O 65: Plasmonics and Nanooptics IV: Waveguides and Antennas

Time: Wednesday 10:30–13:30 Location: WIL A317

O 65.1 Wed 10:30 WIL A317

Plasmonic nanfocusing spectroscopy: from local excitation to local detection of optical near fields — •Abbas Chimeh[1], Sven Stephan[1], Martin Esmann[2], Anke Korte[1], Jinhui Zhong[1], Martin Silies[1], Nahid Talebi[3], and Christoph Lienau[1] — [1]Universität Oldenburg, Oldenburg, Germany — [2]Centre de Nanosciences et de Nanotechnologies, Paris, — [3]Universität Kiel, Kiel, Germany

The nanofocusing of light in tapered plasmonic waveguides efficiently confines electromagnetic radiation into volumes far below the wavelength, breaking the diffraction resolution limit of optical microscopy [1]. Selective delivery of the optical excitation to a specific point near the sample surface has made plasmonic nanofocusing an effective tool for spatially resolved spectroscopy on the nanoscale [2]. Here, we show that a tapered plasmonic guide is also capable of not only nanofocusing of light into nanometric volumes but also detecting light from them. We show by full-wave analysis of electromagnetic fields how surface plasmon polaritons (SPPs) nanofocused onto the apex of a gold nanotaper excite the near fields of a nanorod. These near fields are coupled back to the taper apex and launch back propagating SPPs. We detect the local light scattering spectra of nanorods from these back propagating SPPs and quantify line broadenings and spectral shifts induced by tip-sample coupling. Our finite-difference time-domain simulations are in a good agreement with experimental results. [1] D. K. Gramotnev et al., Nature Photon. 8, 14 (2012). [2] M. Esmann et al., Nature Nanotechnol. 6, 6040 (2019)

O 65.2 Wed 10:45 WIL A317

Surface Polariton-Like s-Polarized Waveguide Modes in Switchable Dielectric Thin-Films on Polar Crystals — •Nikolai Christian Passler[1], Andreas Hessler[2], Matthias Wuttig[2], Thomas Taubner[2], and Alexander Paarmann[1] — [1]Fritz-Haber-Institute of the MPG — [2]RWTH Aachen University

Surface phonon polaritons (SPhP) and surface plasmon polaritons are fundamental building blocks of nanophotonics. These modes are unmatched in field enhancement and spatial confinement, and all-optical control is feasible with phase-change materials such as $Ge_3Sb_2Te_6$ (GST). However, the excitation of surface polaritons is limited to p-polarization. On the contrary, waveguide modes in high-permittivity films can couple to both p- and s-polarized light, and in thin films, their confinement can become comparable to surface polaritons.

For a thin GST film on SiC, we here [1] demonstrate that the s-polarized waveguide mode features a similar dispersion, confinement, and electric field enhancement as the index-shifted SPhP of SiC. Experimentally, employing the Otto geometry for prism coupling [2], we show that switching the GST film between its amorphous and crystalline phase grants non-volatile control over the SPhP and the s-polarized waveguide mode dispersions. Thus, polariton-like waveguide modes in dielectric thin films on polar crystal substrates provide a promising additional building block for actively tunable, low-loss, and omni-polarized nanophotonic applications.

[1] N. C. Passler et al., Adv. Opt. Mater., 1901056 (2019)
[2] N. C. Passler et al., ACS Photonics 4, 1048 (2017)

O 65.3 Wed 11:00 WIL A317

Single Molecule Nonlinearity in Plasmonic Waveguides — •Christian Schörner and Markus Lippitz — University of Bayreuth, Germany

Past room temperature experiments of single quantum emitters coupled to plasmonic waveguides have mainly focused on the highly efficient channeling of the spontaneous emission into waveguide modes. However, quantum emitters can interact with multiple optical fields leading to functional all-optical control capabilities in waveguide circuits. Here, we realize a nonlinear optical experiment, where a pump and a red-shifted depletion pulse interact fully remotely with a single molecule via propagating gap-plasmons. A saturation of the molecules' stimulated emission via confined gap-plasmons is found, that can be up to 50 times more efficient compared to a diffraction limited far-field focus.

