O 4: Plasmonics and nanooptics: Fabrication and characterization

Time: Monday 10:30–12:45 Location: MA 041

O 4.1 Mon 10:30 MA 041

Refractory plasmonics without refractory materials — •Mario Hentschel[1], Gelon Albrecht[1,2], Stefan Kaiser[1,2], and Harald Giessen[1] — [1]4. Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Heisenbergstrasse 1, 70569 Stuttgart, Germany

Refractory plasmonics deals with metallic nanostructures that can withstand high temperatures and intense laser pulses. The common belief was that refractory materials such as TiN are necessary for this purpose. Here we show that refractory plasmonics is possible without refractory materials. We demonstrate that metallic nanostructures which are overcoated with 4 and 40 nm Al_2O_3 (alumina) by an atomic layer deposition process or by thick IC1-200 resist can withstand temperatures of over 800°C and above, depending on the material, at ambient atmospheric conditions. To provide a comprehensive summary, we compare eight different plasmonic materials, namely Ag, Al, Au, Cu, Mg, Ni, Pd, and Pt. Furthermore, we demonstrate that the alumina coating also aids in nonlinear plasmonic applications where these structures can withstand intense laser radiation of over 10 GW/cm^2 at ambient conditions without damage. Thus, it is possible to combine the excellent linear and nonlinear plasmonic properties of commonly used plasmonic materials with material properties that were believed to be only possible with the lossier and less nonlinear refractory materials.

O 4.2 Mon 10:45 MA 041

Tuning the visual appearance of plasmonic metasurfaces by controlled disorder — •Florian Sterl, Thomas Weiss, Nikolai Strohfeldt, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany

The optical properties of plasmonic nanoparticle ensembles are not only determined by the particle shape and size, but also depend on the arrangement of the individual nanoantennas. The angle-dependent transmission and reflection characteristics of a rectangular nanoparticle array are strongly influenced by lattice diffraction effects, while these effects are absent in a completely randomized nanoparticle ensemble. By introducing short-range or long-range disorder into a nanoparticle lattice, one can furthermore strongly influence the optical properties.

We attempt to gain a better understanding of the effect of disorder on the bidirectional reflectance distribution function of complex plasmonic metasurfaces through both simulations and experimental characterization. To this end, we treat the nanoantennas as individual dipoles, and simulate the electric field based on dipole-dipole coupling to approximate the optical image one would obtain from nanoantenna arrays with different degrees of disorder. We compare these results to microscope images and spectroscopic measurements on arrays of gold nanoparticles, addressing both the visual image and the angle-dependent characteristics by using a designated back focal plane spectroscopy setup.

O 4.3 Mon 11:00 MA 041

Fabrication and Near-Field Characterization of Plasmonic Slot Waveguides — •Matthias Liebtrau[1], Mike Prämassing[1], Stephan Irsen[2], and Stefan Linden[1] — [1]Physikalisches Institut, Universität Bonn, D-53115 — [2]Research Center caesar, D-53175

Simulations indicate that plasmonic slot waveguides (PSWs) — based on a sub-wavelength dielectric gap engraved in a thin metal film — permit lateral light confinement siginificantly below the diffraction limit while sustaining mode propagation over several microns [1]. Therefore, PSWs are considered to facilitate highly integrated optical nanocircuits, able to defeat decisive limitations of present electronic and photonic devices [2]. By means of focused ion beam (FIB) milling we manage to fabricate PSWs with slot widths down to 30 nm in a 50 nm gold film, thermally evaporated on silica. We present amplitude- and phase-resolved near-field measurements utilizing a scattering-type scanning near-field optical microscope (s-SNOM) in transmission configuration. Combination with a tunable near-infrared laser source allows for spectroscopic analyses. Following [3] we have deduced the effective index and propagation length of the supported plasmon mode as a function of the slot width at telecom wavelengths. Furthermore, we present our recent studies on slot mode propagation through fundamental integrated circuit elements such as 90°-bends and T-splitters, as well as coupling between neighbouring PSWs.

