MA 21: Ultrafast Magnetization II

Time: Tuesday 9:30–13:15 Location: HSZ 101

MA 21.1 Tue 9:30 HSZ 101

Ultrafast control of spin-spin interactions 2D antiferromagnetic layers — •Alireza Qaiumzadeh — Center for Quantum Spintronics, Norwegian University of Science and Technology

Light enables the ultrafast, direct, and nonthermal control of the spin-spin interactions.

In this work, we consider two types of antiferromagnetic systems: 1. A 2D honeycomb lattice antiferromagnetic spin-orbit Mott insulator, and 2. A 2D metallic Rashba antiferromagnetic system.

Based on the Floquet theory and time-dependent perturbation theory, we demonstrate that by changing the amplitude and frequency of polarized laser pulses, one can tune the amplitudes and signs of and even the ratio between the exchange and Dzyaloshinskii-Moriya spin interactions. Furthermore, the renormalizations of the spin interactions are independent of the helicity. Our results pave the way for ultrafast optical spin manipulation in recently discovered two-dimensional magnetic materials.

[1] J. M. Losada, A. Brataas, and A. Qaiumzadeh, Phys. Rev. B 100, 060410(R) (2019). [2] S. Ø. Hanslin, A. Brataas, and A. Qaiumzadeh, to be submitted (2020).

MA 21.2 Tue 9:45 HSZ 101

Ultrafast dynamics of itinerant and localized magnetic moments in antiferromagnetic $GdRh_2Si_2$ — •Sang-Eun Lee[1], Yoav William Windsor[1], Daniela Zahn[1], Kristin Kliemt[2], Cornelius Krellner[2], Denis V. Vyalikh[3], and Laurenz Rettig[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [2]Goethe-Universität Frankfurt, Frankfurt am Main, Germany — [3]DIPC, San Sebastián, Spain

The magnetic ordering in rare-earth based compounds is governed by the indirect exchange interaction (RKKY interaction) between the large, localized 4f-moments of the rare-earth atoms, mediated via the itinerant, weakly spin-polarized conduction electron bath. Yet how this coupling is active on an ultrafast timescale is still a matter of debate. $GdRh_2Si_2$ is an intermetallic model system, consisting of Gd layers stacked antiferromagnetically along the c-axis, separated by Si-Rh-Si slabs, which act as mediators for the RKKY interaction. Si-terminated surfaces of this compound have been shown to host metallic surface states at the surface Brillouin zone corners which become spin polarized due to the RKKY interaction below T_N [1]. Employing time- and angle-resolved photoemission spectroscopy (trARPES), and time-resolved resonant magnetic X-ray diffraction (trRXRD), we investigate the ultrafast dynamics of itinerant surface state electrons, and of long-range ordered localized magnetic moments, respectively. Combining these results, we will discuss the implications for the RKKY interaction and the demagnetization pathway in this antiferromagnetic compound.
[1] M. Güttler et al., Sci. Rep. 6, 24254 (2016)

MA 21.3 Tue 10:00 HSZ 101

Ultrafast excitation across the transition between antiferromagnetic phases. — •Yoav William Windsor[1], Daniela Zahn[1], Sang-Eun Lee[1], Kristin Kliemt[2], Cornelius Krellner[2], and Laurenz Rettig[1] — [1]Fritz-Haber-Institut der MPG (DE) — [2]Goethe-Universität Frankfurt (DE)

Antiferromagnetic spintronics are a promising route towards more efficient and stable devices. The prospect of employing antiferromagnets in devices opens new functionality pathways through properties that are not available with ferromagnets. One promising direction is light induced variations of the long-range spin arrangement.

Here we study Ho $4f$ spin dynamics in $HoRh_2Si_2$, a material with two antiferromagnetic phases with different spin arrangements: a high-T phase, in which all spins align (anti)parallel to [001], and a low-T phase in which they tilt by $\sim 30°$ away from [001]. This is a change in the local 4f anisotropy, caused by variations in the crystal field.

