O 37: Plasmonics and Nanooptics 1

Time: Wednesday 10:30–12:45 Location: H3

Topical Talk O 37.1 Wed 10:30 H3

Merging integrated photonics with free-electron beams — •Armin Feist — Max Planck Institute for Multidisciplinary Sciences, 37077 Göttingen, Germany

The coherent coupling of electrons and light is at the heart of free-electron quantum optics [1]. However, fully exploring its capabilities requires supreme control over the electron beam and optical quantum states involved. This suggests combining integrated photonics with electron microscopy.

In this talk, I will briefly introduce the basic principles and selected applications of inelastic electron-light scattering in an ultrafast transmission electron microscope (UTEM) [2,3], including the nanoscale imaging of confined optical modes and shaping of electron beams in space and time [4].

Recent progress in coupling single electrons to high-Q integrated photonic microresonators will be discussed, enabling highly efficient continuous-wave optical phase modulation of electron beams and nanoscale-μeV spectroscopy of a photonic mode [5]. Furthermore, spontaneous scattering at the empty resonator modes creates electron-photon pair states [6], opening a pathway towards a new class of heralded single-electron or Fock-state photon sources.

[1] K. Wang *et al.*, Optics & Photonics News **31**, 35 (2020). [2] Barwick *et al.*, Nature **462**, 902 (2009). [3] A. Feist *et al.*, Nature **521**, 200 (2015). [4] F.J. García de Abajo & V. Di Giulio, ACS Photonics **8**, 945 (2021). [5] J.W. Henke *et al.*, Nature **600**, 653 (2021). [6] A. Feist *et al.*, arXiv:2202.12821 (2022).

O 37.2 Wed 11:00 H3

Near-field spectroscopic predictions of low-temperature, gate-tunable plasmon-phonon coupling in the $LaAlO_3/SrTiO_3$ two-dimensional electron gas — •Julian Barnett[1], Yigong Luan[1], Felix Gunkel[2], and Thomas Taubner[1] — [1]I. Institute of Physics (IA), RWTH Aachen University — [2]Peter Grünberg Institute, Forschungszentrum Jülich

Heterointerfaces of $SrTiO_3$ and $LaAlO_3$ give rise to a buried two-dimensional electron gas (2DEG) between polar insulators, that is very sensitive to local defects but difficult to characterize on the nanoscale. It was recently shown that scanning near-field optical microscopy (SNOM) enables the extraction of local 2DEG properties with nanoscale lateral resolution by using phonon-enhanced near-field spectroscopy. Interestingly, the 2DEG mobility increases strongly at low temperatures and the charge carrier concentration can be tuned via gating, allowing control over the electronic properties.

Here, we predict that the plasmon-phonon-coupled near-field response will undergo a transition from a phonon-dominated regime to a plasmon-dominated regime with rising 2DEG mobility, which translates to a fundamentally different near-field spectrum. Additionally, we show that the plasmon-dominated regime could allow for the extraction of the 2DEG depth distribution with nanoscale lateral resolution, potentially enabling its mapping around defects. These insights can be directly transferred to the spectroscopic near-field investigation of 2DEGs, surface accumulation layers, and topologically protected surface states in a variety of bulk materials and heterostructures.

O 37.3 Wed 11:15 H3

Generation of Rotating Fields via Archimedean Spirals — •Esra Ilke Albar, Heiko Appel, and Franco Bonafe — Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science,22761 Hamburg, Germany

Twisted light (optical vortex), has the distinctive feature that it carries orbital angular momentum. This special type of electromagnetic field promises exciting opportunities for the interaction with matter, and it is expected to enhance spectroscopic techniques. Twisted light already has a vast potential of applications ranging from astronomy and optical tweezers to spintronics. Given this broad spectrum of applications and exciting prospects, it becomes worthwhile to investigate new and efficient methods to generate optical vortices. In this sense, metallic Archimedean spirals in the micro- and nanoscale are good candidates to produce such vortices. We design Archimedean spirals and test their performance in terms of generating field vortices. We perform numerical simulations with the Octopus code which employs the Riemann-Silberstein representation to propagate Maxwell's equations in real-time. Circularly-polarized light is passed through the designed structure, which is modeled both as a non-dispersive linear medium, and as Drude medium. We found that the out-coming field's angular momentum is altered by the structure. By using two different material models the effect of the materials' optical properties and the sole geometrical factors on the angular momentum outcome could be distinguished.

