O 50: Poster Session - Plasmonics and Nanooptics: Fabrication and Characterization

Time: Tuesday 18:15–20:00 Location: P2/EG

O 50.1 Tue 18:15 P2/EG

Coupling of Quantum Emitters to Plasmonic Slot Waveguides — •Lok-Yee Yan, Mike Prämassing, Yuhao Zhang, Hans-Joachim Schill, and Stefan Linden — Physikalisches Institut, University of Bonn, Nußallee 12, D-53115 Bonn, Germany

Quantum emitters (QEs) coupled to plasmonic systems are considered as promising candidates for building blocks in quantum plasmonic circuits. So far, several plasmonic platforms such as silver nanowires and gold V-grooves have been exploited. The main idea behind those concepts is that one can easily tailor the electromagnetic density of states by shaping the geometry of the underlying metallic nanostructure. Here, we report on the fabrication of hybrid nanostructures consisting of colloidal semiconductor quantum dots or transition metal dichalcogenide (TMDC) monolayers, coupled to 80 nm wide slot waveguides in single-crystalline gold flakes. We use a two-step electron beam lithography process to deposit a controllable number of quantum dots on freely definable sites on the substrate while monolayers of TMDCs are prepared by mechanical exfoliation of the crystal bulk material. A focused ion beam allows us to mill the nanostructures into the gold film. Depending on the relative placement of the QEs and the plasmonic nanostructures, different coupling strengths can be achieved. We demonstrate this by imaging the fluorescence of the QEs onto an EMCCD camera and showing a reduction of lifetime as a result of an increase of the local photonic density of states.

O 50.2 Tue 18:15 P2/EG

Theoretical analysis on the plasmon-resonant optical response of silver nanoparticles with shapes of sphere, spheroid, and snipped trigonal prism — •Masafuyu Matsui and Hisao Nakamura — AIST, Tsukuba, 305-8568, Japan

Plasmon-resonant optical response of silver nanoparticles with shapes of sphere, spheroid, and snipped trigonal prism are investigated using an analysis method based on dipole–dipole interaction within discrete dipole approximation. In the analysis method, the induced dipole is decomposed into the contributions from incident-light electric field (an incident light term) and that from induced dipole oscillations (a dipole–dipole interaction term) to clarify microscpopic level mechanism of plasmon resonance and near-field effect. The analysis reveals that the diameter corresponding to the polarization direction of the incident light plays a crucial role in determining the optical response of the nanoparticles. In the plasmon resonance along the direction with small diameter, the incident light term is a dominant source of induced dipoles, resulting that the extinction peak appears close to the maximum of imaginary part of polarizability. In contrast, in the plasmon resonance along that with large diameter, the dipole–dipole interaction one is dominant and red-shifts the extinction peak. Therefore, shape control of nanoparticle with high anistropy, for example, nanoplate, is a key factor to exhibit the desired plasmon resonance with sharp peak, leading to development of effective plasmonic devices.

O 50.3 Tue 18:15 P2/EG

Generation of ultrashort laser pulses for nonlinear near-field imaging of plasmonic nanostructures — •Mike Prämassing, Felix Affeld, and Stefan Linden — Physikalisches Institut Universität Bonn, D-53115

Upon resonant excitation with ultrashort laser pulses, specially designed metallic nanoantennas faciliate the generation of light at higher harmonics of the excitation frequency. This effect can be used for example in metasurface designs to combine frequency conversion with other metasurface capabilities like beam fucusing or vortex beam creation.[1] In this work, we report on our progress towards nonlinear near-field imaging of plasmonic nanostructures. We utilize a pulsed tunable near-infrared light source at an operating wavelength of 1550 nm. The initial pulse has a temporal width of about 400 fs and is then spectrally broadened by a single mode fiber and further compressed in time domain by a prism compressor. We show interferometric linear optical near-field measuremetns of V-shaped nanoantennas utilizing a scattering type scanning near-field optical microscope (s-SNOM). As a further step, we plan to couple the compressed pulses into our s-SNOM setup. Thereby, we hope to measure the near-field intensity at the second harmonic frequency to be able to correlate the results with the linear measurements.