We excite the low-T phase with a femtosecond optical laser pulse and probe the antiferromagnetic order's response using time-resolved resonant X-ray diffraction. Using the anisotropy of magnetic scattering, we decouple demagnetization dynamics from spin-tilting dynamics. These dynamics are distinctly different, demonstrating that AF order and collective spin rearrangement do not evolve together upon excitation (unlike upon heating). We identify two regimes: excitation within the low-T phase, and exciting from low-T to the high-T phase. Implications on the crystal field and its relation to the RKKY coupling between the Ho $4f$ moments will be discussed.

MA 21.4 Tue 10:15 HSZ 101

Strain generation via two-photon absorbtion in Bi:YIG visualized with UXRD — •Steffen Peer Zeuschner[1,2], Jan-Etienne Pudell[1], Alexander von Reppert[1], Marwan Deb[1], Elena Popova[3], Niels Keller[3], Matthias Rössle[2], Marc Herzog[1], and Matias Bargheer[1,2] — [1]Institut für Physik und Astronomie, Universität Potsdam, 14476 Potsdam, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Wilhelm-Conrad-Roentgen Campus, BESSY II, 12489 Berlin, Germany — [3]Groupe d'Etude de la Matiére Condensée (GEMaC), CNRS UMR 8635, Université Paris-Saclay, 78035 Versailles, France

By ultrafast X-ray diffraction (UXRD) we quantify the strain from coherent and incoherent phonons generated by one- and two-photon absorption in bismuth-doped yttrium iron garnet (Bi:YIG). This ferrimagnetic insulator is a workhorse for laser-induced spin dynamics that may be excited indirectly via phonons. We identify the two-photon absorption by the quadratic fluence dependence of the transient strain and confirm a short lifetime of the intermediate state via the inverse proportional dependence on the pump-pulse duration. From this, we estimate the two-photon absorption coefficient at 800nm using the linear relation between strain and absorbed energy density. For below band gap excitation, large fluences of about 100 mJ/cm2 and a pulse duration of 120 fs lead to considerable strain amplitudes of 0.1% which are driven exclusively by two-photon absorption.

MA 21.5 Tue 10:30 HSZ 101

Ultrafast lattice dynamics of 3d ferromagnets — •Daniela Zahn[1], Florian Jakobs[2], Tim Butcher[3], Thomas Vasileiadis[1], Yoav William Windsor[1], Dieter Engel[4], Helene Seiler[1], Yingpeng Qi[1], Unai Atxitia[2], Jan Vorberger[3], and Ralph Ernstorfer[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [2]Freie Universität Berlin, Berlin, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [4]Max-Born-Institut, Berlin, Germany

The behavior of ferromagnets after laser excitation is governed by the interplay of electrons, lattice and spins. In the case of 3d-ferromagnets, strong coupling between electrons and spins leads to ultrafast demagnetization on the femtosecond time scale. The lattice plays an important role in the magnetization dynamics, since it drains energy from the electrons on similar timescales and absorbs angular momentum from the spin system. Here, we study the lattice response of the 3d ferromagnets nickel, iron and cobalt directly using femtosecond electron diffraction (FED). We find excellent agreement of the experimental results with DFT calculations in combination with a modified two-temperature model (TTM) that assumes strong coupling between electrons and spins. In addition, we compare the experiment to atomistic spin simulations. Our results suggest that energy transfer between electrons and spins on ultrafast timescales has a strong effect on the lattice dynamics.

MA 21.6 Tue 10:45 HSZ 101

Photoinducing coherent Teraherz spin dynamics without spin waves — •M. Terschanski[1], S. Dal Conte[2], F. Mertens[1], G. Springholz[3], A. Bonanni[3], G. Uhrig[4], G. Cerullo[2], D. Bossini[1], and M. Cinchetti[1] — [1]Experimentelle Physik VI, TU Dortmund, Otto-Hahn-Straße 4, 44227 Dortmund, Germany — [2]Dipartimento di Fisica, Politecnico di Milano, Piazza L. da Vinci 32, 20133 Milano, Italy — [3]Institut fuer Halbleiterphysik, University of Linz, Altenberger Straße 69, 4040 Linz, Austria — [4]Theoretische Physik I, TU Dortmund, Otto-Hahn-Straße 4, 44227 Dortmund, Germany

