MA 8: Ultrafast Magnetization Effects 1

Time: Monday 15:00–18:00 Location: H37

MA 8.1 Mon 15:00 H37

Spectrally resolved spin dynamics of 3d transition metals in EUV T-MOKE — •Henrike Probst[1], Christina Möller[1], Mariana Brede[1], Maren Schumacher[1], Karen Stroh[1], Marcel Reutzel[1], G. S. Matthijs Jansen[1], Sangeeta Sharma[2], Daniel Steil[1], and Stefan Mathias[1] — [1]I. Physikalisches Institut, University of Göttingen — [2]Max-Born-Institute for Non-linear Optics and Short Pulse Spectroscopy, Berlin

Light in the extreme ultraviolet (EUV) range has found increasing application in the field of magneto-optical spectroscopy. It allows to get new insights in light-matter interaction processes, as EUV spectroscopy provides the potential to investigate energy- and element-resolved spin dynamics [1-2].

Here, we carry out a comprehensive study of spectrally resolved spin dynamics of the 3d transition metals Co, Fe and Ni using EUV transverse magneto-optical Kerr spectroscopy (T-MOKE) [3]. Covering the M-edges in the 30-72 eV energy window, this allows to resolve spin dynamics at specific energies around the Fermi-level. We discuss different processes leading to energy dependent changes in the magnetic asymmetry at early times after the optical excitation, i.e. charge excitation and band renormalization.

[1] Hofherr et al., Sci. Adv. 6.3 (2020): eaay8717.
[2] Tengdin et al., Sci. Adv. 6.3 (2020): eaaz1100.
[3] Möller et al., Rev. Sci. Instrum., 92(6) (2021): 065107.

MA 8.2 Mon 15:15 H37

Ultrafast element- and depth-resolved magnetization dynamics probed by transverse magneto-optical Kerr effect spectroscopy in the soft x-ray range — •Martin Hennecke[1], Daniel Schick[1], Themistoklis Sidiropoulos[1], Felix Willems[1], Anke Heilmann[1], Martin Bock[1], Lutz Ehrentraut[1], Dieter Engel[1], Piet Hessing[1], Bastian Pfau[1], Martin Schmidbauer[2], Andreas Furchner[3,4], Matthias Schnuerer[1], Clemens von Korff Schmising[1], and Stefan Eisebitt[1,5] — [1]Max-Born-Institut, Berlin, Germany — [2]Leibniz-Institut für Kristallzüchtung, Berlin, Germany — [3]Helmholtz-Zentrum Berlin, Berlin, Germany — [4]Leibniz-Institut für Analytische Wissenschaften, Berlin, Germany — [5]IOAP, Technische Universität Berlin, Berlin, Germany

Understanding the light-driven spin dynamics occurring at buried interfaces of complex magnetic heterostructures as used in today's opto-spintronics applications requires direct experimental access to the non-local magnetic order on sub-ps time scales. Here, we report on broadband time- and angle-resolved transverse magneto-optical Kerr effect spectroscopy probing the Gd $N_{5,4}$ resonance (≈150 eV) of a ferrimagnetic GdFe nanostructure with fs soft x-ray pulses provided by a laboratory-scale light source based on high-harmonic generation. Employing a pump-probe technique, we follow the fs laser-induced demagnetization of the GdFe layer. Analyzing the fs time-resolved spectra via magnetic scattering simulations allows a quantitative determination of the transient magnetization depth profiles evolving within the magnetic film due to strongly layer-dependent photoexcitation.

MA 8.3 Mon 15:30 H37

Table-top X-ray magnetic circular dichroism at the Fe L edges — •Martin Borchert[1,2], Daniel Schick[1], Clemens v. Korff Schmising[1], Denny Sommer[1], Dieter Engel[1], Bastian Pfau[1], and Stefan Eisebitt[1,2] — [1]Max-Born-Institut, Berlin — [2]TU Berlin

Time-resolved X-ray magnetic circular dichroism (XMCD) is a powerful tool to directly probe the element-specific magnetization in multi-component heterostructures.

Due to the lack of laboratory-scale light sources with sufficient brightness and control over the light's polarization, static and time-resolved XMCD studies in the higher soft X-ray photon energy range have so far been limited to large-scale facilities such as synchrotrons and free-electron lasers.

