O 5: Plasmonics: Nanoantennas, Nanoparticles

Time: Monday 10:30–13:00 Location: MA 042

O 5.1 Mon 10:30 MA 042

Antenna-mediated single molecule FRET — •Janning Hermann, Katharina Ditte, and Christiane Höppener — Physikalisches Institut, Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

Förster Resonance Energy Transfer (FRET) is a wide-spread tool for quantitative evaluation of interaction ranges of molecular systems in single molecule studies. As the FRET efficiency is inversely proportional to the 6th power of the separation distance of donor and acceptor, it serves as a precise nanometer-ruler. Because of the high distance sensitivity, FRET is limited to the sub-8 nm range.

Optical antennas can be utilized to enhance the light-matter interactions, namely the electric field enhancement associated with the irradiated antenna, the modification of the radiative transition rate and the redirection of light [1].

In this contribution, we demonstrate in a single molecule FRET study that a single spherical AuNP antenna opens up the possibility to tune the transition rates of the donor and the acceptor ambivalently in order to boost the energy transfer rate significantly. In addition the FRET efficiency benefits also from the improved photon counting statistics in the presence of an antenna.

[1] C. Höppener and L. Novotny; Quart. Rev. Biophys. 45 (2012), 209-255

O 5.2 Mon 10:45 MA 042

Electrically-driven optical antennas — •René Kullock[1], Johannes Kern[1,2], Jord Prangsma[3], and Bert Hecht[1] — [1]Experimental Physics 5, University of Würzburg, Germany — [2]Physikalisches Institut, University of Münster, Germany — [3]MESA+ Institute for Nanotechnology, University of Twente, Enschede, The Netherlands

Antennas play a key role in today's wireless communication networks as they efficiently link localized electrical signals and electromagnetic waves. Driven by the demand for higher bandwidth, antenna carrier frequencies are ever increasing, however, electrically driven nanoantennas at optical frequencies seemed beyond reach. Although fabrication of optical antennas is already possible, unlike radiowave antennas they are not fed by a generator. Instead they are driven by light directly or via optically active materials in their proximity.

Here, we demonstrate direct electrical driving of an optical nanoantenna featuring an atomic-scale feed gap. Upon applying a voltage, quantum tunneling of electrons across the feed gap creates a broadband quantum shot noise. The optical frequency components of this fluctuating current are efficiently converted into photons by the antenna. We demonstrate that the properties of the emitted photons can be fully controlled by the antenna architecture, and that the antenna improves the quantum efficiency by up to two orders of magnitude with respect to a non-resonant reference system. Our work represents a new paradigm for interfacing electrons and photons at the nanometer scale, e.g. for on-chip wireless data communication.

O 5.3 Mon 11:00 MA 042

Gold Nanoantennas with Reduced Substrate Contact for Plasmonic Enhancement in the Infrared — •Christian Huck[1], Andrea Toma[2], Frank Neubrech[1,3], Manohar Chirumamilla[2], Jochen Vogt[1], Francesco De Angelis[2], and Annemarie Pucci[1] — [1]Kirchhoff Institute for Physics, University of Heidelberg, Germany — [2]Istituto Italiano di Tecnologia, Genova, Italy — [3]4th Physics Institute and Research Center SCoPE, Stuttgart, Germany

Plasmon-polariton excitations of metal nanoparticles can couple to other excitations of similar energy, which enables strong vibrational signal enhancement in the infrared. Commonly used substrates for surface enhanced infrared absorption (SEIRA) consist of meal nanoparticles located on a dielectric substrate. However, this planar arrangement substantially weakens plasmonic resonances because of the substrate polarizability and, furthermore, a great part of the electromagnetic near-field is located inside the substrate and thus not accessible for enhanced vibrational spectroscopy of an analyte. In this contribution we present one way to reduce the undesirable influences of the substrate by fabricating gold nanowires situated on a silicon pedestal and therefore in a reduced contact with the substrate. The influence of the pedestal height is studied by finite-difference time-domain simulation and plays a crucial role for the optimization of near-field intensities. Furthermore we show a comparison of the plasmonic response as well as the SEIRA activity between rods prepared by standard electron beam lithography and rods which were additionally treated with reactive ion etching to remove the silicon substrate around the hot-spots of the rods.

O 5.4 Mon 11:15 MA 042

Photoelectron imaging of resonant modes of plasmonic antennas — •Anna-Katharina Mahro, Deirdre Kilbane, Pascal Melchior, Stefan Mathias, and Martin Aeschlimann — Physics Department and Research Centre OPTIMAS, University of Kaiserslautern, Germany

Knowledge of fundamental light-matter interactions such as the local response of nanostructures to incident light is necessary for designing plasmonic devices such as biosensors. This response is determined on the nanometer scale (below the diffraction limit of light). To achieve high spatial resolution we use a photoemission electron microscope (PEEM) in combination with different laser sources for excitation.

