O 116: Focus Session: Structural Dynamics in Nanoscale Materials, Probed by Ultrafast Electron Pulses III

Time: Friday 10:30–12:45 Location: HE 101

Invited Talk O 116.1 Fri 10:30 HE 101

Imaging Coherent, Nanoscale Acoustic-Phonon Dynamics with Ultrafast Electron Microscopy — •David Flannigan, Daniel Cremons, Daniel Du, Dayne Plemmons, and Spencer Reisbick — University of Minnesota, Dept. of Chemical Engineering and Materials Science, Minneapolis, MN, USA

Here, I will describe our work on the development and the application of ultrafast electron microscopy [1]. I will begin with a brief overview of the UEM technology specific to our lab, focusing on imaging and operating at low instrument repetition rates. Following this, I will describe our progress in resolving the influence of nanoscale structural discontinuities on coherent, elastic strain-wave dynamics in a variety of materials [2-4]. For example, in transition-metal dichalcogenides, we find that wave trains emerge at extended discontinuities and that preferred propagation directions are independent of crystallographic orientation. In Ge, we find that individual phonon wave fronts propagate at hypersonic velocities and display a picosecond phase-velocity dispersion to the speed of sound. Overall, the observed dynamics indicate a single Lamb-type mode is excited several tens of picoseconds after femtosecond photoexcitation, suggestive of a link to charge-carrier dynamics via Auger recombination and the launch of electron-hole plasma waves.

[1] D. A. Plemmons and D. J. Flannigan, Chem. Phys. Lett. 683, 186 (2017). [2] D. R. Cremons, D. A. Plemmons, and D. J. Flannigan, Nat. Commun. 7, 11230 (2016). [3] D. R. Cremons, D. A. Plemmons, and D. J. Flannigan, Struct. Dyn. 4, 044019 (2017). [4] D. R. Cremons, D. X. Du, and D. J. Flannigan, Phys. Rev. Materials 1, 073801 (2017).

O 116.2 Fri 11:00 HE 101

Ultrafast TEM: probing nanoscale dynamics with coherent electron pulses — •Armin Feist[1], Nara Rubiano da Silva[1], Thomas Danz[1], Marcel Möller[1], Nora Bach[1], Katharina E. Priebe[1], Murat Sivis[1], Sascha Schäfer[1,2], and Claus Ropers[1] — [1]IV. Physical Institute, Universität Göttingen, Göttingen, Germany — [2]Institut für Physik, Universität Oldenburg, Oldenburg, Germany

Over the past decades, ultrafast techniques have shaped a rich picture of materials dynamics in spatially homogenous systems. Extending these concepts, ultrafast transmission electron microscopy (UTEM) combines the versatile imaging, diffraction and spectroscopy capabilities of state-of-the-art TEM with femtosecond temporal resolution achieved by a laser pump/electron probe scheme [1,2].

Here, we demonstrate local diffractive probing and phase-contrast imaging with nm-/fs- spatio-temporal resolution. The Göttingen UTEM instrument features photoemission from a nanoscale photocathode, delivering high coherence electron pulses of 0.6 eV energy width, down to sub-1 nm focal spot size, 200 fs pulse duration [2] and attosecond capability [3]. In particular, we employ ultrafast convergent beam electron diffraction (U-CBED) for the quantitative retrieval of the time- and space-dependent local deformation gradient tensor. Hereby, we map the optically induced acoustic lattice distortions, localized at the edge of a single-crystalline graphite thin film [4].

[1] A. H. Zewail, *Science*, **328**, 187 (2010). [2] A. Feist *et al.*, *Ultramicroscopy*, **176**, 63 (2017). [3] K. E. Priebe, *Nat. Photonics* **11**, 793 (2017). [4] A. Feist *et al.*, arXiv: 1709.02805.

