HL 8: Ultra-fast Phenomena I

Time: Monday 15:00–18:15 Location: POT/0006

HL 8.1 Mon 15:00 POT/0006

Lightwave Engineering of Excitonic States in an Atomically Thin Semiconductor — •Omer Kneller[1], Niloufar Nilforoushan[1], Matthias Knorr[1], Markus Borsch[2], Fabian Mooshammer[1], Mackillo Kira[2], and Rupert Huber[1] — [1]Department of Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, Michigan 48109, USA

Coherently shaping excitonic states holds great potential for novel optoelectronics and quantum information processing. Yet, their femtosecond-scale coherence time substantially constrains coherent control. Here, intense phase-stable carrier waves of light resonantly drive the excitonic 1s-2p states in monolayer $MoSe_2$ faster than their natural decoherence rate, driving the excitonic system into multiple Rabi oscillations that occur during a single cycle of light. The dynamics are probed by injecting excitons into the 1s state using femtosecond NIR pulses and measuring the induced high-order sideband emission. The signal exhibits surprising spectro-temporal signatures that are reproduced by many-body simulations and a reduced two-level model, exposing the dominant role of the 1s-2p sub-system, even under these extreme driving conditions. An intuitive Floquet analysis links these features to light-induced avoided crossings between higher-order Floquet replicas of the driven two-level system. Our results bridge lightwave electronics in quantum materials, attosecond science, and atomic physics, and establish an exciting new route to shaping many-body quantum correlations at optical clock rates.

HL 8.2 Mon 15:15 POT/0006

Light-Induced Polarization Switching in R-Stacked Bilayer WSe_2 — •Xiangzhou Zhu, Stefono Mocatti, and Matteo Calandra — Department of Physics, University of Trento, Via Sommarive 14, 38123 Povo, Italy

Sliding ferroelectricity in two-dimensional van der Waals materials enables polarization control by relative layer motion, offering a promising platform for novel memory devices. Recent works show that strong laser pulses can reverse the polarization of such systems by driving shear phonons, but the required interlayer sliding and structural distortions limit the achievable switching speed. Here, we demonstrate a purely electronic pathway for light-induced polarization reversal in rhombohedrally stacked bilayer transition-metal dichalcogenides (TMDs). With constrained density-functional theory (cDFT), we find that photoexcited carrier densities below 0.2 e per unit cell are sufficient to switch the intrinsic ferroelectric dipole without interlayer sliding in WSe_2. This occurs because photoexcitation induces an imbalanced charge redistribution between the layers, which generates a counter-dipole. Using real-time semiconductor Bloch equation simulations, we shows that the total polarization can reverse by light within a few hundred femtoseconds. Furthermore, time-dependent charge analysis reveals that this ultrafast switching is primarily driven by a localized dipole rearrangement around the tungsten sites. These results establish a new mechanism for electronic control in 2D ferroelectrics, relevant for high-speed volatile memory applications.

Funded by the European Union (ERC, DELIGHT, 101052708)

HL 8.3 Mon 15:30 POT/0006

Ultrafast excitonic coherent oscillations in monolayer tungsten disulphide — •Jorge Cervantes Villanueva[1], Davide Sangalli[2], Alberto García-Cristóbal[1], and Alejandro Molina-Sánchez[1] — [1]Institut de Ciència dels Materials (ICMUV), Universitat de València, Catedrático José Beltrán 2, 46980 Paterna, Valencia, Spain — [2]Istituto di Struttura della Materia-CNR (ISM-CNR), Area della Ricerca di Roma 1, Monterotondo Scalo, Italy

Understanding coherent excitonic dynamics in two-dimensional semiconductors is crucial for advancing quantum-optical technologies. Monolayer transition metal dichalcogenides (TMDs) provide an ideal platform due to their strong Coulomb interactions and large exciton binding energies. We perform ab initio pump-probe simulations by propagating the time-dependent density matrix under the influence of overlapping pump and probe fields, capturing the generation and detection of coherent excitons on femtosecond timescales. Focusing on monolayer WS2 with a pump tuned between the A and B excitons, we observe ultrafast oscillations arising from coherent coupling among multiple excitonic states, including the intermediate A* resonance. Exploiting the balance between exciton populations, we propose a scheme to control the coherent response, realizing an optical switch with potential applications in quantum information. These results establish ab initio pump-probe modeling as a predictive tool for characterizing and manipulating coherent excitonic states.

