# O 57: Plasmonics and Nanooptics II

Time: Wednesday 16:00–19:00 Location: GER 38

O 57.1 Wed 16:00 GER 38

**Controlling the emission and movement of electrons on a nanoscale with few-cycle laser pulses** — •Jan Vogelsang, Björn Piglosiewicz, Slawa Schmidt, Doojae Park, Jörg Robin, Petra Gross, and Christoph Lienau — Institut für Physik, Carl von Ossietzky Universität Oldenburg, Germany

Due to their large field enhancement at the apex, metallic nanotapers became a workhorse for studying strong-field effects at solid state surfaces in the last years. Sufficiently high laser electric field strengths exceeding 10 V/nm can be reached without melting the atomic lattice, such that the ocillating laser field becomes comparable or even stronger than the Coulomb field binding the electrons to the nuclei. Since the field enhancement is limited to a volume as small as the taper apex itself, the electrons are influenced by the external electric field only on a potentially nanometersized volume on a time scale given by the laser pulse duration[1].

In this talk, recent results of our group on the direct control of electron emission and acceleration in strong electric fields are discussed[2]. In particular, the influence of the carrier-envelope-phase of the incident laser pulse on the photoelectron spectra will be covered[3].

[1] Herink, G. et al., Nature 483, 190-193 (2012).
[2] Park, D. J. et al., Phys. Rev. Lett. 109, 244803 (2012).
[3] Piglosiewicz, B. et al., Nature Photonics (2013) (doi:10.1038/nphoton.2013.288).

O 57.2 Wed 16:15 GER 38

**Field-driven THz-streaking of Nanotip Photoemission** — •Lara Wimmer, Georg Herink, Katharina E. Echternkamp, Daniel R. Solli, Sergey V Yalunin, and Claus Ropers — 4. Physical Institute - University of Göttingen, Göttingen, Germany

We present an ultrafast, nanoscale streaking scheme for field-driven photoemission control using single-cycle THz transients at the apex of a sharp gold tip [1]. The locally enhanced THz-field allows for a high-contrast enhancement or suppression of the near-infrared photoemission yield and a tuning of the photoelectron kinetic energy distribution, both in spectral position and width. This streaking scheme is unique to nanostructures because of the strong sub-wavelength confinement of the driving field [2]. In particular, the associated electron dynamics are governed by the momentary THz field at the instance of photoemission, rather than by a temporal integral, i.e. the vector potential, as in optical streaking experiments for attosecond spectroscopy [3]. Besides the fundamental interest in the characterization and control of electron trajectories within ultrashort optical near-fields, the approach carries significant potential for pulse compression in ultrafast electron diffraction and microscopy experiments.

[1] Wimmer et al., arXiv: 1307:2581 (2013)
[2] Herink et al., Nature 483, 190-193 (2012)
[3] Corkum, Krausz, Nature Physics 3, 381 - 387 (2007)

O 57.3 Wed 16:30 GER 38

**Reciprocity provides optimal coupling of a single emitter to a plasmonic nanoantenna** — •Thorsten Feichtner[1] and Bert Hecht[2] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Nano-Optics & Biophotonics Group, Department of Experimental Physics 5, Röntgen Research Center for Complex Material Research (RCCM), University of Würzburg, Germany

The emission rate of a point-like single emitter is defined by the local density of states at its position. The local density of states can be enhanced by means of plasmonic nano antennas. The resulting antenna-enhanced emitters are of major interest for many applications as e.g. near-field microscopy, single molecule detection and quantum optics. In the present work we will use reciprocity to derive a set of rules that affords optimal coupling between a single emitter and an optical antenna. After a validation for the analytically solvable case of a dipole in front of a sphere we apply these rules to a numerical study of the outstanding performance of split-ring-antennas [1]. Finally, based on the rules, we propose an optimal antenna design that optimizes both the coupling between single emitter and antenna as well as the coupling between antenna and far-field. The presented framework will also be useful to study surface enhanced spectroscopies, e.g. SERS.