O 37.4 Wed 11:30 H3

Theory of radial oscillations in metal nanoparticles driven by optically induced electron density gradients — •Robert Salzwedel[1], Andreas Knorr[1], Dominik Höing[2,3], Holger Lange[2,3], and Malte Selig[1] — [1]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Institut für Physikalische Chemie, Universität Hamburg, 20146 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

Upon optical excitation, metal nanoparticles oscillate in radial breathing modes. These oscillations are assumed to be driven mainly by the thermalization of hot electrons impulsively heating the lattice, which can be described classically [1,2]. Based on a combined approach of quantum hydrodynamics and Heisenberg equations of motion for the optical excitation of electron gas in metal nanoparticles and the associated electron-phonon interaction, we discuss the contribution of additional coherent sources to the radial breathing oscillations.

Our results reveal a more direct coupling mechanism between the field and phonons compared to the established interpretation of experiments: the optical pulse induces spatial gradients in the electron density that drive phonon oscillations coherently and directly on the time scale of the optical excitation. Therefore, thermal and coherent contributions must be considered in the early times of the oscillation.

[1] Hartland, G. V. et al., *JCP*, **116**, 8048 (2002)
[2] Hodak, J. H. et al., *JCP*, **111**, 8613 (1999)

O 37.5 Wed 11:45 H3

Near-field imaging of hyperbolic shear polaritons in gallium oxide — •Sören Wasserroth[1], Joseph R. Matson[2], Xiang Ni[3], Giulia Carini[1], Katja Diaz-Granados[2], Maximilan Obst[4], Enrico Maria Renzi[3], Emanuelle Galifi[3], Susanne Kehr[4], Lukas M. Eng[4], Martin Wolf[1], Thomas G. Folland[5], Andrea Alu[3], Joshua D. Caldwell[2], and Alexander Paarmann[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [2]Vanderbilt University, Nashville, USA — [3]City University of New York, New York, USA — [4]Technische Universität Dresden, Dresden, Germany — [5]University of Iowa, Iowa, USA

Controlling the propagation direction and other properties of light in a material and at an interface is a very active field in current research. Strong anisotropy in crystals can lead to a hyperbolic dispersion featuring coupled light-matter interactions known as polaritons with highly directional propagation. Recently [1], it was shown that the additional anisotropy in monoclinic crystals, such as beta phase gallium oxide (bGO), gives rise to tilted wave fronts and asymmetric responses, called hyperbolic shear polaritons (HShPs).

Here, we will show mid-infrared free electron laser based near-field imaging of HShPs in bGO. Gold discs are used as local emitters on the bGO substrate. By changing the IR wavelength we observe the rotation and asymmetry of the HShPs. We compare the obtained images to simulated near-field contributions.

[1] Passler et al., Nature **602**, 595 (2022)

O 37.6 Wed 12:00 H3

Long-wave infrared super-resolution wide-field microscopy using sum-frequency generation — •Richarda Niemann[1], Sören Wasserroth[1], Guanyu Lu[2], Christopher R. Gubbin[3], Simone De Liberato[3], Joshua D. Caldwell[2], Martin Wolf[1], and Alexander Paarmann[1] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]Vanderbilt University, Nashville, USA — [3]University of Southampton, UK

We present our approach in infrared-visible (IR-VIS) sum-frequency generation (SFG) microscopy as a new tool for super-resolution imaging in the IR range.[1] Here, the imaging contrast in the microscope emerges from the IR resonances while the spatial resolution is provided by the SFG wavelength, i.e., well below the IR diffraction limit. As a proof of concept, we study localized phonon polaritons in subdiffractional nanostructures made of Silicon Carbide.[2,3] A free electron laser as IR light source offers high-power laser pulses with tunable wavelengths.[4] We are able to resolve phonon polariton modes in individual sub-diffractional nanostructures and achieve a spatial resolution of $\sim 1.4\,\mu$m corresponding to $\lambda_{IR}/9$.[1] Full spectral mapping over the whole SiC Reststrahlenband allows the spectroscopic identification of the polariton resonances, while the high spatial resolution reveals the microscopic origin of the SFG emission.

