DS 14: Plasmonics and nanooptics: Structure, fabrication and characterization (joint session with O)

Time: Tuesday 10:30–13:15 Location: MA 043

DS 14.1 Tue 10:30 MA 043

Large-area spectrally selective plasmonic perfect absorber sensor fabricated by laser interference lithography — •Shahin Bagheri, Nikolai Strohfeldt, Andreas Tittl, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

We employ laser interference lithography to create homogeneous wire and rectangle arrays and utilize them for manufacturing of large-area plasmonic perfect absorbers [1]. Geometry and periodicity of such tailored nanostructures can be precisely controlled by adjusting the interference conditions in single- and double-exposure processes, resulting in spectrally selective perfect absorption of light from the visible to the mid-infrared wavelength range. We also demonstrate the applicability of our fabrication method for detection schemes by measuring the hydrogen sensing performance of a palladium-based perfect absorber operating in the visible wavelength range. Due to the large-area and fast fabrication process, our method offers a great potential for low-cost commercial nanophotonic and plasmonic devices in industrial applications.

[1] S. Bagheri et al., Adv. Opt. Mater. **2**, 1050-1056 (2014)

DS 14.2 Tue 10:45 MA 043

Light trapping and enhanced absorption in femtosecond-laser materials processed amorphous thin-film silicon — Dominik Differt[1], •Walter Pfeiffer[1], Babak Soleymanzadeh[1], and Helmut Stiebig[1,2] — [1]Fakultät für Physik, Universität Bielefeld, Universitätsstr. 25, 33615 Bielefeld, Germany — [2]Institut für Innovationstransfer an der Universität Bielefeld, Universitätsstr. 25, 33615 Bielefeld, Germany

Efficient thin-film solar cells balance the reduced absorption in thin absorber layers by means of various photon management strategies that often involve nanotextured interfaces. We report broadband absorption enhancement in femtosecond (fs) laser materials processed thin amorphous silicon. The absorption of a single amplified fs laser pulse (30 fs, 795 nm, 75 mJ cm^{-2}) creates a thin nanotextured microcrystalline surface layer. Coherent scattered light micro-spectroscopy in combination with spectral interferometry reveals that incident radiation is trapped for about 100 fs in localized photonic modes in the laser processed area. This trapping explains the enhanced absorption and the observed local Raman yield enhancement. The lateral correlation length of the light trapping modes indicates very efficient light scattering in the processed layer that leads to strong localization of light in the absorber layer. Consequently, fs materials processing offers an interesting pathway towards advanced photon management in amorphous silicon based thin-film solar cells.

DS 14.3 Tue 11:00 MA 043

Extreme Ultraviolet Proximity Lithography for fast, flexible and large-scale fabrication of infrared antennas — •Georg Kunkemöller[1,3], Tobias W.W. Mass[2], Ann-Katrin U. Michel[2], Hyun-Su Kim[3], Sascha Brose[1], Serhiy Danylyuk[1], Thomas Taubner[2], and Larissa Juschkin[3] — [1]TOS, RWTH Aachen University — [2]I. Institute of Physics (IA), RWTH Aachen University — [3]Chair for Experimental Physics of Extreme-Ultraviolet EUV, RWTH Aachen University

Recently, several lithographic approaches to improve throughput and costs for the fabrication of infrared antennas by using parallel processes were presented [1-4]. In this contribution, we present Extreme ultraviolet (EUV) proximity lithography as a comparable advantageous technique for the fabrication of large arrays of infrared antennas. Using Fresnel-diffraction, this method offers the potential of a great variety of structures [5]. Depending on deposure time and gap between mask and resist, different dumbbell-shaped structures can be fabricated using only a single mask-geometry. Characterization via SEM imaging and FTIR spectroscopy show a good agreement to lithograpy- and FDTD simulations and turns this fabrication method to a promising tool for a large-area fabrication of infrared nanostructures.

