Werner S. Weiglhofer Symposium on Electromagnetic Theory

17–19 July 2022, 14 India Street, Edinburgh

SUNDAY

- Drinks reception at 14 India Street, Edinburgh: 17.30 – 19.30

MONDAY

- 09.00 – 09.30
  - Co-chairs Welcome
  - Maxwell Foundation Welcome
  - Reminiscences of Werner Weiglhofer by David Fearn (Emeritus Professor, University of Glasgow)
  - Thoughts of Werner Weiglhofer by his mother (read by Mercedes Lakhtakia)

- Coffee/tea: 09.30 – 10.00

Session 1: 10.00 – 10.50	Chair: Akhlesh Lakhtakia (Pennsylvania State University)
T1: 10.00 – 10.25	David Andrews (University of East Anglia) *Symmetry principles in optical vortex interactions*
T2: 10.25 – 10.50	Stephen Barnett (University of Glasgow) *Paraxial optical Skyrmions*

Session 2: 10.50 – 12.05	Chair: Peter Monk (University of Delaware)
T3: 10.50 – 11.15	Partha Banerjee (University of Dayton) *Prediction of metallo-dielectric transmission filter performance based on dispersion relations*
T4: 11.15 – 11.40	Kevin Vynck (Université de Lyon) *Electromagnetic modelling of complex nanostructured surfaces*
T5: 11.40 – 12.05	George Hanson (University of Wisconsin Milwaukee) *Classical Green function as the key to incorporating absorption in quantum optics*

- Lunch: 12.05 – 13.30

Session 3: 13.30 – 15.10	Chair: Martin McCall (Imperial College London)
T6: 13.30 – 13.55	Amir Boag (Tel Aviv University) *Spatial non-uniform grid representations-based fast algorithms*
T7: 13.55 – 14.20	Graham Bruce (University of St Andrews) *Cooling the optical-spin driven limit cycle oscillations of a levitated gyroscope*
T8: 14.20 – 14.45	Ioannis Stratis (National and Kapodistrian University of Athens) *On a Steklov spectrum in electromagnetics*
T9: 14.45 – 15.10	Vadim Markel (University of Pennsylvania) *Electromagnetic force density in condensed matter*

- Coffee/tea: 15.10 – 15.40

Session 4: 15.40 – 17.20	Chair: Natalia Nikolova (McMaster University)
T10: 15.40 – 16.05	Pinar Mengüç (Ozyegin University) *Particles, plasmons, and engineering*
T11: 16.05 – 16.30	Tom Mackay (University of Edinburgh) *Field profiles for exceptional waves*
T12: 16.30 – 16.55	Olivier Martin (École Polytechnique Fédérale de Lausanne) *Electromagnetic multipoles and optical torques*
T13: 16.55 – 17.20	Filiberto Bilotti (Roma Tre University) *Time-modulated metasurfaces as a key enabling technology for the next generation of wireless systems*

- Dinner: 19.00, The Stockbridge Restaurant, 54 St Stephen Street, Edinburgh, EH3 5AL

TUESDAY

Session 5: 08.30 – 10.10	Chair: Tom Mackay (University of Edinburgh)
T14: 08.30 – 08.55	Francesco Chiadini (Università degli Studi di Salerno) *Optical coatings for gravitational wave interferometers*
T15: 08.55 – 09.20	Peter Monk (University of Delaware) *RCWA and transformation optics*
T16: 09.20 – 09.45	Andrei Lavrinenko (Technical University of Denmark) *Hyperbolic anisotropy and low-index modes: Are there any room for photonic applications*
T17: 09.45 – 10.10	Michael Havrilla (Air Force Institute of Technology, Ohio) *Scalar potentials and nondestructive material characterization*

- Coffee/tea: 10.10 – 10.40

Session 6: 10.40 – 11.30	Chair: David Andrews (University of East Anglia)
T18: 10.40 – 11.05	Muhammad Faryad (Lahore University of Management Sciences) *Electromagnetic radiation by finite-sized electric and magnetic dipoles in uniaxial materials*
T19: 11.05 – 11.30	Álvaro Gómez-Gómez (Universidad de Cantabria) *Electromagnetic wave propagation inside rectangular chirowaveguides using the coupled mode method*

