O 59: Plasmonics and Nanooptics

Time: Tuesday 18:30–20:30 Location: P2-OG1

O 59.1 Tue 18:30 P2-OG1

Fabrication of nanoaperture arrays in a free standing gold film for electron energy-loss spectroscopy — •Mike Prämassing[1], Stephan Irsen[2], and Stefan Linden[1] — [1]Physikalisches Institut Universität Bonn, Nußallee 12, D53115 — [2]Forschungszentrum Caesar Bonn, Ludwig-Erhard-Allee 2, D53175

Periodic nanoaperture arrays in thin metallic films are well known to exhibit extraordinary optical transmission orders of magnitude higher than predicted by standard aperture theory [1]. In contrast, for thinner metal films a suppressed optical transmission has been reported [2]. Both effects can be explained by resonant coupling of the incident light to surface plasmon polaritons (SPPs) via the array. Scanning transmission electron microscopy (STEM) in combination with electron energy-loss spectroscopy (EELS) is a powerful tool for the spatial and spectral characterization of the SPPs. However, STEM-compatibility restricts us to fabricate the films either free-standing or on a membrane, transparent for the electron beam. We present two STEM-compatible fabrication approaches for nanoaperture arrays in metallic films with thicknesses from 10 nm to 100 nm: Focused ion beam milling in a free-standing film or electron beam lithography on an electron transparent SiN membrane. The chosen range of film thickness corresponds to the transition region between enhanced and suppressed optical transmission.

[1] Ebbesen et al., Nature 391, 667-669 (1998).
[2] Braun et al., Phys. Rev. Lett. 103, 203901 (2009).

O 59.2 Tue 18:30 P2-OG1

Optimizing Yagi-Uda antennas for high directivity and electrical driving in the visible regime — •Philipp Grimm, René Kullock, and Bert Hecht — NanoOptics & Biophotonics Group, Experimentelle Physik 5, Physikalisches Institut, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Antennas are fundamental devices which couple localized fields to far-field radiation and vice versa. In radio technology, a widespread antenna geometry is found in Yagi-Uda antennas whose far-field emission is highly directional, thus enabling efficient communication between two instances.

In the optical regime metallic nanoparticles exhibiting plasmonic resonances can act as antennas for light. So far they have already been arranged to Yagi-Uda antennas and showed pronounced directivity [1,2]. However, while these attempts were based on optical pumping our aim is to electrically drive them similar to [3]. In order to obtain reasonable working antennas for this more complex case, here we use an analytic dipole interaction model and numerical boundary element simulations to characterize possible geometries and extract design rules. Using that we find fabricable Yagi-Uda antenna geometries which show high directivity and are still suitable for electrical driving.

[1] A. Curto et al., *Science 329, 5994 (2010)*
[2] T. Kosako et al., *Nat. Photonics 4, 5 (2010)*
[3] J. Kern et al., *Nat. Photonics 9, 9 (2015)*

O 59.3 Tue 18:30 P2-OG1

Near Field Investigation of Plasmonic Bowtie Antennas — •Jon Polensky, Bendix Ketelsen, Thomas Klings, Jens Ehlermann, Irene Fernandez-Cuesta, and Robert Blick — Center for Hybrid Nanostructures (CHyN), Hamburg, Germany

Single-molecule detection techniques are revolutionizing the way we understand (bio)chemical processes. But observing single molecules is a big technological challenge. One idea is using the hot-spot yielded by a plasmonic nanoantenna which confines and enhances optical fields. The hot spot can be focused down to less than tens of nanometers.

We have constructed a Scanning Near Field Optical Microscope (SNOM) to investigate the optical near fields of relevant structures. One proof of concept is the study of the optical properties of the aforementioned plasmonic nanoantennas. Two different geometries were characterized and compared. We used the SNOM to measure the intensity of the hotspot by changing the polarization of the incident laser beam.

We investigated triangular and circular antennas made of gold, with triangle side lengths of l = 140 nm and a radius of r = 80 nm, respectively. The antennas were made by nanoimprint lithography and lift-off. It was found out, that both antenna shapes lead to a field enhancement in the nanometric gap between the structures. The polarization change of the incident beam showed a significant effect: light that is parallel polarized to the long axis of the antenna induced a more intense hotspot than perpendicular polarized light. The factor between the two relative hotpot intensities is 1.5.

O 59.4 Tue 18:30 P2-OG1

Babinet principle and plasmonic antennas for enhanced optical processes — Martin Hrtoň[1,2], •Vlastimil Křápek[1,2], and Tomáš Šikola[1,2] — [1]Central European Institute of Technology, Brno University of Technology, Purkyňova 123, CZ-612 00 Brno, Czech Republic — [2]Institute of Physical Engineering, Brno University of Technology, Technická 2, CZ-616 69 Brno, Czech Republic

Babinet principle for localized surface plasmon resonance was theoretically studied in direct and indirect plasmonic antennas (particles and apertures). We focused on two-part antennas with a conductive or non-conductive junction exhibiting strongly localized and enhanced electric near field. We aim at a design of plasmonic antennas that can be used for the enhancement of optical processes.