[1] Hoffmann et al. *J. Phys. Chem. C* **2013** 117, 11311-11316
[2] Cataldo et al. *ACS Nano* **2012** 6, 979-985
[3] Aksu et al. *Nano Lett.* **2010** 10, 2511-2518
[4] Bagheri et al. *Adv. Opt. Mat.* **2014** 2, 1050-1056
[5] Danylyuk et al. *J. Vac. Sci. Technol. B* **2013** 31, 021602

DS 14.4 Tue 11:15 MA 043

Fabrication and Characterization of Plasmonic Nanocone Antennas for Strong Spontaneous Emission Enhancement — •Björn Hoffmann[1], Simon Vassant[1], Xue-Wen Chen[1], Stephan Götzinger[1,2], Vahid Sandoghdar[1,2], and Silke Christiansen[1,3] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [3]Helmholtz Centre Berlin for Materials and Energy, Berlin, Germany

Plasmonic nano-antennas have attracted remarkable attention due to their ability to strongly modify the excitation and emission channels of quantum emitters. Metallic nanocones are a promising candidate for a strong enhancement of spontaneous emission while keeping high quantum efficiencies. Here, we report on the precise fabrication of gold nanocones with tunable dimensions to tailor their plasmon resonance to specific applications. Therefore, we developed a focused ion beam (FIB) etching procedure that offers precise control over the height, diameter and tip radius of the cones. We measured the plasmon resonance spectra of gradually etched cones and were able to reproduce the spectra by BOR-FDTD simulations. The cones show reproducible plasmon resonances between 580 - 700 nm and exhibit theoretical radiative Purcell factors above 500, which renders them promising structures for spontaneous emission enhancement.

DS 14.5 Tue 11:30 MA 043

Creating metallic nanostructures by electron beam induced deposition (EBID) for plasmonic applications — •Caspar Haverkamp[1], Katja Höflich[1], and Silke Christiansen[1,2] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany — [2]Max Planck Institute for the Science of Light, Erlangen, Germany

During EBID a gas-injection system (GIS) inserts a precursor Gas into the vacuum chamber of an scanning electron microscope (SEM). The molecules which adsorb, desorb and diffuse at the substrate surfaces and are locally decomposed by the electron beam. While the volatile part is pumped out the non-volatile part forms the deposit onto the substrate. By controlling the electron beam movement via a patterning engine various shapes can be realized. As precursor gas the metal-organic compound dimethyl-(acetylacetonate) Gold(III), short Me2Au(acac) is used, resulting in nanometer-sized gold particles embedded in a carbonaceous matrix. Since the metal content of this material is very low, two approaches are discussed how to overcome this drawback. The first one is to decrease the carbon content of the structure by an in-situ post-treatment with water vapor irradiated by the electron beam. The splitting of the water molecules by the electron beam results in reactive oxygen species which react with the carbon of the EBID structure creating volatile carbon oxides. The second approach is to use the EBID structure as template and achieving the plasmonic response by a metallic coverage .

DS 14.6 Tue 11:45 MA 043

Cathodoluminescence of sharp Au- and Ag-tips in the vicinity of a Au-film — •Martin Grüsser, Xinzhou Ma, and Rolf Schuster — Institute of Physical Chemistry, Condensed Matter Division, Karlsruhe Institute of Technology (KIT), Germany

Sharp metal tips acting as optical antennas play an important role in many experimental applications. The locally enhanced electromagnetic field allows, e.g., for tip-enhanced raman spectroscopy [1, 2] on the single molecule level. In addition to the lightning-rod effect, also surface plasmons localized at the tip apex and gap plasmons between a tip and a sample surface [3] contribute to the field enhancement.

To investigate the local excitation of surface plasmons and gap plasmons in the tip-surface system we employ, cathodoluminescence upon electron irradiation in a scanning electron microscope (SEM), which accesses the radiative modes of the electron excited plasmons. The distance between tip and surface is controlled by a scanning tunneling microscope, mounted inside the vacuum chamber of the SEM. We observed enhanced photon emission upon electron irradiation near the tip-surface gap, on both the tip as well as on the sample side. Spectra upon irradiation of tip or sample show strong differences in intensity

and peak position, e.g. a redshift for smaller tip-surface distances and evolution of additional peaks, which may depend on the formation of gap plasmons.

