MA 26: Ultrafast Magnetization Effects I

Time: Wednesday 15:00–18:45 Location: H16

MA 26.1 Wed 15:00 H16

Terahertz field assisted magneto-optical effects in nonmagnetic substrates — •Sergey Kovalev[1], Igor Ilyakov[2], Anneke Reinold[1], Patrick Pilch[1], Ahmed Ghalgaoui[1], Ruslan Salikhov[2], Jürgen Lindner[2], Cong Li[3], Jianbing Zhang[3], Pu Yu[3], and Zhe wang[1] — [1]Fakultät Physik, Technische Universität Dortmund, Dortmund, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [3]Tsinghua University, China

Coherent control of matter on ultrafast timescales is attracting much attention due to numerous applications in advanced technologies. Strong terahertz (THz) fields are highly demanded in many of these studies, which focus on the control of carrier flow, spin dynamics, orbital polarisation and various aspects of nonlinear electron dynamics. For these studies it is very important to understand and disentangle different THz field induced processes occurring in the investigated systems and their substrates. In this contribution, we present two effects that occur in fused silica [1] and in LaAlO3 driven by strong THz field, resulting in rotation of laser pulse polarisation. These observations are due to the magneto-optical effect in amorphous systems or the Kerr electro-optical effect in anisotropic systems. Our results show that in general these effects should be carefully considered in the studies of ultrafast THz magnetisation dynamics by ultrafast pump-probe approaches. [1] S. Kovalev et al., Optics Letters 49, 4749 (2024)

MA 26.2 Wed 15:15 H16

Photoinduced spectral manipulation of coherent magnonics in ultrathin iron garnets — •Volker Wiechert[1], Moritz Cimander[1], Hanchen Wang[2], William Legrand[3], Pietro Gambardella[2], and Davide Bossini[1] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [2]Department of Materials, ETH Zürich, Hönggerbergring 64, CH-8093 Zürich, Switzerland — [3]Unité Mixte de Physique, CNRS, Université Paris-Saclay, Palaiseau 91767, France

Iron garnets, particularly Bi:YIG thin films, are promising materials for magnonics and magnetotransport due to their low damping and tunable magnetic properties through doping or external magnetic fields [1]. Recent advances demonstrate the ability of ultrashort laser pulses to excite, control, and even switch magnetization with minimal heating [2-4]. In this study, we investigate Bi:YIG single crystals in quasi-2D ultrathin form (~20 nm), using a femtosecond, balanced-detection scheme to capture simultaneous optical and magneto-optical responses. Our findings reveal two pathways for modifying magnetic resonance eigenfrequency: an impulsive femtosecond modification of magnetocrystalline anisotropy and a nanosecond lattice-mediated heating effect. This dual effect is quantitatively identified in time-resolved experiments, with potential applications in other quasi-2D ultrathin magnetic systems exhibiting temperature-dependent phase transitions.

[1] C. Holzmann et al., ACS Appl. Nano Mater. 5(1), 2022 [2] F. Hansteen et al., PRB 73, 2006 [3] L. Soumah et al., PRL 127, 2021 [4] A. Stupakiewicz et al., Nature 542, 2007

MA 26.3 Wed 15:30 H16

Ultrafast Entropy Production in Non-Equilibrium Magnets — •Finja Tietjen and R. Matthias Geilhufe — Chalmers University of Technology, Gothenburg, Sweden

We present an ultrafast thermodynamics framework to model heat generation and entropy production in laser-driven ferromagnetic systems. By establishing a connection between the magnetic field strength of the laser pulse and magnetization dynamics we model time-dependent entropy production rates and deduce the associated heat dissipation in epitaxial and polycrystalline FeNi and CoFeB thin films. Our theoretical predictions are validated by comparison to experimental magnetization dynamics data, shedding light on thermodynamic processes on picosecond timescales.

