O 54: Nano-optics of metallic and semiconducting nanostructures (experiments II)

Time: Thursday 15:00–18:30 Location: SCH A216

O 54.1 Thu 15:00 SCH A216

Negative-index bi-anisotropic photonic metamaterial by direct laser writing and silver shadow evaporation — •Michael S. Rill[1], Christine E. Kriegler[1], Michael Thiel[1], Georg von Freymann[1,2], Stefan Linden[1,2], and Martin Wegener[1,2] — [1]Institut für Angewandte Physik and DFG-Center for Functional Nanostructures (CFN), Universität Karlsruhe (TH), Wolfgang-Gaede-Str. 1, 76131 Karlsruhe — [2]Institut für Nanotechnologie, Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft, 76021 Karlsruhe, Germany

Metamaterials are artificially fabricated structures composed of subwavelength metallic building blocks ("photonic atoms") that show – unlike natural substances – magnetism at optical frequencies [1].

Here, we present a novel blueprint of a negative-index metamaterial [2]. Our structure is realized using 3D direct laser writing, SiO_2 atomic layer deposition and silver shadow evaporation. The comparison of measured linear optical spectra with theory shows good agreement and reveals a negative real part of the refractive index n at around $3.85\,\mu$m wavelength – despite the fact that the metamaterial structure is bi-anisotropic [3,4] due to the lack of inversion symmetry along its surface normal.

[1] V.M. Shalaev, Nature Photon. **1**, 41 (2007).
[2] M.S. Rill *et al.*, Opt. Lett., accepted.
[3] M.S. Rill *et al.*, Nature Mater. **7**, 543 (2008).
[4] R. Marques *et al.*, Phys. Rev. B **65**, 144440 (2002).

O 54.2 Thu 15:15 SCH A216

Surface enhanced infrared spectroscopy using interacting gold nanowires — •Frank Neubrech[1], Daniel Weber[1], Hong Shen[2], Marc Lamy de la Chapelle[3], and Annemarie Pucci[1] — [1]Kirchhoff-Institut für Physik, Heidelberg, Deutschland — [2]Universite Troyes,Troyes, France — [3]Universite Paris 13, Bobigny, France

We performed surface enhanced infrared spectroscopy (SEIRS) of molecules adsorbed on gold nanowires using synchrotron light of the ANKA IR-beamline at the Forschungszentrum Karlsruhe (Germany). Arrays of gold nanowires with interparticle spacings down to 30nm were prepared by electron beam lithography. The interparticle distance was reduced further by wet-chemically increasing the size of the gold nanowires. The growth of the wires was proofed using IR spectroscopy as well as scanning electron microscopy.

After this preparation step, appropriate arrays of nanowires with an interparticle distance down to a few nanometers were selected to demonstrate the surface enhanced infrared spectroscopy of one monolayer octadecanthiol (ODT). As know from SEIRS studies using single gold nanowires, the spectral position of the antenna-like resonance in relation to the absorption bands of ODT (2850cm-1 and 2919cm-1) is crucial for both, the lineshape of the molecular vibration and the signal enhancement. In contrast to single nanowires studies, a further increase of the enhanced signals is expected due to the interaction of the electromagnetic fields of the close-by nanowires.

O 54.3 Thu 15:30 SCH A216

Bimetallic core-shell nanoparticles: In-situ controlled manipulation of plasmonic properties and material composition — •Thomas Härtling[1], Nadja C. Bigall[2], Alexander Eychmüller[2], and Lukas M. Eng[1] — [1]Institut für Angewandte Photophysik, TU Dresden, 01062 Dresden — [2]Physikalische Chemie und Elektrochemie, TU Dresden, 01062 Dresden, Germany

Due to their distinct physical and chemical properties, metal nanoparticles are crucial components of various nanotechnological applications. For most of them, the particle material composition is a key parameter defining the optical, magnetic, and catalytic particle properties. Here we report on the in-situ controlled manipulation of this material composition atr the surface of single bimetallic core-shell nanoparticles by optically induced metal deposition. Two strategies are followed to illustrate the capabilities of this photochemical approach. On the one hand, single core particles without a localized surface plasmon (LSP) resonance in the VIS are decorated with a plasmonically active shell, which renders the particles visible in the optical microscope. Vice versa, the light scattered from a LSP resonant particle is used to monitor the photochemical deposition of a nonresonant metal shell. These two approaches are demonstrated by the fabrication of Au@Pt and Cu@Au particles, respectively, leading to different, in-situ controlled optical and chemical particle properties. The presented method is applicable to an extremely wide range of material combinations and thus paves the way for the optically in-situ controlled fabrication and manipulation of multi-composite nanostructures.

