaks for free-space objects using surface waves is presented. The bounding surface of a cloaked region can be designed to transform and guide the illuminating plane wave around and along the surface as surface waves. The proposed designs are promising for realization as ultra-thin metasurface cloaks for electrically large objects in free space.

14:15 Design and Experiment of Multifrequency Free-Space Invisibility Cloak for Electrically-Large Objects

Yongjune Kim, Tianwei Deng, Wei Xiang Jiang, Tie Jun Cui, Boyoung Kang, Hak-Joo Lee, Yongshik Lee, and Cheng-Wei Qiu [Center for Advanced Meta-Materials and Yonsei University, South Korea, National University of Singapore, Singapore, and Southeast University, China]

A design method is proposed for optimizing an isotropic medium to enable the multifrequency cloaking for an electrically-large object isolated in free space. First, refractive indices calculated by the quasi-conformal mapping (QCM) technique are sectionalized based on the anisotropy factors. Second, approximated isotropic refractive indices of the sections are scaled optimally to minimize the scattering width (SW) of a diamond object not only by collimating the path of the scattered wave but also by inducing harmonics of 2ϖ phase delay. The cloaking performance is verified with 82.6% reduction of scattering width (SW) at the design frequency 15 GHz based on the full-wave simulation. In addition, 62% and 73.4% SW reductions are confirmed at 5.2 and 2.3 GHz, respectively, in descending order. The proposed method is validated experimentally by the reduced electromagnetic scattering of a double-cone copper at the multiple frequencies.

14:30 Inverse Scattering as a Way to Artificial Dielectric Based Metamaterials (Invited)

Tommaso Isernia and Roberta Palmeri [Univ. Mediterranea di Reggio Calabria, Italy]

Inverse scattering is proposed to design artificial dielectrics-based devices. In particular, a representation basis for the unknown contrast allowing the determination of the value of the inclusions is used. Then, simple analytical arguments are given in order to exploit a filling factor shaping rather than different materials.

15:00 Dissipation-inspired Asymmetric Scattering and Reflection

Dmitry Filonov, Vitali Kozlov, and Pavel Ginzburg [Tel Aviv University, Israel]

The optical theorem, being the manifestation of the energy conservation law, relates the total scattering cross-section with the forward scattering of a structure, but does not impose any restrictions on other directions. Strong asymmetric reflection and back scattering can be achieved in structures with magneto-electric coupling between constitutive elements. Here the scattering properties of single meta-particles, based on near-field coupled electric and magnetic dipoles, and their arrays are analyzed. In particular, it is shown that the dissipation is the key mechanism, responsible for the asymmetric backscattering behavior. While far-field scattering can serve as a sufficient loss mechanism in the case of single structures, Joule dissipation should be added in the case of periodic metasurfaces. In this case, the practical realization is based on split ring resonators, loaded with a resistance, and wires, both printed on a PC board. Theoretical predictions of the phenomena are supported by both numerical and experimental confirmations, obtained at the GHz frequency range, and all are in a good agreement with each other.

15:15 Undetectable Magnetic Sensors

Rosa Mach-Batlle and Alvaro Sanchez [Universitat Autonoma de Barcelona, Spain]

Magnetic sensors play an essential role in many technologies. Because most magnetic sensors include ferromagnetic materials, which attract magnetic field lines, they inherently distort the probing field. This may be an issue, particularly when accurate magnetic field distributions are required. Here we show how magnetic sensors can be made undetectable by surrounding them with a spherical shell with homogeneous isotropic permeability. The sensor is not isolated from its surroundings and, thus, it is still able to sense. Results may be useful for applications requiring non-invasive sensing.