HL 8.4 Mon 15:45 POT/0006

Carrier-envelope phase control of ultrafast photocurrents in layered MoS2 — •Johannes Schmuck[1,2], Björn Sinz[1,2], Nina Pettinger[1,2], Sergey Zherebtsov[1,2], and Alexander W. Holleitner[1,2] — [1]Walter Schottky Institute and Physics Department, Technical University of Munich, Garching, Germany — [2]Munich Center of Quantum Science and Technology, Munich, Germany

We demonstrate carrier-envelope-phase (CEP)-controlled photocurrents in mono-, bi-, and tri-layer MoS2 driven by few-cycle laser pulses. The photocurrent in the two-terminal devices scale quadratically with the field amplitude, indicating perturbative carrier dynamics in the weak-field regime distinct from strong-field tunnelling [1]. Our results extend light-field-sensitive current control from bulk dielectrics, semiconductors, and graphene to two-dimensional transition-metal dichalcogenides, highlighting their potential for electric-field sensitive optoelectronics.

[1] J. Schmuck et al., submitted, arXiv preprint arXiv:2511.08148 (2025).

HL 8.5 Mon 16:00 POT/0006

Development of an ultrafast scanning electron microscope — •Leon Kross[1], Benjamin Schröder[1], Niklas Wemheuer[1], Leon Brauns[1], Murat Sivis[1,2], and Claus Ropers[1,2] — [1]Max Planck Institute for Multidisciplinary Sciences, Göttingen, Germany — [2]University of Göttingen, 4th Physical Institute, Göttingen, Germany

Ultrafast electron microscopy (UEM) enables the study of structural and electronic dynamics in solid-state materials with nanoscale spatial and femtosecond temporal resolution [1]. While UEM at high ($>$ 30 keV) and low ($<$ 1keV) electron energies is well established, ultrafast experiments in the intermediate energy regime have been less employed thus far, despite their potential to bridge the gap between surface- and bulk-sensitive measurements. Here, we present a new ultrafast scanning electron microscope (USEM), designed to investigate physical phenomena in the energy range from 1 to 30 keV. The modular architecture supports diverse experimental configurations and detection schemes, spanning from standard SEM operation modes - such as secondary- and backscattered-electron imaging - to more advanced techniques including cathodoluminescence or electron diffraction. In this contribution, we show example measurements, highlighting the performance of our USEM and its potential for exploring ultrafast physical phenomena. [1] A. Feist et al. Ultramicroscopy, 176, 63-73 (2017)

HL 8.6 Mon 16:15 POT/0006

Ultrafast X-ray diffraction shows dynamics of phase domains make V2O3 films remember photoexcitation ten thousand times longer — •Oleg Gorobtsov[1,2], Yoav Kalcheim[3,4], Ziming Shao[1], Anatoly Shabalin[3], Nelson Hua[3], Daniel Weinstock[1], Ryan Bouck[1], Mathew Seaberg[5], Diling Zhu[5], Oleg Shpyrko[3], Ivan Schuller[3], and Andrej Singer[1] — [1]Cornell University, USA — [2]University of Tübingen, Germany — [3]University of California San Diego, USA — [4]Technion-Israel Institute of Technology, Israel — [5]SLAC National Accelerator Laboratory, USA

Metal-insulator transitions in vanadium oxides combine electronic and structural phase transformations. Memory effects present during the phase transition in thin V2O3 films make the material a candidate for neuromorphic computing, but what role does the structural phase heterogeneity play in memory? We used an X-ray free-electron laser probe to show that strain feedback on structural phase domain nucleation increases the metal-insulator relaxation time after an optically induced insulator-metal transition from nanoseconds to a hundred microseconds. The dynamic range and precision of the experiment distinguish that the memory follows a stretched exponential law, not a power law. We also provide an experimental basis for the transition incubation

times during the first 10 picoseconds after the excitation.