O 57.4 Wed 16:45 GER 38

**Excitation and decay rate enhancements of purely magnetic dipole transitions in $Er^{3+}$ ions near gold nanoparticles** — •Deepu Kumar[1], Florian Hallermann[1], Alexander Sprafke[2], Dmitry Chigrin[1], and Gero von Plessen[1] — [1]RWTH Aachen University, 52056 Aachen, Germany — [2]$\mu$MD Group, Institute of Physics, Martin-Luther University Halle- Wittenberg, 06120 Halle, Germany

The excitation and emission rates of molecular and ionic emitters placed in the vicinity of metal nanoparticles (MNP), can be enhanced due to near-field effects of the particles. In general, magnetic-dipole (MD) transitions can be neglected as their rates are much lower than those of the electric dipole (ED) transitions. In rare-earth ions however, such as trivalent erbium ($Er^{3+}$), MD transitions contribute to some of the intra-4f transitions. For the overall transition rate enhancement in $Er^{3+}$ ions due to the MNP, the changes in both the ED and MD transition rates have to be taken into account. We calculate the effects of gold MNP on the excitation and decay rates of $Er^{3+}$ ions by using Mie theory and the finite element method (FEM). We compare the MNP-induced decay rate changes for purely electric and purely magnetic dipoles.

O 57.5 Wed 17:00 GER 38

**Probing the Local Density of States in Nano-Photonic Systems: a Numerical Discussion** — •Julia F. M. Werra[1], Andreas W. Schell[2], Philip Engel[2], Christian Wolff[3], Oliver Benson[2], and Kurt Busch[1,3] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, D-12489 Berlin, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, AG Nanooptik, D-12489 Berlin, Germany — [3]Max-Born-Institut, D-12489 Berlin, Germany

The photonic local density of states (LDOS) of a nano-photonic system quantifies the position dependent coupling between a point emitter and the electromagnetic modes. Thus, it is the key characteristic of such systems in the context of radiation dynamics; especially in the realm of plasmonics with its strong and highly confined field enhancements and in the nano-scale regime.

In this talk, we will present theoretical and numerical foundations to quantitatively calculate the LDOS of an arbitrary geometry within the discontinuous Galerkin time-domain method. As an example, we will focus on nitrogen-vacancy centers taking especially its specific energy level scheme into account and compare our computations to experimental data. This facilitates a detailed quantitative interpretation and understanding of quantum-emitter based fluorescence life-time imaging (see Ref. [1]).

[1] Andreas W. Schell, Philip Engel, Julia F. M. Werra, *et al.* (submitted).

O 57.6 Wed 17:15 GER 38

**Gold nanocone arrays as effective SERS substrates** — •Julia Fulmes, Christian Schäfer, Falk Anger, Dominik A. Gollmer, Andreas Horrer, Frank Schreiber, Dieter P. Kern, and Monika Fleischer — Institute for Applied Physics, University of Tübingen, Tübingen, Germany

Raman spectroscopy is a well-known technique for the detection and characterization of molecules. Spontaneous Raman scattering is typically very weak, but can be increased by many orders of magnitude by using surface enhanced Raman spectroscopy (SERS). We exploit arrays of plasmonic gold nanostructures (cones) with sharp tips of less than 10 nm in diameter [1] over large areas [2] for SERS. Due to the conical shape a strongly localized and enhanced electromagnetic field can be excited close to the cone apex. This allows for employing gold nanocone arrays for the detection of molecules with high sensitivity [3]. The successful application of gold nanocone arrays as SERS substrates for the analysis of different types of molecules, such as pentacene, 4-mercaptobenzoic acid and rubrene will be shown. By purposefully positioning molecules only on defined parts of the plasmonic nanostructures the Raman signal enhancement activity is investigated.

[1] M. Fleischer et al., Nanotechnology 21, 065301 (2010); [2] A. Horrer et al., Small, doi: 10.1002/smll.201300449 (2013); [3] J. Fulmes et al., in preparation.