- Panel discussion: 11.30 – 12.10, *Theoretical Future - Vision 2030*
  - Panellists:
    * Amir Boag (Tel Aviv University)
    * Vadim Markel (University of Pennsylvania)
    * Olivier Martin (École Polytechnique Fédérale de Lausanne), Chair
    * Pinar Mengüç (Ozyegin University)
    * Kevin Vynck (Université de Lyon)
- Lunch: 12.10 – 13.30

Session 7: 13.30 – 15.10	Chair: Partha Banerjee (University of Dayton)
T20: 13.30 – 13.55	Martin McCall (Imperial College London) *A novel approach to electromagnetic constitutive relations*
T21: 13.55 – 14.20	Didier Felbacq (Université de Montpellier) *Multiple scattering by complex objects: revisiting the methods of fictitious sources*
T22: 14.20 – 14.45	Bernhard Michel (Hembach Photonik GmbH) *Modeling optical systems containing particulate composites*
T23: 14.45 – 15.10	Akhlesh Lakhtakia (Pennsylvania State University) *The Ewald–Oseen extinction theorem*

- Coffee/tea: 15.10 – 15.40

Session 8: 15.40 – 17.20	Chair: George Hanson (University of Wisconsin Milwaukee)
T24: 15.40 – 16.05	Natalia Nikolova (McMaster University) *Near-field microwave imaging employing measured point-spread functions*
T25: 16.05 – 16.30	Vincenzo Fiumara (Università degli Studi della Basilicata) *Correlated disorder in broadband dielectric layered reflectors*
T26: 16.30 – 16.55	Nikolaos Tsitsas (Aristotle University of Thessaloniki) *Analysis of diffraction from all-dielectric gratings with entire-domain integral-equation techniques*
T27: 16.55 – 17.20	Ibrahim Abdulhalim (Ben Gurion University) *Nano-micro structured thermochromic and liquid crystal tunable metamaterials for energy saving and photonic applications*

- 17.20: Closing remarks

T1 **David L. Andrews**
University of East Anglia

Symmetry principles in optical vortex interactions

In the interactions of optical vortices with matter, principles of fundamental symmetry determine the viability of observing various forms of chiral discrimination. The electrodynamic mechanisms that mediate such effects carry the distinctive hallmarks of a vortex structure, and to elicit the underlying principles requires careful analysis of helicity features of the beam wavefront and polarization. The scale of observation becomes especially important for local, sub-wavelength measurements, where quantum interactions occur.

T2 **Stephen M. Barnett**, Sijia Gao, Fiona C. Speirits, Francesco Castellucci, Zhujun Ye, Amy McWilliam, Claire Marie Cisowski, Jörg B. Götte and Sonja Franke-Arnold
School of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ

Paraxial optical Skyrmions

Amongst even the simplest structured light beams we find that there exist topological polarisation patterns that resemble closely the so-called baby Skyrmions famiilar from studies of spins on magnetic surfaces. The stability of these topological features derives from a simple conservation law for a Skyrmion field the properties of which are reminiscent of those of vortices in some classes of superfluids. We shall explore these mathematical properties and present results of experiments performed to prepare and measure the properties of these optical Skyrmions.

T3 **Partha P. Banerjee**, Hammid Al-Ghezi, Guo Chen
Electro-Optics and Photonics, University of Dayton, Dayton, OH 45469, USA

Prediction of metallo-dielectric transmission filter performance based on dispersion relations

Dispersion relations contain valuable information about the propagation of waves through the structure. In quantum mechanics, the band structure of a periodic crystal comprising passbands and stopbands can be determined from the underlying dispersion relation for propagating electron waves. Similarly, in periodic metallo-dielectric (MD) structures, the underlying dispersion relation for the electromagnetic (EM) wave can be derived using the Bloch theorem, and be used to predict the center wavelength and the cutoff wavelengths. For an ideal dielectric and ideal metal, the dispersion relation is real. We show that a finite number of super-periods of metallo-dielectrics, comprising D/2-(MD)n-M-D/2 layers, where n is an integer, yields a similar transmission spectrum. The findings can be used to synthesize transmission filters comprising MD structures with a given center wavelength and passband. The use of dispersion relations along with artificial neural networks should provide an efficient design technique for EM/optical filters.