[1] Li, G., Zhang, S. & Zentgraf, T. Nonlinear photonic metasurfaces. Nat Rev Mater **2**, 17010 (2017)

O 50.4 Tue 18:15 P2/EG

Fabrication and near-field characterisation of plasmonic chiral couplers — •Hans-Joachim Schill, Mike Prämassing, and Stefan Linden — Physikalisches Institut Universität Bonn, D-53115

For particularly designed on-chip coupling structures the polarization properties of incident free-space radiation can steer the propagation direction in plasmonic waveguides.[1] Here we investigate an approach based on optical spin-orbit coupling utilizing a circularly polarized laser beam. Different planar coupler geometries, fabricated by focused ion beam milling and electron beam lithography are studied in order to yield switchable directional coupling depending on the helicity of the incident light. As a tool to investigate the properties and functionality of individual couplers we use scattering type scanning near-field optical microscopy (s-SNOM), where a sharp metallic tip is raster-scanned over the sample and scatteres the nearfield signal into the farfield. The obtained spatially resolved amplitude- and phase-information, reveal the intensity and propagation direction of the surface plasmon polaritons (SPPs). The experimental near-field measurements are compared with finite element simulations.

[1] Y. Lefier, T. Grosjean, Opt. Lett. 40, 2890-2893 (2015)

O 50.5 Tue 18:15 P2/EG

Near-Field characterization of sponge-like gold structures using optical frequencies — •Nicolai Grund, Mike Prämassing, and Stefan Linden — Physikalisches Institut Universität Bonn, D-53115

Three-dimensional nanoporous gold films exhibit strong, plasmonic "hot spots" with resonance frequencies ranging from the visible to the infrared regime, depending on the average pore size. This feature distinguishes these samples as promising substrates for chemical sensing applications in a broad spectral range[1]. We present an experimental near-field study of nanoporous gold films showing resonances from the visible to the near-infrared wavelength regime. To fabricate the nanoporous gold films, we make use of the composition of commercially available leaf gold. It consists of Gold (Au) and Silver (Ag), where a large fraction of the Ag can be etched away using salpeter acid (HNO_3). The average pore size can be controlled by choosing the initial ratio of Au and Ag. We utilize scattering-type scanning near-field optical microscopy (s-SNOM) in reflection mode in order to measure the near fields above the sample. The resulting two-dimensional near-field distributions allow to study the spatial distribution and density of plasmonic "hot-spots" on the film. Near-field imaging with different excitation wavelengths is used to determine the spectral occurrence and width of distinct hot spots.

[1] Wallace, Gregory Q., et al., Analyst 140.21 (2015): 7278-7282

O 50.6 Tue 18:15 P2/EG

Nanometer precise fabrication of electrically connected gold nanoantennas using a helium ion microscope — •Jessica Meier, René Kullock, Thorsten Feichtner, and Bert Hecht — Nano-Optics and Biophotonics Group, Experimental Physics 5, University of Würzburg, Germany

Optical antennas can be used to control and enhance light-matter interaction on a nanometer scale and are therefore interesting for e.g. spectroscopy, optical sensing applications, and - if combined with electric connections - for electrically driven light emission. In all cases, a high fabrication accuracy, especially in the gap region, is mandatory for stable operation. Standard nanofabrication techniques including electron beam lithography and focused ion beam (FIB) milling using gallium (Ga) ions in combination with polycrystalline metal films achieve minimum feature sizes of 10 nm. The combination of Ga-FIB and helium ion microscope (HIM) based milling improves on that and allows to fabricate gap sizes down to 6 nm [1].

We present a Ga-FIB/HIM based milling approach combined with single-crystalline gold flakes, which already showed great improvements for pure Ga-FIB milling [2]. We are thus able to achieve nanometer precise antenna dimensions with high aspect ratios as well as gap sizes down to 3 nm. This opens the possibility to study field emission and nonlinear optical processes, namely second harmonic generation and two-photon photoluminescence.