[1] R. Niemann et al., Appl. Phys. Lett. 120, 131102 (2022)
[2] J.D. Caldwell et al., Nanophotonics 4, 1 (2015)
[3] I. Razdolski et al., Nano Letters 16, 6954 (2016)
[4] W. Schöllkopf et al., Proc SPIE 9512, 95121L (2015)

O 37.7 Wed 12:15 H3

Observation of Hyperbolic Shear Polaritons in Monoclinic Crystals — •Giulia Carini[1], Nikolai C. Passler[1], Xiang Ni[2], Guangwei Hu[2,3], Joseph R. Matson[4], Martin Wolf[1], Mathias Schubert[5], Andrea Alù[2], Joshua D. Caldwell[4], Thomas G. Folland[6], and Alexander Paarmann[1] — [1]FHI, Berlin, Germany — [2]CUNY, NY, USA — [3]NUS, Singapore, Singapore — [4]Vanderbilt University, Nashville, TN,USA — [5]University of Nebraska, Lincoln, NE, USA — [6]University of Iowa, Iowa City, IA, USA

Surface phonon polaritons, light-matter coupled waves, have recently attracted much attention due to their versatility in nanophotonic applications in the infrared. In particular, highly anisotropic materials have been shown to support hyperbolic polaritons, which enable a deep sub-wavelength confinement of light [1,2].

In our contribution, we investigate the emergence of a new class of hyperbolic surface waves, that we call hyperbolic shear polaritons (HShPs), in the monoclinic crystal β-gallium oxide (bGO) [3]. The symmetry breaking in the in-plane hyperbolic propagation is directly linked to the frequency dependence of the optical axis directions within the monoclinic plane, resulting in shear phenomena in the non-diagonalizable dielectric permittivity tensor. We experimentally demonstrate the hyperbolic in-plane dispersion of these new polariton modes by means of Otto-type prism coupling.

[1] J. D. Caldwell, et al., Nat. Commun. 5, 5221 (2014).
[2] W. Ma, et al., Nature 562, 557-562 (2018).
[3] N. C. Passler, et al., Nature 602, 595-600 (2022).

O 37.8 Wed 12:30 H3

Transverse magnetic routing of light emission in hybrid plasmonic-semiconductor nanostructures: Towards operation at room temperature — •Lars Klompmaker[1], Alexander N. Poddubny[2], Eyüp Yalcin[1], Leonid V. Litvin[3], Ralf Jede[3], Grzegorz Karczewski[4], Sergij Chusnutdinow[4], Tomasz Wojtowicz[5], Dmitri R. Yakovlev[1,2], Manfred Bayer[1,2], and Ilya A. Akimov[1,2] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany — [2]St. Petersburg — [3]Raith GmbH, Konrad-Adenauer-Allee 8, 44263 Dortmund, Germany — [4]Institute of Physics, Polish Academy of Sciences, PL-02668 Warsaw, Poland — [5]International Research Centre MagTop, PL-02668 Warsaw, Poland

We studied the transverse magnetic routing of light emission from a hybrid plasmonic-semiconductor quantum well (QW) structure where the exciton emission from the QW is routed into surface plasmon polaritons propagating along a nearby semiconductor-metal interface. In our diluted magnetic semiconductor (Cd,Mn)Te/(Cd,Mg)Te QW structure the magnitude of routing is governed by the circular polarization of the exciton optical transitions, induced by the magnetic field. A strong directionality of emission of 15 % was measured at low temperatures of 20 K, but for increasing temperatures it decreases to 4 % at about 65 K due to the decreasing magnetic susceptibility. To avoid this strong temperature dependence we also suggest an alternative design based on a non-magnetic (In,Ga)As/(In,Al)As QW structure.