O 59.5 Tue 18:30 P2-OG1

Fabrication and Characterization of Photonic Metasurfaces — •Alexander Fassbender, Felix Bleckmann, and Stefan Linden — Physikalisches Institut, Rheinische Friedrich-Wilhelms Universität Bonn, Nußallee 12, D-53115 Bonn, Germany

Photonic metasurfaces can be used to locally control the phase of incoming electromagnetic waves by scattering the wave from the subwavelength building blocks of the metasurface. In combination with the Generalized Snell's law this allows to nearly arbitrarily control the refraction at such surfaces. Depending on the exact structure of the used metasurface one can construct various optical elements, e.g., lenses and holograms.

Here, we want to demonstrate a metasurface that generates an optical vortex. For that purpose, we fabricate an antenna array using electron beam lithography. We employ gold antennas with a length of 200 nm to modify the properties of a circular polarized wave at 750 nm wavelength. More specific, we control the locally induced phase of light with the opposite helicity by rotating each antenna by a certain angle relatively to a reference axis. To achieve a radial phase gradient, necessary to generate an optical vortex, the orientation of the antennas rotates by π per turn. Using an interferometer we plan to demonstrate that our photonic metasurface generates an optical vortex exhibiting the characteristic spiral phase distribution.

O 59.6 Tue 18:30 P2-OG1

Far-field characterization of colloidal light management structures for PV — •Lutz Mühlenbein[1], Peter M. Piechulla[1], Alexander Sprafke[1], and Ralf B. Wehrspohn[1,2] — [1]FG Mikrostrukturbasiertes Materialdesign, MLU Halle-Wittenberg — [2]Fraunhofer IMWS, Halle

Light management strategies are object of extensive research in the field of thin film photovoltaics, with the primary goal of increasing the short circuit current J_{SC} of PV cells. However, while J_{SC} is the figure of merit in the final device, in order to optimize light management structures, we are interested in the more fundamental optical properties, e.g. angular and wavelength resolved scattering. Using conventional fabrication technologies, controlling those properties is either expensive (for example by photolithography) or severly limited (random etching processes). In contrast, layers of self-organized colloidal particles can be produced on a large scale at low cost and allow for a wide range of scattering properties. In the presented work, we are focussing on appropriate and practicable characterization techniques in order to link the optical response to the microstructure of these colloidal layers.

O 59.7 Tue 18:30 P2-OG1

Enhancement of the second harmonic signal of nonlinear crystals by nanoantennas — •Emre Gürdal[1], Markus Kalmutzki[2], Anke Horneber[3], Hans-Jürgen Meyer[2], Alfred J. Meixner[3], Dai Zhang[3], Dieter Kern[1], and Monika Fleischer[1] — [1]Applied Physics, Tübingen, Germany — [2]Inorganic Chemistry, Tübingen, Ger-

many — [3]Physical and Theoretical Chemistry, Tübingen, Germany

In the last decade nonlinear crystals have become a common tool for frequency conversion. A commonly observed second order nonlinear optical process is the so-called second harmonic generation (SHG). The interaction of two photons with e.g. a nonlinear crystal allows the creation of one photon with twice the energy. The efficiency of this nonlinear process can be enhanced using localized surface plasmons (LSPs). At the resonant wavelength of LSPs excited within metallic nanostructures, a strong electric near-field is created in their close vicinity, which improves the nonlinear optical process. We investigate nonlinear crystals that are nanostructured with gold nanodiscs by electron beam lithography. We measure and simulate the optical properties of dimers. The scattered intensities and resonance frequencies depend on the size and distance of the respective discs. For excitation we use a pulsed femtosecond laser with a wavelength of 774 nm, to which the nanodimer resonances are matched. The spectrally resolved nonlinear intensity at the position of the nanostructures is compared with the nonlinear signal of the unstructured crystal surface.

O 59.8 Tue 18:30 P2-OG1

Raman enhancement due to gold nanoparticles on a graphene monolayer — •Marcel Weinhold, Sangam Chatterjee, and Peter J. Klar — Justus Liebig University Giessen, Institute of Experimental Physics I, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany

Tip-enhanced Raman spectroscopy (TERS) is a powerful technique for analyzing molecular vibrations as well as lattice dynamics in bulk materials with a high spatial resolution down to a few nanometers, and combines the advantages of ordinary Raman spectroscopy and atomic force microscopy.

Despite the huge progress in improving the achievable spatial resolution of tip-enhanced Raman spectroscopic techniques, there remain many questions unanswered regarding the mechanisms, that lead to the enhancement of Raman signals. The understanding of these effects is essential for improving the TERS techniques. We study the enhancement effects of gold nanoparticles (representing a TERS tip) deposited on a graphene monolayer. Graphene was employed because of its two-dimensionality, its strong Raman signals, and the opportunity of purchasing samples with coverages close to 100%. We used Raman mapping with different excitation lasers, and various laser powers to determine the influence on the Raman enhancement. The enhancement factor shows a dependence on the excitation wavelength and varies for the different graphene modes. Additionally, we obtain a systematic shift in the measured phonon-frequencies probably related to a plasmonic coupling between gold and graphene that correlates with the applied laser power.