[1] H. Kollmann et al., Nano Lett. **14**, 4778-4784 (2014)
[2] J.-S. Huang et al., Nat. Commun. **1**, 150 (2010)

O 50.7 Tue 18:15 P2/EG

Plasmonic nanoantennas embedded in zinc oxide — •Ruth Volmert, Nils Weber, Maximilian Albert, and Cedrik Meier — Department Physik, Universität Paderborn, 33098 Paderborn

Plasmonic nanoantennas for visible and infrared radiation can strongly enhance the interaction of light with nanoscale materials due to their strong near-field enhancement. In this work we show the effective generation of second harmonic generated light in zinc oxide (ZnO) by using double-resonant gold nanoantennas embedded in ZnO. By fully embedding the nanoantennas in the ZnO, the strong increase in the electric field between the antennas, triggered by their plasmonic resonance, is utilized for the frequency conversion. In order to embed gold nanoantennas in a ZnO environment, different approaches are demonstrated and analysed. The nanoantenna structure consists of three rods with two localized surface plasmon resonances at ω and 2ω. Two long antennas lead to strong localization of light at the fundamental frequency ω within the ZnO and the third antenna, placed between the two fundamental antennas, provides an improved reemission of the second harmonic generation (SHG) at 2ω into the far field. We show that embedding gold nanoantennas in ZnO is possible by MBE overgrowth of ZnO on the nanoantennas. In addition, nonlinear optical measurements show that the embedded structures lead to a significant enhancement of the SHG compared to the emission of nanoantennas placed on the ZnO substrate. These promising results demonstrate the potential of SHG emission from embedded metallic nanostructures and paves the way for further investigation on other fabrication parameters.

O 50.8 Tue 18:15 P2/EG

Tailoring energy and dimensionality of plasmonic nanostructures — •Hongdan Yan[1,2], Bo Liu[1,2], Dirk Wulferding[1,2], Frank Ludwig[2,3], and Peter Lemmens[1,2] — [1]IPKM, TU-BS, Braunschweig, Germany — [2]LENA, TU-BS, Braunschweig, Germany — [3]EMG, TU-BS, Braunschweig, Germany

Novel routes for energy tuning and adaption of surface plasmon resonances within 3-dimensional Au nanowire arrays are presented. Based on a defect management of the substrate (anodic aluminum oxide, AAO) via annealing we demonstrate a tuning of the longitudinal resonance of plasmons towards higher energy [1]. To induce a 3D-1D crossover the Au nanowires are released in a self-controlled etching and annealing process. Optical absorption experiments demonstrate a very efficient coupling to molecular excitons with resulting "plexcitons" [2]. Theoretical modelling of the plasmonic spectrum supports our experimental findings. Work support by QUANOMET-NL4. [1] H. Yan, P. Lemmens, D. Wulferding, J. Shi, K. D. Becker, C. T. Lin, A. Lak, M. Schilling, J. Mat. Chem. Phys. 135, 206 (2012). [2] B. Liu, B. Thielert, A. Reutter, R. Stosch, P. Lemmens, J. Phys. Chem. C 123, 19119 (2019).

O 50.9 Tue 18:15 P2/EG

Manipulating single 3D plasmonic nanostructures with a focused helium ion beam — •Annika Bräuer, Christoph Dreser, Dieter P. Kern, and Monika Fleischer — Institute for Applied Physics and Center LISA+, Tübingen, Germany

Although particle plasmonics is a well-studied topic and quite well understood when it comes to confining light to the nanometer scale or tuning resonances, there still is ample scope in engineering nanostructures for higher near-field enhancements (NFE) [1] on the one hand and a better positioning and accessibility of hot spots on the other hand. In view of far-field properties, defining the directionality of the antenna emission is of strong interest.

Improvements in tuning such properties are mostly limited by fabrication processes. A helium ion microscope is a powerful tool for manipulating structures on a sub-5 nm-scale, offering a broad spectrum of features for NFE. By processing conical nanoantennas with a focused helium ion beam [2,3], we show that the resonant behavior can be changed as well as the emission characteristics, and near-field enhancement can be induced at defined positions.