T4 **Kevin Vynck**
Université de Lyon

Electromagnetic modelling of complex nanostructured surfaces

Planar, disordered assemblies of resonant particles in layered media are becoming widespread in optical and photonic applications, but predicting (theoretically or numerically) the optical properties of such complex systems has remained challenging. In this talk, I will introduce the concept of Global Polarizability Matrix (GPM) for electromagnetic scattering by particles and show how this can enable efficient, quantitative predictions of the optical response of disordered particulate media in thin-film stacks. Comparisons with analytical predictions for the specular and diffuse reflectances of complex nanostructured surfaces will be given.

T5 **George W. Hanson**
University of Wisconsin-Milwaukee

Classical Green function as the key to incorporating absorption in quantum optics

Methods for the study of the quantum properties of light, and the interaction of quantized light and atoms and other multi-leveled systems, were initially developed for vacuum. The observation of Purcell in 1946 that the spontaneous emission rate of an atom was dependent on the atoms environment was a motivating factor for the study of how materials affect quantized light. The incorporation of simplified models of materials (lossless, dispersionless dielectrics, perfect metals) is accommodated in quantum models in a fairly straightforward manner. However, the KramersKronig relations require that absorption is always accomplished by dispersion, and vice versa. Whereas in classical electromagnetics dispersion and absorption are easily accounted for, in macroscopic quantum models this is not the case, since a naive implementation of absorption causes the commutators to vanish at long times, violating the Heisenberg uncertainty principle. In this talk, I will discuss how a version of macroscopic quantum electrodynamics incorporates the classical Green function in a rigorous manner, and allows for very general media, including anisotropic, nonreciprocal, and nonlocal materials.

T6 **Amir Boag**[a], Yaniv Brick[b]
[a]School of Electrical Engineering, Tel Aviv University, Tel Aviv, Israel
[b]School of ECE, Ben-Gurion University of The Negev, Beer-Sheva, Israel

Spatial non-uniform grid representations-based fast algorithms

A family of fast multilevel algorithms of computational electromagnetics and acoustics based on hierarchical spatial sampling representations has been developed. Optimal sampling and interpolation include compensation and restoration procedures based on the particular field behavior. Numerically efficient near-field computations often lead to sparse non-uniform grids (NG), while far-field cases are simpler and involve uniform sampling. The spatial sampling algorithms achieve computational complexity comparable to that of best fast algorithms based on spectral representations with fewer constraints. Spatial sampling representations allow for seamless transition between various computational regimes including the frequency and time domains, as well as statics and quasi-statics.

T7 Yoshihiko Arita, Stephen H. Simpson, **Graham D. Bruce**, Ewan M. Wright, Pavel Zemánek, Kishan Dholakia
University of St Andrews

Cooling the optical-spin driven limit cycle oscillations of a levitated gyroscope

An anisotropic particle trapped in light carrying angular momentum can be made to rotate at an angular velocity restricted by viscous drag, and in low pressure environments spinning nanoparticles can reach rotational frequencies in the GHz regime. Previous results in the optical levitation of microspheres have reported an interesting difference in the effect of this rotation on the stability of the particles motion, depending on their material properties. Silica microspheres were shown, at low pressure, to experience a destabilizing force in circularly- polarized light which resulted in orbital motion and eventual expulsion from the trap [Nat. Commun. 9, 5453, 2018]. Similarly, birefringent vaterite microspheres in linearly polarized optical traps have been shown to undergo linear oscillations of increasing amplitude at lower pressures, once again eventually leading to particle loss [Sci. Adv. 6, eaaz9858, 2020]. However, seemingly in contradiction, birefringent microspheres can be rapidly rotated in circularly polarized optical traps, and the rotation actually causes the particles translational motion to stabilize [Nat. Commun. 4, 2374, 2013]. The non-conservative, azimuthal forces associated with inhomogeneous optical-spin angular momentum play the critical role in all these observations. Here we show that the resolution of the apparent paradox comes from the orientationally averaged, effective forces acting on the spinning birefringent particle, which cause the particle to undergo nanometre-scale limit cycles or orbits. [arXiv:2204.06925] Finally, we show that parametric feedback on the particles motion can provide an additional stabilization to create orbital oscillations with effective temperatures on the order of a milliKelvin. The tailoring of azimuthal spin forces through the material structure of a spinning, non-spherical particle opens up new opportunities for the design of ultra stable optical rotors.

