O 50: Coupled Nanostructures and Light Localization

Time: Wednesday 10:30–13:00 Location: MA 043

O 50.1 Wed 10:30 MA 043

Babinet to the half: Coupling of solid and inverse plamonic structures — •Mario Hentschel[1,2], Thomas Weiss[1], Shahin Bagheri[1], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany — [2]Materials Science Division, Lawrence Berkeley National Laboratory, Berkeley, USA

We study the coupling between the plasmonic resonances of solid and inverse metallic nanostructures [1]. While the coupling between solid-solid and inverse-inverse plasmonic structures is well-understood, mixed solid-inverse systems have not yet been studied in detail. We find that an efficient coupling between inverse and solid resonances is possible, identify the necessary geometrical prerequisites, and demonstrate a novel solid-inverse plasmonic electromagnetically induced transparency (EIT) structure as well as mixed chiral systems. We furthermore show that for the coupling of asymmetric rod-shaped inverse and solid structures symmetry breaking is crucial. In contrast, highly symmetric structures such as nanodisks and nanoholes are straightforward to couple. Moreover, we demonstrate our concept experimentally in lithographically fabricated multilayered systems and explore a novel fabrication route combining top-down ion-etching techniques with high quality wet-chemically synthesized nanoparticles. Our results constitute a significant extension of the plasmonic coupling toolkit, and we thus envision the emergence of a large number of intriguing novel plasmonic coupling phenomena in mixed solid-inverse structures. [1] M. Hentschel et al., Nano Lett. 13, 4428 (2013)

O 50.2 Wed 10:45 MA 043

Tunable plasmon polaritons in cubic crystals of interacting metallic nanoparticles — •Simon Lamowski[1], Felicitas Hellbach[1], Guillaume Weick[2], and Fabian Pauly[1] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [2]Institut de Physique et Chimie des Matériaux de Strasbourg, Université de Strasbourg, CNRS UMR 7504, F-67034 Strasbourg, France

In this work we extend previous studies of plasmons supported by interacting metallic nanoparticles in honeycomb [1] and simple cubic lattices [2] to body-centered cubic (bcc) and face-centered cubic (fcc) lattices. The near-field interaction between the localized surface plasmons on each nanoparticle results in collective plasmons that extend over the whole lattice. Considering dipolar interactions up to fourth nearest neighbors, we derive analytical expressions for the collective plasmon dispersion. Following Hopfield [3], we couple the collective plasmons to light to form plasmon polaritons. The plasmon polariton dispersion depends on the direction of the wavevector and the polarization of light. We discuss this dependence for the different lattices and the range of the dipolar interactions [4].

[1] G. Weick, C. Woollacott, W. L. Barnes, O. Hess, and E. Mariani, Phys. Rev. Lett. 110, 106801 (2013).
[2] G. Weick and E. Mariani, Eur. Phys. J. B (2014), to appear; arXiv:1403.2205
[3] J. J. Hopfield, Phys. Rev. 112, 1555 (1958).
[4] S. Lamowski, F. Hellbach, G. Weick, and F. Pauly, in preparation.

O 50.3 Wed 11:00 MA 043

Dirac-like plasmons in honeycomb lattices of metallic nanoparticles — •Guillaume Weick[1], Claire Woollacott[2], William L. Barnes[2], Ortwin Hess[3], and Eros Mariani[1] — [1]Institut de Physique et Chimie des Matériaux de Strasbourg, Université de Strasbourg, CNRS UMR 7504, F-67034 Strasbourg, France — [2]Centre for Graphene Science, Department of Physics and Astronomy, University of Exeter, EX4 4QL Exeter, UK — [3]The Blackett Laboratory, Department of Physics, Imperial College London, South Kensington Campus, London SW7 2AZ, UK

We consider a two-dimensional honeycomb lattice of metallic nanoparticles, each supporting a localized surface plasmon, and study the quantum properties of the collective plasmons resulting from the near field dipolar interaction between the nanoparticles. We analytically investigate the dispersion, the effective Hamiltonian and the eigenstates of the collective plasmons for an arbitrary orientation of the individual dipole moments. When the polarization points close to the normal to the plane the spectrum presents Dirac cones, similar to those present in the electronic band structure of graphene. We derive the effective Dirac Hamiltonian for the collective plasmons and show that the corresponding spinor eigenstates represent Dirac-like massless bosonic excitations that present similar effects to electrons in graphene. We further discuss how one can manipulate the Dirac points in the Brillouin zone and open a gap in the collective plasmon dispersion by modifying the polarization of the localized surface plasmons. Ref: G. Weick et al., PRL 110, 106801 (2013)

