O 7: Plasmonics and Nanooptics I

Time: Monday 10:30–13:00 Location: H31

O 7.1 Mon 10:30 H31

Nanoantennas as Common Substrate for Simultaneous Surface-Enhanced Raman and Infrared Spectroscopy — •Jörg Bochterle[1], Cristiano D'Andrea[2], Frank Neubrech[1,3], Barbara Fazio[2], Pietro Gucciardi[2], and Annemarie Pucci[1] — [1]Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]CNR IPCF Istituto per i Processi Chimico-Fisici, Viale F. Stagno D'Alcontres 37, I-98156, Messina, Italy — [3]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

It is well known, that localized surface plasmon resonance (LSPR) frequency of nanoscopic metal particles, i.e. nanoantennas, is tunable by changing their geometric dimensions, such as length or widths for example. In our experiments, we utilize elongated nanoantennas with lengths of about 1 μm and widths and heights of 60 nm for the demonstration of simultaneous surface enhanced Raman scattering (SERS) and surface enhanced infrared spectroscopy (SEIRS). When exciting the nanoantennas with light that is polarized along the long axis, the nanoantennas feature LSPRs in the infrared (IR) spectral range, whereas light polarized along the short axis excites a LSPR in the visible. With molecules adsorbed on the nanoantennas, these two distinct resonances are tuned to match the optimum frequency simultaneously for SERS and for SEIRS. We present a prove of principle using methylene blue as probe molecule and achieve enhancements of the particular signals in the order of 10^3 for SERS and 10^5 for SEIRS.

O 7.2 Mon 10:45 H31

Quantitative mapping of plasmonic near-field intensity using infrared far-field vibrational spectroscopy — •Daniel Dregely[1], Frank Neubrech[1], Huigao Duan[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany — [2]Key Laboratory for Micro-Nano Optoelectronic Devices of Ministry of Education, Hunan University, P.R. China

Nanoantennas confine electromagnetic fields at visible and infrared wavelengths to volumes of only a few cubic nanometers. Assessing their near-field distribution offers fundamental insight into light-matter coupling and is of special interest for applications such as radiation engineering, attomolar sensing, antenna enhanced vibrational spectroscopy [1], and nonlinear optics. Most experimental approaches to measure near-fields employ either diffraction-limited far-field methods or intricate near-field scanning techniques. Here, by diffraction-unlimited far-field spectroscopy in the infrared, we map the intensity of the electric field in the vicinity of plasmonic nanoantennas with 10 nm spatial accuracy. Specifically, we place a patch of probe molecules at different locations in the near-field of a resonant antenna and extract the molecular vibrational excitation. We map the field intensity along a dipole antenna and confirm our findings with numerical simulations. Furthermore, we quantify the near-field intensity of a gap-type antenna, observing a 5.9 times vibrational strength enhancement inside the gap.

[1] F. Neubrech et al., Phys. Rev. Lett. 101, 157403 (2008).

O 7.3 Mon 11:00 H31

Antenna enhanced sensing of surface phonon polaritons — •Frank Neubrech[1,2], Tadaaki Nagao[3], and Annemarie Pucci[1] — [1]Kirchhoff Institute for Physics, University of Heidelberg, Heidelberg, Germany — [2]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Stuttgart, Germany — [3]International Center for Materials Nanoarchitectnics, National Institute for Materials Science, Tsukuba, Japan

Excited resonantly, antenna-like nanostructures confine the electromagnetic radiation on the nanoscale and therefore enhance the electromagnetic field in their vicinity, which can be exploited for surface enhanced infrared spectroscopy. The only precondition is a good match between the fundamental resonant excitation of the nanoantenna and the vibrational signal of the adsorbate of interest. To demonstrate the influence of the vibrational signal strength on the signal enhancement we performed infrared spectroscopic measurements using Si wafers covered with SiO2 layers of different thickness. For thin layers we observe only a small change of the relative transmittance due to the SiO2 vibration. For thicker layers the coupling between the plasmonic excitation and the SiO2 surface phonon polariton becomes stronger and the relative transmission at the respective frequency increases. Layers with thickness larger than some tens of nanometers feature a transmission close to 100% at the SiO2 frequency.