T8 Francesco Ferraresso, Pier Domenico Lamberti, **Ioannis G. Stratis**
National and Kapodistrian University of Athens

On a Steklov spectrum in electromagnetics

After presenting various concepts and results concerning the classical Steklov eigenproblem, we focus on analogous problems for time-harmonic Maxwell equations in a cavity. In this direction we discuss recent rigorous results concerning natural Steklov boundary value problems for the curlcurl operator. Moreover, we explicitly compute eigenvalues and eigenfunctions in the unit ball of the three dimensional Euclidean space by using classical vector spherical harmonics.

T9 **Vadim Markel**
University of Pennsylvania

Electromagnetic force density in condensed matter

Despite a long history of extensive research, the subject of electromagnetic forces in continuous media still attracts significant attention and controversy. One can readily find dozens of recent papers discussing the fundamental aspects of electromagnetic forces. The controversies are rooted in the phenomenological nature of macroscopic electrodynamics. Even in the static limit, different expressions can be found in the literature for the force density acting on a dielectric medium. These expressions predict the same total force and torque but different elastic deformations. I will use a model of an ionic crystal to simulate elastic deformations of a solid under an applied electric field and compare the predictions to those of the commonly used expressions for the macroscopic force density. This is a work in progress.

T10 **M. Pinar Mengüç**
Center for Energy, Environment and Economy (CEEE/EÇEM) Ozyegin University, Cekmekoy, Istanbul 34794, Turkey
pinar.menguc@ozyegin.edu.tr

Particles, plasmons, and engineering

Interaction of light with particles provides significant amount of information about their size, shape, structures, and color. These details are crucial for evaluating the impact of many types of particles in atmospheric and engineering processes. In this presentation, first an overview will be provided based on our studies related to particle characterization and the development of diagnostic tools as related to elliptically-polarized light scattering concept. Next, a discussion will be presented on near-field plasmonic interactions between particles and surfaces which can be used for the development of engineering tools varying from sensors to energy harvesting and radiative cooling devices.

T11 **Tom G. Mackay**[a,b], Akhlesh Lakhtakia[b], Waleed Waseer[c]
[a] University of Edinburgh
[b] Pennsylvania State University
[c] Quaid-i-Azam University Islamabad and COMSATS University Islamabad

Field profiles for exceptional waves

Exceptional varieties of plane waves in bulk materials, surface waves, and compound waves can exist when certain anisotropic materials are involved. Such plane waves in bulk

materials are called Voigt waves. We have identified Dyakonov–Voigt waves or surface-plasmon-polariton–Voigt waves as examples of such surface waves.We have also identified compound-plasmon-polariton–Voigt waves. For each variety, an exceptional wave is supported for isolated propagation directions when the corresponding propagation matrix for the anisotropic material exhibits non-semi-simple degeneracy. Numerical studies have revealed that spatial profiles of the electric and magnetic field phasors, as well as of the time-averaged Poynting vector, do not change abruptly as the direction of propagation converges upon the direction of exceptional-wave propagation, for all three varieties of thee exceptional wave.

T12 **Olivier Martin**
École Polytechnique Fédérale de Lausanne

Electromagnetic multipoles and optical torques

While multipoles expansions have become ubiquitous in the analysis of plasmonic and dielectric nanostructures and metasurfaces, their zoology remains quite complex and different multipoles families are utilized in the literature (Cartesian primitive multipoles, Cartesian irreducible multipoles and spherical multipoles). I will illustrate the links between them and demonstrate their utilization to compute optical torques acting on plasmonic nano-rotors.