A11 Special session: Nanogap plasmonics and devices

Hall: Aalto **Chairs:** Cristian Ciraci, David Smith, and Antoine Moreau

Organizers: Cristian Ciraci, David Smith, and Antoine Moreau

16:00 Light-Forbidden Transitions in Plasmon-Emitter Coupling (Invited)

Antonio Fernández Domínguez [Universidad Autónoma de Madrid, Spain]

In this talk, we will investigate the impact that light-forbidden exciton transitions have in the near-field population dynamics and far-field scattering spectrum of hybrid plasmon-emitter systems [1]. Specifically, we will consider a V-type quantum emitter sustaining one dipolar and one quadrupolar (dipole-inactive) excited states, placed at the nanometric gap of a particle-on-a-mirror metallic cavity. A fully analytical description of plasmon-exciton coupling based on Transformation Optics will be presented for both exciton transitions [2]. Using this theoretical approach, we will reveal the conditions in which the presence of the light-forbidden exciton alters greatly the Purcell enhancement and Rabi splitting phenomenology in the system.

16:30 Gap-Plasmon Based Metasurfaces with Diversified Functionalities (Invited)

Sergey Bozhevolnyi [University of Southern Denmark, Denmark]

Integration of multiple diversified functionalities into a single metasurface has recently attracted a considerable attention due to fascinating possibilities for realization of very dense integration and miniaturization in photonics. In this talk, I overview our latest achievements in this area using gap-plasmon based phase-gradient metasurfaces operating in reflection geometry.

17:00 Using Optical Nanocavities to Improve Devices (Invited)

Giuliana Di Martino [University of Cambridge, UK]

Trapping light with noble metal nanostructures overcomes the diffraction limit and can confine light to volumes typically on the order of 30 cubic nanometers. Individual atomic features inside the gap of a plasmonic nanoassembly can localize light to volumes well below 1 cubic nanometer, enabling optical experiments on the atomic scale [Science 354, 726 (2016)]. Fabricating nanocavities in which optically active single quantum emitters are precisely positioned is crucial for building nanophotonic devices [Nano Lett. 18, 405 (2018)]. Photon emitters placed in an optical cavity experience an environment that changes how they are coupled to the surrounding light field [Nature 535, 127 (2016)]. Plasmonic mode hybridization between tightly confined plasmonic cavity modes and a radiative antenna mode sustained in the optical nanocavities shows how optics can reveal the properties of electrical transport across well-defined metallic nanogaps to study and develop innovative technologies [Nano Lett. 16, 5605 (2016)]. One of the most promising contenders for ultralow-energy electronic devices is resistive switching memory (RRAM) which delivers sustainably-scalable 'neuromorphic' computing, potentially capable of reducing energy consumption in IT by >50%. Understanding the nanoscale kinetics of the switching mechanisms is needed to enable high-endurance devices – only this can unlock their integration into fast, low-energy, logic-in-memory architectures. RRAMs are currently studied by electron microscopy however this is destructive, invasive, and under drastically different conditions, so is not sufficient for developing true understandings. Using the ultra-concentration of light we recently achieved [Small 12, 1334 (2016)], we develop innovative fast ways to study real-time movement of individual atoms that underpins this new generation of ultra-low energy memory nano-devices, thus overcoming the limitations of traditional investigation techniques and opening up new routes to sustainable future IT.

17:15 Gap Plasmons Explored with Electron Energy-loss Spectroscopy (Invited)

Søren Raza [Technical University of Denmark, Denmark]

In this talk, I will present two recent works on gap surface plasmons (GSPs). The first work focuses on GSPs propagating in very narrow silver slits, which have potential for integrated optical circuits. Here, we use electron energy-loss spectroscopy (EELS) to experimentally show the propagation, bending, and splitting of GSPs. The second work relates to GSPs localized in between two gold nanoparticles. By preparing the gold dimer on a microelectromechanical system, we can actively control the gap between the nanoparticles through electrical actuation. This allows us to control the optical response of the dimer, which we measure with in situ EELS -- a new technique for characterizing optical devices.

17:30 Nanogap Plasmonics: Dynamic Tuning, Perfect Absorbers and Photodetection (Invited)

Maiken Mikkelsen [Duke University, USA]

Plasmonic film-coupled nanocubes are used to demonstrate large-area perfect absorbers, pixel arrays and ~10,000 combinatorial colors. Integrating either optically or electrically tunable materials in a ~10 nm gap between the metallic film and silver nanocubes enables broad dynamic tuning of the plasmon resonance.

