O 43: Plasmonics and Nanooptics III: Periodic Structures and Theory

Time: Tuesday 10:30–13:45 Location: WIL A317

O 43.1 Tue 10:30 WIL A317

Mie Theory in terms of Axion-Plasmonics — •Johannes Schultz[1], Axel Lubk[1,2], Flavio S. Nogueira[3], and Bernd Büchner[1,2] — [1]IFF, IFW Dresden, Helmholtzstr. 20, 01069 Dresden — [2]IFMP, TU Dresden, Haeckelstr. 3, 01069 Dresden — [3]ITF, IFW Dresden, Helmholtzstr. 20, 01069 Dresden

Calculations of the scattering of electromagnetic (e.m.) waves is a usefull and important tool to investigate the dielectric response of nanoparticles (NPs) theoretically. Of particular interest are NPs with negativ dieletric function and low damping in a certain frequency regime at the same time. This leads to standing waves of oscillating electrons at the surface of the NP, so called localized surface plasmons. Solving the problem using Maxwells equations leads to determin the so called scattering coefficients from the boundary conditions at the interface. For arbitrary geometries it is hard to obtain the boundary conditions and consequently to get a complete analytic solution. However, exploiting the symmetry of spherical NPs we can determin a full analytic solution. This approach is known as Mie-Thoery and can be applied on many scattering problems including scattering at plasmonic NPs. In our study we generalized the common Mie-Theory to spheres consisting of Topological Insulators (TIs). The exceptional so called Axion-coupling of the e.m. fields in TIs leads to modified boundary conditions and resultant scattered fields. In summary we found uncommon magnetic field contributions for the scattering on TIs which vanish for trivial materials. This exceptional field contributions can maybe measured in the transmission electron microscope.

O 43.2 Tue 10:45 WIL A317

Broadband plasmonic spectroscopy of vectorial near-field coupling — •Martin Esmann[1,2], Simon F. Becker[2], Julia Witt[2], Jinxin Zhan[2], Abbas Chimeh[2], Anke Korte[2], Jinhui Zhong[2], Ralf Vogelgesang[2], Gunther Wittstock[2], and Christoph Lienau[2] — [1]CNRS Centre for Nanoscience and Nanotechnology (C2N), Palaiseau, France — [2]Carl von Ossietzky University, Oldenburg, Germany

The coherent coupling of optical near fields between dipole momenta determines the function and optical properties of many nanostructures[1]. These interactions extend over a few nanometers only and depend sensitively on the vectorial properties of the coupled near fields, i.e., on relative dipole orientation, spectral detuning and dephasing. This makes it challenging to analyze and control them experimentally.

Here, we introduce plasmonic nanofocusing [2] spectroscopy [3] as a tool to record coherent light scattering spectra with 5-nm spatial resolution from a small dipole antenna, excited solely by evanescent fields. We couple the antenna to plasmon resonances in single gold nanorods and resolve mode couplings, resonance energy shifts and Purcell effects as a function of dipole distance and relative orientation. We show how they arise from different vectorial components of the interacting near-fields. Our results pave the way to using dipolar alignment for the in-situ control of optical properties and function in nanoscale systems.

[1] Zhang, Y. et al., Nature 531, 623 (2016).
[2] Stockman, M.I., PRL 93, 137404 (2004).
[3] Esmann, M. et al., Nature Nanotech. 14, 698 (2019).

O 43.3 Tue 11:00 WIL A317

Solution of electrodynamics on plasmonic nanohelices by boundary element method — •Daniel Nürenberg[1], Peer Fischer[2], and Helmut Zacharias[1] — [1]Uni Münster Center for Soft Nanoscience, Münster — [2]MPI für intelligente Systeme, Stuttgart

We present electrodynamical simulations of the absorption, scattering and near-fields of plasmonic Ag, Cu and Ag:Cu alloy nanohelices from the UV to the near infrared of the optical spectrum. The helix models were designed to reproduce helices, which were fabricated by nano glancing angle vapor deposition [1]. The calculations were carried out with a boundary element approach using the MNPBEM toolbox [2]. The inherent chirality of the nanohelices leads to a strong circular dichroism (CD), which was calculated for all directions of incidence. The CD is found to be very sensitive to the direction of the impinging light. Infact, even changes in sign of the CD are common for most wavelengths, if the incidence is changed from parallel to the helical axis to a perpendicular orientation.

[1] A.G. Mark, J.G. Gibbs, T.-C. Lee, and P. Fischer, Nat. Mater. 12, 802 (2013).
[2] J. Waxenegger, A. Trügler, and U. Hohenester, Comput. Phys. Commun. 193, 138 (2015).