O 59.9 Tue 18:30 P2-OG1

Polarization resolved microscopy of plasmonic nanoparticles — •Jasmin Schönzart, Markus Pfeiffer, and Klas Lindfors — Department of Chemistry, University of Cologne, Luxemburger Str. 116, 50939 Köln, Germany

The plasmon resonance of metal nanoparticles may be modified by changing the shape or material of the particle or the medium surrounding the nanostructure. Varying the shape of resonant metal nanoparticles allows controlling the optical properties of the structure. Using the polarization of the incident light the excitation of different plasmonic modes can be controlled. This is of great interest, as the localization of the near field enhancement can be controlled on a sub-wavelength scale. Here we present a microspectroscopy setup, which enables interference-contrast microscopy of very small plasmonic nanostructures using complex polarization states of the incident light such as radial and azimuthal polarization.

In initial experiments we determined the size-dependent interference scattering signal for spherical gold nanospheres down to particle sizes of 20 nm. In further studies we investigated gold nanorods. These show a longitudinal- and transversal plasmon mode, which can be excited separately, depending on illumination wavelength and orientation of the polarization with respect to the nanorod axis.We further show some first results on measurements with radial and azimuthal illumination polarizations. Here magnetic and electric modes of higher order can be excited.

O 59.10 Tue 18:30 P2-OG1

Magneto-plasmonic interactions in Ni/Au, Co/Au and YIG/Au nanostructures — •Ellen R. Wiedemann[1,3], Jochen Greser[1], Björn Heinz[1], Bert Lägel[2], Sandra Wolff[2], Gereon Niedner-Schatteburg[3], Burkard Hillebrands[1], and Evangelos Th. Papaioannou[1] — [1]Fachbereich Physik, TU Kaiserslautern, Germany — [2]Nano Structuring Center, TU Kaiserslautern, Germany — [3]Fachbereich Chemie, TU Kaiserslautern, Germany

Magnetoplasmonics is an emergent research field that aims to strongly modify the magneto-optic response in the presence of surface plasmons and to control plasmonic resonances with magnetic fields [1,2] In this work we show a new way to manipulate the magneto-optic response of magnetoplasmonic structures, taking advantage of the presence of the magnetic layer. We use patterned Ni, Co and YIG films covered with Au in the form of 2D (antidot lattices) and 1D (stripes) patterns. Different thicknesses and different geometries of the patterns generate a large enhancement of the polar and transverse magneto-optical signal close to SPP resonances. Furthermore we reveal that the choice of a ferrimagnetic dielectric (YIG) or ferromagnetic metal leads to different enhancement factors of the magneto-plasmonic interaction. These magneto-plasmonic interactions will be shown by magnetical, optical and magnetooptical methods including magnetooptical Kerr-effect, ellipsometry, and Brillouin light scattering measurements.

[1] M. Rollinger et al. Nano Letters 16, 2432 (2016).
[2] E. Melander et al. http://arxiv.org/abs/1611.00078 (2016).

O 59.11 Tue 18:30 P2-OG1

Self-Organized Nanostructures as a Large Area Substrate for Plasmonic Surface-Enhanced IR-Spectroscopy — •Michael Tzschoppe[1], Jochen Vogt[1], Maria Caterina Giordano[2], Filippo Canepa[2], Carlo Mennucci[2], Francesco Buatier De Mongeot[2], and Annemarie Pucci[1] — [1]Kirchhoff Institute for Physics, Heidelberg, Germany — [2]Dipartimento di Fisica-Università di Genova, Genova, Italy

Large area arrays of self-organized plasmonic Au nanoantennas were fabricated on soda lime glass wafers over several cm^2. To this end, Au was deposited on glass substrates, patterned by an ion beam sputtering technique. In this way it was possible to fabricate nanoantennas with a controlled length distribution leading to highly dichroic plasmonic resonances in the mid-infrared. A self-assembled monolayer of octadecanthiol (ODT) was used to investigate the potential of these nanoantennas as a substrate for surface-enhanced infrared absorption (SEIRA) spectroscopy. Calculations lead to a lower limit of the enhancement factor in the order of 10^3. The homogeneity of the arrays, which allows measurements on a macroscopic scale with a standard FTIR spectrometer, prove this self-organizing technique to be promising for the synthesis of large area SEIRA substrates for sensing applications.

O 59.12 Tue 18:30 P2-OG1

Higher Harmonics Generation in tapered Plasmonic Waveguides — •Julian Obermeier and Markus Lippitz — Experimental Physics III, University of Bayreuth

Higher harmonics generation in single gold nanostructures is a commonly known effect. Many fascinating experiments showed that the nonlinear emission is strongly influenced and shaped by the particle plasmon resonance. However, when the structure dimension exceeds the diffraction limited excitation area, the higher order modes of the structure and even propagation of the fundamental field and waveguiding effects become important. In our experiments we investigate the local nonlinear response of single tapered plasmonic slab waveguides with finite width. After excitation with pulsed infrared light, the locally generated second and third harmonic field is emitted in the near ultraviolet and visible spectrum and collected by a high NA oil immersion objective. This configuration allows a high spatial resolution of the origin of the nonlinear emission far below the diffraction limit of the excitation wavelength. In addition power dependent measurements help to understand the nonlinear effects in the extended nanostructures but also show deviations from basic expectations. We present our measurement technique and experimental results to determine the local emission properties of extended gold nanostructures.