O 54.4 Thu 15:45 SCH A216

Wave-Particle Duality of Single Surface Plasmon Polaritons — •Bernhard Grotz[1], Roman Kolesov[1], Gopalakrishnan Balasubramanian[1], Rainer Stöhr[1], Aurélien Nicolet[1], Philip Hemmer[2], Fedor Jelezko[1], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Germany — [2]Department of Electrical and Computer Engineering, Texas A&M University, College Station, USA

When light interacts with metal surfaces it excites electrons which can form propagating excitation waves called surface plasmon polaritons (SPP). These collective electronic excitations have many applications due to their ability to produce strong electric fields, localized to subwavelength distance scales. However many potential applications, in particular those related to quantum networks, require a deep understanding of fundamental quantum properties of SPPs. Remarkably these collective electron states preserve many key quantum mechanical properties of the original photons used to excite them, like entanglement and sub-poissonian statistics. Here we experimentally show that single surface plasmon polaritons also exhibit wave and particle properties similar to those of single photons. Furthermore, we demonstrate that a detailed analysis of spectral interference pattern provides a new method to characterize dimensions of metallic waveguides with nanometer accuracy.

O 54.5 Thu 16:00 SCH A216

Optical characterisation of ripple formation through oblique incidence ion sputtering of Ag(001) — •Frank Everts, Herbert Wormeester, and Bene Poelsema — Solid State Physics, MESA+ Institute for Nanotechnology, University of Twente, Enschede, The Netherlands

Oblique incidence ion sputtering leads to the formation of ripple patterns on the surface of many materials. The temporal evolution of these ripple patterns can be measured in-situ with Reflection Anisotropy Spectroscopy (RAS). The periodicity of the ripple pattern supports the excitation of surface plasmons on a Ag(001) surface. This enables a rather straightforward interpretation of the measured optical spectrum. Ion sputtering at a polar angle of incidence with the normal of 70 deg. and beyond, provides a RAS spectrum that is characterized by a single peak, related to the periodicity between the ripples. Sputtering at a polar angle of incidence with the normal of 61 deg. also leads to an additional feature in the RAS spectrum that is attributed to an average periodicity of the ripple length, next to the peak that is related to the periodicity perpendicular to the ripples. The analysis of the optical spectra will be discussed in relation to the results of Low Energy Electron Diffraction (LEED) images obtained after sputtering.

O 54.6 Thu 16:15 SCH A216

Photoluminescence enhancement of Sm^{3+} ions in the vicinity of noble-metal nanoparticles — •Florian Hallermann, Andreas Schmitz, and Gero von Plessen — Institute of Physics (IA), RWTH Aachen University, 52056 Aachen, Germany

The photoluminescence intensity of an optical emitter changes when placed in close proximity to a noble-metal nanoparticle, due to two contributions. First, the optical near-field of the nanoparticle leads to a change in excitation rate of the emitter. Secondly, the emission efficiency is changed due to an optical energy transfer from the emitter to the metal nanoparticle, which provides additional radiative and non-radiative decay channels. In this work we investigate the photoluminescence of Sm^{3+} ions, which are embedded in SiO_2. The photoluminescence spectrum of ions in proximity to single silver and gold nanoparticles is measured. The influence of the spectral position of the nanoparticle plasmon peak on the photoluminescence yield will be discussed and compared with model calculations.

O 54.7 Thu 16:30 SCH A216

Optical characterization of metal- dielectric- metal resonant

systems — Andreas Englisch, •Stefan Griesing, and Uwe Hartmann — Experimental Physics, Saarland University, P.O. Box 15 11 50, D-66041 Saarbrücken, Germany.

Reflectivity and Raman measurements were carried out on the sandwich systems consisting of substrate- metal mirror- dielectric 1/4 resonator- metallic thin film, introduced in [1]. The thickness of the metallic cover layer has been variied from 1nm to 40nm. Its morphology was investigated by SEM and AFM. Measurements showed that the reflectivity of the system can be dramatically reduced for a certain spectral region. For a given thickness of the dielectric layer, the system exhibits a close-to-zero reflectivity for a cover layer being just at the percolation threshold, corresponding to a mass thickness of about 3nm. By varying the thickness of the cover layer, the width and position of the spectral regime of decreased reflectivity can be tuned. In contrast, by varying the thickness of the dielectric layer at a given thickness of the cover layer, the spectral position of the reflectivity minimum can be shifted due to the l /4 condition. Raman measurements carried out on optical systems with percolating metallic cover layer revealed an intensity enhancement of up to four orders of magnitude. This result is compared with a model based on the effective refractive indices of the individual layers and local field enhancements of the metallic nanoparticles.