[1] R. M. Stöckle et al., Chem. Phys. Lett. 2000, 318, 131. [2] B. Pettinger et al., Annu. Rev. Phys. Chem. 2012, 63, 379. [3] Z. Yang, J. Aizpurua, H. Xu, J. Raman Spectrosc. 2009, 40, 1343.

DS 14.7 Tue 12:00 MA 043

Nanowire-film gap plasmon waveguides for spaser resonators — •Friedemann Gädeke, Günter Kewes, and Oliver Benson — AG Nano Optik, Institut für Physik, Humboldt-Universität zu Berlin

Surface plasmon amplification by stimulated emission of radiation (spaser) might be an essential part of future nano-photonic devices. Spasers are subwavelength sized light sources and could be used in quantum information technology or nano-lithography [1].

We report on numerical and experimental investigations on an ultra-compact resonator design for spasers. We use organic gain media in a waveguide which is formed by a gap between a gold film and a gold nanowire. The design follows Ref. [2] and [3] and includes emitter-free spacing layers between active medium and metal [4] which will be benefitial to achieve lower spasing thresholds. We optimize our design towards a well defined energy distribution in the gap and low propagation losses. We present a feasible fabrication technique based on relatively simple and quick methods like spin-coating, ellipsometry and stamping as well as first fluorescence studies.

[1] Stockman, M. I., Journal of Optics 12, 024004 (2010) [2] Oulton, R. F. et al., Nature 461, 629-632 (2009) [3] Russell, K. J. et al., Nature Photonics 6, 459-462 (2012) [4] Kewes, G. et al., Arxiv 1408.7054 (2014)

DS 14.8 Tue 12:15 MA 043

Material contrasts of layered Phase Change Materials in s-SNOM — •Martin Lewin, Benedikt Hauer, Ann-Katrin U. Michel, and Thomas Taubner — Institute of Physics (IA), RWTH Aachen University, 52056 Aachen, Germany

Phase Change Materials (PCM) show at least two stable states in the solid phase with significantly different physical properties. They can be switched reversibly by optical or electronical means, which enables their use for storage and logical applications [1].

Scattering-type Scanning Near-field Optical Microscopy (s-SNOM) is based on an illuminated metal coated tip being scanned over a sample. Due to the local detecting approach, the optical properties of the sample can be analysed wavelength-independently on a nm-scale [2].

Hence, s-SNOM can be used to investigate the switching in nanometre sized phase change devices: We could show that it is possible to distinguish amorphous and crystalline regions of AgInSbTe even below 100 nm of capping layer. Firstly, the material contrasts of a bare 30 nm thick layer of AgInSbTe with and without capping layer are analysed. Secondly, correlative TEM and s-SNOM analyses are performed of a sandwiched amorphous layer with crystalline spots. The found complex material contrasts are explained by theoretical calculations taking into account the layered structure of the sample.

[1] M. Wuttig and N. Yamada, Nature Mater. 6, pp. 824-832 (2007) [2] F. Keilmann and R. Hillenbrand, Phil. Trans. R. Soc. Lond. A 362, pp. 787-805 (2004)

DS 14.9 Tue 12:30 MA 043

Surfactant-Controlled Kinetic Overgrowth of Gold Rods into Gold-Core Silver-Shell Rodboids to Induce Controlled Internal Mirror Charges — •Tobias König, Moritz Tebbe, Martin Mayer, Christian Kuttner, and Andreas Fery — Physical Chemistry II, University of Bayreuth, 95447 Bayreuth, Germany