[1] G. Veronis et al., Opt. Lett. 30, 3359–3361 (2005)
[2] J. A. Schuller et al., Nat. Mater. 9, 193–204 (2010)
[3] A. Andryieuski et al., Nano Lett. 14, 3925–3929 (2014)

O 4.4 Mon 11:15 MA 041

An experimental near-field study of subwavelength nanoaperture arrays in freestanding gold films — •Mike Prämassing[1], Stephan Irsen[2], and Stefan Linden[1] — [1]Physikalisches Institut, Universität Bonn, D-53115 — [2]Research Center caesar, D-53175

Periodic nanoaperture arrays in metallic films with a thickness of several tens of nanometers are well known to exhibit extraordinary optical transmission orders of magnitude higher than predicted by standard aperture theory [1]. In contrast, for very thin 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. Here, we present a new fabrication approach for nanoaperture hole arrays in freestanding gold films with thicknesses ranging from 20 nm to 80 nm. Optical transmission spectra of our samples reveal extraordinary transmission, as well as suppressed transmission for the thinner films. Furthermore, we utilize electron energy-loss spectroscopy (EELS) and scattering-type scanning near-field optical microscopy (s-SNOM) as two complementary near-field imaging techniques. EELS directly yields full spectroscopic data of the out-of-plane electric field amplitude $|E_z|$. Combining an interferometric transmission s-SNOM setup with a tunable near-infrared laser source allows for amplitude- and phase-resolved spectroscopic data of E_z. In summary, we are able to connect the SPP near-field patterns to the features in the far-field spectra.

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

O 4.5 Mon 11:30 MA 041

Synthesis of atomically flat single crystalline gold platelets for plasmonic applications — •Bettina Frank[1], Timothy J. Davis[1,2], Frank-J. Meyer zu Heringdorf[3], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany — [2]2School of Physics, University of Melbourne, Australia — [3]Faculty of Physics and Center of Nanointegration Duisburg-Essen, University of Duisburg-Essen, Germany

We introduce two different methods to produce single crystalline gold platelets. First, we electrochemically create atomically flat single crystalline gold platelets of several tens of micrometers thickness. We investigate their morphology and atomic structure by using AFM, LEEM, and TEM. The second method is a phase transition reaction, where gold ions are transferred to an organic phase which under heating forms single crystalline seeds. After several hours of reaction time single crystalline gold platelets with lateral dimensions of several hundred micrometers are the result. These gold platelets are ideal templates to produce nanostructures via focused ion beam milling. Furthermore, we utilize them for plasmonic applications and demonstrate localized and propagating surface plasmons with EELS and PEEM.

O 4.6 Mon 11:45 MA 041

Perfect Gold Nanoantennas — •René Kullock, Xiaofei Wu, Monika Emmerling, and Bert Hecht — NanoOptics & Biophotonics Group, Experimental Physics 5, University of Würzburg, Germany

Gold nanoantennas find a growing interest in the scientific community as they efficiently link localized electrical fields with propagating electromagnetic light waves. Hence, they can be used to optically excite small volumes of e.g. molecules or – the other way around – enhance the light emission due to inelastic electron tunneling inside the antenna gap [1]. Unfortunately, the performance of antennas often varies strongly as the precision of fabrication methods is limited. Although a lot of advances have been made over the years to increase the accuracy [2], most structures in literature look rather potato-shaped than powerpoint-perfect.

Here, we present a method for fabricating perfect gold nanoantennas on transparent glass substrates in 21 easy steps. The antennas consist of two arms, show crystalline facets and their gaps can be tuned to desired dimensions. The fabrication utilizes top-down as well as button-up methods and will be discussed in detail. We believe that these antennas open up the field to plasmonic experiments with atomic precision.