[1] J. Sukmanowski et al., J. Appl. Phys. 97, 104332 (2005).

O 54.8 Thu 16:45 SCH A216

Raman scattering from single gold nanostars — •Calin Hrelescu, Tapan K. Sau, Andrey Rogach, Frank Jäckel, and Jochen Feldmann — Photonics and Optoelectronics Group, Physics Department und CeNS, Ludwig-Maximilians-Universität München, Amalienstraße 54, 80799 München, Germany

We report on surface-enhanced Raman scattering (SERS) from single star-shaped gold nanoparticles coated with self-assembled monolayers of 4-mercaptobenzoic acid. SERS is observed without the formation of gold nanoparticle aggregates or resonant excitation of the analyte. Total Raman scattering enhancement factors for single nanostars are comparable to those of nanoparticle assemblies exhibiting coupled plasmon resonances. This renders gold nanostars promising for Raman imaging applications in complex environments such as cells or membranes.

O 54.9 Thu 17:00 SCH A216

Enhanced LED emission by metal nanoparticles — •Tino Göhler[1], Andreas Hille[1], Stefan Grafström[1], Lukas M. Eng[1], and Reiner Windisch[2] — [1]Technische Universität Dresden, 01069 Dresden, Germany — [2]OSRAM Opto Semiconductors GmbH, 93055 Regensburg, Germany

The external quantum efficiency of light emitting-diodes (LEDs) based on AlGaAs is limited by internal total reflection because of the of high refractive index (n=3.6). Metal nanoparticles (MNPs) can be used as dipole scatterers in order to enhance the emission of LEDs.

We investigate the enhancement produced by single gold MNPs onto red LEDs ($\lambda_{emission}$ = 645 nm FWHM=20 nm) by using a confocal imaging set-up. The enhancement depends strongly on the particle size and on the surrounding medium (air n=1.0, immersion oil n=1.5). While in air particles of all sizes investigated (80-150 nm) enhance the LED emission, we observed a strong size dependence when embedding the particle in immersion oil. Here, the surrounding medium shifts the plasmon resonance of the particles such that it overlays the LED emission spectrum for larger particles. Then absorption leads to suppression rather than enhancement of the emission.

O 54.10 Thu 17:15 SCH A216

Phase contrast imaging in near-field superlensing — •Thomas Taubner[1,2], Jon Schuller[2], Mark Brongersma[2], Chris Fietz[3], Gennady Shvets[3], and Rainer Hillenbrand[4] — [1]I. Physikalisches Institut, RWTH Aachen, Germany — [2]Department of Material Science, Stanford University, USA — [3]Department of Physics, UT Austin, USA — [4]Max-Planck-Institut für Biochemie, Martinsried, Germany

Here we study the optical imaging properties of novel near-field imaging device called a SiC superlens. A superlens is a planar device that allows for subwavelength imaging by employing coupled surface waves on a thin slab of a negative-permittivity material. As opposed to previous intensity-only measurements, we now perform amplitude and phase-measurements of the near-fields in the image plane of a superlens by mapping the field distribution with a scattering-type near-field optical microscope (s-SNOM). When investigating the spectral properties of the SiO2/SiC/SiO2 superlens, we observe a sign change in the phase of the transmitted near-fields when tuning the illumination wavelength over the superlenses resonance condition.

This change will be explained by the dispersion relation of the superlens, in combination with a fundamental interference effect. When operating a superlens off-resonance, the interference of evanescent fields causes the intensity contrast to decrease. This can be compensated for with phase-sensitive imaging to practically maintain the spectral range of high-resolution operation. Our results are important for future spectroscopic applications of superlenses and other devices such as hyperlenses or 2D plasmon lenses.

O 54.11 Thu 17:30 SCH A216

Spectroscopy of Individual “Artificial Atoms” — •Martin Husnik[1], Nils Feth[1,2], Matthias Wolfram Klein[1], Michael König[3], Jens Niegemann[3], Kurt Busch[2,3], Stefan Linden[1,2], and Martin Wegener[1,2] — [1]Institut für Angewandte Physik, Universität Karlsruhe (TH), 76131 Karlsruhe, Germany — [2]Institut für Nanotechnologie, Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft, 76021 Karlsruhe, Germany — [3]Institut für Theoretische Festkörperphysik, Universität Karlsruhe (TH), 76131 Karlsruhe, Germany

Metamaterials exhibiting a magnetic response at optical wavelengths have recently attracted much attention [1]. The magnetic response depends on both the design of the individual building blocks (“artificial atoms”) and on electromagnetic coupling effects between the “artificial atoms”. Thus for future developments, investigation of the individual “artificial atoms”is crucial.