O 57.7 Wed 17:30 GER 38

**Probing antenna enhanced near-fields with nanometer-scale**

**resolution** — •F. Neubrech[1,2], S. Beck[2,3], T. Glaser[2,3], M. Hentschel[1], H. Giessen[1] und A. Pucci[2,3,4] — [1]4th Physics Institute and Research Center SCoPE, Stuttgart, Germany — [2]Kirchhoff Institute for Physics, Heidelberg, Germany — [3]InnovationLab GmbH, Heidelberg, Germany — [4]Centre for Advanced Materials (CAM), Heidelberg, Germany

Nanoantenna-assisted surface enhanced infrared spectroscopy is a powerful tool to detect minute amounts of analytes. Based on the confined electromagnetic near fields of the resonantly excited metal nanoparticles, the molecular vibrations of the analytes are enhanced by orders of magnitudes. On the other hand, the enhanced vibrational signal strength of well-known probe molecules can also be utilized to obtain information on the near field enhancement with resolution only limited by the size of the probe molecule. Following this approach, we employed 4,4*-bis(N-carbazolyl)-1,1*-biphenyl (CBP) to measure the local near fields of resonantly excited nanoantennas with nanometer-scale resolution. Therefore, we stepwise evaporated CBP molecules under ultra-high vacuum conditions onto the metal nanostructures and acquired infrared spectra after each evaporation step. Besides the decreasing vibrational signal per nanometer, we observed a red-shift of the resonance frequency with increasing thickness. This shift originates from the polarizability change caused by the evaporated material. Furthermore, we performed finite different time domain simulations and found a good qualitative agreement with our experimental data.

O 57.8 Wed 17:45 GER 38

**Hybrid plasmonic oligomer for large-area low-cost nano-size gas sensors** — •Jun Zhao, Nikolai Strohfeldt, Andreas Tittl und Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany

Plasmonic gas sensing on the single nanoparticle level has drawn a lot of attention over the last years [1, 2]. We demonstrate direct contact gas sensing using hybrid complex plasmonic nanostructures, such as multilayer oligomers, where gold directly touches the palladium. Optimizing the sensing nanogeometry, we obtain spectral shifts of more than 10 nm depending on different H2 concentrations, which show a very high sensitivity of our system. We investigate the optical response of varied sandwich structure geometries, which can be used for different sensing applications. Our samples are fabricated by low-cost hole-mask colloidal nanolithography [3, 4] over areas of 1 cm2, and give very large absorption and scattering signals.

[1] N. Liu et al., Nature Mater. 2011, 10, 631. [2] A. Tittl et al., Nano Lett. 2013, 13, 1816. [3] S. Cataldo, J. Zhao et al., ACS Nano 2012, 6, 979. [4] J. Zhao et al., Adv. Mater. 2012, 24, 247.

O 57.9 Wed 18:00 GER 38

**Plasmonic sensing with functionalized hydrogels** — •Martin Mesch[1], Chunjie Zhang[2], Paul V. Braun[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany — [2]Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign, USA

Plasmonic structures have shown to be a sensitive and versatile tool for different sensing applications. As they inherently respond to anything that changes their dielectric environment, selectivity has to be added separately. In our approach, we utilize a thin layer of a functionalized hydrogel to embed our gold nanostructures. This layer is about 1 micrometer in thickness and consists of a cross-linked polymer network soaked with water.

One possible functionalization makes the hydrogel swell in the presence of glucose. This effect implies a change in the refractive index, and hence is in turn subject to detection via the plasmon resonance shift.

Experiments demonstrate that this system allows for detection of glucose concentrations in the physiological (low millimolar) range, as the hydrogel additionally amplifies the signal, compared to just the refractive index change introduced by glucose in the solution. Response times depend, besides the thickness of the layer, also on the composition of the polymer, and are currently in the order of a few minutes.