O 7.4 Mon 11:15 H31

Experimental realization of an optical point-to-point connection with nanoantennas — •Daniel Dregely[1], Klas Lindfors[1,2], Markus Lippitz[1,2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, D-70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, D-70569 Stuttgart, Germany

Advances in nanofabrication in the past years allowed for the adaption of radiofrequency and microwave concepts to optical wavelengths. It was theoretically proposed that optical nano-antennas outperform direct wire connects in energy transmission on the nanoscale [1]. We experimentally realized an optical antenna link using a transmitter and a receiver antenna. We furthermore used different antenna geometries to increase the energy transmission efficiency and show that the direction of the transmitted beam can be spatially steered using phase control.

[1] A. Alù and N. Engheta, Phys. Rev. Lett. 104, 213902 (2010).

O 7.5 Mon 11:30 H31

Nonlinear optical response of complex plasmonic nanoantennas and Fano structures — •Bernd Metzger[1], Mario Hentschel[1,2], Thorsten Schumacher[1,2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Heisenbergstr. 1, 70569 Stuttgart, Germany

For the design of optical materials with desired functionality and optical response, we require a deep understanding of the light-matter interaction. In particular plasmonic nanoantennas have shown great potential for tailoring the linear as well as the nonlinear optical response. To gain insight into the nonlinear optical processes that occur upon illumination of these nanoantennas with strong light fields, we perform third harmonic spectroscopy of different complex nanoantenna structures using widely tunable sub-30 fs laser pulses. We find the peak efficiency of the third harmonic emission of rod-type antennas slightly red-shifted to their far-field extinction spectrum. This behavior can be understood and modeled using a classical anharmonic oscillator [1]. Furthermore, we investigate complex nanoantennas, such as dolmen-type and oligomer structures, which exhibit Fano resonances in their linear extinction spectrum. The nonlinear response of these structures is as well strongly related to their linear optical properties and originates mostly from the interplay of bright and dark modes as well as the intense localized near-fields within the metallic nanostructures.

[1] M. Hentschel et al., Nano Lett. 12, 3778 (2012).

O 7.6 Mon 11:45 H31

Tunable Nano-Cavities as optical antennas for near-field scanning probes — •Heiko Gross, Michail Kromm, and Bert Hecht — Experimental Physics 5, University of Würzburg, Germany

Plasmon resonances of nanoslit cavities at the edge of single crystalline gold flakes are experimentally characterized. Controlling the length of the slits created by focused ion beam milling enables us to tune the plasmon resonance through the visible wavelength range while still maintaining highly confined fields within the gap. Unidirectional emission is also observed from the open end of the cavity.

Exploiting the mechanical rigidness of gold flakes makes it possible to use these cavities as a scanning probe with an optical antenna to enhance the emission of single molecules at spatial resolutions well beyond the diffraction limit.

O 7.7 Mon 12:00 H31

Evolutionary optimization, realization and analysis of high-performance optical antennas — •Thorsten Feichtner[1], Oleg Selig[2], Markus Kiunke[1], and Bert Hecht[1] — [1]Nano-Optics & Biophotonics Group, Experimentelle Physik 5, Physikalisches Institut, Wilhelm- Conrad-Röntgen-Center for Complex Material Systems, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]FOM Institute AMOLF, Biomolecular Photonics Group, Science

Park 104, 1098 XG Amsterdam, The Netherlands

Optical antennas have a wide range of useful applications, e.g. increase of solar cell absorption, coupling of energy into plasmonic waveguides or enhancement of single emitter decay rates. Most nano antenna designs so far are based upon radio wave antenna technology which might not yield optimal performance. Structures with enhanced optical properties can be found by means of evolutionary algorithms [1]. We present an extension of this concept to geometries suitable for nano-fabrication, where we use structures with rounded edges and feature sizes of 22 nm that are described by a binary square matrix containing '0' and '1'. We show in experiments using two-photon-photoluminescence that the resulting evolutionary nano-antennas indeed show a two-fold increase compared to linear dipolar two-wire nano-antennas as suggested by simulations. We also outline a theory explaining this surprising finding based on the reciprocity theorem.

[1] Feichtner, T., Selig, O., Kiunke, M. & Hecht, B. Evolutionary Optimization of Optical Antennas. Physical Review Letters 109, 127701 (2012).