O 43.4 Tue 11:15 WIL A317

Perturbation theory as an efficient tool for modelling chiral and achiral plasmonic sensors — •Steffen Both, Harald Giessen, and Thomas Weiss — 4th Physics Institute and Research Center SCoPE, University of Stuttgart

Plasmonic nanostructures comprise optical resonances with strong electromagnetic near-fields. If we place chemical substances in these near-fields, even tiny amounts of the substance can have dramatic effects on the resulting spectral responses. This effect is the key to various kinds of sensing applications. Conventionally, the theoretical modelling of such interactions utilizes extensive numerical simulations. As we have recently shown [1,2], an alternative approach consists in the use of perturbation theories, which provide the benefit of drastically reduced computational times and allow to gain deep insights into the underlying physical mechanisms. Here, we discuss this approach especially with regard to applications in chiral sensing [3].

[1] T. Weiss, et al., Phys. Rev. Lett. **116**, 237401 (2016).
[2] S. Both and T. Weiss, Opt. Lett., *accepted* (2019).
[3] M. Nesterov et al., ACS Photonics **3**, 578 (2016).

O 43.5 Tue 11:30 WIL A317

Generalized 1D description of light coupling to arbitrarily curved plasmonic wires — •Thorsten Feichtner[1], Katja Höflich[2], Jer-Shing Huang[3], and Bert Hecht[1] — [1]Nano-Optics & Biophotonics Group, Wilhelm-Conrad-Röntgen-Center for Complex Material Systems (RCCM), Experimental physics 5 - Universität Würzburg, Germany — [2]Max Planck Institute for the Science of Light, Erlangen, Germany — [3]Leibniz Institute of Photonic Technology, Albert-Einstein Strasse 9, Jena D-07745, Germany

Plasmons propagating on metallic nano wires (MNWs) with spherical cross sections are fully understood and analytical solutions for the decomposition of the fields in Mie modes exist. We have already shown that for helically curved wires, so-called plasmonic helices, also an analytical one-dimensional model can be used to calculate their coupling to circular polarized planar wave far-field excitation [1].

Here we first extend this model to also describe coupling of helices to point dipoles. This is done to explain the results from [2] which shows strongly directed emission. We also extend the model to more arbitrary curved wires to explain the near-field behavior of 3D Archimedian spirals as introduced in [3]. This powerful tool will allow the fast development of plasmonic wire geometries for tailored near-fields or far-field scattering.

[1] Hoeflich, Katja, et al., *Optica* 6.9 (2019): 1098-1105.
[2] Wang, Mengjia, et al., *Light: Science & Applications* 8.1 (2019): 1-8.
[3] Tseng, Ming Lun, et al., *Adv. Opt. Mat.* (2019): 1900617.

O 43.6 Tue 11:45 WIL A317

Polar semiconductor heterostructures as hyperbolic metamaterials — •Christopher J. Winta[1], Daniel C. Ratchford[2], Martin Wolf[1], Joshua D. Caldwell[3], and Alexander Paarmann[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin (Germany) — [2]U.S. Naval Research Laboratory, Washington, D.C. (USA) — [3]Vanderbilt University, Nashville, TN (USA)

We present a novel approach towards engineering the infrared dielectric response of polaritonic materials by means of atomic-scale superlattices of polar semiconductors. [1] With layer thicknesses on the order of just a few atomic monolayers, new optic phonon modes arise at the many interfaces, resulting in a unique and strongly anisotropic dielectric response of the heterostructure.

We show experimentally that these crystalline hybrids exhibit multiple spectral regions where the principal dielectric components have opposite signs. These so-called hyperbolic bands support hyperbolic phonon polariton (h-PhP) modes, i.e., large-momentum states with rigid directionality, facilitating, e.g., subdiffractional imaging by means of hyperlens designs. [2] We employ transfer-matrix calculations [3], simulating the h-PhP dispersion, showing that these modes are highly dispersive, as well as finite elements calculations, revealing their rigid

directionality. The crystalline hybrid approach presents itself as a versatile platform for user-designed hyperbolic metamaterials.
[1] Ratchford, Winta et al., *ACS Nano* **13**, 6730-6741 (2019)
[2] Liu et al., *Science* **23**, 1686 (2007)
[3] Passler, Paarmann, *JOSA B* **34**, 2128-2139 (2017)

O 43.7 Tue 12:00 WIL A317

Optical Nano-Imaging of Electronic Shear Modes — Jun Yong Khoo[1], Po-Yao Chang[2,1], Inti Sodemann[1], and •Falko Pientka[1] — [1]Max-Planck Institute for the Physics of Complex Systems, D-01187 Dresden, Germany — [2]Department of Physics, National Tsing Hua University, Hsinchu 30013, Taiwan