O 116.3 Fri 11:15 HE 101

Generation of attosecond electron pulses via ponderomotive interaction with tailored light fields — •Martin Kozák[1,2], Timo Eckstein[1], Norbert Schönenberger[1], and Peter Hommelhoff[1] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstrasse 1, 91058 Erlangen, Germany, EU — [2]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 12116 Prague 2, Czech Republic, EU

In this contribution we experimentally demonstrate the generation of attosecond electron pulse trains via a novel technique based on the inelastic ponderomotive scattering of electrons at an optical travelling wave created by two laser pulses at different frequencies. A large modulation of the kinetic energy of 29 keV electrons with a peak acceleration gradient of G=2.2 GV/m (energy gain/travelled distance) was observed using this technique [1]. After the interaction, a time-correlated energy modulation of the electrons leads to a ballistic compression due to the dispersive propagation of the electrons in vacuum. Detection of the sub-cycle temporal structure in the post-interaction electron distribution was performed via energy streaking using a second phase-controlled travelling wave interaction. Measured spectrograms and their comparison with numerical calculations allow monitoring the evolution of the electrons' longitudinal phase space distribution. In the temporal focal plane, attosecond electron pulse trains are formed with an individual pulse duration of 300 as. [1] Kozák, M., Eckstein, T., Schönenberger, N. & Hommelhoff, P., Nat. Phys. (2017), DOI: 10.1038/NPHYS4282.

O 116.4 Fri 11:30 HE 101

meV Resolution in Laser-Assisted Energy-Filtered Transmission Electron Microscopy — •Enrico Pomarico[1], Ivan Madan[1], Gabriele Berruto[1], Giovanni Maria Vanacore[1], Kangepeng Wang[2], Ido Kaminer[2], F. Javier García de Abajo[3,4], and Fabrizio Carbone[1] — [1]Institute of Physics, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne CH-1015, Switzerland — [2]Andrew and Erna Viterbi Department of Electrical Engineering, Technion Israel Institute of Technology, 32000 Haifa, Israel — [3]ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [4]ICREA-Institució Catalana de Recerca i Estudis Avançats, Passeig Lluís Companys, 23, 08010 Barcelona, Spain

Dynamical characterization and manipulation of low energy excitations of quantum solids requires combining simultaneously nm-spatial, fs-temporal, and meV-spectral resolution.

We demonstrate a new method of spectrally-resolved photon induced near-field electron microscopy that allows us to obtain nm-fs resolved maps of nanoparticle plasmons with an energy resolution determined by the laser linewidth (20 meV in this work), and no longer limited by electron beam and spectrometer energy spreading (arXiv:1710.01183).

This technique can be extended to any optically-accessible low-energy mode, thus pushing TEM to a previously unattainable spectral domain with an unprecedented combination of space, energy, and temporal resolution.

O 116.5 Fri 11:45 HE 101

Time resolved X-Ray Photoelectron Diffraction of Quasi Freestanding Monolayer Graphene — •K Volckaert[1], D Kutnyakhov[2], M Bianchi[1], J Miwa[1], C Sanders[1], S Ulstrup[1], F Pressacco[2], G Brenner[2], K Medjanik[3], D Vasilyev[3], S Agustsson[3], Y-J Chen[8], F Speck[5], K Bühlmann[6], R Gort[6], F Diekmann[7], K Rossnagel[7], Y Acremann[6], T Seyller[5], C Tusche[4], H-J Elmers[3], G Schönhense[3], W Wurth[2], P Hofmann[1], and D Curcio[1] — [1]Aarhus University — [2]DESY Photon Science — [3]Johannes Gutenberg Universitat Mainz — [4]Forschungszentrum Jülich (FZJ) — [5]Technische Universitat Chemnitz — [6]ETH Zurich — [7]Christian-Albrechts-Universitat zu Kiel — [8]Universität Duisburg-Essen

We report the expansion for the first time of x-ray photoelectron diffraction (XPD) to the ultra-fast time domain by implementing it as a pump probe photoemission technique.

Conventional XPD has proven to be a powerful and efficient tool to probe structural order in matter. The expansion to the time domain allows the exploration of the structural dynamics in surfaces giving a completely new tool for the direct observation of surface structural dynamics.