B11 Nonreciprocal metamaterials

Hall: B **Chairs:** Jordi Prat Camps and Andrea Alù

16:00 Slow Light and Nonreciprocity in Metamaterials (Invited)

Andrea Alu [Advanced Science Research Center, CUNY, USA]

In this talk, we discuss our recent results in the area of nonreciprocal devices based on magnetic bias, temporal modulations, nonlinearities and mechanical motion, with a focus on their potential impact in the context of slow light propagation and the delay bandwidth limit. First, we show that, different from recent claims presented in the literature, there are fundamental bounds and relations on the bandwidth and time delay that can be imparted on a given signal by nonreciprocal cavities. They obey bounds consistent with reciprocal cavities, and as such nonreciprocity is not necessarily advantageous in the context of the delay bandwidth limit. Then, we propose a class of spatiotemporally modulated systems, which, under specific conditions, can operate as broadband delay lines exhibiting no group velocity dispersion. Such networks can serve as a platform to achieve slow light over a small footprint, ideal in the quest to realizing integrated, deeply subwavelength photonic topological insulators.

16:30 Dynamic Nonreciprocity in Piezophononic Media

Aurélien Merkel, Morten Willatzen, and Johan Christensen [Universidad Carlos III de Madrid, Spain, and Beijing Institute of Nanoenergy and Nanosystems, Beijing, China]

In this work, nonreciprocal propagation of acoustic waves in piezoelectric semiconductors is demonstrated. By taking advantage of the acoustoelectric effect, we demonstrate a nonreciprocal linear isolator for acoustic waves in elastic solids of large bandwidth, high contrast ratio and high power transmission efficiency in the passing direction.

16:45 Unusual Electromagnetic Modes based on Codirectional Coupled Space-time Harmonics

Nima Chamanara, Zoé-Lise Deck-léger, and Christophe Caloz [Polytechnique Montreal, Canada]

This paper introduces new electromagnetic modes generated in space-time modulated dispersion engineered media. These modes are produced by intercoupling between codirectional space-time harmonics. They exhibit peculiar properties such as periodic transfer of energy between their constituent space-time harmonics and exponential growth. They may find applications in low-noise amplifiers and perfect mixers.

17:00 Nonlinear Isolators and Circulators Based on Networks of Coupled Resonators

Dimitrios Sounas, Jason Soric, Giuseppe D' Aguanno, and Andrea Alu [The University of Texas at Austin and City University of New York, USA]

We present our recent results in the area of nonlinear nonreciprocal devices, including isolators and circulators. We show that the nonlinear isolators based on single Fano resonators are subject to a fundamental trade-off between transmission and isolation intensity range or bandwidth, stemming from time reversal symmetry. We also show how we can overcome this limitation by using multiple nonlinear resonators. Finally, we show that networks with many nonlinear resonators can also be used to realize more advanced devices, such as circulators.

17:15 Asymmetric Cherenkov Emission in a Graphene Sheet with a Drift-Current

Filipa Prudêncio and Mário Silveirinha [University of Lisbon - Instituto de Telecomunicacoes, Portugal]

We study the impact of the nonreciprocal response of a graphene sheet with an electric current bias in the context of the Cherenkov problem. The drift bias enables strongly asymmetry Cherenkov emissions with spectrum dependent on the sign of the charges velocity.

17:30 Circumventing Magnetic Reciprocity: a Diode for Magnetic Fields (Extended)

Jordi Prat-Camps, Patrick Maurer, Gerhard Kirchmair, and Oriol Romero-Isart [University of Sussex, UK, and IQOQI - UIBK, Austria]

Lorentz reciprocity establishes a stringent relation between electromagnetic fields and their sources. For static magnetic fields, a relation between magnetic sources and fields can be drawn in analogy to the Green's reciprocity principle for electrostatics. Here we theoretically and experimentally show that a linear and isotropic electrically conductive material moving with constant velocity is able to circumvent the magnetic reciprocity principle and realize a diode for magnetic fields. This result is demonstrated by measuring an extremely asymmetric magnetic coupling between two coils that are located near a moving conductor. The possibility to generate controlled unidirectional magnetic couplings breaks down one of the most deeply-established relations in classical electromagnetism, namely that mutual inductances are symmetric.

