HL 29: Focussed Session: Metasurfaces I

Metasurfaces are optical components, which rely on metamaterials, but are further confined below the wavelength in the direction of light propagation. The ability of metasurfaces to manipulate wavefronts arises fundamentally from the optical responses of the individual nanoparticles that comprise the surface. This response is dominated by the morphological resonances of the particles, which depend on the size, shape, material composition, and environment of the particles. For metal particles the resonances have a plasmonic character, whereas for dielectric particles several Mie-type multipoles can contribute. Such resonances can also lead to strong local optical fields near (metallic) or even inside (dielectric) the particles. Such local-field enhancement is crucial for a number of potential applications of metasurfaces, including nonlinear optics, tunable optics, and sensing.

Organizers: Isabelle Staude and Carsten Ronning (U Jena)

Time: Wednesday 15:00–18:30 Location: EW 201

Invited Talk HL 29.1 Wed 15:00 EW 201

Device Applications of Metafilms and Metasurfaces — •Mark Brongersma — Stanford

Many conventional optoelectronic devices consist of thin, stacked films of metals and semiconductors. In this presentation, I will demonstrate how one can improve the performance of such devices by nanostructuring the constituent layers at length scales below the wavelength of light. The resulting metafilms and metasurfaces offer opportunities to dramatically modify the optical transmission, absorption, reflection, and refraction properties of device layers. This is accomplished by encoding the optical response of nanoscale resonant building blocks into the effective properties of the films and surfaces. To illustrate these points, I will show how nanopatterned metal and semiconductor layers may be used to enhance the performance of solar cells, photodetectors, and enable new imaging technologies. I will also demonstrate how the use of active nanoscale building blocks can facilitate the creation of active metafilm devices.

Invited Talk HL 29.2 Wed 15:30 EW 201

Harmonic generation and photon management at the nanoscale in AlGaAs nanoantennas — •Costantino De Angelis[1], Dragomir Neshev[2], Luca Carletti[1], Lavinia Ghirardini[3], Davide Rocco[1], Valerio Gili[4], Giovanni Pellegrini[3], Marco Finazzi[3], Andrea Locatelli[1], Ivan Favero[4], Giuseppe Marino[4], Michele Celebrano[3], and Giuseppe Leo[4] — [1]Department of Information Engineering, University of Brescia, 25123 Brescia, Italy — [2]Nonlinear Physics Centre, The Australian National University, Canberra ACT 2601, Australia — [3]Department of Physics, Politecnico di Milano, 20133 Milano, Italy — [4]Matériaux et Phénomènes Quantiques, Université Paris Diderot, 75013 Paris, France

High-permittivity semiconductor resonators are emerging as potential platforms for nonlinear nanophotonics due to a rich variety of resonances, lossless operation, and strong volume nonlinearity. Harnessing these aspects can lead to efficient and controlled nonlinear light generation in nanoscale devices. In this work, we review recent advances for efficient frequency conversion and tunable control of the spatial and polarization properties of the emitted photons exploiting second order nonlinear processes in AlGaAs nanoantennas. By means of both numerical and experimental approaches, we demonstrate dynamic control over the directionality of the second harmonic radiation pattern generated in nanodisks by varying the angle of incidence of the pump beam and the shape of nanoresonator.

HL 29.3 Wed 16:00 EW 201

Broadband Laguerre-Gaussian Metasurfaces and Direct Phase Mapping — •Alexander Fassbender[1], Jiří Babocký[2], and Stefan Linden[1] — [1]Physikalisches Institut, Rheinische Friedrich-Wilhelms Universität Bonn, Nußallee 12, D-53115 Bonn, Germany — [2]Institute of Physical Engineering, Brno University of Technology, Technická 2, CZ-616 69 Brno, Czech Republic

We demonstrate metasurfaces based on off-resonant optical scatterers generating Laguerre-Gaussian modes. These modes are characterized by a helical phase profile with radial discontinuities. The metasurfaces are based on gold rods with a length of 220 nm which modify the properties of circular polarized waves. More specifically, the local phase of the scattered light with the opposite helicity can be controlled by the orientation of the rods relative to a reference axis. To accomplish a helical phase gradient, the orientation of the rods placed on a circle around the metasurface center rotates by multiples of π per turn. To achieve radial discontinuities, neighboring rods are shifted by $\pi/2$. Since the rods are not required to be driven in resonance, this metasurface allows for a broadband operation in the visible and near-infrared regime. Our interferometric measurements reveal a spiral phase distribution resulting from the introduced helical phase profile. We further present a multifunctional metasurface that coalesces the properties of two conventional optical elements. It generates a doughnut-shaped intensity pattern in combination with the focusing property of a lens. The phase distribution of the beam is measured in two and three dimensions by a holographic microscope and the method of digital holography.

HL 29.4 Wed 16:15 EW 201

Manipulation of electric and magnetic dipole emission from Eu3+ with silicon metasurfaces — •Aleksandr Vaskin[1], Soheila Mashhadi[2], Natalia Noginova[2], Katie. E. Chong[3], Stefan Nanz[4], Aimi Abass[4], Ivan Fernandez-Corbaton[4], Evgenia Rusak[3,4], Mikhail A. Noginov[2], Yuri S. Kivshar[3], David Keene[2], Carsten Rockstuhl[4], Thomas Pertsch[1], Dragomir Neshev[3], and Isabelle Staude[1] — [1]Friedrich Schiller University Jena, Jena, Germany — [2]Norfolk State University, Norfolk, USA — [3]The Australian National University, Canberra, Australia — [4]Karlsruhe Institute of Technology, Karlsruhe, Germany

Mie-resonant dielectric nanoparticles were theoretically predicted to provide a viable platform for enhancing both electric and magnetic dipole transitions. While the electric dipole transition enhancement by dielectric nanoparticles was experimentally demonstrated, the case of magnetic dipole transition remains to be explored. We study enhancement of spontaneous emission of Eu3+ ions featuring electric (at 610 nm) and magnetic-dominated (at 590 nm) transitions by Mie-resonant metasurfaces consisting of silicon nanocylinders. By fabricating a set of metasurfaces with nanocylinders of different diameter we sweep the spectral positions of the Mie resonances over the spectral range of the electric and magnetic dipole transitions. The samples were covered by a 40 nm-layer of polymer doped by Eu3+ compound. We observed an enhancement of the Eu3+ emission associated with the electric and magnetic-dominated dipole transitions. We further perform numerical simulations using two different approaches.