Crucially, we incorporate recently observed inertial spin dynamics, to describe their impact on heat generation in pump-probe experiments. As such, this formalism provides novel insights into controlling heat production in magnetic systems, and contributes to advancing the understanding of non-equilibrium thermodynamics in magnetic systems, with implications for future experimental protocols in spintronics and nanotechnology.

[1] F. Tietjen, & R. M. Geilhufe (2024). Ultrafast Entropy Production in Non-Equilibrium Magnets. arXiv preprint arXiv:2410.23205.

MA 26.4 Wed 15:45 H16

Spin-lattice modeling of elastic waves generated by ultrafast demagnetization in fcc Ni — •Ievgeniia Korniienko[1], Pablo Nieves[2], Alberto Fraile[3], Roberto Iglesias[2], and Dominik Legut[1] — [1]IT4Innovations, VSB-TU Ostrava, Ostrava, Czech Republic — [2]University of Oviedo, Oviedo, Spain — [3]Catalan Institute of Nanoscience and Nanotechnology (ICN2), Barcelona, Spain

Picosecond ultrasonics is a fast growing and advanced research field with broad application to the imaging and characterization of nanostructured materials as well as at a fundamental level. Experiments that provide direct, layer-specific, and quantitative information on the picosecond strain response [1], however, face comparably limited theoretical descriptions and modeling. In our work we propose a 3D model on the base of atomistic spin-lattice simulations [2] for laser-induced elastic response. As an example for testing our modeling approach we use ferromagnetic fcc Ni. Such choice allows us not only to calculate the lattice elastic response including ultrafast thermal expansion, but also to characterize the magnetic contribution to stress in this material [3]. The theoretical approach presented in our work [3] can be useful for further interpretations of experiments in the picosecond ultrasonics, as well as for providing other required parameters (like ultrafast thermal expansion coefficient) in micromagnetic models, e.g. within a multiscale approach. References: [1] M. Mattern, et al.: Photoacoustics 31, 100503 (2023); [2] P. Nieves, et al.: Phys. Rev. B 103, 094437 (2021); [3] I. Korniienko, et al.: Phys. Rev. Research 6, 023311 (2024).

MA 26.5 Wed 16:00 H16

Ultrafast orbital Hall effect in metallic nanoribbons — •Oliver Busch, Franziska Ziolkowski, Börge Göbel, Ingrid Mertig, and Jürgen Henk — Institut für Physik, Martin-Luther-Universität, D-06099 Halle

The orbital Hall effect can generate currents of angular momentum more efficiently than the spin Hall effect in most metals. However, so far, it has only been understood as a steady-state phenomenon [1]. In this theoretical study, the orbital Hall effect is extended into the time domain [2]. We investigate the orbital angular momenta and their currents induced by a femtosecond laser pulse in a Cu nanoribbon.

Our numerical simulations provide detailed insights into the laser-driven electron dynamics on ultrashort timescales with atomic resolution. As we show, the ultrafast orbital Hall effect described here is consistent with the familiar pictorial representation of the static orbital Hall effect, but we also find pronounced differences between physical quantities that carry orbital angular momentum and those that carry charge. For example, there are deviations in the time series of the respective currents. This work lays the foundations for investigating ultrafast Hall effects in confined metallic systems.

[1] D. Go *et al.* Europhysics Letters **135**, 37001 (2021)
[2] O. Busch *et al.*, Physical Review Research **6**, 013208 (2024)

MA 26.6 Wed 16:15 H16

Ultrafast magnetization dynamics of magnetic garnet thin films — •Paul Herrgen[1], Christian Holzmann[2], Manfred Albrecht[2], Benjamin Stadtmüller[2], and Martin Aeschlimann[1] — [1]Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]Institute of Physics, University of Augsburg, 86159 Augsburg, Germany

The rare-earth iron garnets (REIG) are a class of magnetic oxide materials, known for their excellent magneto-optical properties, high magnetic permeability, and applications in photonics and spintronics. [1]

