O 76: Plasmonics & Nanooptics V: Nanostructures and Nanoantennae

Time: Thursday 10:30–13:00 Location: H8

O 76.1 Thu 10:30 H8

Near-field characterization of V-shaped plasmonic antennas — •Lukas Naumann, Mike Prämassing, and Stefan Linden — Physikalisches Institut der Universität Bonn, D-53115 Bonn

Optical metasurfaces offer fascinating possibilities for controlling light e.g. beam-shaping, steering or polarizing conversion [1,2]. The functionality of a metasurface is governed by the geometry of its subwavelength building blocks, so called metaatoms. One possible type of a metaatom is a V-shaped plasmonic antenna, providing two plasmonic resonances which are tunable by the geometric parameters and can introduce arbitrary phase shifts to the scattered light [2].

Here we investigate the near-field distribution of single V-shaped antennas by the means of scattering-type scanning near-field optical microscopy (s-SNOM) in transmission mode configuration with an interferometric detection scheme, enabling amplitude- and phase-resolved measurements. Depending on wavelength and polarisation of the incoming laser beam as well as on the size of the antennas either the fundamental (asymmetric) mode, the first higher (symmetric) mode or a mixture of both can be excited. The relative phase offsets between different antennas can be deduced from our measurements and can be explained by simple theoretical considerations.

[1] Flat optics with designer metasurface; Nanfang Yu, Federico Capasso; Nature Naterials 13, 139-150 (2014)

[2] Light Propagation with Phase Discontinuities: Generalized Laws of Reflection and Refraction; Federico Capasso et al.; Science 334 (6054), 333-337 (2011)

O 76.2 Thu 10:45 H8

Fabrication of Plasmonic Nanostructures by He$^+$ and Ga$^+$ Milling — •Michael Westphal[1], Sven Stephan[2], Vladimir Smirnov[2], Daniel Emmrich[1], Henning Vieker[1], Andre Beyer[1], Martin Silies[2], and Armin Gölzhäuser[1] — [1]Bielefeld University, Germany — [2]Oldenburg University, Germany

Plasmonic nanostructures are essential for controlling and directing light on the nanoscale. While fabrication techniques like standard electron beam lithography (EBL) methods or focused ion beam (FIB) milling with Ga$^+$ ions are approaching their limit in the 10-nm-regime, ion beam milling with He$^+$ ions is capable of milling features below 6 nm [1]. We will show a combined approach using a Ga$^+$ FIB for milling large features and employing the fine resolution of the helium ion microscope (HIM) for milling small features. We will discuss different patterning strategies to optimize the writing speed and minimize substrate swelling. In addition, the problem of quantifying the sizes of milled gaps will be addressed and an automated, reproducible approach for measuring the size of written features will be demonstrated.

[1] H. Kollmann et al., Nano Letters. 14, 4778-4784 (2014).

O 76.3 Thu 11:00 H8

A freestanding 40 nm thick metasurface lens — •Till Leuteritz, Mike Prämassing, and Stefan Linden — Physikalisches Institut, Universität Bonn, D-53115

Miniaturization of electronics has lead to a rapid rise of new technologies like cellphones and tablets. The limiting factor of a cellphones thickness today is the lens. A solution to reduce the thickness of lenses was presented by A. Francesco et al in 2012 [1]. They demonstrated a metasurface consisting of V-shaped antennas which introduces the phase profile required for lensing. Even though most metasurfaces are a few ten nanometers thick they are typically fabricated on a 100 um thick inflexible glass substrate. In our work we present a solution to overcome this problem.

Considering Babinets principle, we use an inverted design of V-shaped plasmonic slot antennas in a freestanding 40nm gold film. They are produced by milling the V-shaped structures into carbon film with a focused ion beam. Thermal evaporation of the gold film followed by a plasma etching step to remove the carbon yields the desired structure.

We find an agreement between modes of an individual V-shaped antenna determined by energy electron loss spectroscopy and simulations done with a finite elemente solver. In addition we experimentally show the focusing of our metasurface lens and the simulations to optimize it.

[1] Aieta, Francesco, et al., Nano letters 12.9 (2012): 4932-4936.