Ultrafast coherent spin dynamics is generally induced generating magnon modes at their specific frequencies and according to their selection rules. Here we present a different approach: First, absorption measurements of hexagonal bulk α-MnTe revealed a coupling between the magnetic order and the band gap energy E_g below the Neél temperature ($T_N = 307$ K): a contribution to E_g proportional to the sublattice magnetization $\vec{M}$ was observed. Second, in a pump-probe experiment a 5 THz coherent phonon was induced, modulating the band-gap energy and thus the reflectivity of MnTe. Finally, we perform time-resolved magneto-optical measurements to assess whether the photo-induced band-gap dynamics affect the spin system. The temperature dependence of the magneto-optical signal proves that a 5 THz oscillation of the sublattice magnetization is driven by the band-gap dynamics. We thus disclose the excitation of coherent THz spin dynamics without the generation of magnons.

MA 21.7 Tue 11:00 HSZ 101

Spin-lattice dynamics from isotropic and anisotropic exchange — •Danny Thonig[1], Jacob Persson[2], Johan Hellsvik[3,4], Lars Nordström[2], Manuel Pereiro[2], and Jonas Fransson[2] — [1]School of Science and Technology, Örebro University, SE-70182 Örebro, Sweden — [2]Department of Material Theory, Uppsala University, Sweden — [3]Department of Physics, KTH Royal Institute of Technology, SE-106 91 Stockholm, Sweden — [4]Nordita, SE-106 91 Stockholm, Sweden

The understanding how magnons couple with phonons is of fundamental importance. It is dominantly caused by distance dependent exchange between the magnetic moment, such as RKKY-like Heisenberg or dipole-dipole interaction. Both exhibits changes in the magnetic order, say from ferro to antiferromagnetic states, related to the crystal structure, which is affected by displacements and call for deeper studies.

We report on an investigation of atomistic coupled spin-lattice dynamics by means of the Landau-Lifshitz-Gilbert and Newton equation. The exchange and force constant parameters of the Hamiltonian are approached by RKKY, Dzyaloshinskii-Moriya, and dipole-dipole interaction as well as Born-Landé exchange, respectively.

For low dimensional systems, we focus on the evolution from disordered to ordered states in dependence on temperature, island size, and external magnetic field. It turns out that spin and displacements have a crucial influence on each other, especially near magnetic order changes.

MA 21.8 Tue 11:15 HSZ 101

First-principles theory of laser-induced dynamics on the magnetic Dy_2Ni_2(DMF) complex — •Bharadwaj C. Mummaneni, Stefan Sold, Georgios Lefkidis, and Wolfgang Hübner — Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Kaiserslautern, Germany

We study the functional role of d and f electrons in the tetraheteronuclear Dy_2Ni_2(DMF) magnetic complex, which harbors a great potential as a magnetic-logic-element building block in future nanospintronic devices [1]. We focus on the theoretical characterization of the magnetic properties and the laser-induced spin dynamics of the complex, which adopts a defect dicubane geometry and has a ferromagnetic electronic ground state [2].

The highly correlated electronic excited states are computed with the state-of-the-art equation-of-motion coupled-cluster method and the perturbative inclusion of spin-orbit coupling. We are able to theoretically explain the experimental electronic absorption spectrum, as well as several time-resolved differential absorption spectra, after two different pump pulses (at 300 and 400 nm, respectively).

[1] D. Chaudhuri, G. Lefkidis, and W. Hübner, Phys. Rev. B **96**, 184413 (2017)
[2] D. K. C. Mondal, G. E. Kostakis, Y. Lan, W. Wernsdorfer, C. E. Anson, and A. K. Powell, Inorg. Chem. **50**, 11604 (2011)
[3] S. Sold, G. Lefkidis, B. Kamble, J. Berakdar, and W. Hübner, Phys. Rev. B **97**, 184428 (2018)

15 min. break.