We present the surfactant-controlled overgrowth of gold nanorods into gold-core silver-shell nanoparticles (rodboids) to gain low growth rates for full control of the kinetic process. In gold-core silver-shell rodboids not much attentions has been paid to the overlap region of the intraband gaps of gold and silver (326 to 515 nm). In this optical region, the gold core acts as a retarding element because of the much higher damping in the core compared to the silver shell. Electromagnetic simulations show that the silver shell induces mirror charges at the core/shell interface which results in a similar signature as an antibonding mode. An excitation outside the overlap region yields in-phase oscillations of the surface charges (signature of a bonding mode). In contrast to plasmonic hybridization, the energetic splitting of the two modes is weaker so that both modes are present in the optical spectrum. Consequently, full control over the kinetic process allows for precise tailoring of the resonance wavelengths of both modes. Tailored rodboids represent ideal candidates as a building block for metamaterials and are suitable for application as optical sensor, light harvesting, and information technology.

DS 14.10 Tue 12:45 MA 043

Strongly Coupled Plasmonic Modes of Self-Assembled Particles Lines in the Context of Ensemble-Averaging and Disorder — •Christian Kuttner, Christoph Hanske, Moritz Tebbe, Tobias König, and Andreas Fery — Physical Chemistry II, University of Bayreuth, 95447 Bayreuth, Germany

We present ensembles of gold nanoparticle arranged in single and double lines on solid substrates.[1] These linear assemblies were formed by template-assisted self-assembly[2,3] of monodisperse protein-coated gold nanoparticles in wrinkle templates. The substrates exhibit high structural regularity on centimeter-squared areas which allow for characterization of their extinction cross-sections by conventional UV/vis/NIR spectroscopy.

Modeling based on electrodynamic simulations shows a clear signature of strong plasmonic coupling with an interparticle spacing of 1-2 nm. We find evidence for well-defined plasmonic modes of quasi-infinite chains.[1] Beyond elementary simulations on the individual chain level, we introduce an advanced model taking parameters like the chain length distribution, ensemble-averaging, as well as interchain disorder into account.[1]

[1] C. Hanske et al. Nano Lett. 2014, in press.
[2] C. Lu et al. Soft Matter, 2007, 3, 1530-1536.
[3] N. Pazos-Perez et al. Chem. Sci., 2010, 1, 174-178.

DS 14.11 Tue 13:00 MA 043

New details about monocrystalline goldflakes for plasmonic applications — •Thorsten Feichtner[1], Muhammad Bashouti[1], Björn Hoffmann[1], Achmed Salaheldin[2], Mirza Mačković[3], Christel Dieker[3], Peter Richter[4], Ovidiu Gordan[4], Dietrich Zahn[4], Erdmann Spieker[3], and Silke Christiansen[1,5] — [1]Max Planck Institute for the Science of Light (MPL), 91058 Erlangen, Germany — [2]Universität Erlangen-Nürnberg, Institute of Particle Technology, 91058 Erlangen, Germany — [3]Universität Erlangen-Nürnberg, Center for Nanoanalysis and Electron Microscopy (CENEM), 91058 Erlangen, Germany — [4]Semiconductor Physics, Technische Universität Chemnitz, 09107 Chemnitz, Germany — [5]Helmholtz Centre Berlin for Materials and Energy (HZB), 14109 Berlin, Germany

Wet-chemical synthesis of nm-thin, large area gold flakes is a viable method to realize a flat, monocrystalline raw material for fabricating high quality plasmonic devices. Transmission electron microscopy (TEM) proved the gold flakes being single crystalline except for twin boundary formation parallel to the flake surface. Micro-ellipsometry allowed to determine their complex dielectric constant for the first time. The flakes were polished by focused ion beam (FIB) milling and analyzed with electron backscatter diffraction (EBSD). The gold flakes remain monocrystalline down to a thickness of ≈10 nm allowing state-of-the-art nanofabrication processing to obtain nano-antennas or other desired plasmonic structures at sizes and structure perfections impossible with evaporated, poly-crystalline gold thin films.