O 76.4 Thu 11:15 H8

Plasmonic resonators in 1D and 2D: quality factor of resonances and near-fields — •Manuel Gonçalves[1], Gregor Neusser[2], Christine Kranz[2], and Othmar Marti[1] — [1]Ulm University - Institute of Experimental Physics, Ulm, Germany — [2]Ulm University - Institute of Analytical and Bioanalytical Chemistry, Ulm, Germany

Plasmonic particles present broad optical reasonances and reach therefore only small Q-factors. In many applications where narrow resonances are required 1-dimensional multilayered metal-dielectric films and periodically arranged 2-dimensional nanostructures can form resonators performing much better than single particles. The design of theses resonators can be optimized for reflectance and/or transmittance sensing applications, or for large near-field enhancement. We show how 1D multilayered metal-dielectric thin films with quality factors over 100 can be fabricated. We also have fabricated 2D nanostructures based on deep grooves milled in crystalline metal films, which achieve large Q-factors, strongly confine light at the grooves and simultaneously present remarkable dependence of the reflectance on the polarization of the incident light. We present experimental results as well as simulations.

O 76.5 Thu 11:30 H8

Ingenious 3D gap-plasmonic Ag@Ag strawberry galactic nanostructure for SERS detection — •Qun Fu[1,2], Huaping Zhao[1], and Yong Lei[1] — [1]Institut für Physik & IMN MacroNano (ZIK), Technische Universität Ilmenau, 98693, Ilmenau, Germany — [2]Institute of Nanochemistry and Nanobiology, School of Environmental and Chemical Engineering, Shanghai University, Shanghai, 200444, China

The realization of the strongly confined and enhanced electromagnetic (EM) field with gap-plasmon resonance at ultrasmall (sub-10-nm) gaps is crucial for ultrasensitive SERS (surface-enhanced Raman scattering) detection. However, most traditional methods for creating gap-plasmon are based on the lithography techniques, and it remains a challenge to cost-effectively produce high-density sub-nanometer gaps over large-scale. An ingenious 3D gap-plasmonic Ag@Ag strawberry galactic nanostructure is therefore developed by employing an UTAM (ultrathin alumina mask) nano-patterning process. The UTAM-based nanopatterning strategy enables to fabricating Ag@Ag strawberry galactic nanostructures with multiple ultra-small SERS hotspots in super-high density and over large scale. A strongly enhanced Raman signal (detection limit of R6G molecule as low as 10-16 M) with good reproducibility is obtained based on Ag@Ag strawberry galactic nanostructures, attributing to the coupling effect at multiple hot spots around the six kinds of nanogaps and the intense EM fields at numerous ordered roughness and tips in two-level particle arrays of this structure.

O 76.6 Thu 11:45 H8

Near-field characterization of plasmonic slot waveguides in single-crystalline gold films — •Mike Prämassing[1], Hans-Joachim Schill[1], Matthias Liebtrau[1], Stephan Irsen[2], and Stefan Linden[1] — [1]Physikalisches Institut Universität Bonn, D-53115 — [2]Center of advanced european studies and research (caesar), Bonn, D-53175

Plasmonic slot waveguides (PSW's) consist of a sub-wavelength gap engraved in a thin metal film. PSW's support guided plasmonic modes with a lateral confinement siginificantly below the diffraction limit, while sustaining propagation over several microns. Therfore PSW's are attractive canditates e.g. as building blocks for integrated optoelectronic circuits [1], or for enhanced coupling to quantum emitters [2]. Here, we investigate the dependency of the the effective mode index n_{eff} and the propagation length L_{p} on the slot width. For the first time, we use focused ion beam milling on chemically grown 50 nm thick single-crystalline gold flakes to fabricate down to 50 nm wide PSW's. We utilize scattering-type scanning near-field optical microscopy (s-SNOM) in transmission mode configuration with an interferometric detection scheme for amplitude- and phase-resolved measurements. A 2D model-function is fitted to the measured near-field distributions in order to extract n_{eff} and L_{p}. Our experimental results are in accordance with finite element simulations. The presented results may offer

design rules to optimize PSW's for potential future applications.
[1]Gramotnev, and Bozhevolnyi. Nature photonics 4, 83 (2010).
[2]Jun et al. Phys. Rev. B 78, 153111 (2008).

O 76.7 Thu 12:00 H8

Visible light operation of a single-crystalline silver plasmonic nanocircuit — •Christian Schörner, Subhasis Adhikari, and Markus Lippitz — University of Bayreuth, Germany

The miniaturization of optical devices is of great importance for future ultrafast integrated nano-optical circuitry. High quality plasmonic nanostructures, such as nano-antennas, nano-resonators and waveguides, need to be fabricated by focused-ion beam milling of single-crystalline metal flakes or films. However, for waveguide applications, gold limits the operation wavelength to the infrared spectral range. Here, we demonstrate multimode operation of a silver plasmonic two-wire transmission line in the visible range. We further remotely excite 20nm fluorescent beads along the waveguide and shift excitation centers by applying different superpositions of the available waveguide modes.