MA 21.9 Tue 11:45 HSZ 101

Elucidating the mechanism for all-optical switching by tuning the femtosecond pulses into the infrared wavelength range — Robin John[1], •Jakob Walowski[1], Cai Müller[2], Marco Berritta[3], Deninse Hintzke[4], Oksana Chubykalo-Fesenko[5], Tiffany Santos[6], Henning Ulrichs[7], Ritwik Mondal[4], Peter Oppeneer[3], Ulrich Nowak[4], Jeffrey McCord[2], and Markus Münzenberg[1] — [1]Greifswald University, Greifswald, Germany — [2]Kiel University, Kiel, Germany — [3]Uppsala University, Uppsala, Sweden — [4]Konstanz University, Konstanz, Germany — [5]CSIC, Madrid, Spain — [6]Western Digital, San Jose, CA, United States — [7]Göttingen University, Göttingen, Germany

The energy transfer from electrons to spins upon laser excitation is the basis for the response dynamics, it determines the speed of ultrafast magnetization. In FePt nanoparticles, a material developed for heat-assisted magnetic recording, all-optical writing has been demonstrated by Lambert et al. in Science 2014. In the current understanding of the interaction of ultrafast excitation and heating, the influence of magnetic dichroism MCD and the presence of the inverse Faraday effect IFE jointly work as forces causing magnetization reversal.

We calculate the switching rates of the individual FePt nanoparticles in ab-initio calculations of the optical effects (IFE and MCD induced heating) included in thermal modelling, which provide switching rates for the ensembles. This theoretical description allows us to optimize the required number of shots to write the magnetization in experiments and optimize the process by tuning the laser fluence and wavelength.

MA 21.10 Tue 12:00 HSZ 101

Influence of the inverse Faraday effect on ultrafast switching processes in ferro- and antiferromagnets — •Tobias Dannegger[1], Marco Berritta[2], Severin Selzer[1], Ulrike Ritzmann[2,3], Peter M. Oppeneer[2], and Ulrich Nowak[1] — [1]Fachbereich Physik, Universität Konstanz, D78457 Konstanz, Germany — [2]Department of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala, Sweden — [3]Dahlem Center of Complex Quantum Systems and Department of Physics, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

Ultrafast all-optical magnetisation reversal has been of interest due to its promising potential in the development of fast magnetic recording devices. This talk presents atomistic spin dynamics simulations used with input from DFT calculations [1] to study the role of the inverse Faraday effect (IFE) in laser-induced switching processes in ferro- and antiferromagnetic spin systems, specifically $L1_0$-ordered FePt and CrPt. The magnitude of the magnetisation induced by the IFE as well as the duration for which it remains present after the laser pulse are varied as parameters. The simulation results for FePt show, in agreement with previous results [2], that single-pulse switching in FePt is not possible but the IFE can, at least for certain parameter values, significantly enhance the switching probability. In antiferromagnets, the faster dynamics of the spin system make those materials more susceptible to the influence of the optically induced magnetisation.

[1] M. Berritta et al. Phys. Rev. Lett. **117**, 137203 (2016)
[2] R. John et al. Sci. Rep. **7**, 4114 (2017)

MA 21.11 Tue 12:15 HSZ 101

The orbital angular momentum of light in ultrafast magnetism — •Eva Prinz[1,2], Stephan Wust[1], Martin Stiehl[1], Jonas Hoefer[1], Benjamin Stadtmüller[1], and Martin Aeschlimann[1] — [1]Department of Physics and Research Center OPTIMAS, TU Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Staudingerweg 9, 55128 Mainz, Germany

Optical fields can carry an orbital angular momentum (OAM) in helical beams with an azimuthal phase dependence. Since its discovery in 1992 [1], a variety of applications for the OAM of light has been brought forward, such as data storage, quantum cryptography, astronomy, communication, enhanced sensitivity in imaging techniques and optical tweezers [2].

Our research is focused on exploring potential effects of the orbital angular momentum of light on both laser-induced ultrafast demagnetization and all-optical switching (AOS). The light-matter interactions could be influenced either by a transfer of angular momentum from photons to the electron system, or by the induction of a magnetic field in the material via the inverse Faraday effect. We present first measurements of both time-resolved MOKE and MOKE-microscopy pumped with OAM light.