O 59.13 Tue 18:30 P2-OG1

Signatures of strong coupling on nanoparticles: Revealing absorption anticrossing by tuning the dielectric environment — •Felix Stete[1,2], Wouter Koopman[1], and Matias Bargheer[1,3] — [1]Institut für Physik & Astronomie, Universität Potsdam, Karl-Liebknecht-Str. 24-25, 14476 Potsdam, Germany — [2]Humboldt-Universität zu Berlin, School of Analytical Sciences Adlershof (SALSA), Unter den Linden 6, 10999 Berlin, Germany — [3]Helmholtz Zentrum Berlin, Albert-Einstein-Str. 15, 12489 Berlin, Germany

This contribution presents a method to unambiguously identify the strong coupling regime in plasmon-exciton core-shell systems via absortpion measurements. Two examples of core-shell nanoparticles were used, both with a shell of the J-aggregate forming cyanine dye TDBC and a gold core. In one case the core was formed by gold nanospheres, in the other by gold nanorods. The resonances were tuned by changing the particles' environment on a substrate by layer-by-layer deposition of thin polyelectrolyte films replacing air und thus shifting the plasmon resonance. The extinction spectra of both systems show an anticrossing indicating a regime of strong coupling. However true absorption spectra reveal that only the rods are strongly coupled whereas the spheres' absorption does not show an anticrossing indicating that the spheres are rather in a regime of induced transparency. The observations are discussed within a classical coupled oscillator model that reveals differences in contributions from excitons and plasmons.

O 59.14 Tue 18:30 P2-OG1

Optical microspectroscopy of DNA origami-assembled complex and dynamic plasmonic nanostructures — •Mo Lu[1], Markus Pfeiffer[1], Chao Zhou[2], Na Liu[2], and Klas Lindfors[1] — [1]Department of Chemistry, University of Cologne, Luxemburger Str. 116, D-50939 Köln, Germany — [2]Max-Planck-Institute for Intelligent Systems, Heisenbergstrasse 3, D-70569 Stuttgart, Germany

Metal nanoparticles can serve as optical antennas due to their capacity to support collective oscillations of conduction electrons, known as localized surface plasmons. This can be used to enhance the reception and emission of light from quantum emitters such as semiconductor quantum dots or dye molecules. In our work, we study active plasmonic systems based on DNA origami nanotechnology, where a gold nanorod acts as a nanoantenna and use a single organic fluorescent dye molecule as a quantum emitter. In this system, the plasmonic nanorods can execute progressive and reversible walking to the predefined destination with a stepwise of 7nm [1]. The interaction of the light-emitting molecules with the plasmonic particles is characterized in fluorescence microscopy experiments, where we observe a decrease in fluorescence lifetime and brightness as the distance between emitter and antenna is decreased. Furthermore, we also perform interferometric scattering microscopy to detect the plasmonic particles in this active system in order to track the dynamic process in real time. Our microspectroscopy results provide evidence of the promise of merging nano-optics and DNA technology.

References [1]. C. Zhou, et al., Nat. Commun. 6, 8102 (2015).

O 59.15 Tue 18:30 P2-OG1

Low-temperature scattering-type scanning near-field optical microscopy — •Denny Lang[1,2], Jonathan Döring[2], Susanne C. Kehr[2], Lukas M. Eng[2], Stephan Winnerl[1], Harald Schneider[1], and Manfred Helm[1,2] — [1]HZDR, 01328 Dresden, Germany. — [2]IAP, TU Dresden, 01062 Dresden, Germany.

We present a combination of a versatile low-temperature scattering-type near-field optical microscope (LT-s- SNOM [1]) with a tunable infrared free-electron laser (FEL [2]). Our s-SNOM operates over a broad temperature range from 15 - 300 K [1,3,4] and is unique in being tunable over a broad frequency range, thanks to the FEL. The overall LT-s-SNOM functionality down to lowest temperature was tested on both standard Au and structured Si-SiO_2 samples, revealing net near-field contrasts and no topography cross-talk. Secondly, we investigated several ferroelectric phase transitions in barium titanate single crystals at 273 K [1] and 193 K [5], allowing to associate clear near-field resonances to every phase and each ferroelectric domain; here, the clear benefit of our LT-s- SNOM pays off, being able to record s-SNOM, PFM, KPFM and topographic data with one and the same tip from every sample surface spot. Thirdly, we used these piezoelectrics to quantify the local temperature increase under the AFM tip upon IR irradiation. [1] Döring et al., Appl. Phys. Lett. 105, 053109 (2014). [2] Kuschewski et al., Appl. Phys. Lett. 108, 113102 (2016). [3] Yang et al., Rev. Sci. Instrum. 84, 023701 (2013). [4] McLeod et al., Nature Phys. (2016); DOI: 10.1038/NPHYS3882. [5] Döring et al., J. Appl. Phys. 120, 084103 (2016).

O 59.16 Tue 18:30 P2-OG1

Shaping of Femtosecond Laser Pulses for Plasmonics — •Moritz Heindl, Jonas Albert, and Markus Lippitz — Experimental Physics III, University of Bayreuth, Germany

Ultrashort and well defined laser pulses are used in a wide range of nonlinear optics experiments. In combination with plasmonic nanostructures, they allow to define the optical nearfield in time and space. The temporal degree of freedom is controlled by a pulse shaper using a spatial light modulator. It gives us control over the phase and amplitude in frequency space and thus the form of the pulse. Here we will present the design of our pulse shaper and experiments to check the functionality of the setup. Furthermore, we give an outlook on future experiments making use of spatial and temporal control of optical fields.