Here, we present first XMCD spectroscopy data recorded at the Fe $L_{3,2}$ resonances employing a laboratory-scale soft X-ray source utilizing a magnetic thin-film polarizer to circularly polarize the soft X-rays from the continuous, broadband (50–1500 eV) emission of a laser-driven plasma source with <10 ps pulse duration. A reflection zone plate (RZP) is used as the single optical element to collect, disperse and focus the full spectrum across the Fe L edges through a thin-film sample, to which an external magnetic field can be applied to observe the resulting asymmetry spectrum, as well as hysteresis loops.

Utilizing different RZPs, this setup enables the first laboratory-based whitelight XMCD spectroscopy with picosecond time resolution, covering the full spectrum of the magnetically relevant resonances from the transition metal M and L edges up to the rare earth M edges.

MA 8.4 Mon 15:45 H37

Temperature dependence of spin interaction parameters in two-sublattice ferrimagnets — •Levente Rózsa[1], Severin Selzer[1], Niklas Windbacher[1], Ulrich Nowak[1], and Unai Atxitia[2] — [1]University of Konstanz, Konstanz, Germany — [2]Instituto de Ciencia de Materiales de Madrid, Madrid, Spain

Ferrimagnets consist of two antiferromagnetically coupled sublattices with different magnetic moments, thereby possessing a finite magnetization like ferromagnets. The ferrimagnet magnetite has been known since ancient times, yet ferrimagnets continue to attract research interest in various areas of spintronics from magnons to skyrmions. The properties of ferrimagnets may be tuned between those of ferromagnets and antiferromagnets by changing the temperature. Therefore, determining the temperature dependence of model parameters of ferrimagnets is essential for their accurate description.

Here we present an analytical method for describing the temperature dependence of spin interactions in ferrimagnets, based on Callen's Green's function formalism [1]. The temperature dependence of the Heisenberg and Dzyaloshinsky-Moriya interactions, as well as of the anisotropy terms are derived and compared to known expressions in ferromagnets [2,3]. The role of spin correlations is highlighted in reduced dimensions. The results are compared to numerical simulations of the magnon frequencies and of reversal times of nanoparticles.

[1] H. B. Callen, Phys. Rev. 130, 890 (1963).
[2] L. Rózsa et al., Phys. Rev. B 96, 094436 (2017).
[3] R. F. L. Evans et al., Phys. Rev. B 102, 020412(R) (2020).

MA 8.5 Mon 16:00 H37

Electron-Magnon Scattering Dynamics in a two-band Stoner Model — •Félix Dusabirane, Kai Leckron, Sanjay Ashok, Bärbel Rethfeld, and Hans Christian Schneider — Physics Department & Research Center OPTIMAS, University of Kaiserslautern, Germany

We use a microscopic model to study carrier dynamics in ferromagnets due to electron-magnon scattering on ultrafast timescales. We employ a simple model band structure (Stoner model), for which the electron magnon-interaction is formally obtained as coupling to a Heisenberg spin system in the Hamiltonian. We compute the dynamics of momentum resolved electron and magnon distributions due to electron-magnon and statically screened electron-electron scattering, which are treated at the level of Boltzmann scattering integrals. We find that electron-magnon scattering leads to a pronounced non-equilibrium for magnon modes that couple directly to Stoner transitions. The spin-flip scattering with electrons results in a transient electron spin polarization, which is similar for excitations either within the minority or the majority band. The influence of model parameters such as band filling and exchange coupling strengths will be discussed.

MA 8.6 Mon 16:15 H37

Ultrafast optical generation of antiferromagnetic spin texture — •Sumit Ghosh[1,2], Stefan Blügel[1], and Yuriy Mokrousov[1,2] — [1]PGI1, Forschungszentrum Jülich, Germany. — [2]Institute of Physics, Johannes Gutenberg-University Mainz, Germany.

We present here an unified picture of ultrafast manipulation of collinear antiferromagnetic order by combining both electronic and magnetic degrees of freedom via a hybrid quantum classical evolution scheme. Our approach allows us to probe slow magnetic relaxation for several picoseconds with a sub-femtosecond resolution and thus allows us to identify the emergent interactions driving the formation of nontrivial textures which remains hidden from classical magnetisation dynamics. In case of a one dimensional spin chain this mechanism can lead to the formation of spin spirals [1] where the induces chirality can be tuned with the laser parameter. In case of two dimensional antiferromagnets this mechanism can lead to more exotic outcome - generation of a texture and anti-texture which can survive for 100ps [2] and is fairly robust against impurity. Our results thus opens new possibilities to generate higher order nontrivial magnetic texture with ultrafast laser.