O 65.4 Wed 11:15 WIL A317

Mode-selective electrical excitation of optical waveguides — •Maximilian Ochs, Luka Zurak, Enno Krauss, Jessica Meier, René Kullock, Monika Emmerling, and Bert Hecht — NanoOptics & Biophotonics Group, Experimental Physics 5, University of Würzburg, Germany

Downscaling light-based communication to the nanoscale, i.e. optical nanocircuitry, promises higher data transfer rates than currently available technologies. Waveguides, routing optical modes in a controlled way, are fundamental components in such circuits and have already been demonstrated utilizing optical excitation schemes [1]. However, the electrical driving - necessary to integrate these devices into common circuits and reduce their footprint - still remains a challenge.

Here, we demonstrate the mode-selective electrical excitation of optical waveguides using inelastic electron tunneling. The tunnel gap is fabricated with high accuracy and reproducibility by combining helium ion milled single-crystalline gold flakes and feedback-controlled dielectrophoresis [2]. Based on the position of excitation, specific modes can be launched and their interference enables control over the polarization of the out-coupled light. In this context, we propose an integrated system allowing to switch between the excitation of two different modes. This work paves the road for more complex optical nanocircuits, such as logic gates at optical frequencies.

[1] E. Krauss et al.,*Nano Lett. 19, 3364 (2019)*
[2] R. Kullock et al.,*Nat. Commun. accepted (2019)*

O 65.5 Wed 11:30 WIL A317

Limits of optical Yagi-Uda antennas — •René Kullock, Maximilian Ochs, Philipp Grimm, Monika Emmerling, and Bert Hecht — NanoOptics & Biophotonics Group, Experimental Physics 5, University of Würzburg, Germany

Yagi-Uda antennas are a promising building block for light-based on-chip data communication which allows much higher bandwidths than conventional electrical circuitry. On the macroscopic scale they provide a highly directed emission of radio waves and scaled down to the nanometer regime they do the same for light. Already a while ago optically driven Yagi-Uda antenna have been realized [1] and recently we were able to demonstrate the crucial electrical driving using inelastic electron tunneling [2].

Here we show how such antennas are fabricated using advanced focused-ion beam milling and feedback-driven dielectrophoresis. We compare the resulting directional antennas with FB ratios of up to 9 dB to conventional RF Yagi-Uda antennas, discuss their scalability and design limits. Despite increased losses of metals at optical frequencies we show that by utilizing dielectric guiding layers, which are only available in the optical domain, the antennas can actually outperform their RF counterparts.

[1] A. Curto et al., Science 329, 5994 (2010)
[2] R. Kullock et al., Nat. Comm. *accepted* (2019)

O 65.6 Wed 11:45 WIL A317

Strongly coupled, high-quality plasmonic dimer antennas fabricated using a sketch-and-peel technique — •Moritz Gittinger[1], Katja Höflich[2], Vladimir Smirnov[1], Heiko Kollmann[1], Christoph Lienau[1], and Martin Silies[1] — [1]AG Ultrafast Nano-Optics, Carl von Ossietzky University Oldenburg, Germany — [2]Helmholtz Zentrum für Materialien und Energie, Berlin, Germany

A combination of helium- and gallium-ion beam milling together with a fast and reliable sketch-and-peel technique is used to fabricate gold nanorod dimer antennas with an excellent quality factor and with gap distances of less than 6 nm. The high fabrication quality of the sketch-and-peel technique compared to a conventional ion beam milling technique is proven by polarization resolved linear dark-field spectromicroscopy of isolated dimer antennas. We demonstrate a strong coupling of the two antenna arms for both fabrication techniques, with a quality factor of more than 14, close to the theoretical limit, for the sketch-and-peel produced antennas compared to only 6 for the conventional fabrication process. The obtained results on the strong coupling of the plasmonic dimer antennas are supported by finite-difference time-domain simulations of the light-dimer antenna interaction. The presented fabrication technique enables the rapid fabrication of large-scale plasmonic or dielectric nanostructures arrays and metasurfaces with single-digit nanometer scale milling accuracy. [https://doi.org/10.1515/nanoph-