15 min. break

HL 8.7 Mon 16:45 POT/0006

Carrier-envelope phase modulation of ultrafast photocurrents in indium nitride — •Maximilian A. Gruber, Alexandra V. Nemmaier, Johannes Schmuck, Abhilash Ulhe, Gregor Koblmüller, and Alexander W. Holleitner — Walter Schottky Institute and Physics Department, Technical University of Munich, Munich, Germany

Few-cycle laser pulses allow for electronic transport at petahertz frequencies, where the carrier-envelope phase (CEP) controls the direction and strength of the ultrafast photocurrents. While such effects have been studied in graphene, bulk semiconductors and wide-bandgap dielectrics, their realization in group-III nitrides remains largely unexplored. We demonstrate CEPdependent photocurrents in InN devices excited by stabilized 6 fs optical pulses. The response reveals fieldsensitive contributions and strong interface effects close to the contacts of the investigated sample, highlighting the microscopic role of builtin electric fields in device architecture. The results position InN as a promising platform for CEP-controlled ultrafast transport.

HL 8.8 Mon 17:00 POT/0006

Towards studying quasi-particle interactions on the nanoscale — •Philipp Kessler, Matthias Hensen, Victor Lisinetskii, and Tobias Brixner — Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg

Investigating the properties and dynamics of quasi-particles is essential for tailoring material functionality in device fabrication. Nonlinear optical spectroscopy has become a standard tool for probing ultrafast single quasi-particle dynamics. However, the use of high light intensities, intended to improve the signal-to-noise ratio, can also generate multiple quasi-particle excitations, which may interact with each other. As a result, the measured signal consists of overlapping contributions from single- and multi-particle processes, each with distinct dynamics. To address this, our group recently developed the intensity cycling technique, which enables the experimental separation of individual perturbative orders in nonlinear light–matter interaction [1,2]. Here, we report our progress in extending this technique to time-resolved photoemission electron microscopy (PEEM) to study quasi-particle interactions with high spatial resolution. In our PEEM setup [3], we employ a 680 nm pump pulse with variable intensity for excitation and a 340 nm probe pulse for photoemission. This scheme allows us to investigate organic thin films of molecular aggregates, focusing primarily on exciton–exciton annihilation as a probe of exciton diffusion.

[1] P. Malý et al., Nature 616, 280-287 (2023).
[2] J. J. Krich et al., J. Phys. Chem. Lett. 16, 5897-5905 (2025).
[3] B. Huber et al., Rev. Sci. Instrum. 90, 113103 (2019).

HL 8.9 Mon 17:15 POT/0006

Watching polarons form in real time — •Victor Garcia-Herrero and Fabio Caruso — Institute of Theoretical Physics and Astrophysics, Christian-Albrechts University of Kiel, Germany

Polaron formation in pump-probe experiments is a fast, non-equilibrium process arising from the coupled motion of electrons and lattice vibrations, leading to the emergence of a localized quasiparticle. A new first-principles quantum-kinetic approach is introduced to track the real-time dynamics of electrons and the lattice under electron-phonon interactions. We applied this method to the polar insulators MgO and LiF, and determine the characteristic timescales of polaron localization and identify its unique dynamical signatures. The results reveal distinct dynamical signatures of polaron formation and establish clear, practical criteria for its detection in ultrafast pump-probe experiments, providing a direct connection between theory and experiment.

Founded by Marie Skłodowska-Curie Actions (MSCA), TIMES network.