O 59.17 Tue 18:30 P2-OG1

Near-field imaging and spectroscopy of hybridized plasmonic nanocavities — •Anna-Katharina Mahro[1], Deirdre Kilbane[1,2], Michael Hartelt[1], Tobias Eul[1], Eva Prinz[1], Mirko Cinchetti[1,3], and Martin Aeschlimann[1] — [1]Physics Department and Research Center OPTIMAS, TU Kaiserslautern, Germany — [2]School of Physics, University College of Dublin, Ireland — [3]Experimentelle Physik VI, TU Dortmund, Germany

Knowledge of fundamental light-matter interactions such as the spectral response of nanostructures to incident light is necessary for designing plasmonic devices. This response is determined on the nanometer scale (below the diffraction limit of light). To achieve this high spatial resolution we use a photoemission electron microscope (PEEM). It images the near-field distribution of the photoelectrons in a parallel data acquisition scheme.

To gain information about the spectral response, we combine PEEM with a highly tunable femtosecond laser source, in our case an optical parametric oscillator (OPO). We demonstrate the potential of this experimental setup by investigating localized, propagating and hybridized surface plasmons in different arrangements of gold whispering gallery mode antennas (WGM) which are fabricated via focussed ion beam milling (FIB).

O 59.18 Tue 18:30 P2-OG1

Coupling of Quantum Emitters to Plasmonic Metamaterials — •Daniel Kuckla, Manuel Peter, and Stefan Linden — Physikalisches Institut, University of Bonn, Nußallee 12, D-53115 Bonn, Germany

Metamaterials consisting of sub-wavelength structures such as split-ring resonators (SRRs) can give rise to unusual optical properties and allow the shaping of electromagnetic waves. In most experiments so far, the investigated metamaterials have been passive structures. However, active metamaterials are attracting more and more interest. For instance, the coupling of semiconductor quantum dots to the different modes of a SRR array has been investigated recently. Here, we focus on the effect of the electromagnetic interactions between the elements of an active metamaterial on its emission properties. For this purpose, we fabricate a series of rectangular SRR arrays with intentionally deposited quantum dots by electron beam lithography in combination with a process that allows us to chemically link nanoparticles from an aqueous solution to freely definable sites on the substrate. To study the influence of the interactions within the metamaterial, we vary within the series the lattice periods while keeping the unit cell size constant. Our SRRs are designed in such a way that the second and third plasmonic mode of the metamaterial with equal lattice periods overlap with the emission spectrum of the uncoupled quantum dots.

O 59.19 Tue 18:30 P2-OG1

Route to high-resolution scanning optical microscopy — •Daniel Friedrich, Heiko Gross, and Bert Hecht — Nano-Optics and Biophotonics Group, Experimental Physics 5, University of Würzburg, Germany

Using confined photons for atomic-scale spectroscopic imaging offers new possibilities in high-resolution scanning optical microscopy and enhanced light-matter coupling. Recent investigations employ scanning probe microscopy to reveal strong coupling between single quantum dots and a single crystal broadband nanoresonator.(1)

By tuning the coupling strength between a plasmonic resonator and single quantum dots, (bio-)molecules or novel 2D-materials using scanning probe microscopy we expect new spectroscopic information with nanometer spatial resolution. Measuring photoluminescence and Raman scattering over the full visible range, in combination with state-of-the-art scanning probe technology with different optical accesses paves the way to novel spectroscopic imaging modalities and observation of a single-photon non-linearity.

(1) Groß, H., Hamm, J. M., Tufarelli, T., Hess, O. and Hecht, B., Strong coupling spectroscopy of single quantum dots at room temperature using a broadband nanoresonator. (submitted)

O 59.20 Tue 18:30 P2-OG1

Fourier Analysis of Overlapping Surface Plasmon Polaritons with Different Propagation Directions — •Pascal Dreher, Pierre Kirschbaum, David Janoschka, Amran Al-Ashouri, Martin Paul Geller, Michael Horn-von Hoegen, and Frank Meyer zu Heringdorf — Faculty of Physics and Center for Nanointegration (CENIDE), Duisburg, Germany

In the past, photoemission electron microscopy (PEEM) has been proven to be an excellent tool for studying surface plasmon polaritons (SPPs). Plasmonic contrast in the real space PEEM images is generated by two photon photoemission. Using femtosecond laser pulses in a pump-probe fashion, time resolution can be achieved. The combination of PEEM and time resolved techniques provides for the spatio-temporal observation of propagating SPPs. Using normal incidence geometry, the result is a direct conceptual visualization of the SPPs.

The estimation of ratios of electric field amplitudes of overlapping SPPs with different propagation directions is a cumbersome and erroneous task, if attempted from real space PEEM images. We present a novel approach based on an FFT analysis that allows the separation of several overlapping SPPs in Fourier space. Using this approach, it was possible to extract the coefficients of transmission and reflection of plasmonic Bragg reflectors as a function of the number of reflector grooves.