[1] S. Ghosh, et.al. Communications Physics, 5(1), 69, 2022. https://doi.org/10.1038/s42005-022-00840-3

[2] S. Ghosh, S. Blügel and Y. Mokrousov. arXiv:2205.12100. http://arxiv.org/abs/2205.12100

MA 8.7 Mon 16:30 H37

Polarized phonons carry the missing angular momentum in femtosecond demagnetization — •Hannah Lange[1], Martin Evers[1], Andreas Donges[1], Sonja Tauchert[1,2], Mikhail Volkov[1,2], Peter Baum[1,2], and Ulrich Nowak[1] — [1]University of Konstanz, Fachbereich Physik, 78464 Konstanz — [2]LMU Munich, Am Coulombwall 1, 85748 Garching

When a thin nickel film is subjected to ultrashort laser pulses, it can lose its magnetic order almost completely on within hundreds of femtoseconds. This phenomenon offers opportunities for rapid information processing or ultrafast spintronics. However, a crucial question has remained elusive: Where is the angular momentum transferred to in such short time? Here we use molecular dynamics simulations to investigate the role of phonon angular momentum. When exciting a rotational lattice motion which carries the amount of angular momentum corresponding to the demagnetization, we observe an anisotropy of the atoms' velocities which violates the equipartition theorem. When calculating the corresponding electron diffraction pattern, this results in an anisotropy of normally equivalent Bragg spots. This is in line with ultrafast electron diffraction which show an almost instantaneous, long-lasting, non-equilibrium population of phonons. Theory and experiment hence indicate the formation of polarized phonons that take up the missing angular momentum [1] before the onset of a macroscopic Einstein-de Haas rotation [2].

[1] Tauchert et al. Nature 602, 73-77 (2022).

[2] Dornes et al. Nature 565, 209-212 (2019).

MA 8.8 Mon 16:45 H37

Does the orbital angular momentum of light affect ultrafast demagnetization? — •Eva Prinz[1], Benjamin Stadtmüller[1,2], and Martin Aeschlimann[1] — [1]Department of Physics and Research Center OPTIMAS, TU Kaiserslautern, Germany — [2]Institute of Physics, Johannes Gutenberg University 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], there has been a variety of applications of light with additional OAM, such as quantum entanglement, micro manipulation, communication, and microscopy [2].

Our research is focused on exploring the potential effects of the OAM of light on laser-induced ultrafast demagnetization. In this field, the question of how the angular momentum is conserved during spin-flips is not fully answered. Pumping the system with photons carrying OAM offers the potential to provide new insights, not only into the dissipation of angular momentum in the material but also into the interaction of photonic OAM with matter in general.

We investigate ultrafast demagnetization of ferromagnetic thin films induced by OAM light with time-resolved magneto-optic Kerr-effect measurements. We observed peculiar demagnetization dynamics that have so far not been observed for light without OAM.

[1] Allen et al., Phys. Rev. A 45 (1992)

[2] Shen et al., Light: Science & Applications 8 (2019)

MA 8.9 Mon 17:00 H37

Role of diffusive transport in ultrafast demagnetization dynamics — •Sanjay Ashok, Sebastian T. Weber, Christopher Seibel, Johan Briones, and Bärbel Rethfeld — Fachbereich Physik and OPTIMAS Research Center, TU Kaiserslautern, Kaiserslautern, Germany

Ultrafast demagnetization dynamics in thick metallic magnetic films is greatly influenced by transport processes. In this contribution we present the space-resolved magnetization dynamics in a thick Nickel film induced by a femtosecond laser pulse [3]. Starting from the thermodynamic μT-model [1], we explicitly include diffusive heat transport, spin-resolved charge transport, as well as Seebeck and Peltier effects.

Our results show that the spatial dependence of maximal magnitude of quenching is induced by a depth-dependent energy deposition and is only moderately equilibrated by transport processes. We reveal a stronger influence of transport on the time of quenching which becomes nearly independent of depth [3].

Additionally, we present the influence of pump-wavelength [2] on spatially resolved magnetization dynamics.

