TT 36: Focus Session: Ultrafast Spin, Lattice and Charge Dynamics of Solids

This focus session deals with a current and interdisciplinary topic, which is of interest to many researchers in solid state physics. The focus is on the generation and manipulation of new effects such as switching the macroscopic magnetic order, the driving of metal-insulator transitions, and the observation of purely quantum mechanical phenomena in excited states (e.g., the squeezing of phonons) on the femtosecond time scale using laser pulses. The long-term goal is the coherent control of degrees of freedom in solids. The relevant issues are light-matter interaction on the ultrashort time scale, non-equilibrium dynamics of magnetic, phononic and electronic degrees of freedom, many-particle physics and strong correlations.

Organizers:

Davide Bossini, University of Konstanz and Götz S. Uhrig, TU Dortmund University

Time: Friday 9:30–12:15 Location: H10

Invited Talk TT 36.1 Fri 9:30 H10
Coherent control of lattice and electronic states — •Steven Johnson — ETH Zurich, Zurich, Switzerland — Paul Scherrer Institut, Villigen, Switzerland

In this presentation I discuss a selection of recent efforts to use ultrafast light pulse excitation ranging from near-infrared to THz wavelengths to achieve control over both structural and electronic degrees of freedom in condensed phase materials. In one example, ultrafast excitation of a quasi-2D material results in a large-scale coherent modulation of structure (as seen by femtosecond x-ray diffraction) and associated carrier effective masses. These modulations are strongly connected to a nearby topological phase transition. In another example I discuss experiments uisiing high field THz pulses to drive both coherent and incoherent carrier dynamics in a narrow-gap semiconductor, and describe how these dynamics can be inferred from multidimensional THz spectroscopy. The results demonstrate that carrier multiplication effects become dominant at moderately intense field strengths. In the final example I will discuss ongoing efforts to use combinations of high- and low-frequency light excitation to drive nonlinear structural dynamics in a soft mode ferroelectric.

Invited Talk TT 36.2 Fri 10:00 H10
New opportunities for light-matter control of quantum materials — •Michael Sentef — Max Planck Institute for the Structure and Dynamics of Matter, Hamburg

In this talk I will discuss recent progress in controlling and inducing materials properties with light [1]. Specifically I will discuss recent experiments showing light-induced superconducting-like optical responses through phonon driving in an organic kappa salt [2], and their possible theoretical explanation via dynamical Hubbard U [3]. I will then highlight some recent theoretical and experimental progress in cavity quantum materials [4,5], where the classical laser as a driving field of light-induced properties is replaced by quantum fluctuations of light in confined geometries. Ideas and open questions for future work will be outlined.

[1] Rev. Mod. Phys. 93, 041002 (2021)
[2] Phys. Rev. X 10, 031028 (2020)
[3] Phys. Rev. Lett. 125, 137001 (2020)
[4] Applied Physics Reviews 9, 011312 (2022)
[5] J. Phys. Mater. 5, 024006 (2022)

Invited Talk TT 36.3 Fri 10:30 H10
Coherent electronic control of an insulator-to-metal transition — •Claudio Giannetti, Paolo Franceschini, and Alessandra Milloch — Università Cattolica del Sacro Cuore, Brescia (Italy)

Managing light-matter interaction on timescales faster than the loss of electronic coherence is key for achieving the full quantum control of final products in solid-solid transformations. Here, we demonstrate coherent electronic control of the photoinduced insulator-to-metal transition in the prototypical Mott insulator V_2O_3. Selective excitation of a specific interband transition with two phase-locked light pulses manipulates the orbital occupation of the correlated bands in a way that depends on the coherent evolution of the photoinduced superposition of states.

Comparison between experimental results and numerical solutions of the optical Bloch equations indicates an electronic coherence time on the order of 5 fs. Temperature dependent experiments suggest that the electronic coherence time is enhanced in the vicinity of the insulator-to-metal transition critical temperature, thus highlighting the role of fluctuations in determining the electronic coherence. These results open new routes to selectively switch functionalities of quantum materials and store quantum information in solid-solid transformations.

15 min. break

Invited Talk TT 36.4 Fri 11:15 H10
Nanoscale transient magnetization dynamics: A comprehensive EUV TG study — •Laura Foglia — Elettra Sincrotrone Trieste, Trieste, Italy

The advent of X-ray free electron lasers (FELs) has allowed to overcome the wavelength limitations of optical radiation to manipulate and study magnetic phenomena on nanometer length- and femtosecond time-scale, which is paramount for light-controlled ultrafast magnetic data processing and storage applications. In this talk, we review the most recent advances on the EUV TG-based investigation of nanoscale transient magnetization dynamics, a technique pioneered at the FERMI FEL in Trieste, Italy. First, we show how EUV-TG is capable of inducing transient magnetization gratings which decay within tens of picoseconds via thermal diffusion. Building upon this first demonstration, we investigate the transition from ultrafast demagnetization to all-optical switching (AOS) by looking at the ratio between the first and the second order of diffraction as a function of excitation fluence. Indeed, the non-linear fluence dependence of AOS induces a non-uniform spacing of the magnetization pattern that results in the appearance of even diffraction orders. Finally, we compare the magnetization dynamics induced by intensity gratings with those launched by polarization gratings, obtained when the two excitation beams have orthogonal polarization. Here, the intensity distribution on the sample is uniform and ultrafast the formation of transient magnetization gratings has to be associated to the coupling of majority and minority spins with the electric field polarization.

Invited Talk TT 36.5 Fri 11:45 H10
Ultrafast magnetism of antiferromagnets — •Alexey Kimel — Radboud University, Nijmegen, The Netherlands

Antiferromagnets are ideal candidates to reach the THz landmark in data storage with no additional energy costs. However, the lack of a net magnetization in the antiferromagnetic ground state requires exceedingly high magnetic fields to manipulate the spins, hindering even fundamental studies on the control and switching of antiferromagnets. Here we propose an approach to empower THz control of antiferromagnetic order by pushing antiferromagnet out of equilibrium through a generation of coherent magnonic states. We will show that an antiferromagnet out of equilibrium is practically a different material. Generation of coherent magnonic states in antiferromagnets substantially modifies the susceptibility of antiferromagnetic spins to THz magnetic fields and facilitates energy transfer between otherwise noninteracting phononic and magnonic modes [1,2]. In this case, the generated impact on spins goes far beyond trivial superposition of excitations and can facilitate conceptually new ways for controlling antiferromagnetism. The proposed theoretical description suggests that spin dynamics in antiferromagnets is intrinsically non-linear and once coherent magnonic state is induced, additional channels of energy transfer between otherwise orthogonal modes open up.

[1] E. A. Mashkovich, K. Grishunin, R. Dubrovin, R. V. Pisarev, A. K. Zvezdin and A. V. Kimel, Science 374, 1608 (2021)
[2] Th. Blank et al. (in preparation)