O 59.21 Tue 18:30 P2-OG1

Plasmon dispersion and dielectric funtion at a silver/porphyrin interface — •Klaus Stallberg and Winfried Daum — Institute of Energy Research and Physical Technologies, TU Clausthal, Leibnizstraße 4, 38678 Clausthal-Zellerfeld, Germany

Multi-photon photoelectron microscopy (nP-PEEM) is a valuable tool for the investigation of propagating surface plasmon polaritons (SPP). It has been demonstrated by other groups that nP-PEEM allows for a determination of the complex SPP wavevector. In our contribution we adapt this method to determine the SPP dispersion curve on a microscopic Ag(111) island. Our results are in good agreement with results from the literature which were obtained with all-optical methods on extended silver films. We further investigate the SPP dispersion at a silver/zinc-tetraphenylporphyrin interface, which can be regarded as a model system for SPP propagation in the presence of a dielectric with a strong optical absorption band. For excitation wavelengths near the porphyrin absorption (Soret-) band, the shape of the SPP dispersion curve signals an interaction of molecular and plasmonic excitations. In addition, we demonstrate that with nP-PEEM the complex dielectric constant of a thin organic film can be determined as a function of the film thickness during growth. Moreover, we investigate the frequency dispersion of the complex dielectric function of the porphyrin film.

O 59.22 Tue 18:30 P2-OG1

Long-Lived Electron Emission Reveals Ultra-localized Plasmon Modes in Gold Nanosponges — •Germann Hergert[1], Jan Vogelsang[1], Felix Schwarz[2], Dong Wang[2], Heiko Kollmann[1], Petra Gross[1], Erich Runge[2], Peter Schaaf[2] und Christoph Lienau[1] — [1]1Carl von Ossietzky Universität, Oldenburg, Germany — [2]2Technische Universität Ilmenau, Ilmenau, Germany

Materials with disorder on the nanometer scale are known to exhibit large field enhancement properties, making them viable for enhancing non-linear optical effects or for investigating quantum optical processes. Different 2D model systems have been used to study the role of disorder. Promising 3D models for this are nanoporous gold particles ("nanosponges") which have recently attracted attention as templates for surface-enhanced Raman sensing due to their multiple plasmon resonances from the visible to the NIR spectral range, a high surface-to-volume ratio, and a high density of catalytic sites [1].

Here we report the observation of long-lived, spatially highly localized plasmon states on the surface of nanosponges. Using a 16-fs excitation pulse at 1600nm wavelength, we measure light-induced electron emission from single sponges with lifetimes of several tens of fs. We observe the long-lived electron emission, as a nonlinear process with the exponent n=5-7. This in combination with optical extinction measurements and FDTD calculations, points to a strong coupling of the localized modes with the delocalized dipolar plasmon mode, resulting in an extraordinary high excitation efficiency of the hot spot resonances.

[1] Wang, D.; Schaaf, P. J. Mater. Chem. 2012, 22, 5344-5348

O 59.23 Tue 18:30 P2-OG1

Polymer Orientation Sensitive Scanning Near-field Optical Microscopy — •Jinxin Zhan[1], Jens Brauer[1], Daniel Trefz[2], Sabine Ludwigs[2], Petra Gross[1], and Christoph Lienau[1] — [1]Carl von Ossietzky Universität, Oldenburg, Germany — [2]Institut für Polymerchemie, Stuttgart, Germany

Well aligned polymer fibers attract wide interest in film transistor, solar cell, and display applications etc. due to their excellent optical-to-electric transfer efficiency and their charge transport characteristics. Their latter performance is greatly influenced by the alignment of polymer chains on a nano- to microscopic scale. Hence, in order to study the relationship between their structure and propertity, especially the local fluctuations below the domain size of typically a few ten nanometers, an optical imaging method sensitive to polymer orientation with nanometer resolution is required. Here we use a Scanning Near-field Optical Microscope (SNOM) based on a backscattering geometry to investigate fiber alignment in a polymer P(NDI2OD-T2) film. Spectral absorption measurements reveal an optimum optical contrast of the polymer film near the resonance wavelength of P(NDI2OD-T2). Changing the polarization direction of the linearly polarized excitation laser enables us to determine the molecular orientation with a resolution of about 10 nm. Extracting the polymer orientation from the SNOM optical signal is facilitated by adapting a well-established model that describes the tip as a dipole.[1]

O 59.24 Tue 18:30 P2-OG1

Relaxation dynamics of plasmonic hot-carriers in gold nanoparticles — •Emanuele Minutella[1,2], Florian Schulz[1], and Holger Lange[1,2] — [1]Physikalische Chemie, Universität Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, CUI

Using light to drive or control chemical or physical processes is a very interesting field of research. One problem is to guide the light's energy to the specific place where reaction takes place. Due to their plasmonic properties noble metal nanoparticles have the ability to collect very efficiency photons and convert them into hot-electron-hole-pairs. As a result of size and photon energy dependent transient absorption measurements we found a binary kinetic for the relaxation times of the hot electrons. Depending on the photon energy either interband or intraband excitations are possible. We found faster decay rates for the intraband relaxation than for the interband. These results can help to improve possible hot-carrier devices.