T13 M. Barbuto, Z. Hamzavi, M. Longhi, A. Monti, D. Ramaccia, L. Stefanini, S. Vellucci, A. Toscano, **F. Bilotti**
Roma Tre University

Time-modulated metasurfaces as a key enabling technology for the next generation of wireless systems

The next generation of wireless systems will integrate many services together, such as communication, sensing, data monitoring and processing, tactile interactions, etc., just to name a few of them. At the same time, global, seamless, and secure connectivity will be required, leading to ultra-high capacity and near-zero latency and jitter. In this scenario, engineering electromagnetics can significantly contribute, proposing conceptually new devices and systems, which can manipulate information at the speed of light and reduce complexity and hardware virtualization. Leaving some of the functionalities typically performed by signal processing algorithms to the physical layer, in fact, is the key to match the challenging key performance indicators in terms of latency and jitter. In this frame, the third generation of metasurfaces (i.e. Metasurfaces 3.0, whose properties can be controlled point by point not only in space but also in time) can represent the key enabling technology to achieve signal processing at the physical layer. In particular, we will show that time-modulated metasurfaces can be used to compensate for the Doppler shift in wireless links involving fast moving vehicles, estimate the direction of arrival of impinging signals at RF and in an analog way (avoiding the operation in the baseband and the A/D conversion), implement a matrix beam-forming network without involving phase-shifters and couplers, create a number of different channels in different angular directions, implement frequency-span jammers and deception devices, etc., i.e. all functionalities that are typically performed by signal processing algorithms/modules with a dramatic use of time and computational resources.

T14 **Francesco Chiadini**[a,b*], Vincenzo Pierro[b,c], Vincenzo Fiumara[b,d], Roberta De Simonea[b], Fabrizio Bobba[b,e], Giovanni Carapella[b,e,f], Cinzia Di Giorgio[b,e], Ofelia Durante[b,e], Rosalba Fittipaldi[b,f], Veronica Granata[b,e], Innocenzo M. Pinto[b,g,h]
[a] Department of Industrial Engineering, DIIn, University of Salerno, I-84084 Fisciano, Salerno, Italy
[b] INFN, Sezione di Napoli Gruppo Collegato di Salerno, I-80126 Napoli, Italy
[c] Department of Engineering, DING, University of Sannio, I-82100 Benevento, Italy

[d] School of Engineering, University of Basilicata, I-85100 Potenza, Italy
[e] Department of Physics E.R. Caianiello, University of Salerno, 84084 Fisciano (SA), Italy
[f] CNR-SPIN, c/o University of Salerno, I-84084 Fisciano, Salerno, Italy
[g] Department Electrical and Information Technology Engineering, University of Naples "Federico II", 80125 Napoli, Italy
[h] Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi, I-00184 Roma, Italy
* Send correspondence to: fchiadini@unisa.it

Optical coatings for gravitational wave interferometers

Gravitational waves (GWs) are ripples of space-time generated by catastrophic events occurring in the universe billions of light-years away. Due to the enormous distance traveled to reach the Earth, GWs generate extremely small perturbations that, to be detected, required the construction of kilometric Michelson interferometers. In the GW frequency band where the first gravitational signals have been detected (50 300 Hz), the sensitivity of the presently operating detectors is limited by the thermal noise in the high-reflectance multilayer optical coatings of the interferometer test-masses placed in the ends of the interferometer arms. Decreasing thermal noise without reducing the reflectance performance is a current challenge to increase the visibility distance of GW interferometric detectors. An overview of the recent results of our Group on coating optimization are presented.