2019-0379]

O 65.7 Wed 12:00 WIL A317

Comparative study of plasmonic antennas fabricated by electron and ion beam lithography — •Vlastimil Křápek, Michal Horák, Lukáš Kejík, Kristýna Bukvišová, Vojtěch Švarc, and Tomáš Šikola — CEITEC, Brno University of Technology, Purkyňova 123, 61200 Brno, Czech Republic

We present a comparative study of plasmonic antennas (gold nanodiscs) fabricated by electron beam lithography and focused ion beam milling. Plasmonic antennas were characterized using transmission electron microscopy including electron energy loss spectroscopy and energy dispersive X-ray spectroscopy, and atomic force microscopy. We have found stronger plasmonic response with better field confinement in the antennas fabricated by electron beam lithography, which is attributed to their better structural quality, homogeneous thickness, and only moderate contamination mostly of organic nature [1].

Further, we compare monocrystalline and polycrystalline plasmonic antennas (gold nanorods) fabricated by focused ion beam lithography. Interestingly, monocrystalline nanorods feature inclined facets due to anisotropic rate of focused ion beam milling, while the facets of the polycrystalline nanorods are upright. Electron energy loss spectroscopy revealed that the parameters of the localized surface plasmon modes (energies, Q factors, and peak loss probabilities) in both structures are within the experimental error identical. We conclude that the polycrystallinity does not deteriorate the optical properties of plasmonic antennas.

[1]. M Horák et al., Sci. Rep. **8**, 9640 (2018).

O 65.8 Wed 12:15 WIL A317

Generating ultra-narrow gaps in bow-ties utilizing break junctions — •Florian Laible[1], Kai Braun[2], Martin Eberle[2], Dieter P. Kern[1], Alfred J. Meixner[2], and Monika Fleischer[1] — [1]Institute for Applied Physics and Center LISA+, University of Tübingen, 72076, Tübingen, Germany — [2]Institute for Physical and Theoretical Chemistry and Center LISA+, University of Tübingen, 72076, Tübingen, Germany

Investigations on the interplay of localized plasmonics and electron tunneling require electrically contacted dimer nanoantennas with ultra-narrow, i.e. sub-1 nm, gaps. The realization of this configuration is a challenging task. It has been achieved in [1], but this experiment is hardly suitable for more general investigations.

We present an alternative approach to reach ultra-narrow gaps in the focus of a confocal microscope. Gapless bow-tie antennas are integrated into mechanically controllable break junctions. The nanostructures are optically decoupled from the electrical leads. The gap is created by bending the substrate. Its size is measured (in situ) using the tunnel effect and controlled by increasing or decreasing the bending of the substrate.

Due to the decoupling of the nanostructures from the leads, localized plasmon polaritons are excited in the bow-tie when illuminated by the laser of a confocal microscope. Combined electrical and optical measurements will be presented alongside with the fabrication process.

[1] K. J. Savage, et al. Nature, 491(7425),574, 2012.

O 65.9 Wed 12:30 WIL A317

Electro-Chemistry of two closely spaced electrically-connected plasmonic antennas in air — •Luka Zurak, Bert Hecht, and Thorsten Feichtner — Nano-Optics & Biophotonics Group, Wilhelm-Conrad-Röntgen-Center for Complex Material Systems (RCCM), Experimental physics 5 - Universität Würzburg, Germany

It has been shown that small resonant plasmonic nano particles can be tuned by applying a voltage, when placed in an electro-chemical environment. Resonance shifts can be due to double-layer formation, surface chemistry or charging which are notoriously difficult to distinguish.

We have developed a system of two parallel electrically connected gold nanorods with unequal lengths and resonances. They are placed at a distance of 150 nm. We show by means of time dependent white light spectroscopy that the humidity of ambient air is sufficient to support electrochemistry at the rod surfaces when voltages of up to ± 20 V are applied. Electrochemical processes reveal themselves by small shifts of the nanorod resonances with a slow time constant on the order of 10 seconds. When the same experiments are performed under a N_2 atmosphere, the resonance shifts nearly completely vanish.