Plasmons are collective excitations of metals that consist of modulations of the electron density similar to compressional waves in classical liquids, which allows for an efficient coupling to light. In addition, moderately interacting two-dimensional metals can feature a second type of collective mode, involving electron motion transverse to the propagation direction. Such shear modes are akin to transverse sound waves in a crystal and have no counterpart in classical liquids. Experimental evidence of such shear modes has remained elusive so far, as a lack density fluctuations strongly suppresses the coupling to light. Here, we show that shear modes can nevertheless be probed by optical techniques in the presence of a static magnetic field. Specifically, we predict signatures in scanning near-field optical microscopy, where spatial oscillations of the near-field signal at the wavelength of the shear mode emerge as the field strength is increased. Our proposals is largely based on existing experimental technology operating at frequencies in the far infrared to terahertz regime.

O 43.8 Tue 12:15 WIL A317

Chiral Scatterometry on Chemically Synthesized Single Plasmonic Nanoparticles — •Julian Karst[1], Nam Heon Cho[2], Hyeohn Kim[2], Hye-Eun Lee[2], Ki Tae Nam[2], Harald Giessen[1], and Mario Hentschel[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany — [2]Department of Materials Science and Engineering, Seoul National University, Korea

Being intrinsically scalable, bottom-up nanoparticle synthesis shows an ever-growing control over particle morphology, enabling even chirally selective shapes. So far, imaging technologies such as electron microscopy are mostly used to investigate the quality of the synthesis. We show that single particle chiral scatterometry holds great potential as a feedback to characterize the (chir-)optical quality of chemically synthesized nanoparticles. The spectra of single helicoid nanoparticles reveal a diverse set of chiroptical responses with hugely varying absolute chiral asymmetry in spite of the well-controlled morphology of the particles. Averaging over the single nanoparticles reproduces the solution ensemble measurement remarkably well. This demonstrates that the single particles, despite their morphological and consequently chiroptical differences, exhibit a clearly pronounced chiral spectral and structural feature. We find that the g-factor of single nanoparticles can be up to four times larger than the ensemble g-factor. This proves that chiral scatterometry can be a highly important optical feedback for bottom-up nanoparticle synthesis as it reveals that the asymmetry of the ensemble solution can be further increased and maximized by appropriate refinement methods or by post-fabrication purification.

O 43.9 Tue 12:30 WIL A317

Reconfigurable high-quality surface phonon polariton resonators — Andreas Hessler[1], •Konstantin G. Wirth[1], Yvonne Bente[1], Laric Bobzien[1], Joshua Caldwell[2], Matthias Wuttig[1], Dimitry N. Chigrin[1], and Thomas Taubner[1] — [1]Institute of Physics (IA), RWTH Aachen — [2]Department of Mechanical Engineering, Vanderbilt University, United States

The recent discovery of highly confined mid-infrared surface phonon polaritons (SPhPs) on SPhP-resonant substrates covered by a thin dielectric layer and the reversible switching of laser written circular resonators in a thin film of the phase change material $Ge_3Sb_2Te_6$ (GST) offer new exciting potential for tailoring light-matter interactions [1]. Planar circular cavities in a gold film on GST and SiC have been shown to yield high Q-factors of 150 [2]. Using the low loss polar crystal SiC as substrate should result in an increased resonance quality compared to SiO_2 in [1]. Here we will present the optical writing of arbitrary infrared-resonant structures into an amorphous GST film on top of an SiC substrate. The resonances have a high Q factor, despite the absence of any metal boundary like in a metallic cavity. The laser written structures are characterized and spatially resolved with an FPA detector and near-field optical microscopy (s-SNOM). The resulting resonances will be verified by an analytical model, which can be used to predict the characteristic features of such a resonance.
[1] Li et al., Nat. Mater. 15, 870-875 (2016)
[2] Sumikura et al., Nano Lett. 19, 2549-2554 (2019)

O 43.10 Tue 12:45 WIL A317

Photonic wheels and magnetic field induced directional emission of excitons — •Lars Klompmaker[1], Felix Spitzer[1], Alexander N. Poddubny[2], Ilya A. Akimov[1,2], Leonid V. Litvin[3], Ralf Jede[3], Grzegorz Karczewski[4], Maciej Wiater[4], Tomasz Wojtowicz[5], Dmitri R. Yakovlev[1,2], and Manfred Bayer[1,2] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany — [2]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia — [3]Raith GmbH, 44263 Dortmund, Germany — [4]Institute of Physics, Polish Academy of Sciences, PL-02668 Warsaw, Poland — [5]International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences, PL-02668 Warsaw, Poland

Photonic wheels carry transverse spin, which is locked to the propagation direction of the electromagnetic wave. Therefore, photonic wheels are attractive for spin manipulation and read-out in magnetic media. Emission effects are of particular interest. In this work emission phenomena are discussed where directionality is established perpendicular to an externally applied magnetic field for light sources (excitons) located near a surface, breaking the mirror symmetry. In hybrid plasmonic semiconductor structures, we observe a significantly enhanced directionality of up to 60%. The directional emission is studied regarding period dependence of the plasmonic grating and different emission geometries are considered.