[1] A. García-Etxarri et al., Optics Express 20, 25201-25212 (2012)
[2] M. Fleischer et al., Nanotechnology 21, 65301 (2010)
[3] F. Laible et al., Nanotechnology 30, 235302 (2019)

O 50.10 Tue 18:15 P2/EG

Nanostructuring with the aid of atomic layer deposition — •Benjamin Trzeciak[1], Eric N'Dohi[2], Florian Laible[1], Christoph Dreser[1], and Markus Turad[1] — [1]1Institute for Applied Physics and Core Facility LISA+, Eberhard Karls University Tübingen, Germany — [2]2University of Technology Troyes, France

Thin layers are indispensable in today's fabrication of nanostructures. In order to reduce the size of complex and innovative structures like MEMS sensors, fuel or solar cells it is not only necessary to produce smaller conductive structures. It is also crucial to be able to insulate the structures with even thinner layers. Atomic layer deposition (ALD) offers a solution for depositing ultra-thin layers with the accuracy of single layers. Their high aspect ratio, homogeneity, linear and isotropic growth are regarded as major advantages of this deposition technique.

In this work the technique of ALD is utilized in combination with plasmonic nanostructures, in particular silver nanodiscs. Non-passivated silver easily oxidizes or sulfidizes, which means that its optical properties are not stable over time. In order to guarantee long-term stability and maintain their optical properties, such as plasmonic resonances, the silver discs are passivate with a closed layer of minimal thickness. Building on this, ALD layers can be used as spacers with Angstrom distance control for hybrid structures such as dimers or nanostructure-quantumdot-systems.

The mechanism of ALD and the methods of ellipsometry and X-ray diffraction will be briefly discussed together with the preparation of silver nanodiscs and their spectra.

O 50.11 Tue 18:15 P2/EG

Comparison and analysis of ultra-narrow gaps fabricated by electron and helium ion beam lithography — •Hao HU[1,2], Monika Fleischer[2], and Pierre-Michel Adam[1] — [1]Universite* de Technologie de Troyes, 12 Rue Marie Curie, CS42060, 10004 Troyes Cedex, France — [2]Institute for Applied Physics and Center LISA+, Eberhard Karls University Tübingen, Auf der Morgenstelle 10, 72076 Tübingen, Germany

Metal nanostructures with ultra-narrow gaps, which enable strong field enhancements in plasmonic structures, have attracted widespread attention in physics, chemistry, and biology. However, fabricating ultra-narrow nanogaps is still challenging at present, and controllable gap size, accurate dimensions, and scalable fabrication are desired for further applications. The most common methods for fabricating nanogaps arrays are electron beam lithography (EBL) and focused ion beam (FIB) milling. Depending on the difference of cross-linking reaction and degradation reaction occurring under the electron beam, the photoresist can be classified into two types: positive tone and negative tone. FIB can be divided into He-ion and Ga-ion beam depending on the ion source used. In this study, we provide a comparison of nanostructures fabricated with different methods including different types of EBL and FIB. By varying the fabrication methods of the nanostructures, we aim to find optimized approaches for fabricating ultra-narrow nanogaps.

O 50.12 Tue 18:15 P2/EG

Micro-ellipsometric Investigation of Ordered Plasmonic Nanostructures — •Jia Tang[1], Ilya Milekhin[2], Fang Dai[1], Eugene Bortchagovsky[3], Dietrich R. T. Zahn[2], and Monika Fleischer[1] — [1]Institute for Applied Physics, Eberhard Karls Universität Tübingen — [2]Semiconductor Physics, Technische Universität Chemnitz — [3]V. Lashkarev Institute of Semiconductor Physics of NAS of Ukraine

Nanoparticles of metals have size-dependent optical properties different from the corresponding bulk materials. Such properties originating from the ability of their conduction electrons to sustain collective oscillations known as plasmons, are key ingredients in applications including surface-enhanced spectroscopies, chemo- and bio-sensing, and holographic techniques. Here the interparticle interactions in plasmonic structures are focused on. Systems with strong coupling of localized modes or localized and propagating plasmons demonstrate hybridization of resonances. The main aim of this work is to investigate the influence of geometrical parameters and the form-factor of lattices on the plasmonic and optical properties by high spatial resolution ellipsometric measurements. This technique makes it possible to obtain detailed geometric as well as amplitude and phase information about the coupled systems, providing a better insight into the hybridization of plasmon modes. In this presentation, extinction spectroscopy and imaging spectroscopic ellipsometry with high spatial resolution are employed to investigate ordered metal-insulator-metal (MIM) nanostructures, which are prepared by electron beam lithography.