HL 8.10 Mon 17:30 POT/0006

Dynamic control of electron correlations in photodoped charge-transfer insulators — •Thomas C. Rossi[1,2], Nicolas Tancogne-Dejean[3], Malte Oppermann[1,4], Michael Porer[5], Arnaud Magrez[6], Rajesh V. Chopdekar[7], Yayoi Takamura[7], Urs Staub[5], Renske M. van der Veen[2], Angel Rubio[3,8], and Majed Chergui[1,9] — [1]LSU and LACUS, EPFL, Lausanne, Switzerland — [2]PS-ADLU, HZB, Berlin, Germany — [3]MPI for the Structure and Dynamics of Matter, Hamburg, Germany — [4]Department of Chemistry, University of Basel, Switzerland — [5]SLS, PSI, Villigen, Switzerland. — [6]Crystal Growth Facility, EPFL, Lausanne, Switzerland — [7]Department of Materials and Science Engineering, UC Davis, USA — [8]ICC and CCQ, Simons Foundation Flatiron Institute, New York, USA — [9]Elettra-Sincrotrone, Trieste, Italy

Tuning the electronic properties of materials is typically achieved by altering their chemical composition or thermodynamic parameters. An alternative route relies on ultrafast light excitation, which can create transient phases such as light-induced superconductivity and hidden insulator-to-metal transitions. In this talk, I will present evidence of light-driven dynamic screening of electron correlations in a prototypical charge-transfer insulator, nickel oxide (NiO). The excited state, characterized by weakened electron correlations, is metastable for hundreds of picoseconds. The high degree of control achieved over both the energetic and temporal aspects of electronic correlations offers a promising path toward full optical control of the electronic properties of correlated systems and the Mott transition.

HL 8.11 Mon 17:45 POT/0006

Photostriction-Driven Phase Transition in Layered Chiral $NbOX_2$ Crystals: Electrical-Field-Controlled Enantiomer Selectivity — •Jorge Cardenas-Gamboa[1], Martin Gutierrez-Amigo[2], Aritz Leonardo[3], Gregory A. Fiete[4], Juan L. Mañes[3], Jeroen van den Brink[1], Claudia Felser[5], and Maia G. Vergniory[3] — [1]Institute for Theoretical Solid State Physics, IFW Dresden — [2]Department of Applied Physics, Aalto University — [3]Donostia International Physics Center — [4]Northeastern University, Boston — [5]Max Planck Institute for Chemical Physics of Solids

Controlling the handedness of crystal structures is essential for developing next-generation optical, electronic, and information technologies. Yet, achieving reversible and selective control over crystal chirality remains a major challenge. In this work, we demonstrate a two-step pathway for enantiomer selectivity in layered chiral $NbOX_2$ (X = Cl, Br, I) crystals based on photostriction-driven phase transitions. *Ab-initio* simulations reveal that optical excitation is capable of inducing a structural phase transition in $NbOX_2$ from the monoclinic ($C2$) ground state to the higher-symmetry ($C2/m$) structure. In the resulting transient high-symmetry state, an applied electric field breaks the residual inversion-symmetry degeneracy, selectively stabilizing one enantiomeric final state configuration over the other. Our results establish a combined optical-electrical control scheme for chiral materials, enabling reversible and non-contact enantiomer selection with potential applications in ultrafast switching, optoelectronics, and chiral information storage.

HL 8.12 Mon 18:00 POT/0006

Efficient Two-Dimensional Spectroscopy Simulations including Realistic Pulse Shapes, Overlapping, and Time-Ordering Effects — Rémi Gilliot[1,2], •Matteo Russo[1], Alexander Blech[1], Manuel Joffre[2], Christiane Koch[1], and Hélène Seiler[1] — [1]Freie Universität Berlin, Berlin, Germany — [2]Institut Polytechnique de Paris, Palaiseau, France

We present an approach capable of simulating Two-Dimensional Electronic Spectroscopy (2DES) spectra with arbitrary pulse shapes, pulse overlap, and pulse ordering on a standard laptop. Under the assumption of simple dephasing, we show that the 2DES emitted signal - a convolution integral that involves pulses* fields and material response and that is traditionally challenging to evaluate numerically - reduces to a simple product of three independent one-dimensional integrals. This fortunate simplification makes this approach fast and computationally less expensive than others, while still capturing most of the realistic pulse-dependent effects listed above. Finally, we benchmark the effectiveness of this approach on three canonical systems - an anharmonic oscillator, two coupled oscillators, and a dimer model - studying how spectral phase distortions and strongly non-Gaussian pulse shapes, such as those produced by hollow-core fibers, can influence the 2DES emitted signal.