O 43.11 Tue 13:00 WIL A317

Tuning the coupling of plasmonic structures with photonic crystals — •Rahim Benrali, Constance Schmidt, Teresa I. Madeira, and Dietrich R. T. Zahn — Semiconductor Physics, Chemnitz University of Technology, D-09107 , Germany

One-dimensional photonic crystals (PCs) are multilayered stacks with alternating refractive index (RI) and layer thicknesses (LT). PCs show a high reflectivity in a broad spectral range known as photonic bandgap (PBG). It was already shown that coupling of PCs with metallic nanoparticles (MNPs) in a photonic crystal plasmonic hybrid system (PCPHS) provides new ways of controlling and enhancing the optical response of plasmonic resonances [1]. Here we investigate the coupling of PCs with MNPs and the effect of tuning the PBG over the visible spectral range. PCs were prepared by electrochemical etching of p-doped silicon with hydrofluoric acid (HF), resulting in porous silicon (PS). MNPs show a plasmonic behaviour, known as localized surface plasmonic resonance (LSPR). The LSPR depends mainly on the metal and the geometry of the MNPs. Here triangular MNPs were obtained by nanosphere lithography (NSL). We used spectroscopic ellipsometry to investigate the effects of etching time and current density on PS. Furthermore, different parameters to influence the PBG (LT, RI, interface roughness) were investigated. Raman spectroscopy was used to test the performance of the PCPHS. The impact on the intensity of the Raman signal due to the PCPHS is demonstrated using organic molecules as Raman probes. [1] M. Fränzl, S. Moras, O. D. Gordan, D. R. T. Zahn, J. Phys. Chem. C 2018, 122, 18, 10153-10158

O 43.12 Tue 13:15 WIL A317

Influence of number of grooves on spectral shape of grating-coupled surface plasmon polaritons — •Sven Stephan, Christoph Bennenhei, Christoph Lienau, and Martin Silies — Institute of Physics, Carl von Ossietzky Universität, Oldenburg

Surface plasmon polaritons (SPP) are evanescent waves that can propagate along metal-dielectric interfaces over mesoscopic distances. Since they can be used to confine light beyond the diffraction-limit of free-space light, SPPs can combine the high bandwidth of optics with the small feature size of electronics and are believed to enable all-optical circuitry [1]. A common way of converting light to SPPs is to use focused-ion beam written grating couplers in metal films. However, most models that investigate grating-coupling assume an infinitely extended grating, i.e. an infinite number of grooves and do not take into account a finite number of grooves [2, 3]. Here, we present a systematic study of the influence of the number of illuminated grooves, both for in- as well as outcoupling, on the spectrum of the generated SPP waves. Our experimental results enable for tailoring the spectral response of the grating coupler for ideal spectral selection of wavelengths and spectral bandwidth of the SPP, to suit experimental demands where specific spectral shapes are required.

[1] Surface-plasmon circuitry, T.W. Ebbesen et al., Physics Today, 61(5), 2008 [2] Physical origin of photonic energy gaps in the propagation of surface plasmons on gratings, W. L. Barnes et al., Phys. Rev. B, 54(9), 1996 [3] S. A. Maier, Plasmonics: Fundamentals and applications, Springer, 2007

O 43.13 Tue 13:30 WIL A317

Laser-induced periodic surface structures formation on various materials — •Pavel N. Terekhin, Pascal D. Ndione, Sebastian T. Weber, and Baerbel Rethfeld — Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schroedinger-Strasse 46, 67663 Kaiserslautern, Germany

The use of ultrashort laser pulses for surface nanostructuring is of great importance in technological and medical applications. Thus, understanding of the basic governing mechanisms of energy deposition to the irradiated material is very important. On a rough material surface, grating structures or at a step edge ultrashort laser pulses can excite surface plasmon polaritons (SPP), i.e. surface plasmons coupled to a laser electromagnetic wave. One of the possible scenarios for the description of laser-induced periodic surface structures (LIPSS) is based on the SPP excitation and their interference with the incident beam.

The spatial and temporal evolution of the periodically modulated absorbed laser energy is studied after irradiation of various metals in the framework of the two-temperature model (TTM). We present a new analytical source term in the TTM, which takes into account the excited plasmon subsystem and therefore spatial periodicity. The developed method can be used to study the mechanisms of laser energy absorption under controlled conditions and for investigation of the properties of the excited SPP.