The novel technique has been implemented at the FLASH free electron laser facility at DESY (Hamburg) by employing a time-of-flight momentum microscope, and it has been applied for the first time to give structural information on the dynamics of a quasi-freestanding monolayer graphene sample following excitation by a 800nm laser pulse.

O 116.6 Fri 12:00 HE 101

Femtosecond Electron Dynamics at the Single Atom Level — •Mohamad Abdo[1,2,3], Steffen Rolf-Pissarczyk[2,3], Björn Schlie[1,2,3], Luigi Malavolti[1,2,3], Jacob Burgess[3,4] und Sebastian Loth[1,2,3] — [1]Universität Stuttgart, Institut für Funktionelle Materie und Quantentechnologien, Stuttgart, Germany — [2]Max-Planck-

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Layered transition metal dichalcogenides (TMD) have complex electronic structure. Some of them as NbSe2 and TaS2, feature charge density wave (CDW) phases in which the electrons order with a periodicity that is incommensurate with the atomic lattice. Studies using optical pump probe techniques showed a picosecond response of the CDW [1] as well as a strong impact of pinning to atomic-sized defects [2]. Here we apply THz-coupled scanning tunneling microscopy [3] to measure the ultrafast dynamics of a CDW locally at individual atomic defects. Pairs of THz pulses excite the CDW and probe the response in the sample's density of states with a time resolution better than 200 fs. We find that the CDW responds to an excitation on a timescale well below 1ps and exhibits rich dynamics with a string spatial variation on the scale of one unit cell of the CDW. [1] X. Xi, et al. Nature Nanotechnology 10, 765-769 (2015) [2] P. Soumyanarayanan, PNAS 110, 1623-1627 (2013). [3] T. Cocker, et al., Nature Photonics 7, 620-625 (2013).

O 116.7 Fri 12:15 HE 101

Attomicroscopy: from femtosecond to attosecond electron pulse — •Mohammed Hassan — Physics Department, University of Arizona, Tucson, AZ, USA.

Ultrafast Electron Microscopy (UEM) has been demonstrated to be an effective table-top technique for imaging the atomic motion in real time and space. However, imaging the faster motion of electron dynamics has remained beyond the reach due to the lack of temporal resolution. Here, we demonstrate more than an order of magnitude (16 times) enhancement in the typical temporal resolution of UEM by generating isolated 30 fs electron pulses, accelerated at 200 KeV, via the optical-gating approach, with sufficient intensity for efficiently probing the electronic dynamics of matter in real time. Moreover, we explore the feasibility of attosecond optical gating to generate subfemtosecond electron pulses utilizing the optical attosecond pulse. which allow attaining the desired temporal resolution in electron microscopy for establishing the Attomicroscopy and image the electron motion in the act.

O 116.8 Fri 12:30 HE 101

Ultrafast electron diffraction in Troitsk: present state and perspectives — •Sergei Aseyev[1], Boris Mironov[1], Victor Kompanets[1], Anatoly Ischenko[2], Oleg Misochko[3], Sergei Chekalin[1], and Evgeny Ryabov[1] — [1]Institute of Spectroscopy, Russian Academy of Sciences, Troitsk, Moscow, 108840 Russia — [2]Moscow Technological University, pr. Vernadskogo 86, Moscow, 119571 Russia — [3]Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, Moscow region, 142432 Russia

The generation of coherent optical phonons in Sb film has been directly observed using table-top ultrafast electron diffractometer. The sample has been excited by a femtosecond laser pulse (λ = 800 nm) and probed with femtosecond photoelectron beam. Oscillations of the intensity corresponding to vibration frequencies of optical phonons excited by the laser have been observed in the obtained diffraction patterns: totally symmetric (A1g) and twofold degenerate (E2g) phonon modes of antimony and their combinations. Ultrafast electron diffraction method paves the way to study nonlinear phononics in perovskites and nonlinear photonics in molecular clusters.