T15 **Peter Monk**
University of Delaware

RCWA and transformation optics

In order to predict the performance of a thin film solar cell, the first step is to solve Maxwells equations throughout the device so as to predict the electron-hole generation rate in the semi-conductor layers. While many numerical methods are applicable, the Rigorous Coupled Wave Approach (RCWA) is attractive due to the speed of solution. In addition, during the design process it is easy to model different cells without remeshing that is inherent in finite element solution techniques. In recent work with Benjamin Civiletti and Akhlesh Lakhtakia we have undertaken a mathematical analysis of RCWA for p-polarized light and shown that the method is convergent, even if the worst case rate of convergence is quite slow. To remedy this in the case when the periodic interfaces between materials are graphs of functions, we have introduced a modified C-method where we use transformation optics to flatten the interfaces, at the cost of encountering anisotropic material coefficients in the governing equations. After transformation, discontinuities in the solution can be handled exactly. Using RCWA on the transformed problem results in the C-RCWA scheme, and we have shown much improved convergence compared to using RCWA directly. This approach can also be used for Maxwells equations, so ameliorating the loss of convergence due to field discontinuities at material interfaces inherent in the standard RCWA. In this talk I will describe the work on RCWA and C-RCWA for p-polarized light and also introduce the C-RCWA for Maxwells equations.

T16 **Andrei V. Lavrinenko**
Department of Electrical and Photonics Engineering, Technical University of Denmark, Kgs. Lyngby, 2800, Denmark
alav@fotonik.dtu.dk

Hyperbolic anisotropy and low-index modes: Are there any room for photonic applications

Structures with hyperbolic dispersion profiles are one of the most successful example in application of homogenization procedure for subwavelength structured materials in optics as the keystone of the metamaterial concept. Another possible breakthrough is associated with epsilon-near-zero materials and their current successors effectively exhibiting near-zero mode indices. I will discuss the state-of-the-art of both concepts and consider

their potentially most promising linear and nonlinear photonic applications in the real-world optics.

T17 **Michael Havrilla**
Air Force Institute of Technology, Ohio

Scalar potentials and nondestructive material characterization

Abstract: Evaluating the electromagnetic properties of materials is vital for understanding material-embedded antenna performance, scattering, propagation, and radiation in complex environments. Electromagnetic material characterization is often quite challenging when measurements are performed in the field in a nondestructive manner. It will be shown how scalar potentials, pioneered by Professor Werner Weiglhofer, greatly simplify mathematical analysis and enhance physical insight. An example of the nondestructive material characterization of a uniaxial medium will be provided to highlight the scalar potential formulation.

T18 **Muhammad Faryad**
Lahore University of Management Sciences

Electromagnetic radiation by finite-sized electric and magnetic dipoles in uniaxial materials

Analytical results of electromagnetic radiation from a source inside uniaxial materials are available only for point sources. In this talk, the finite-sized sources are considered and analytical results are presented in the near and far zones for an electric dipole and a uniform current loop. The uniform current loop is taken to generalize the magnetic dipole. The numerical results for different sizes of the dipoles show that the electromagnetic fields strongly depend upon the size of the dipoles.

T19 **Álvaro Gómez-Gómez**, Óscar Fernández, Gregorio J. Molina-Cuberos
Departamento de Ingeniería de Comunicaciones, Universidad de Cantabria, Plaza de la Ciencia, 39005, Santander, Spain
Departamento de Electromagnetismo y Electrnica, Universidad de Murcia, Campus Universitario, 30100, Murcia, Spain

Electromagnetic wave propagation inside rectangular chirowaveguides using the coupled mode method

In this work it is presented an overview of the application of Coupled Mode Method to the analysis of rectangular waveguides containing isotropic chiral media considering two modifications of the method dealing to the starting field expansions of the procedure: E and H or E and B. The correct selection of these field will feature the satisfaction of the boundary conditions over the metallic walls.

Acknowledgement: This work is part of the R+D+i Project PGC2018-098350-B-C22 funded by MCIN/AEI/ 10.13039/501100011033/ and by ERDF A way to make Europe

T20 **Martin McCall**, Paul Kinsler, Jonathan Gratus
Imperial College London

We re-appraise electromagnetic constitutive relations by developing a framework that relates material response directly to the fundamental electromagnetic fields. The inhomogeneous Maxwell relations are replaced with first order operator relations that contain a much richer gamut of possibilities. Focussing on the simplest terms, we show how an axion-like response can be generated in meta-media. Augmenting vacuum with such a topological axionic response gives rise to interesting conclusions when the fields propagate on a non-trivial manifold. A careful analysis of Stokes theorem in a simple but non-trivial model shows how the link between local and global charge conservation can be severed.