In our work we investigate the ultrafast magnetization dynamics of a gadolinium iron garnet (GdIG) thin film after an excitation with an ultrashort laser pulse. Our static characterization of the magnetic properties revealed hysteresis loops with opposite sign of the saturation magnetization for equal field directions depending on the probe photon energy. This points to a photon energy dependent magnetic response of both sublattices and allows us to disentangle their ultrafast response after optical excitation. We observe an ultrafast demagnetization of both sublattices within the first few hundred fs, after excitation with photon energies larger than the material's band gap. We find a different quenching for the signals of both sublattices despite the otherwise very similar demagnetization time. On longer timescales, we find another different behavior for the sublattices, with the iron sublattice starting to remagnetize much earlier than the gadolinium one.

[1]: C. Holzmann and M. Albrecht: Encyclopedia of Materials: Electronics 1, 777 (2023)

MA 26.7 Wed 16:30 H16

Accelerated ultrafast demagnetization of an interlayer-exchange-coupled Co/Mn/Co trilayer — •Jendrik Gördes[1], Ivar Kumberg[1], Chowdhury S. Awsaf[1], Marcel Walter[1], Tauqir Shinwari[1], Sangeeta Thakur[1], Sangeeta Sharma[2], Christian Schüssler-Langeheine[3], Niko Pontius[3], and Wolfgang Kuch[1] — [1]Institut für Experimentalphysik, Freie Universität Berlin, Berlin — [2]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin — [3]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin

We studied the influence of the spin structure of an antiferromagnetic (AFM) layer at the interface to a ferromagnetic (FM) layer on the FM magnetization dynamics in epitaxial Co/Mn/Co/Cu(001) trilayers. The two FM layers are coupled indirectly by the Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction and directly by exchange through the AFM spin structure [1]. Deposition of Mn in a wedge allowed for access to different coupling regimes on the same sample. Magnetization dynamics were probed after excitation with 800 nm fs laser pulses by X-ray magnetic circular dichroism in reflectivity. A difference in demagnetization time between the two regimes for parallel and antiparallel alignment of FM is observed. We explain this by differences in the AFM spin structure leading to presence or absence of optically induced intersite spin transfer [2] between Mn and Co. [1] B. Zhang *et al.*, J. Appl. Phys. 115, 233915 (2014). [2] J. K. Dewhurst *et al.*, Nano Letters 18, 1842 (2018)

15 min. break

MA 26.8 Wed 17:00 H16

Development of planar micro optics for ultrafast in-situ measurements in the TEM — •Max Herzog[1], Johannes Schultz[1], and Axel Lubk[1,2] — [1]IFF, IFW Dresden, Helmholtzstraße 20, 01069 Dresden — [2]IFMP, TU Dresden, Haeckelstraße 3, 01069 Dresden

The miniaturization of magnetic electron optics has been a goal for at least the past decade, because it will not only allow for smaller and easier to build electron optics, but will also result in other favorable scaling effects. Namely, the small scale allows for magnetic flux densities in the hundreds of millitesla with a significantly reduced power consumption and lower overall complexity regarding vacuum, cooling and power supply. More important for this work, however, is the small inductance that follows from the small size, which in turn allows the optics to be switched with radio frequencies (RF). The aim of this work is to lithographically produce planar micro optics (e.g. deflectors, focusing quadrupoles, vector magnets, etc.), that are capable of utilizing this RF switching to image ns-scale processes (e.g. the movement of magnetic domain walls) stroboscopically in a transmission electron microscope. The optics were characterized using differential phase contrast (DPC) to determine the spatial distribution of the magnetic field and by measuring the optical power (e.g. deflection, focusing behaviour) at varying switching frequencies. Using an acceleration voltage of 80 kV, the optics show a promising performance with a deflection power of up to 330 μrad at an excitation frequency of 7.5 MHz and still 120 μrad at 2 GHz with a very homogeneous magnetic field as determined by DPC.