Here, we present absolute extinction cross-section spectra of individual split-ring resonators (SRR) measured by means of a modulation technique [2,3]. The extinction cross-section at the fundamental magnetic resonance is found to be eight times the geometrical area covered by the SRR. The experimental results are in excellent agreement with microscopic calculations and can be understood by a simple electric-circuit model.

[1] V. M. Shalaev et al., Nature Photon. **1**, 41 (2007).
[2] A. Arbouet et al., Phys. Rev. Lett. **93**, 127401 (2004).
[3] M. Husnik et al., Nature Photon. **2**, 614 (2008).

O 54.12 Thu 17:45 SCH A216

Transform limited focusing of few cycle optical pulses using all-reflective optics — •Diyar Sadiq, Bjoern Piglosiewicz, Manfred Maschek, Wjatscheslaw Schmidt, Robert Pomraenke, Parinda Vasa, and Christoph Lienau — Institut für Physik, Carl von Ossietzsky Universität, 26129 Oldenburg, Germany

The availability of high-intensity few-cycle optical pulses from turn-key laser oscillators is important for various applications in the emerging field of extreme nonlinear optics. This requires focussing few-cycle pulses down to - or even beyond - the diffraction limit. Using conventional microscope objectives this is highly challenging due to their complex spatio-temporal dispersion properties. All-reflective objectives, minimizing chromatic dispersion, are expected to have much more favorable focussing characteristics. So far, however, little is known about the spatio-temporal distribution of electromagnetic fields of few-cycle pulses in the focus of such an all-reflective-objective. Here, we demonstrate focussing 6-fs, 2.25-cyle optical pulses from an 80-MHz repetition rate Ti-sapphire oscillator down to a diffraction-limited spot size of less than 1 μm while maintaining the pulse duration. Three-dimensional mapping of the spatial intensity profile near the focus is performed using a scanning near-field optical microscope. The time profile of the focussed pulse is characterizing by interferometric autocorrelation measurements using second harmonic generation or - with sub-100-nm spatial resolution - using electron generation at sharp metallic tips. Progress towards direct space- and time-resolved electric field measurements will be reported.

O 54.13 Thu 18:00 SCH A216

Near-field radiative heat transfer between a spheroid and a surface — •Oliver Huth, Felix Rüting, and Svend-Age Biehs — Institut für Physik, Carl von Ossietzky Universität Oldenburg

A near-field scanning thermal microscope has been developed at Oldenburg University. This instrument measures the heat transfer between the tip of a sensor and the surface of a sample with a different temperature at nanometer distances. Our objective is to describe this near-field heat transfer theoretically, and to compare the theory to the measured data. To this end, the foremost part of the sensor can be modelled as a small sphere. Then the heat transfer between the sphere and the sample is calculated within the framework of Rytov's fluctuational electrodynamics. Actually, however, the shape of the senor's tip deviates from a sphere, which requires more refined strategies for modelling the tip. An analytically tractable generalisation of the sphere model is obtained by considering general spheroids, which allows one to assess the influence of the tip's shape on the magnitude of the heat transfer. In this talk we present first results of such calculations, together with comparisons to results given by the sphere model.

O 54.14 Thu 18:15 SCH A216

Near-field radiative heat transfer between a sphere and a nano-structured surface — •Felix Rüting, Oliver Huth, and Svend-Age Biehs — Institut für Physik Carl von Ossietzky Universität Oldenburg

We study the near-field radiative heat transfer between a probe and a structured sample at nanometer distances. The probe is modeled as a nanosphere by means of a dipole model, while the surface of the sample is treated by a perturbative ansatz based on the Rayleigh hypothesis and the Ewald-Oseen theorem. We obtain characteristic signatures of the heat transfer between a sphere and a simple model geometry, computed numerically up to the second order in the profile. The validity of the approximations employed is ascertained. Furthermore, we show that signals measured with a near-field scanning thermal microscope (NSThM) operated in constant-distance mode are in good qualitative agreement with the theoretical results already to the first order in the surface profile, even though the theoretical model is subject to restrictions which are not obeyed in the experiment.