30 min. break.

Invited Talk HL 29.5 Wed 17:00 EW 201

Meta-optics and functional metasurfaces driven by Mie resonances — •Yuri Kivshar — Nonlinear Physics Center, Australian National University, Canberra, Australia

Rapid progress in plasmonics is associated with the ability to enhance near-field effects with subwavelength localization of light. Recently, we observed the emergence of a new branch of nanophotonics and meta-optics aiming at the manipulation of strong optically-induced electric and magnetic Mie-type resonances in dielectric nanoscaled structures with high refractive index. Unique advantages of dielectric resonant optical nanostructures over their metallic counterparts are low dissipative losses, low heating, and the enhancement of both electric and magnetic fields. In this talk, I will review this new emerging field of nanophotonics and metasurfaces and demonstrate that Mie-type resonances in high-index dielectric nanoparticles and subwavelength structures can be exploited for new physics and novel functionalities of photonic structures especially in the nonlinear regime.

Invited Talk HL 29.6 Wed 17:30 EW 201

Nonlinear Metasurface Holography — •Thomas Zentgraf — Department of Physics, University of Paderborn, Germany

For efficient nonlinear processes, the engineering of the nonlinear optical properties of media becomes important. A continuous tailoring of the phase of the nonlinear susceptibility would greatly enhance flexibility in the design of nonlinear elements. Here we will discuss a novel nonlinear metamaterial which can exhibit homogeneous linear optical properties but continuously controllable phase of the local effective nonlinear polarizability. For the demonstration, we use plasmonic metasurfaces with various designs for the meta-atom geometry together with circular polarized light states. The controllable nonlinearity phase results from the phase accumulation due to the polarization change along the polarization path on the Poincare sphere (the so-called Pancharatnam-Berry phase) and depends therefore only on the spatial geometry of the metasurface. We will demonstrate the concept of phase engineering for the manipulation of second- and third-harmonic generation from metasurfaces and the restriction with respect to symmetry and geometry of meta-atoms on a few examples.

HL 29.7 Wed 18:00 EW 201

Towards actively programmable metasurfaces: Local addressing and fine-tuning of individual nanostructures covered with phase-change material — •Andreas F. Hessler[1], Ann-Katrin U. Michel[1,2], Martin Lewin[1], Henrik Wördenweber[1], Julian Hanss[1], Thomas Kalix[1], Angela De Rose[1], Dmitry N. Chigrin[1], Matthias Wuttig[1], and Thomas Taubner[1] — [1]Institute of Physics (IA), RWTH Aachen — [2]Optical Materials Engineering Laboratory, ETH Zurich

Despite their nanometer thickness, metasurfaces offer comprehensive control over light fields and allow for the creation, detection and transformation of light. For optimal functionality, they need to be freely programmable and have low optical losses.
Phase-change materials provide an effective and convenient way to add active functionality to a metasurface post-fabrication. They characteristically have a high optical contrast between their amorphous and crystalline phases, while only suffering low optical losses in the infrared [1,2].
Here, we present on how we can fine-tune individual elements of a metasurface covered with the phase-change material $Ge_3Sb_2Te_6$ by locally addressing them with laser pulses. This work represents an advance towards actively programmable metasurfaces and the concept can be applied to a multitude of already present metasurface designs.

[1] A.-K. U. Michel et al., Nano Lett. 13, 3470 (2013).
[2] M. Wuttig et al., Nat. Photon. 11, 465 (2017)

HL 29.8 Wed 18:15 EW 201

Sub-wavelength phase coexistence patterning of phase change materials by means of ion irradiation — •Martin Hafermann, Jura Rensberg, and Carsten Ronning — Institute of Solid State Physics, Friedrich Schiller University Jena, Max-Wien-Platz 1, 07743 Jena, Germany

Phase change materials such as the chalcogenide $GeSb_xTe_y$ (GST) enable the fabrication of reconfigurable devices like rewritable optical data storage media. In such devices switching between two states (amorphous - crystalline) is usually accomplished by applying intense laser pulses. The two states show a tremendous difference of the optical and electrical properties. Using direct laser writing GST based metasurfaces were created by structuring regular patterns of amorphous GST within the crystalline film or vice versa. However, the size of any pattern element is diffraction limited and cannot be smaller than the wavelength of laser light used. To circumvent the diffraction limit, instead of a laser we use a focused ion beam. The ion irradiation induced defect formation triggers the phase transition from crystalline to amorphous in predefined regions, which enables the patterning of GST films down to structure sizes much smaller than the wavelength of visible light. Here, we demonstrate the influence of homogenous ion irradiation on the optical properties of GST thin films. These results were used to design and fabricate sub-wavelength patterns of irradiated GST using area-selective ion irradiation. With this method we are able to create reconfigurable, inherently flat metasurfaces, which is a main desire of modern optics.