O 50.4 Wed 11:15 MA 043

Mode normalization and mode sensitivity in metallic photonic crystal slabs and complex plasmonic nanostructures — •Thomas Weiss[1], Martin Mesch[1], Harald Giessen[1], Wolfgang Langbein[2], and Egor A. Muljarov[2] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany — [2]School of Physics and Astronomy, Cardiff University, United Kingdom

The optical properties of a given structure are strongly determined by its resonances. Of significant importance are plasmonic resonances, which occur in metallo-dielectric systems. Problems arise whenever it becomes necessary to properly normalize the optical resonances, because optically active resonances couple to the far-field, so that a straight-forward integral over the whole space will diverge. In 2010, Muljarov et al. have developed an analytical mode normalization [1], which allows not only to expand the Green's function in terms of resonant states, but also to derive the modification of the optical response due to changes in the occurring material distributions via the so-called resonant state expansion. We will present how to adapt the analytical normalization to periodic structures such as metallic photonic crystal slabs, for which we have developed efficient procedures for finding the optical modes [2]. Moreover, we will show how we can use first order perturbation theory in order to derive the sensitivity of plasmonic resonances with respect to refractive index changes, which provides new routes to develop advanced sensing devices.

[1] E. A. Muljarov et al., Europhys. Lett. 92, 50010 (2010).
[2] T. Weiss et al., J. Opt. Soc. Am. A 28, 238-244 (2011).

O 50.5 Wed 11:30 MA 043

Simple plasmonic design for homogeneous chiral near-fields — •Martin Schäferling[1], Nader Engheta[2], Thomas Weiss[1], and Harald Giessen[1] — [1]4th Physics Institute and Research Centers SCoPE and SimTech, University of Stuttgart, Germany — [2]Department of Electrical and Systems Engineering, University of Pennsylvania, Philadelphia, USA

Chiroptical spectroscopy utilizes chiral electromagnetic fields to probe the handedness of natural chiral molecules. The strength of the chiroptical interaction can be quantified by the so-called optical chirality, which is a property of the electromagnetic field [1].

Plasmonic nanostructures can tailor the optical chirality of their near-fields [2]. We have shown recently that geometrically chiral nanostructures can lead to strong chiral fields over an extended region [3]. However, our proposed design of four intertwined helices is difficult to fabricate and therefore not the optimum for potential applications.

In this contribution, we present a novel design combining a layer of diagonal slits with a mirror for the generation of chiral near-fields. The design is easy to fabricate by electron-beam lithography. Access to the chiral near-fields is straightforward. Although the optical chirality is weaker than for helices, our structure might be preferable for applications due to its simplicity. We examine the strength and shape of the generated chiral near-fields and discuss optimization strategies.

[1] Y. Tang and A. E. Cohen, Science **332**, 333 (2011).
[2] M. Schäferling et al., Phys. Rev. X **2**, 031010 (2012).
[3] M. Schäferling et al., ACS Photonics **1**, 530 (2014).

O 50.6 Wed 11:45 MA 043

Superluminescence from an Optically Pumped Molecular Tunneling Junction by Injection of Plasmon Induced Hot Electrons — •Kai Braun, Xiao Wang, Dai Zhang, Heiko Peisert, Thomas Chassé, and Alfred J. Meixner — Institute of Physical and Theoretical Chemistry, University of Tübingen, Auf der Morgenstelle 18, 72076 Tübingen, Germany

Here, we introduce and experimentally demonstrate amplification of the tip enhanced optical signal from a very low number of molecules

enclosed in the optically pumped gap of a STM. The gap between a sharp gold tip and a flat gold substrate covered with a self-assembled monolayer of 5-chloro-2-mercaptobenzothiazole (Cl-MBT) can be used as an extremely small optical gain medium. When a bias-voltage is applied between tip and sample such that electrons tunnel from the Cl-MBT's highest occupied molecular orbital (HOMO) to the tip, holes are left behind in the molecules. These can be repopulated by hot electrons that are created by the laser-driven plasmon oscillation on the metal surfaces. Emission of photons occurs from the recombination of plasmon excited hot electrons with holes in the HOMO of surface bound molecules facing the tip apex. Varying the laser pump power or alternatively the applied bias voltage shows in both cases a distinct threshold above which amplification of the optical signal occurs. Solving the laser-rate equations for this system shows that the repopulation process can be efficiently stimulated by the gap modes near field. TERS scattering from neighboring molecules acts as an optical seed and feed-back is provided by the cavity plasmon-polariton.