[1] Allen et al., Phys. Rev. A 45 (1992)
[2] Shen et al., Light: Science & Applications 8 (2019)

MA 21.12 Tue 12:30 HSZ 101

Thermally induced magnetic switching in GdFeCo using picosecond laser pulses - experiment vs theory — Florian Jakobs[1], Thomas Ostler[2], Jon Gorchon[3], and •Unai Atxitia[1] — [1]Fachbereich Physik, Freie Universität Berlin Germany — [2]Département de Physique, Universitè de Liege — [3]Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, USA

There are still many open questions about the driving mechanisms behind ultrafast magnetic switching in GdFeCo alloys by a single femtosecond (fs) optical pulse. Phenomenological models suggest a fs-scale exchange relaxation between the sublattices, which would limit the stimuli time a fs-scale. However the recent observations of single-pulse switching with either optical, or electrical stimuli of up to ten picosecond, have questioned this previous understanding. In this work, we aim to bridge this gap of knowledge. To that end, we have studied single-pulse optical switching, both experimentally and theoretically, for a wide range of system parameters, such as composition, laser power and pulse duration. For the first time we have found excellent quantitative agreement between our atomistic spin model and experiments across a broad range of compositions and laser durations ranging from fs to ps. Furthermore we explore numerically the impact of various switching parameters, that are typically unaccessible to experiments. Such as Gd-concentration, element-specific relaxation parameter, pulse duration and fluence. In agreement with previous experiments, we find the conditions for switching up to pulse durations close to ten ps.

MA 21.13 Tue 12:45 HSZ 101

All Optical Switching in FePtCr Alloys — •Stephan Wust[1], Martin Stiehl[1], Nataliia Schmidt[2], Ritwik Mondal[3], Benjamin Stadtmüller[1,4], Ulrich Nowak[3], Manfred Albrecht[2], and Martin Aeschlimann[1] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern — [2]Institute for Physics, University of Augsburg, Universitätsstraße 1 Nord, 86159 Augsburg, Germany — [3]Universität Konstanz, Universitätsstraße 10, 78464 Konstanz, Germany — [4]Graduate School Materials Science in Mainz, Staudinger Weg 9, 55128 Mainz, Germany

The speed of magnetic data storage and information processing technologies is particularly important for magnetic device performances but currently limited to a few nanoseconds. In this regard, all-optical switching (AOS) is a highly promising effect to overcome this limit. Here, we focus on the AOS phenomena and the corresponding fs magnetization dynamics in $L1_0$ ordered FePt thin films doped with Cr. For investigating the effect of optical excitation, we employ magneto-optical-effects to image the optically induced change of magnetic domains in real space. For a Cr concentration of 5%, we observe a helicity-dependent switching. Since this effect happens with an efficiency below 100%, parameters like sample thickness and temperature are systematically varied to optimize the switching process. We compare this experimental finding for different Cr concentrations to gain insight into the role of the dopant for the observed magnetization reversal. Our results are an important step towards a deeper understanding of AOS in FePt based materials.

MA 21.14 Tue 13:00 HSZ 101

Ultrafast magnetization switching in a model system of alloys with exchange coupling - a parameter study — •Kai Leckron and Hans Christian Schneider — University of Kaiserslautern, Department of Physics

Optically induced deterministic switching was demonstrated in GdFeCo with antiferromagnetic coupling between the sublattices [1] and theoretically related to thermal effects [2,3].

We study antiferromagnetically coupled-sublattice dynamics in a model consisting of two subsystems with itinerant and localized single-particle states [4]. After an instantaneous excitation of the itinerant subsystem we dynamically calculate the carrier dynamics in both subsystems using Boltzmann scattering integrals for exchange scattering processes. In agreement with Ref. [4], we find that on ultrashort time scales (some 10 fs) exchange dominates over Elliott-Yafet like spin-flip scattering.

We identify parameter regions where the so called "transient ferromagnetic state" appears and others where even a revearsal of the magnetization occurs. We also find a connection between the existence of a compensation temperature in the equilibrium magnetization curve and the magnetization switching, which is in agreement with recent atomistic simulations [5].

[1] Radu et al., Nature 472, 205 (2011) [2] J. H. Mentink et al., Phys. Rev. Lett. 108, 057202 (2012) [3] T. A. Ostler, Nat. Commun. 3, 666 (2012) [4] A. Baral and H. C. Schneider, Phys. Rev. B 91, 100402(R) (2015) [5] Moreno et al., Phys. Rev. B 99, 184401 (2019)