T21 **Didier Felbacq**
Université de Montpellier

Multiple scattering by complex objects: revisiting the methods of fictitious sources

We present a numerical method allowing to solve efficiently the Maxwell system in the presence of many obstacles. Each obstacle is characterized by a scattering matrix that is a local operator defined in the boundary of the obstacle, it is written in the adapted basis of the Laplace-Beltrami operator of the boundary. The scattered field is then represented by fictitious sources in the form of a single layer potential.

T22 **Bernhard Michel**
Hembach Photonik GmbH, Germany
bm@hembach-photonik.de

Modeling optical systems containing particulate composites

Composites made from small particulates can have optical properties that differ significantly from those of their constituents. They often turn out to be useful basic materials for optical components such as polarizers. A raytracing-based simulation software is presented in which users can easily implement homogenization formalisms themselves to estimate the electromagnetic constitutive properties of these composites. This allows examining the functionality of such optical components within complete optical systems.

T23 **Akhlesh Lakhtakia**
Pennsylvania State University

The Ewald–Oseen extinction theorem

Formulated independently by Ewald and Oseen in the mid-1910s for frequency-domain scattering by a homogeneous isotropic dielectric obstacle embedded in free space, the extinction theorem is the cornerstone of frequency-domain scattering theory. It was extended to include a homogeneous bianisotropic obstacle embedded either in a homogeneous biisotropic medium (1990s) or in another homogeneous bianisotropic medium (2010s) with some restrictions. The requirement of homogeneity of the obstacle appears now appears unnecessary. Also, surface states can be accommodated.

T24 **Natalia Nikolova**
McMaster University

Near-field microwave imaging employing measured point-spread functions

Recently, real-time imaging methods have been proposed to quantitatively reconstruct the complex permittivity of an object from microwave or millimeter-wave measurements. These fast inversion strategies rely on a linearized model of scattering, which allows for image reconstruction within seconds even if the imaged volume contains millions of voxels. To attain quantitative capability, these methods employ the measured data point spread function (PSF) through which the transfer function of the linearized scattering model is defined. This work reviews the latest advances in quantitative real-time imaging along with simulation-based and experimental examples illustrating the methods accuracy and limitations.

T25 **Vincenzo Fiumara**[a], Paolo Addesso[b], Francesco Chiadini[c], Antonio Scaglione[c]
[a] School of Engineering, University of Basilicata
[b] Department of Information Engineering, Electrical Engineering and Applied Mathematics, University of Salerno
[c] Department of Industrial Engineering, University of Salerno

Correlated disorder in broadband dielectric layered reflectors

A disordered one-dimensional photonic structure can be realized by a dielectric multilayer consisting of two materials with different refractive indices that alternate in the structure with random thicknesses. Generally, such a multilayer exhibits a large reflection wavelength range, in which, however, transmission notches that break the reflectance band continuity may be present due to stochastic resonances. Statistical analysis reveals that multilayer configurations characterized by correlated disorder (i.e., thickness sequence presents a non-negligible degree of autocorrelation) do not suffer from these stochastic resonances and behave as high performing broadband reflectors. Examples of families of broadband dielectric layered reflectors based on correlated disorder are presented.

T26 **Nikolaos L. Tsitsas**
Aristotle University of Thessaloniki

Analysis of diffraction from all-dielectric gratings with entire-domain integral-equation techniques

Boundary-value problems concerning the diffraction of electromagnetic waves from periodic all-dielectric gratings are analyzed by means of a rigorous entire-domain integral equation method. The standard electric-field integral equation is employed for the electric field on the gratings. Semi-analytical solutions are determined by applying entire-domain Galerkins techniques and are characterized by high numerical stability and controllable accuracy. All integrals involved in the method are analytically calculated. The effect of the grating's parameters on the computed fields is examined with respect to the structures efficient operation as a frequency filter. Applications related to steering the diffracted waves in specific reflected or refracted orders are discussed.