[1] B.Y. Mueller and B. Rethfeld, Phys. Rev. B. 90, 144420 (2014)

[2] U. Bierbrauer et al., JOP Cond. Mat., 29 (24), 244002 (2017)

[3] S. Ashok et al., Appl. Phys. Lett. 120, 142402 (2022)

MA 8.10 Mon 17:15 H37

Spin fluctuations around a reorientation transition in $Sm_{0.7}Er_{0.3}FeO_3$ — •Julius Schlegel[1], Martin Evers[1], Tobias Dannegger[1], Andreas Donges[1], Marvin Weiss[1], Takayuki Kurihara[2], Sebastian T.B. Goennenwein[1], and Ulrich Nowak[1] — [1]Department of Physics, University of Konstanz — [2]ISSP, University of Tokyo

The competition between thermal fluctuations, spin-spin interactions and magnetic anisotropies can lead to various magnetic phase transitions. For example the antiferromagnetic orthoferrite $Sm_{0.7}Er_{0.3}FeO_3$ undergoes a reorientation transition at approximately room temperature. On the basis of an atomistic spin model and the Landau-Lifshitz-Gilbert equation of motion we numerically calculate the time evolution of the magnetization around the reorientation transition on a timescale from picoseconds up to one nanosecond and investigate the thermal fluctuations of the magnetization. By Fourier-transforming the time dependent magnetization we find that the spectra of the noise are temperature dependent and change significantly while going through the reorientation. We also observe several resonances in the spectra. By means of analytical calculations based on linear spin wave theory these peaks can be assigned to the different modes of a model with four sublattices.

Finally, these results are compared to current experimental data from spin noise measurements.

MA 8.11 Mon 17:30 H37

Ultrafast spin dynamics: complementing theoretical analyses by quantum state measures — Franziska Ziolkowski, •Oliver Busch, Jürgen Henk, and Ingrid Mertig — Institut für Physik, Martin-Luther-Universität, D-06099 Halle

In theoretical studies of ultrafast spin dynamics, one usually analyses and discusses observables — such as magnetization. On top of this, quantum state (QS) measures defined for density matrices may provide additional valuable insights into the dynamics [1].

We report on a study on QS measures that complement simulations of ultrafast spin dynamics [2]. For a Co/Cu heterostructure which is excited by a femtosecond laser pulse and coupled to a bosonic heat bath, we discuss the time dependence of QS measures, in particular distances in Hilbert space and degree of purity in the density matrix [3].

We identify observables and modifications of the investigated system to which both the distance and the purity measures are in particular sensitive: the polarization of the laser pulse and the composition of the sample. In contrast, temperature and photon energy affect the QS measures mildly. Our study shows that QS measures are complementary and beneficial quantities for spin dynamics simulations.

[1] S. Barnett, *Quantum Information* (Oxford University Press, Oxford, 2009)

[2] F. Töpler *et al.*; New Journal of Physics **23**, 033042 (2021)

[3] R. Jozsa, Fidelity for Mixed Quantum States, Journal of Modern Optics **41**, 2315 (1994)

MA 8.12 Mon 17:45 H37

Tuning all-optical magnetization switching efficiency by laser pulse wavelength variation — •Marcel Kohlmann[1], Lucas Vollroth[1], Kristýna Hovořaková[2], Eva Schmoranzerová[2], Robin John[1], Denise Hinzke[4], Peter Oppeneer[3], Ulrich Nowak[4], Markus Münzenberg[1], and Jakob Walowski[1] — [1]Greifswald University, Greifswald, Germany — [2]Charles University, Prague, Czech Republic — [3]Uppsala University, Uppsala, Sweden — [4]Konstanz University, Konstanz, Germany

Heat-assisted magnetic recording (HAMR) presents a promising candidate for high data density devices. Leaving investigation of magnetization manipulation a topic of interest for research and development. We study all-optical helicity-dependent switching of FePt granular HAMR media[2] as an alternative writing mechanism. The latest perception of interaction of heating and ultra fast excitation suggests the contribution of magnetic dichroism and the inverse Faraday effect as interchanging driving forces behind the magnetization reversal. The switching rates for individual FePt nano particles from ab-initio calculations of the inverse Faraday effect and magnetic dichroism induced heating provide a model to describe the switching as a stochastic process.

We extend the study to wavelength dependent switching experiments from 800 nm up to 1550 nm for all-optical writing experiments on FePt granular media evaluating the writing efficiency.

We greatly acknowledge the DFG funding within the project "Fundamental aspects of all-optical single pulse switching in nanometer-sized magnetic storage media.