To gain information about the spectral properties of the nanoantennas we apply two approaches in the time and frequency domain. The time domain experiment involves phase-resolved interferometric PEEM using a broadband ultrashort pulse laser. The frequency domain experiment is wavelength dependent PEEM using a narrow bandwidth highly tuneable laser source, in our case an optical parametric oscillator (OPO). Comparing spectra from both techniques gives us insight into the local response of our nanoantennas.

O 5.5 Mon 11:30 MA 042

Fano resonances and near-field coupling efficiency in plasmonic nanostructures based on nanorods — •Manuel Gonçalves[1], Madeleine Nilsen[1], Ines Martin[1], Taron Makaryan[2], Armen Melikyan[3], Hayk Minassian[4], and Othmar Marti[1] — [1]Ulm University - Inst. of Experimental Physics, Ulm, Germany — [2]Yerevan State University - Radiophysics Department, Yerevan Armenia — [3]Russian-Armenian (Slavonic) University, Yerevan, Armenia — [4]Yerevan Physics Institute, Yerevan, Armenia

Nanorods present well separated dipolar and higher order multipolar plasmon resonances. These resonances scale up approximately with the aspect ratio. Several configurations of rods of non-identical size can be used to produce Fano resonances, by coupling one radiant mode (dipole) with one sub-radiant mode (quadrupole). The near-field coupling between rods arranged in T- and H-like configurations is very efficient and leads to well pronounced Fano resonances in the absorption and scattering spectra. On the other hand, these structures are among the most simple to fabricate.

We have investigated several structures by varying the geometrical and optical parameters and their influence in the Fano resonance. The near-field coupling between rods can be quantitatively characterized, using the ratio between absorption cross sections calculated separately for each part of the resonant system. At the Fano resonance this ratio achieves a maximum. It can also be generalized for other structures presenting Fano resonances, like heptamers and pentamers of coupled disks.

O 5.6 Mon 11:45 MA 042

The influence of porphyrin adsorption on the LSP resonances of individual silver clusters investigated with multi-photon photoemission electron microscopy — •Klaus Stallberg and Winfried Daum — Institut für Energieforschung und physikalische Technologien, TU Clausthal, Leibnizstraße 4, 38678 Clausthal-Zellerfeld

Photoemission electron microscopy (PEEM) in combination with short-pulse laser excitation is a valuable probe for the investigation of plasmonic excitations, as it allows for direct imaging of the electric field enhancement with a lateral resolution down to 50 nm. In this talk we adress the application of energy-resolved multi-photon PEEM for the investigation of localized surface plasmons (LSPs) of silver clusters in contact with zinc-tetraphenyl-porphyrin (ZnTPP) molecules. ZnTPP is a metal-organic dye with a strong absorption band at 422 nm, which is close to the LSP resonances of selected silver nanoparticles on Si(100). Recording PEEM images for incrementally

increased laser wavelengths enables us to derive spatially resolved excitation spectra. We observe the electronic $S_0 \rightarrow S_2$ Soret transition of porphyrin molecules as a strong resonance in the excitation spectra of thin porphyrin films. Similarly LSP resonances of individual silver clusters are obtained. Deposition of zinc-tetraphenyl-porphyrin (ZnTPP) molecules results in a shift of the LSP resonance towards shorter wavelengths while the porphyrins' Soret resonance appears to be shifted to lower wavelengths indicating a coupling of the silver clusters' LSP with the molecular Soret excitation.

O 5.7 Mon 12:00 MA 042

Plasmon spectroscopy of metal nanoparticles — •Viktor Myroshnychenko[1], Naoki Yamamoto[2], Javier Garcia de Abajo[3], and Jens Förstner[1] — [1]University of Paderborn, Paderborn, Germany — [2]Physics Department, Tokyo Institute of Technology, Tokyo, Japan — [3]ICFO-Institut de Ciencies Fotoniques, Castelldefels (Barcelona), Spain

The current interest in the optical properties of metal nanoparticles is due to their ability to host localized surface plasmon excitations in the visible and near-infrared parts of the spectrum [1]. The study of the electromagnetic field distributions associated to localized plasmon excitations in metal nanoparticles are of critical importance for applications. In this work, we use optical spectroscopy (which records light scattering exerted by the particles on externally incoming light) and cathodoluminescence (based on electron-induced radiation emission produced by interaction with an electron beam) to study plasmon excitations in sub-wavelength noble-metal nanoparticles [2]. We provide a theoretical description of these techniques and numerical modeling of the spectral features and spatially resolved maps of nanoparticle plasmon modes.