D11 Metasurfaces II

Hall: D **Chairs:** Anthony Grbic and Ariel Epstein

16:00 A Fundamental Speed Limit For Optomechanical Metasurfaces

Sophie Viaene, Vincent Ginis, Jan Danckaert, and Philippe Tassin [Vrije Universiteit Brussel, Belgium, Harvard University, USA, and Chalmers University of Technology, Sweden]

We show that switching speeds of optomechanical metasurfaces are limited by their nonlinear response to an external pump beam, which is demonstrated by solving for the transient dynamics of unit cells under influence of a pump-induced force or torque.

16:15 Surface Topology Specific Metasurfaces

James Burch and Andrea Di Falco [University of St Andrews, UK]

In this work we extend holographic metasurfaces from flat to arbitrary substrates. We show that the substrate topology can be exploited to control the holograms, with applications in security printing and topology sensors.

16:30 An Alternative to Huygens' Meta-Atoms: Transmitarray with Only Electric Response

Grigorii Ptitcyn, Ana Diaz-Rubio, and Sergei Tretyakov [Aalto University, Finland]

We explored ways of obtaining the functionality of Huygens' meta-atoms without the use of magnetic response. We show that this approach is beneficial considering frequency bandwidth and the inclusions size. Finally, we present a design of an optical transmitarray that bends normally incident waves.

16:45 Broadband-Reflectionless Perfect Absorber Made of Planar Resonators

Juan P. del Risco, Manuel A. Londoño, Andrey Sayanskiy, Stanislav B. Glybovski, and Juan D. Baena [Universidad Nacional de Colombia, Colombia, and ITMO University, Russia]

In this work we have numerically designed a metasurface with narrowband perfect absorption and broadband low reflection. The unit cell is formed by couple of split ring resonators. We have developed two theoretical models, one for the transmission/reflection coefficients of the metasurface and a second describing the basic mechanism of the unit cell.

17:00 Achieving Anomalous Refraction with Metasurfaces Composed by Two Ordinary Dielectric Materials

Nikolaos Tsitsas and Constantinos Valagiannopoulos [Nazarbayev University, Kazakhstan, and Aristotle University of Thessaloniki, Greece]

The optimal parameters of a dielectric metasurface, composed of two alternating rectangular rods, are investigated so that it exhibits significant enhancement in the -1 diffracted order in the transmission region. An efficient integral-equation methodology is used for the numerical computations. Representative results of initial optimizations are presented.

17:15 Ultrafast Optical Pulse Shaping using Dielectric Metasurfaces

Amit Agrawal, Shawn Divitt, Wenqi Zhu, Cheng Zhang, and Henri Lezec [CNST and NIST, USA]

Arbitrary control over the amplitude, phase and polarization of individual spectral lines in an ultrafast optical pulse forms an integral part of the field of ultrafast science, and compliments pulse generation and characterization methods. Here, we experimentally demonstrate shaping of ultrabroadband sub-15 fsec ultrafast laser pulses using a silicon-metasurface acting as both the spectral amplitude and phase mask.

17:30 Stacked Metasurface Slab

Nima Chamanara, Yousef Vahabzadeh, and Christophe Caloz [Polytechnique Montreal, Canada]

This paper presents "stacked metasurface slabs", stacked array of cascaded metasurfaces synthesized using a GSTC-based algorithm that circumvent fabrication difficulties in metasurfaces involving sharply varying field transformations. The specified transformation is subdivided into several smoother transformations and shared between cascaded bianisotropic metasurfaces. This algorithm relaxes the fabrication requirements dramatically.