O 65.10 Wed 12:45 WIL A317

Coupling of phosphorescent single molecules to plasmonic nanostructures — •Marcel Krumrein[1], Maximilian Rödel[1], Ulrich Müller[1], and Jens Pflaum[1,2] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Bavarian Center for Applied Energy Research (ZAE Bayern), 97074 Würzburg

Phosphorescent materials are widely used in OLED applications to improve the external quantum efficiency of these devices. After excitation, the intersystem crossing in such molecules converts the S_1 singlet state into a long-living T_1 triplet state where a radiative, phosphorescent decay into the S_0 ground state takes place on, typically, μs time scale. In this work we couple single molecules of the phosphorescent emitter $Ir(piq)_3$ to plasmonic nanostructures to influence their dynamics and, thus, their effective emissive rates. For this purpose, long-range ordered metallic nanoarrays were fabricated by means of shadow nanosphere lithography and the $Ir(piq)_3$-doped PMMA host-guest system was deposited via spin-coating on-top. Effects by coupling to the underlying plasmonic array were investigated by lifetime analysis and photon-correlation functions measured with a confocal microscope setup. By comparison with $Ir(piq)_3$:PMMA reference samples on glass we observe an enhancement of the emission intensity by more than an order of magnitude which indicates a change of the intramolecular transition rates in proximity to the metallic nanostructures. We will discuss these results in context to the implementation of metal-organic hybrid structures in electrically driven photonic devices.

O 65.11 Wed 13:00 WIL A317

Fourier-space microspectroscopy of disordered plasmonic metasurfaces — •Florian Sterl, Ediz Herkert, Steffen Both, Thomas Weiss, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

The optical properties of plasmonic nanoparticle ensembles are not only determined by the particle shape and their size, but also by the nanoantenna arrangement. We present computational and experimental approaches to gain a better understanding of the impact of disorder on the far-field behavior of complex plasmonic metasurfaces. We treat the nanoantennas as dipoles, and simulate the electric field based on dipole-dipole interaction. We can then extract the wavelength-resolved far-field response and convert it into real-space and Fourier space RGB images. A designated Fourier microspectroscopy setup allows us to record the real- and Fourier-space images of plasmonic metasurfaces.

We consider different types of spatial disorder. In the case of 'frozen-phonon disorder', each element is displaced from its initial lattice position by a random amount within a variable range. In the case of correlated disorder, the displacement of any element affects the surrounding elements with a certain correlation length and function. Our results show that the two classes of disorder can be clearly distinguished in real and Fourier space. These insights provide the possibility to design the visual appearance of a metasurface by tailored disorder.

O 65.12 Wed 13:15 WIL A317

Investigating Surface Plasmons and Photonic Bandgap of Ordered Nanoarray Constructed by Hierarchical Alumina Membranes — •Yi Wang, Yudie Huang, Jiaxu Chen, Fanzhou Lv, and Wenxin Wang — Photonic Materials Group, College of Physics and Optoelectronic Engineering, Harbin Engineering University, Harbin, China

The purpose to manipulate photonics and the trend of device miniaturization prompt people to design sophisticated ordered nanostructures with well practicability over large scale. Attributing to the inherent structure feature of ordered pore array, alumina membranes (AMs) are widely used in preparation of ordered nanoarrays for various device applications. For the reason that, artificial modulated AMs can offer porous membranes with uniform geometric parameters, in order to achieve controllable distribution of nanomaterials. Here, we demonstrate the idea to fabricate hierarchical alumina membrances (HAMs) with controllable subwavelength patterns as promising platform to construct plasmonic structures. By precisely controlling the anodization potential, sophisticated structures of AMs are regulated into distinctive patterns. After replicating HAMs with functional polymer and noble metal, hierarchical nanostructures (HNs) with unique surface plasmon resonance (SPR) properties are obtained, which is developed as dynamic plasmonic sensing device. In addition, the photonic bandgap brought by HNs are investigated in detail. This approach for elaborate HNs fabrication broadens the scope for the design and application of functional nanostructures in the field of nanophotonic devices.