O 50.7 Wed 12:00 MA 043

Experimental verification of super- and hyperlensing with two dimensional materials: Graphene and Bornon nitride — •Peining Li[1], Martin Lewin[1,2], Fabian Gaussmann[2], Joshua Caldwell[3], and Thomas Taubner[1,2] — [1]1st Institute of Physics (IA), RWTH Aachen University, Aachen 52056, Germany — [2]Fraunhofer Institute for Laser Technology ILT, 52074 Aachen, Germany — [3]U.S. Naval Research Laboratory, 4555 Overlook Ave, S.W., Washington, D.C. USA

Two-dimensional atomic crystals (TDACs), such as graphene [1] and hBN [3], support highly confined plasmon- or phonon-polaritons for concentrating electromagnetic energies into manometer scale, which open ups the possibility for many different subdiffractional nanophotonic applications.

Here, we present the experimental studies that use these two typical TDACs,graphene and hexagonal boron nitride (hBN), to overcome the diffraction limit for achieving high-resolution infrared near-field imaging[4-6].

[1] J. Chen et al.,Nature 487, 77 (2012). Z. Fei et al.,Nature 487, 82 (2012).
[3] S. Dai et al.,Science 343, 1125 (2014).
[4] P. Li and T. Taubner., ACS nano 6, 10107 (2012).
[5] P. Li, et al., Nano Lett. 4, 4400 (2014)
[6] P. Li, et al., Submitted

O 50.8 Wed 12:15 MA 043

Real space imaging of nano-tip plasmons using electron energy-loss spectroscopy — •Thorsten Weber[1,2], Benjamin Schröder[3], Sergey Yalunin[3], Christian Matyssek[4], Thomas Kiel[4], Felix von Cube[1,2], Stephan Irsen[2], Kurt Busch[4,5], Stefan Linden[1], and Claus Ropers[3] — [1]Physikalisches Institut, Rheinische Friedrich-Wilhelms-Universität Bonn, Germany — [2]Research center caesar, center of advanced european studies and research, Bonn, Germany — [3]IV. Physikalisches Institut, Georg-August-Universität Göttingen, Germany — [4]Institut für Physik, Humboldt-Universität zu Berlin, Germany — [5]Max-Born-Institut, Berlin, Germany

Focusing light beyond the diffraction limit is of great interest in photonics. Metallic nano-tips offer the ability to concentrate light in nanometric volumes on femtosecond timescales using adiabatic compression of surface plasmon polaritons, facilitating applications in tip-enhanced Raman scattering, optical near field microscopy or ultra fast photoemission. Here, we show real-space imaging of surface plasmon polaritons on a gold nano-tip using electron energy-loss spectroscopy (EELS) in combination with scanning transmission electron microscopy. We demonstrate the predicted nanofocussing towards the apex and measure the local dispersion relation of the plasmon. The observations are in good agreement with ab-initio electrodynamic computations via the discontinous-Galerkin time-domain method and a semi-analytical model including reflection at the apex and higher order azimuthal modes.

O 50.9 Wed 12:30 MA 043

Localization of Light in ZnO Nano-Forests — •David Leipold[1], Manfred Maschek[2], Martin Silies[2], Christoph Lienau[2], and Erich Runge[1] — [1]Technische Universität Ilmenau, Germany — [2]Carl von Ossietzky Universität Oldenburg, Germany

The localization of waves due to multiple scattering is a particularly interesting phenomenon. In this contribution we present several aspects of ongoing research in light localization. Earlier, we reported hot spots in the second harmonic generation in random ZnO nano-needle arrays[1]. These were interpreted as due to the localization of light by multiple scattering. We compare theoretical results of electromagnetic calculations to the experiments in order to give further insight to the formation of localized optical near-fields. While the 3D calculations reproduce various aspects of the experimental results very well, the open-boundary 2D calculations proof the coexistence of propagating and lossy localized modes[2].

[1] M. Maschek et al., Nature Photonics **6**, 293 (2012)
[2] D. Leipold et al., Annalen der Physik **525**, 199 (2013)

O 50.10 Wed 12:45 MA 043

Observation of Anderson localization in disordered plasmonic waveguide arrays — •Tim Vogler, Felix Bleckmann, and Stefan Linden — Physikalisches Institut, Nussallee 12, 53115 Bonn

Evanescently coupled waveguide arrays have become important model systems to investigate the evolution of coherent waves in complex structures. Here, we use arrays of dielectric loaded surface plasmon polariton waveguides (DLSPPWs) to study the propagation of surface plasmon polaritons (SPPs) in disordered media. The DLSPPWs consist of dielectric ridges that are deposited by negative-tone gray-scale electron beam lithography on top of a gold film. Disorder is intentionally introduced by either varying the heights of the individual DLSPPWs (on-diagonal disorder) or by varying their separations (off-diagonal disorder). The evolution of the SPP intensity inside of the arrays is monitored by leakage radiation microscopy. We observe a cross-over from discrete diffraction to Anderson localization as we increase the degree of disorder. Our experimental results are in excellent agreement with theoretical predictions from condensed matter physics and numerical calculations based on the coupled mode theory.