17:45 Detecting Coherence of Light with Metasurfaces

Vassili Fedotov, Tom Frank, Oleksandr Buchnev, Tamsin Cookson, Malgosia Kaczmarek, and Pavlos Lagoudakis [University of Southampton, UK]

We report on a recent discovery that metasurfaces of a certain class respond differently to coherent and incoherent light, enabling robust discrimination between these two states of radiation. The effect has no direct analogue in conventional optics and may find application in compact metadevices enhancing imaging, vision, detection, communication and metrology.

E11 Theory and modeling III

Hall: E **Chairs:** Jonathan Gratus and Tsuyoshi Ueta

16:00 Artificial Localized Magnon Resonance for Super Scattering Applications

Dmitry Filonov, Hani Barhom, Andrey Shmidt, Amir Boag, and Pavel Ginzburg [Tel Aviv University, Israel]

The concept of metamaterials enable considering material degree of freedom as a design parameter in a range of electromagnetic applications. In particular, subwavelength structures made of materials with negative susceptibilities can exhibit strong resonant behaviors. Here the concept of artificial magnon resonance in subwavelength objects with effective negative permeability is demonstrated theoretically, numerically and experimentally. Strongly localized oscillations of the magnetic fields within an array of SRRs, forming a sphere, hybridize in a collective mode of the structure. As a result, extremely high scattering cross section, exceeding that of a steel sphere with the same radius by four orders of magnitude. From the application standpoint, the demonstrated supper scatterer has VHF radar signature, prevailing the one of a big military aircraft.

16:15 Nonlocal Homogenization Theory for Centro-Symmetric Optical Metamaterials

Karim Mnasri, Andrii Khrabustovskyi, Christian Stohrer, Michael Plum, and Carsten Rockstuhl [Karlsruhe Institute of Technology, Germany]

The introduction of effective material parameters is of paramount importance to predict observable features from actual metamaterials. Frequently, only local material properties, i.e. permittivity and permeability for a centro-symmetric metamaterial, are considered. However, when the period-to-wavelength ratio tends to be rather large, this assumption is insufficient. Here, we overcome this issue by introducing effective properties of metamaterials with constitutive relations beyond a local response. We study bulk properties of metamaterials in terms of the dispersion relation of the eigenmodes and reflection and transmission from a slab of finite thickness. We demonstrate the importance of the introduction of advanced material properties to capture the properties of the metamaterial when compared to a local description.

16:30 Optical Emission and Light Propagation in Spatially Dispersive Metamaterial Structures

Markus Nyman, Ville Kivijärvi, Andriy Shevchenko, and Matti Kaivola [Aalto University, Finland]

We describe advanced methods to design anisotropic and spatially dispersive optical metamaterials for controlling propagation and radiation of light. Our methods allow one to use remarkably accurate semi-analytical calculations that make it possible to consider the interaction of light with large metamaterial structures.

16:45 Spatial Dispersion: From the Ground Up

Paul Kinsler and Jonathan Gratus [Lancaster University, UK]

By examining simple transfer matrix and scatterer models that provide analytically and numerically solvable systems, we see how spatially dispersive properties emerge in the many unit-cell limit.

17:00 Predicting Observable Quantities of Self-Assembled Metamaterials from the T-Matrix of Its Constituting Meta-Atoms (Extended)

Radius Suryadharma and Carsten Rockstuhl [Karlsruhe Institute of Technology, Germany]

Self-assembly processes attract a great amount of interest from the research community because of their ability to enable metamaterials with isotropic properties, in large quantities, and at relatively low cost. For such class of metamaterials, the bulk optical response can be deduced from the response of its individual constituent, i.e. the meta-atoms. It usually requires to calculate the average response of an individual meta-atom from many illumination directions that cover the entire 4ϖ-solid angle. This approach, however, is time consuming and requires a lot of computational efforts. Here, we demonstrate that several experimentally observable parameters, such as many different cross sections, can be deduced directly from the T-matrix of the individual meta-atom. This method allows to extract experimental parameters directly in an efficient manner without averaging the response manually.