O 59.25 Tue 18:30 P2-OG1

Individual addressing and fine-tuning of mid-IR metallic and dielectric nanoantenna resonances by reversible optical switching of $Ge_3Sb_2Te_6$ thin-films — •Andreas F. Hessler, Ann-Katrin U. Michel, Julian Hanss, Martin Lewin, Tobias W.W. Mass, Peining Li, Xiaosheng Yang, Dmitry N. Chigrin, Thomas Kalix, Angela De Rose, Matthias Wuttig, and Thomas Taubner — Institute of Physics (IA) RWTH Aachen

Optically resonant thin film systems which are structured on the nanometer scale offer comprehensive control over light fields. Despite their nanometer thickness, these nano films can be used for the creation, detection and transformation of light. For optimal functionality, they need to be freely programmable and low optical losses.
By combining phase-change materials (PCMs) with a custom laser-setup, we addressed both issues. PCMs can have a high optical contrast between their amorphous and crystalline phases, while having low optical losses in the infrared. Moreover, they can be switched between phases with short high-energy laser pulses [1].
Here, we show two examples of metallic and dielectric nanostructures which can be addressed with our setup. We could directly and reversibly write arrays of dielectric resonators into a surface [2]. Additionally, we can address individual metallic nanoantennas, covered by a layer of $Ge_3Sb_2Te_6$, with ns-laser pulses to fine-tune their resonances.

[1] A.U.Michel et al., ACS Photonics 1, 833 (2014)
[2] P.Li et al., Nature Materials 15, 870 (2016)

O 59.26 Tue 18:30 P2-OG1

Surface-enhanced infrared spectroscopy with nanorod antenna arrays for investigating alkanethiols with different chain lengths — •Tobias W. W. Mass, Andreas F. Hessler, and Thomas Taubner — Institute of Physics (IA) RWTH Aachen

Metallic structures can efficiently couple light into a region of subwavelength size. In these regions, large local field enhancements can occur and enable an increased light absorption of molecules which are placed in these so called "hot spots". Arrays of nanorod antennas which are designed for surface-enhanced infrared absorption (SEIRA)

spectroscopy enable the detection of molecular vibrations with high sensitivity [1,2].
Alkanethiol molecules of different chain length differ only in their number of CH_2-groups, while they all have one single CH_3-group. It has been shown with grazing incidence reflection spectroscopy that the absorption signals from the CH_2-groups depend linearly on the chain length, while those of the CH_3-groups stay constant [3].
In our work, we investigated how well we can distinguish small quantities of alkanethiol molecules by SEIRA spectroscopy. We calculated the quotient of the absorption signals of the CH_2- and CH_3-groups, which is largely independent of the specific nanoantenna geometries and observed a linearly rising trend.
[1] C.Huck et al., ACS Nano 8, 4908 (2014)
[2] T.W.W.Maß and T.Taubner., ACS Photonics 2, 1498 (2015)
[3] M.D.Porter et al., J. Am. Chem. Soc. 109, 3559 (1987)

O 59.27 Tue 18:30 P2-OG1

Local Field Enhancement in Nano-Slit Arrays for Nonlinear THz Studies — •Thomas Rittmann[1,2], Zhiren Zheng[1], Scott Dhuey[3], Stefano Cabrini[3], Jan Heye Buss[1], and Robert A. Kaindl[1] — [1]Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, USA — [2]4th Physical Institute, Georg-August-University, Göttingen, Germany — [3]Molecular Foundry, Lawrence Berkeley National Laboratory, Berkeley, USA

Nanoscale slit arrays in thin metal films act as strong field enhancers at terahertz (THz) frequencies while simultaneously retaining extraordinary optical transmission [1,2]. When driven with ultrashort THz pulses, this enables novel nonlinear THz studies of quantum materials [3]. We report time-domain THz spectroscopy of gold nano-slit arrays on single crystal quartz substrates for several slit widths down to 70 nm and for variable periodicities up to 50 um.

Besides confirming the general dependency of the field enhancement on inverse slit width and frequency, we observe its stagnation below a periodicity-dependent saturation frequency that results from spatio-temporal charge dynamics. The results are consistent with our numerical finite elements analysis and yield essential figures of merit for optimizing future nonlinear THz studies.

[1] M.A. Seo, *et al.* Nat. Photon. **22**, 152-156 (2009).
[2] M. Shalaby, *et al.* Appl. Phys. Lett. **99**, 041110 (2011).
[3] Z. J. Thompson, *et al.* Nano Lett. **15**, 5893 (2015).

O 59.28 Tue 18:30 P2-OG1

Constructing core/shell nanostructures with optimal structure and composition could maximize the solar light utilization. — •Max Sommerfeld, Rui Xu, and Yong Lei — TU Ilmenau, Ilmenau, Deutschland

Here, using an Au nanocone array as a substrate, a well-defined regular array of SnO2/TiO2 core/shell nanocones with uniformly dispersed Au nanoparticles (SnO2/TiO2/Au NCA) is successfully realized through atomic layer deposition, physical vapor deposition and annealing processes. By tuning the structural and compositional parameters, the advantages of light trapping and short carrier diffusion from the core/shell nanocone array, as well as the surface plasmon resonance and catalytic effects from the Au nanoparticles can be maximally utilized. Accordingly, a remarkable photoelectrochemical (PEC) performance can be acquired. The photocurrent density of the SnO2/TiO2/Au NCA electrode is four times that of a flat SnO2/TiO2 electrode at 1.23 V versus reversible hydrogen electrode (RHE) under simulated sunlight illumination. These results demonstrate a feasible route toward the scalable fabrication of well-modulated core/shell nanostructures and can be easily applied to other metal/semiconductor composites for high-performance PEC.