O 76.8 Thu 12:15 H8

Strong Spatial and Spectral Localization of Surface Plasmons in Individual Randomly Disordered Gold Nanosponges — •Anke Korte[1], Jinhui Zhong[1], Abbas Chimeh[1], Felix Schwarz[2], Juemin Yi[1], Dong Wang[3], Jinxin Zhan[1], Peter Schaaf[3], Erich Runge[2], and Christoph Lienau[1] — [1]Institut für Physik & Center of Interface Science, Carl von Ossietzky Universität, 26129 Oldenburg, Germany — [2]Institut für Physik & Institut für Mikro- und Nanotechnologien MacroNano, TU Ilmenau, 98693 Ilmenau, Germany — [3]Institut für Werkstofftechnik & Institut für Mikro- und Nanotechnologien MacroNano, TU Ilmenau, 98693 Ilmenau, Germany

Porous nanosponges, percolated with a three-dimensional network of 10 nm sized ligaments, recently emerged as promising substrates for plasmon-enhanced spectroscopy and (photo)catalysis. Experimental and theoretical work suggests surface plasmon localization in some hot-spot modes as the physical origin of their unusual optical properties, but so far the existence of such hot-spots has not been proven. Here we use scattering-type scanning near-field nanospectroscopy on individual gold nanosponges to reveal spatially and spectrally confined modes at 10 nm scale by recording local near-field scattering spectra. High quality factors of individual hot-spots of more than 40 are demonstrated, predicting high Purcell factors up to 10^6. The observed field localization and enhancement make such nanosponges an appealing platform for a variety of applications ranging from nonlinear optics to strong-coupling physics.

O 76.9 Thu 12:30 H8

Electric, magnetic and electromagnetic hot spots — •Vlastimil Křápek, Michal Horák, Martin Hrtoň, Filip Ligmajer, and Tomáš Šikola — Central European Institute of Technology, Brno University of Technology, Purkyňova 123, 612 00 Brno, Czech Republic

We study plasmonic antennas featuring areas of extremely concentrated electric or magnetic field, known as hot spots. To this end we use optical spectroscopy and electron beam spectroscopy together with numerical modeling. We combine two types of electric-magnetic complementarity to increase the degree of freedom for the design of the antennas: bow-tie and diabolo duality and Babinet's principle. We evaluate the figures of merit for different plasmon-enhanced optical spectroscopy methods: field enhancement, decay rate enhancement, and quality factor of the plasmon resonances. The role of Babinet's principle in interchanging electric and magnetic field hot spots and its consequences for practical antenna design are discusses. Finally, we propose Babinet-type dimer antenna featuring electromagnetic hot spot with both the electric and magnetic field components treated on equal footing.

We particularly focus on antennas featuring magnetic hot spots in the THz spectral range, and discuss their application in plasmon-enhanced electron spin resonance.

O 76.10 Thu 12:45 H8

First-order perturbation theory for material changes in the surrounding of open optical resonators — •Steffen Both and Thomas Weiss — 4th Physics Institute and Research Center SCoPE, University of Stuttgart

Nanophotonic structures such as photonic crystals or plasmonic nanoparticles allow the realization of optical resonances with strong electromagnetic near-fields. In such structures, even tiny material changes in the environment can have significant influence on the resonances frequencies. This effect is the key to various kinds of optical sensing applications [1]. So far, the modeling of these interactions often relies on extensive numerical simulations, which can be rather inefficient, since in many practical cases, the variations in the material properties are extremely small. Here, we present a simple perturbation theory, that is particularly suited for these cases, and that allows to very efficiently calculate the resonance shifts and linewidth changes induced by small material modifications in the surrounding of almost any kind of open optical resonator. Our main result is a simple integral expression over the fields of the unperturbed system, which extends previous works from the field of resonant state expansion [1-4].
[1] T. Weiss, et al., Phys. Rev. B **96**, 045129 (2017).
[2] M. B. Doost, et al., Phys. Rev. A **90**, 013834 (2014).
[3] J. Yang, et al., Nano Lett. **15**, 3439 (2015).
[4] T. Weiss et al., Phys. Rev. B **98**, 085433 (2018).