[1] N. J. Halas et al., Plasmons in strongly coupled metallic nanostructures, Chem. Rev. 111, 3913-3961, 2011.

[2] V. Myroshnychenko et al., Plasmon spectroscopy and imaging of individual gold nanodecahedra: A combined optical microscopy, cathodoluminescence, and electron energy-loss spectroscopy study, Nano Letters 12, 4172-4180, 2012.

O 5.8 Mon 12:15 MA 042

A novel dielectric unidirectional antenna — •Andre Hildebrandt, Matthias Reichelt, Torsten Meier, and Jens Förstner — University of Paderborn, Germany

Optical and infrared antennas provide a promising way to couple photons in and out of nanoscale structures. As counterpart to conventional radio antennas, they are able to increase optical fields in subwavelength volumes [1], to enhance excitation and emission of quantum emitters or to direct light, radiated by quantum emitters [2]. The directed emission of these antennas has been mainly pursued by surface plasmon based devices, e.g. Yagi-Uda like antennas, which are rather complicated due to the coupling of several metallic particles. Also, like all metallic structures in optical or infrared regime, these devices are very sensitive to fabrication tolerances and are affected by strong losses.

In this paper we present a design idea and numerical simulations for a dielectric antenna, which performs better than plasmonic counterpart, due to the lack of losses by an appropriate choice of the dielectric material. These antennas are robust concerning fabrication tolerances and can be realized with different materials for both the antenna and the substrate, without using high index materials.

[1] A. Hildebrandt et al., "Optimization of the intensity enhancement in plasmonic nanoantennas," AIP Conference Proceedings 1475, pp. 59-61 (2012)

[2] A. G. Curto et al., "Unidirectional Emission of a Quantum Dot Coupled to a Nanoantenna," Science 329, 930 (2010)

O 5.9 Mon 12:30 MA 042

Near-field trapping of nanoparticles on plasmonic nanoantenna arrays — •Anastasia Babynina[1,2,3] and Theobald Lohmüller[1,2,3] — [1]Photonics and Optoelectronics Group, Ludwig Maximilian University of Munich, Munich, Germany — [2]Nanosystems Initiative Munich (NIM), Munich, Germany — [3]The Center for NanoScience (CeNS), Munich, Germany

Optical trapping of nano-sized particles is challenging. In general, high laser powers are required to generate sufficient gradient forces for keeping such small objects confined in a trap. This is particularly problematic for biological samples. Plasmonically coupled nanostructures, such as bowtie nanoantennas, on the other hand, can be used to focus far-field propagating light down to a nanoscale volume in the optical near-field. The strong and localized field in such a plasmonic "hot-spot" results in strong gradient forces that can be harnessed for trapping of nano-sized objects.

We have fabricated and characterized large-scale arrays of plasmonic nanoantennas for optical near-field trapping of nanoparticles. Merely bottom-up nanofabrication methods are employed to control the size and the spacing of billions of gold triangles on one single substrate with nanometer precision. We show that such nanoantenna arrays can be applied for parallel near-field trapping and for releasing nanoobjects with a size and refractive index similar to that of a virus. The laser powers used here are orders of magnitude lower compared to a conventional far-field trapping experiment.

O 5.10 Mon 12:45 MA 042

Nanoscale noble metal clusters: First principles atomistic time-dependent density functional calculations — •Mikael Kuisma and Paul Erhart — Applied Physics, Chalmers University of Technology, Sweden

Nanoscale plasmonics has a variety of potential applications from cancer treatment to renewable energy. At these length scales a quantum mechanical treatment is required in order to obtain a reliable representation of the plasmonic response.

We have developed and implemented an efficient basis set based real-time propagation method in the GPAW code. The method is used together with the time-dependent GLLB-SC potential and applied to nanoscale noble metal clusters. For the first time, systems with over 10,000 valence electrons are available in *ab initio* all-electron time-dependent density functional (TDDFT) calculations with moderate computational effort. Using this approach we simulate the optical spectra of icosahedral silver clusters Ag ranging from 55 to 561 atoms (1.06–2.68 nm). We observe that localized surface plasmon resonances enter the asymptotic region already at diameters between 1-2 nm, converging to the classical quasistatic limit of 3.4 eV. We show that proper description of both *d*-band position and bandwidth is crucial.

As a further demonstration of the practicality of our method, we establish the nature of plasmonic response in palladium hydride nanoclusters. To this end, we combine the absorption spectra of hundreds of large palladium clusters with varying hydrogen content.