17:30 Modular Approach to Understanding and Synthesis of Metamaterials and Metasurfaces

Viktar Asadchy and Sergei Tretyakov [Aalto University, Finland]

The vast majority of previously proposed metamaterials and metasurfaces are anisotropic or bianisotropic (exhibiting magnetoelectric coupling). Nevertheless, their anisotropy was not fully exploited as they were designed only for one or several specific illumination directions. In this talk, we propose a simple analytical approach to characterize properties of general bianisotropic meta-atoms for an arbitrary illumination. The approach is based on the qualitative decomposition of an arbitrary meta-atom into separate basic "modules" with elementary polarization properties. Such decomposition can be used for comprehensive characterization of previously designed structures as well as for synthesizing novel bianisotropic inclusions of arbitrary complexity and with desired response.

17:45 Resonance with Virtual Bound States and Amplification within a Vibrating 1D Photonic Crystal

Tsuyoshi Ueta [The Jikei University School of Medicine, Japan]

Within an artificially vibrating one-dimensional metallic photonic crystal, the lattice vibration amplifies the incident wave resonantly. In the present study, it has been confirmed that the amplification of an incident EM field is caused by resonance with the virtual bound states.

STUDENT PAPER COMPETITION

Following the tradition of past editions, particular attention will be paid to the student achievements. This comprises Bachelor, Master, or PhD students. A total of 18 students participated in the competition, and after a careful evaluation process, 5 students were selected as finalists. The selected finalists are:

Hafssaa Latioui
University of Lisbon, Portugal
"Lateral Optical Forces on Linearly-Polarized Emitters near a Reciprocal Substrate"

Philipp del Hougne
Institut Langevin, France
"Could Wi-Fi Waves Bouncing Around Inside an Indoor Room Perform Analog Computation?"

Emanuele Galiffi
Imperial College, UK
"Singular Graphene Metasurfaces"

María Rosendo López
Universidad Carlos III de Madrid, Spain
"Sound Propagation in a One-Dimensional PT Symmetric Sonic Crystal"

Zhanni Wu
University of Michigan, USA
"A Transparent, Time-Modulated Metasurface"

The Student Best Paper Awards will be announced during the Closing Ceremony on Thursday, August 30.

EUROPEAN SCHOOL ON METAMATERIALS

31 August - 1 September, 2018

Nonreciprocal and Time-Modulated Metamaterials and Metasurfaces

The course will be focused on emerging engineered materials with broken time-reversal symmetry. Strong current interest in this topic is motivated by new possibilities to engineer and optimize nonreciprocal response of materials and open up possibilities to create new types of nonreciprocal devices. We will discuss the use of nonlinear, active, moving, and time-modulated structures, extending the metamaterials paradigm into the four-dimensional space.

Lecturers:

Andrea Alù (CUNY Advanced Science Research Center, USA)

Nader Engheta (University of Pennsylvania, USA)

Romain Fleury (École polytechnique fédérale de Lausanne, Switzerland)

Dimitrios Sounas (University of Texas at Austin and Wayne State University, USA)

Sergei Tretyakov (Aalto University, Finland)

Richard Ziolkowski (University of Arizona, USA)

EVENING PROGRAM

Monday, August 27, at 19:00–20:30

Espoo City Reception *in Espoo Cultural Centre (address: Kulttuuriaukio 2, Espoo), the main venue for performing arts and cultural life in Espoo. The walking distance from the conference venue is about 20 minutes. Departure (guided walk) starts from the conference venue, Otakaari 1, at 18:30.*

Tuesday, August 28, at 19:00–20:30

Excursion to Nuuksio. *The busses will leave from Aalto University campus (address: Otakaari 1) at 17.45. Come and meet your old friends and make new ones. See and experience Finnish nature.*

Wednesday, August 29, at 17:30–22:00

Aniversary Event. *In 1968 the English translation of Viktor Veselago's paper "The electrodynamics of substances with simultaneously negative values of* ε *and* μ*" appeared. In celebration of the 50th anniversary of this seminal paper, a special event will be organized in Dipoli. The event will include exposition of metamaterials samples, short talks reflecting on the early history of metamaterials research, and small drinks and treats.*
Gala Dinner. *The conference dinner will take place at Dipoli starting at 20.00.*