[1] J. Kern et al., Nat Photon 9, 9 (2015)
[2] J.-S. Huang et al., Nat Comm 1, 150 (2010)

O 4.7 Mon 12:00 MA 041

Optimizing Plasmonic Nanorod Antenna-Arrays — •Tino Uhlig[1], Fabian Patrovsky[1], Vera Fiehler[1], Matthias Böhm[1], Susan Derenko[1], Stephan Barth[2], Hagen Bartzsch[2], Peter Frach[2], and Lukas M. Eng[1] — [1]Institute of Applied Physics, TU Dresden, Germany — [2]Fraunhofer FEP, Dresden, Germany

Gold nanorod antenna arrays provide a strong plasmonic field enhancement and a broad spectral tunability, as needed, for example, for label-free biosensing, surface-enhanced Raman spectroscopy, or optical filter design. However, key issues in utilizing these features, are a reliable fabrication of mostly defect-free nanostructure arrays, as well as a thorough understanding and controlled tuning of the associated optical phenomena. In our work here, we extensively study the plasmonic system based on nanorod arrays, as manufactured by electrochemical pore filling of anodized aluminum oxide (AAO) templates. We present a process that greatly improves anodization of sputtered aluminum thin films, hence dramatically reducing the defect density of such nanorod arrays [1]. The improved homogeneity of our samples is the prerequisite for the clear identification and the detailed analysis of the plasmonic features [2]. Lastly, we introduce an elegant method how to transfer these optimized nanorod arrays from the rigid glass substrate onto an elastically bendable, optically transparent polymer film for mechanically tuning the plasmon resonances over a broad range [3].

[1] F. Patrovsky et al., Mater. Res. Express 4, 055010 (2017).
[2] V. Fiehler et al., J. Phys. Chem. C 120, 12178 (2016).
[3] M. Böhm et al., Opt. Mater. Express 7, 1882 (2017).

O 4.8 Mon 12:15 MA 041

Nano-forging of Gold Rods with Light — •Francis Schuknecht, Christoph Maier, Anastasia Babynina, and Theobald Lohmüller — Ludwig Maximilians Universität München, Deutschland

V-shaped plasmonic nanoantennas display useful properties as building blocks for meta- surfaces and flat optical devices. Yet, the fabrication of such particles is not a simple task. E-beam lithography is widely used, but shows limitations when it comes to the fabrication of very small nanostructures with high crystallinity. The bending and printing of straight nanorods into desired patterns with light has shown to be a valid alternative approach [1].

Here, we discuss the physical processes governing the bending and orientation of gold nanorods with widths between 8 and 50nm and a length of up to 300nm for varying laser intensities. Additionally to the usage of the particle longitudinal surface plasmon resonance, the transverse plasmonic mode is employed for particle manipulation to examine localised heating effects as a function of the nanorod geometry. The understanding, and parameterisation of the nano-forging process represents a first step to the in-situ creation of efficient ultrathin optical devices.

[1] A. Babynina et al.: Bending Gold Nanorods with Light; Nano Lett, 2016 16(10), pp 6485-6490

O 4.9 Mon 12:30 MA 041

Characterization of 2D nearly-hyperuniform colloidal light management structures — •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

Interfaces defined by the self-organization of colloidal particles to a monolayer on a substrate are promising candidates for cheap and effective light management structures. By controlling the colloidal size distribution and manipulating the interaction potentials between particles and substrate during the deposition process, we strive to produce structures with tailored light scattering properties to fit the specific requirements of a wide range of potential applications, such as thin-film solar cells and LEDs.

We present a method for fabricating large-area nearly-hyperuniform 2D colloidal structures by a self-stabilized immersion process. Furthermore, we develop a simulative description of the microscopic deposition process by a random sequential adsorption (RSA) model that allows for accurate prediction of structural characteristics of the fabricated samples. On the basis of the structure factor we are able to calculate the optical response by simple means and find good agreement with experimental measurements.