MA 26.9 Wed 17:15 H16

Ultrafast energy-resolved spin dynamics in nickel — Christopher Seibel, Tobias Held, Markus Uehlein, •Sebastian T. Weber, and Baerbel Rethfeld — Department of Physics and Research Center OPTIMAS, RPTU Kaiserslautern-Landau

Magneto-optical methods were used when ultrafast magnetization dynamics were discovered and are still used intensively. Recent experiments show a strongly energy-dependent magneto-optic response and indicate spin transfer processes on the timescale of the pulse duration in a pure metallic ferromagnet [1].

We investigate the non-equilibrium spin dynamics on these early timescales by full spin-resolved Boltzmann collision integrals [2]. We trace the temporal evolution of the individual distribution functions of up and down electrons, where spin-flips due to electron-electron and electron-phonon collisions are taken into account.

From the dynamics of the distributions, we extract the spin-resolved densities of both, electrons and holes, at various energies. The energy-resolved spin polarization can vary significantly depending on the considered energy range. It can deviate from the overall magnetization dynamics, both in terms of the qualitative behavior and the timescales involved. Additionally, we present results on the non-equilibrium magneto-optic response calculated from the distribution functions.

[1] H. Probst et al., *Phys. Rev. Res.* **6**, 013107 (2024)
[2] B. Müller et al., *Phys. Rev. Lett.* **111**, 167204 (2013)

MA 26.10 Wed 17:30 H16

Differentiating mechanisms that drive ultrafast magnetization precession — •Fried-Conrad Weber[1,2], Maximilian Mattern[3], Jasmin Jarecki[3], Marwan Deb[1], Dieter Engel[3], Daniel Schick[3], Alexander von Reppert[1] und Matias Bargheer[1,2] — [1]Universität Potsdam — [2]Helmholtz-Zentrum für Materialien und Energie, Berlin — [3]Max-Born-Institut, Berlin

We use the time-resolved polar magneto-optical Kerr effect to measure the laser-induced magnetization precession of a 20 nm and 200 nm thin nickel film for different external magnetic field angles. We identify the role of quasi-static strain, strain pulses, and demagnetization for driving the precession in these samples. The magnetization response is modeled using the udkm1Dsim toolbox, which calculates the temperature, strain, and subsequent magnetization response with a modified Landau-Lifshitz-Gilbert equation that incorporates demagnetization. Contributions from the demagnetization-induced change in anisotropy, quasi-static strain, and propagating strain pulses are included in the time-dependent effective field. In the case of nickel, the quasi-static strain drives the effective field in the opposite direction to the demagnetization-induced change in anisotropy. For the samples and fluences measured, we identify the laser-induced strain and the subsequent change in the magnetoelastic field as the dominant mechanism controlling the precession. In a subsequent double-pulse excitation experiment, we balance the effect of the demagnetizationinduced change in anisotropy and the magnetoelastic contribution in a non-conventional coherent control scheme.

MA 26.11 Wed 17:45 H16

Temperature and Magnetic Field Dependence of Ultrafast Magnetization Dynamics — •Leon Seidel[1], Clemens von Korff Schmising[2], Tino Noll[2], Wolfgang-Dietrich Engel[2], Simon Gaebel[2], Daniel Metternich[2], and Stefan Eisebitt[1,2] — [1]Technische Universität Berlin — [2]Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie

In this work, we present a wide-field optical microscope designed to study the temperature and magnetic field dependence of ultrafast magnetization dynamics with femtosecond temporal and micrometer spatial resolution. The compact device integrates xyz, yaw and tilt adjustments as well as a motorized sample manipulation. The sample temperature is controlled by a continuous flow cryostat in a temperature range between 20 K / 80 K and 500 K using either LN2 or LHe. An inbuilt electromagnet provides an external magnetic field of up to one Tesla.

We show first results of ultrafast all-optical magnetization switching (AOS) in ferrimagnetic rare earth-transition metal alloys. We characterize two CoTbGd films with different stochiometries and systematically examine the role of the magnetization and angular momentum compensation for AOS.