O 59.29 Tue 18:30 P2-OG1

Biosensing with plasmonic gold nanorod arrays — •Tino Uhlig[1], Stephanie Klinghammer[2], Larysa Baraban[2], Gianaurelio Cuniberti[2], and Lukas Eng[1] — [1]Institute of Applied Physics, Chair of Experimental Physics/ Photophysics, Technische Universität Dresden, D-01062 Dresden, Germany — [2]Institute for Material Science, Chair of Material Science and Nanotechnology, Technische Universität Dresden, D-01062 Dresden, Germany

Label-free biosensing based on localized surface-plasmon resonances (LSPR) in noble-metal nanostructures has gained a lot of interest in past years. This is mostly due to the possibility of spectral tuning, miniaturization and flexible integration into nanobiotechnological architectures (e.g. microfluidics). Here we report on the fabrication of such a LSPR biosensor based on extended arrays of gold nano-antennas [1,2]. These nanorod carpets are prepared by electro-chemical filling of gold into nanometer-sized pores in an anodized aluminum oxide (AAO) template [3]. The chosen fabrication method [3] allows for a wide range of spectral tunability at visible wavelengths [2], hence facilitating optimized sensor-array performance at the highest sensitivity in the nanomolar range. We demonstrate the feasibility of our approach through monitoring the reproducible binding/unbinding of complementary single-stranded DNA molecules used here as a model system.
[1] R. Kullock et al., J. Opt. Soc. Am. B **27**, 1819 (2010).
[2] V. Fiehler et al., J. Phys. Chem. C **120**, 12178 (2016).
[3] F. Patrovsky et al., Thin Solid Films (2016) submitted.

O 59.30 Tue 18:30 P2-OG1

Photon Correlation Measurements on Quantum Dots — •Lok-Yee Yan, Manuel Peter, and Stefan Linden — Physikalisches Institut, University of Bonn, Nußallee 12, D-53115 Bonn, Germany

Semiconductor quantum dots (QDs) can be used as single photon emitters in various applications. In our group we have developed a lithographic method that allows us to deposit colloidal semiconductor QDs on freely definable sites on the substrate. So far, we have used this method for the precise placement of small patches of QDs containing several emitters. The aim of this work is its improvement to reliable single QD placement. In order to show photon-antibunching of the fluorescence of a single QD we are performing a Hanbury-Brown-Twiss experiment (HBT). In the HBT the fluorescence is divided by a 50:50 beam splitter and detected by two avalanche photodiodes. By connecting the output signals of the photodiodes to a Time-Correlated Single Photon Counting unit, one signal serves as start and the other as stop signal. By measuring the histogram of the time difference between the two signals, we obtain the second-order correlation function $g^{(2)}(\tau)$. Since the excitation is done by a pulsed laser, we expect $g^{(2)}(\tau)$ to be periodic. To show photon-antibunching, we want to measure a significant decrease at $g^{(2)}(0)$.

O 59.31 Tue 18:30 P2-OG1

A time of flight delay line detector for characterization of electron emission from metal nanostructures — •Andreas Wöste, Jan Vogelsang, Thomas Quenzel, Petra Gross, and Christoph Lienau — Institut für Physik, Carl von Ossietzky Universität, 26129 Oldenburg, Germany

Strong-field photoemission from metallic nanostructures has recently been of considerable interest since e.g. electrons can be accelerated in large near field gradients or above threshold ionization may be induced from long-lived image potential states. A microscopic understanding of those processes requires detector systems capable to collect information about the emitted electron momentum distribution. One way to investigate this is via a hemispherical deflection analyzer. The recorded kinetic energy and the emission angle then enables extracting information about the local optical nearfields at the surface. However these kind of detectors lack the capability to measure the complete momentum distribution of the photoemitted electrons. To overcome those restrictions we implement a time of flight delay line detector (TOF-DLD) enabling simultaneous measurement of emission angles as well as the perpendicular and parallel momentum of each photoelectron individually. We test this by investigating the strong field electron emission from a sharply etched gold nanotip. With the TOF-DLD we are able to study the dependency of emission angle on the kinetic energy. To verify proper working of the new detector system we compare selected measurements with the results of a known hemispherical deflection analyzer.

O 59.32 Tue 18:30 P2-OG1

Large-area, low-cost, ultra-broad bandwidth Nickel-based plasmonic perfect absorber — •Ramon Walter[1], Matthias Zilk[2], Izzatjon Allayarov[1], Forian Sterl[1], Audrey Berrier[3], Thomas Pertsch[2], Thomas Weiss[1], and Harald Giessen[1] — [1]4th Physics Institute, University of Stuttgart — [2]Institute of Applied Physics, Friedrich-Schiller University Jena — [3]1st Physics Institute, University of Stuttgart

Plasmonic devices with a very high absorption over a wide wavelength range have the potential for many applications such as light trapping, photo catalysis, and as black background for novel displays. Perfect absorber devices are the first choice to achieve such applications. Such

systems can show a very high absorption at their plasmonic resonance, just by optimizing their system impedance to vacuum values.

We present a way to realize such system, just by using the "bad" plasmonic material nickel for nanostructures, placed over an aluminum mirror and a magnesium fluoride spacer. By using a variation of the well-known nanosphere lithography, we present a way to create such devices on a large-area scale. Simply by drop coating deposited polystyrene nanospheres, we create a mask for a subsequent dry-etching process with an Argon ion beam. The resulting device shows a very high absorption over 90% nearly over the complete visible range, very high over a wide range of incident angles, nearly independently of the polarization.

We believe that our design has to potential for many applications where a large bandwidth of light absorption is preferable.