O 7.8 Mon 12:15 H31

Using low-loss phase-change materials for IR antenna resonance tuning — •Ann-Katrin U. Michel, Tobias W. W. Mass, and Thomas Taubner — 1st Institute of Physics, RWTH Aachen University, Sommerfeldstraße 14, 52074 Aachen, Germany

Metallic nanoantennas are able to produce significantly enhanced and highly confined electromagnetic fields. The variation of nanorod material, geometry and substrate allows a wide tuning range of their resonance frequency.

We show a concept for resonance tuning of aluminum nanorods with defined geometry via variation of the refractive index n of an embedding medium. Phase-change materials (PCM) offer a huge contrast in n due to a phase transition from amorphous to crystalline state, which can be thermally triggered. Due to a negligible small imaginary part of the dielectric function of both phases, in the mid-IR resonance damping is avoided. Exemplary we used the two PCM InSb and $Ge_3Sb_2Te_6$ [1],which provide a huge contrast in n and a negligible small losses in the mid-IR spectral range. We present resonance tuning to lower as well as to higher wavenumbers with a maximum shift of about 11.5%, which is confirmed via FDTD simulations.

Since nanoantennas represent a model system for metamaterials, our study enable a variety of new applications for sensing, enhanced IR spectroscopy [2] and programmable optical nanostructures [3].

[1] Sittner et al. *Phys. Status Solidi A* **2012**.
[2] Adato et al. *PNAS* **2009** 106(46), 19227-19232.
[3] Xingjie Ni et al. *Science* **2012** *335*, 427.

O 7.9 Mon 12:30 H31

Extreme ultraviolet light generation enhanced by plasmonic nanostructures — •Murat Sivis[1], Matthias Duwe[1], Bernd Abel[2], and Claus Ropers[1] — [1]Materials Physics Institute and Courant Research Centre, University of Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen — [2]Leibniz Institute of Surface Modification, University of Leipzig, Permoserstr. 15, 04318 Leipzig

The near-field enhancement in metallic nanostructures can be used to study numerous strong-field effects within confined volumes, such as the generation of extreme ultraviolet (EUV) light. [1,2] Here, we present a comprehensive study of highly nonlinear processes in plasmonic nanostructures, including resonant bow-tie antennas as well as tapered hollow waveguides. In particular, we will discuss the excitation mechanisms and spectral characteristics of nanostructure-enhanced fluorescent line emission from noble gases. To this end, we have developed a method to gauge plasmonic fields in nanostructures, which is based on the spectral fingerprint of strong-field fluorescence. Prospects and limitations of EUV generation in nanoscopic volumes will be elucidated.

[1] S. Kim, *et al.*, Nature **453**, 757 (2008)
[2] M. Sivis, *et al.*, Nature **485**, E1 (2012)

O 7.10 Mon 12:45 H31

Nanoantenna supported internal photoemission in metal-isolator-metal junctions — Dieter Akemeier[1], Detlef Diesing[2], Dominik Differt[1], Adelheid Godt[3], Ingo Heesemann[3], •Matthias Hensen[1], Andreas Hütten[1], Walter Pfeiffer[1], and Christian Strüber[1] — [1]Fakultät für Physik, Universität Bielefeld, Universitätsstr. 25, 33615 Bielefeld, Germany — [2]Fakultät für Chemie, Universität Duisburg-Essen, Universitätsstr. 5, 45141 Essen, Germany — [3]Fakultät für Chemie, Universität Bielefeld, Universitätsstr. 25, 33615 Bielefeld, Germany

Thin-film metal-isolator-metal (MIM) heterosystems, i.e. Ta-TaO_x-Ag and Ta-TaO_x-Au junctions, are investigated as devices for ultrafast nanoscale electron injection in nanophotonic applications. Internal photoemission (IPE) microscopy provides lateral maps of the induced multiphoton photocurrents that are excited by few-cycle pulses from a Ti:Sapphire laser (6 fs). Nanostructures acting as optical antennas are prepared on the Ag top electrode by deposition of Au nanoparticles and Au nanoparticle aggregates or by means of local focussed ion beam milling. The multiphoton internal photoemission current is strongly enhanced in the vicinity of these nanoantennas. Based on FDTD model calculations (a grid-based differential time-domain numerical modeling method) this enhancement is attributed to field enhancement effects in the MIM structure.