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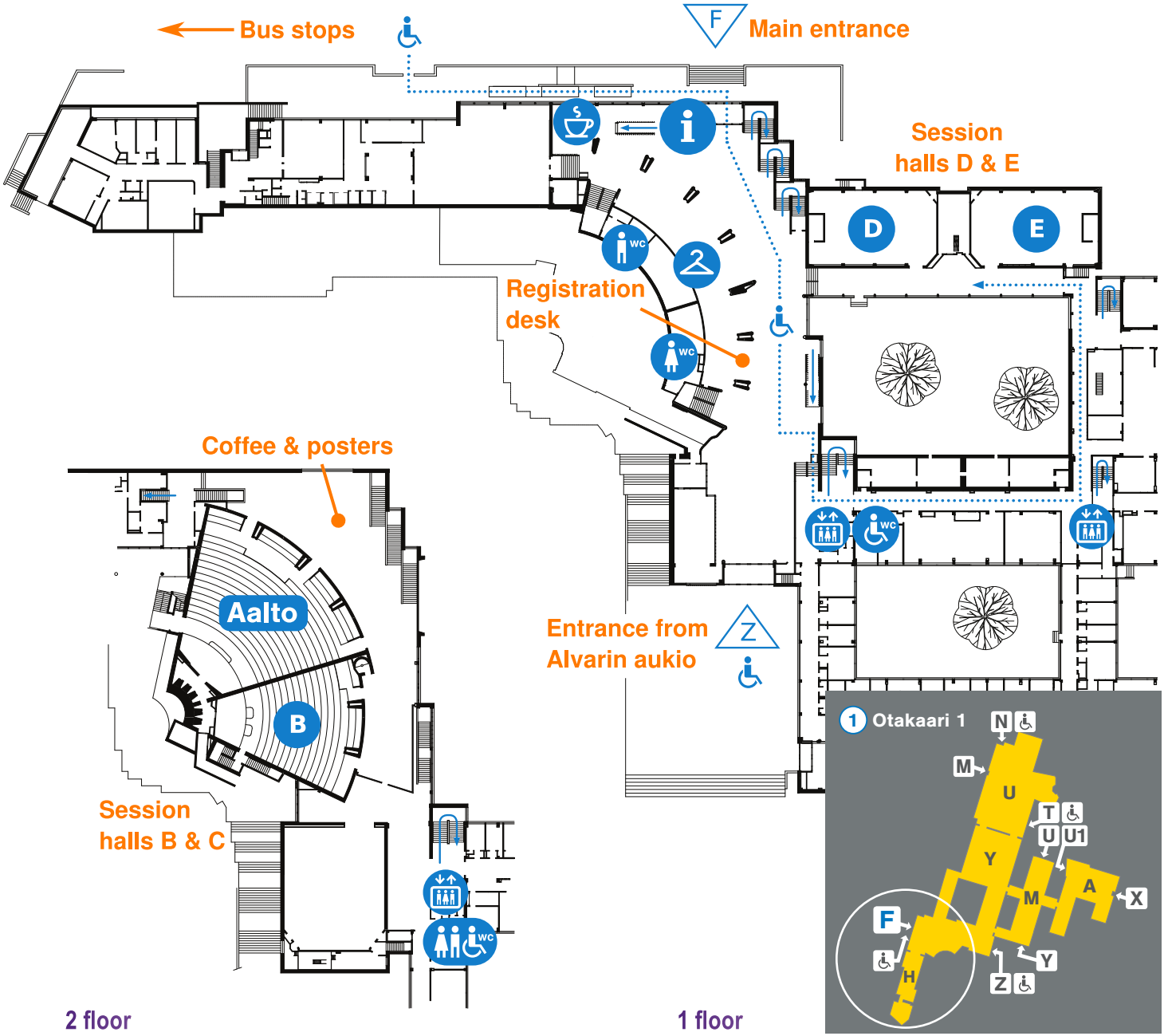
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