O 57.10 Wed 18:15 GER 38

**Metal plasmonic structures based on anodic aluminum oxide (AAO) and ultrathin alumina membranes (UTAM) for SERS and sensor applications** — •Wenxin Wang, Yan Zheng, Ranjith Vellacheri, Lin Cheng, Chengliang Wang, Huaping Zhao, Ahmed Al-Haddad, and Yong Lei — Ilmenau University of Technology, Institute of Physics & IMN MacroNano* (ZIK) Prof. Schmidt-Str. 26, 98693 Ilmenau (Germany)

A variety of nano-structures can be fabricated by using anodic aluminum oxide template (AAO) and ultrathin alumina membranes (UTAM) through controlling the anodization voltage, time, and other parameters. With wet chemical etching process, pore size can be further adjusted. Additionally, dual even triple kind of pore sizes in a single template can be obtained if a third even fourth anodization process is applied, Here, we present Au, Ag , and Au-Ag composite nanostructured arrays prepared by the above-mentioned templates for enhanced Raman and Bio-sensing. The results show that these nanostructured arrays exhibit special absorption and senseing response to light, therefore implying the promising potencial of Au, Ag , andAu-Ag composite nanostructured arrays as suitable candidates for the applications of SERS substrate as well as bio-assay.

O 57.11 Wed 18:30 GER 38

**the applications of Au nanostructure arrays to sensors** — •Zhijie Wang, Dawei Cao, Liaoyong Wen, Yan Mi, Ranjith Vellacheri, and Yong Lei — Ilmenau University of Technology, Institute of Physics & IMN MacroNano* (ZIK) Prof. Schmidt-Str. 26, 98693 Ilmenau

Noble nano-materials, particularly Au nanoparticles and nanowires, show an outstanding localized surface plasmon property associated with the enhanced surface electromagnetic field due to its localization in nano-scale. The surface plasmon resonance peaks and intensities of the Au nano-materials are tunable through the manipulation of the shape, the size and the surface modifications of the Au nanoparticles. In contrast to the conventional sensor applications of Au nanoparticles, just by dispersing them in the analyte solution to collect optical signal, herein, we fabricated Au nanowires and particles arrays on substrates. Through surface modifications by cysteine, the surface plasmon peaks of these Au nanostructures shifted obviously according to the different analytes. Possibility to design Au nano-sensors for collecting electronic signal from the reaction between the surface plasmons and analytes will be discussed.

O 57.12 Wed 18:45 GER 38

**Theoretical investigation of the emission statistics of a spaser** — •Michael Gegg[1,2], T. Sverre Theuerholz[1], Andreas Knorr[1], and Marten Richter[1] — [1]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Freie Universität Berlin, Berlin, Germany

Surface plasmons have recieved considerable attention over the past few years. Surface plasmons bypass the diffraction limit in conventional optics. Moreover they are bosonic quasiparticles, thus exhibiting the same rich quantum statistical phenomenology as photons and phonons.

We present a theoretical model for the interaction of an arbitrary number of identical quantum dots with a metal nanoparticle. The quantum dots act as a gain medium, inducing plasmons on the metal nanoparticle via dipole-dipole coupling [1]. This system was proposed as a candidate for a spaser [2] and it was employed to construct a nanosized laserlike device [3]. We analyse the plasmon statistics and its dependency on the number of quantum dots, dipole coupling and incoherent processes.

We find that the system reaches the spasing regime in all investigated cases for the limit of many quantum dots.

[1]T. Sverre Theuerholz, Alexander Carmele, Marten Richter and Andreas Knorr. *Phys. Rev. B*, 87, 2013 [2]M. I. Stockman. *Nature Photon.*, 2, 2008 [3]M. A. Noginov, G. Zhu, A. M. Belgrave, R. Bakker, V. M. Shalaev, E. E. Narimanov, S. Stout, E. Herz, T. Suteewong and U. Wiesner. *Nature*, 460, 2009