MA 26.12 Wed 18:00 H16

Heterogenity of the laser-induced magneto-structural phase transition in FeRh revealed by ultrafast x-ray diffraction — •Maximilian Mattern[1], Jan-Etinne Pudell[2], Vojtech Uhlir[3], Jon Ander Arregi[3], Angel Rodriguez-Fernandez[2], Roman Shayduk[2], Wonhyuk Jo[2], Anders Madsen[2], and Daniel Schick[1] — [1]Max-Born-Institut, Germany — [2]European XFEL, Germany — [3]CEITEC BUT, Czech Republic

Laser-induced heterogeneities play an important role for ultrafast dynamics especially of first-order phase transitions due to the phase coexistence during nucleation. However, their probing on picosecond time and nanometer length scales is challenging.

We use time-resolved x-ray diffraction to reveal the transient nanoscale heterogeneity of the laser-induced first-order antiferromagnetic (AFM) to ferromagnetic (FM) phase transition in FeRh that is accompanied by a lattice expansion. Utilizing the good reciprocal space and femtosecond time-resolution of the MID instrument at the

European X-ray Free-electron laser, we individually track the picosecond shifts of the structural AFM and FM Bragg peak. The integral of the latter quantifies the transient fraction of the FeRh layer that is in the FM phase, and the signatures of the propagating picosecond strain pulses in the shift of both Bragg peaks reveal its spatial distribution. Our results can distinguish between different nucleation scenarios and reveal that the FM phase nucleates as laterally separated columns through the photoexcited near-surface region, finally forming a closed FM layer at the surface of the inhomogeneously excited FeRh film.

MA 26.13 Wed 18:15 H16

Ultrafast electron dynamics in altermagnetic materials — Marius Weber[1,2], •Kai Leckron[1], Luca Haag[1], Libor Šmejkal[2], Jairo Sinova[2], and Hans Christian Schneider[1] — [1]Department of Physics, University of Kaiserslautern-Landau, Germany — [2]Institut für Physik, Johannes Gutenberg University Mainz, Germany

One of the intriguing properties of altermagnetic materials is that a linearly polarized optical pulse can induce a spin polarization of the electrons depending on the direction of the linear polarization [1]. This contribution investigates the impact of the polarization direction and fluence of the optical excitation on the ultrafast magnetization dynamics in the prototypical altermagnetic band structure of KRu4O8. We explicitly consider electron-electron scattering and electron-phonon scattering contributions to the light-driven carrier dynamics. The optical excitation is computed using ab initio dipole transition rates in the whole Brillouin zone. Our momentum-dependent calculation of the subsequent scattering dynamics fully includes the anisotropies of the altermagnet, which leads to unique k-resolved electron dynamics at ultrashort times and a long-lived spin polarization [2]. We present a numerical study of the influence of the excitation conditions on the lifetime of this spin polarization.

[1] M. Weber et al., arXiv:2408.05187 (2024) [2] M. Weber et al., arXiv:2411.08160 (2024)

MA 26.14 Wed 18:30 H16

The dynamics of a memory-enhanced LLG equation — •Felix Hartmann[1] and Janet Anders[1,2] — [1]University of Potsdam, Institute of Physics and Astronomy, Karl-Liebknecht-Str. 24-25, 14476 Potsdam, Germany — [2]Department of Physics and Astronomy, University of Exeter, Stocker Road, Exeter EX4 4QL, UK

Recently, Anders et al. [1] have proposed a stochastic Landau-Lifshitz-Gilbert (LLG) equation which takes into account memory effects and colored thermal fluctuations, with either a classical, semi-classical or quantum thermostat. In this talk we will present some recent results that characterize the spin dynamics in different parameter regimes. We show how the proposed stochastic LLG equation has a well-described white-noise and Markovian limit of the spin dynamics. Further, going beyond the white-noise and Markovian limit, we present numerical results that show strong ultrafast and inertial effects in the spin dynamics, such as a faster relaxation and the appearance of nutation oscillations.

[1] J. Anders et al., New J. Phys. 24 033020 (2022)