T27 **Ibrahim Abdulhalim**
Ben Gurion University

Nano-micro structured thermochromic and liquid crystal tunable metamaterials for energy saving and photonic applications

Tunable photonic metamaterials allow building new miniature devices with superior properties such as achromatic lenses and waveplates. Recently we have been studying several nanostructures tunable with liquid crystals for variety of applications such as tunable achromatic waveplate and smart windows. The smart windows are a promising approach to reduce the energy consumption of buildings, which contributes up to 40% of the worlds energy usage. There are several types of them, for example the ones which are voltage controlled such as the liquid crystalline based ones or the electrochromic materials usually control the transparency of the whole solar spectrum. However, thermochromic materials such as VO2 based, they block a large fraction of the sunlight on hot days, while transmitting solar energy in cold weather. Thus through temperature or voltage responsive solar energy modulation, smart windows are a key component of green buildings that have been extensively studied in the recent years. In this talk I will review our latest results on thermochromic and tunable liquid crystal metamaterials along the following lines:
1. Liquid crystalline new composite metamaterial made of nanoporous microparticles (nano-micro-LCs) infiltrated with liquid crystal and controlled by temperature and voltage [1-3].
2. Tunable liquid crystal waveplate composed of periodic structure and liquid crystal layer.
3. VO2 thermochromic nanophotonic structures with optimum luminous transmittance while maintaining the solar modulation ability [4-6].
4. Hybrid smart window that controls both the visible transparency and the infrared radiation entering the building [7].

References

[1] Ibrahim Abdulhalim, et.al., Novel easy to fabricate liquid crystal composite with potential for electrically or thermally controlled transparency windows, Optics Express, 27(12), 17387-401 (2019).

[2] P. Lakshmi Madhuri, R.J. Martin-Palma, B. Martn-Adrados, Ibrahim Abdulhalim, Voltage controlled scattering from porous silicon Mie-particles in liquid crystals, J. Molec. Liqu., 281, 108-116 (2019).

[3] Pappu Lakshmi Madhuri, Shuddhodana, Zaher M. A. Judeh, and Ibrahim Abdulhalim, Cochleate-Doped Liquid Crystal as Switchable Metamaterial Window Mediated by Molecular Orientation Modified Aggregation, Part. Part. Syst. Charact., 2000067(8p) (2020).

[4] Igal Balin, et.al., Enhanced Transition Temperature Reduction in Half Sphere Au/VO2 Core-shell Structure: Local Plasmonics versus Induced Stress and Percolation Effects, Phys.Rev.App., 11, 034064(13p) (2019).

[5] Saranya Bhupathi, Shancheng Wang, Mohammad Abutoama, Igal Balin, Lei Wang, Peter G. Kazansky, Yi Long, Ibrahim Abdulhalim, ACS Applied Materials & Interfaces, Femtosecond Laser-Induced Vanadium Oxide Metamaterial Nanostructures and the Study of Optical Response by Experiments and Numerical Simulations, ACS Applied Materials and Interfaces 12, 37 (2020).

[6] Saranya Bhupathi, Mohammad Abutoama, Yi Long, and Ibrahim Abdulhalim, Sculptured Thin Film Vanadium dioxide Thermochromic Coatings Grown by Oblique Angle Deposition: Investigation of Transmittance Response and Modulation Enhancement by Experiment and Theoretical Modeling, J. Mater. Chem. C 9, 13304-16p (2021).

[7] P. Lakshmi Madhuri, Saranya Bhupathi, Shuddhodana, Zaher M A Judeh, Sheng-Hsiung Yang, Long Yi, Ibrahim Abdulhalim, Hybrid Vanadium Dioxide - Liquid Crystal Tunable Non-Reciprocal Scattering Metamaterial Smart Window for Visible and Infrared Radiation Control, Optical Materials Express, 11(8), 3023-37 (2021).