MA 23: Spin Dynamics and Transport: Ultrafast Effect

Time: Tuesday 9:30–12:15 Location: HSZ 403

MA 23.1 Tue 9:30 HSZ 403

Terahertz Radiation Driven Dynamics of Magnetic Domain Structures Probed by Free-Electron Laser Light — •L. Müller[1], M.H. Berntsen[2], W. Roseker[1], A. Philippi-Kobs[1], T. Golz[1], K. Bagschik[3], J. Wagner[3], R. Frömter[3], N. Stojanovic[1], C. Gutt[4], H.P. Oepen[3], and G. Grübel[1] — [1]Deutsches Elektronen-Synchrotron DESY, FS-CXS, Hamburg, Germany — [2]KTH Royal Institute of Technology, Stockholm, Sweden — [3]Institut für Nanostruktur- und Festkörperphysik, Universität Hamburg, Hamburg, Germany — [4]Department of Physics, University of Siegen, Siegen, Germany

Controlling magnetism on ultra-fast time scales and on nanometer length scales is a challenge for modern research in magnetism, with direct implication for future data storage devices. Means for inducing dynamics on these time scales are femtosecond optical lasers and, more recently, THz sources. Probing the dynamics on a nanometer length scale has become possible with free-electron laser sources. We report on a THz-pump–XUV-probe scattering experiment on $(Co/Pt)_n$ multilayers ($n = 8,\ 16$) with perpendicular magnetic anisotropy exhibiting a maze domain pattern. An electromagnetic undulator installed at FLASH behind the permanent-magnet FEL undulator was used to produce 10-cycle linearly polarized THz pulses. The fundamental wavelength was set to $150\,\mu$m and higher harmonics down to $30\,\mu$m have been used as a pump. The resulting dynamics have been probed on femtosecond time scales by resonant magnetic small-angle scattering at the cobalt $M_{2,3}$ edge.

MA 23.2 Tue 9:45 HSZ 403

Ultrafast magnetization dynamics triggered by intense terahertz pulses — •Julius Heitz, Tom Seifert, and Tobias Kampfrath — Fritz-Haber-Institute of the Max Planck Society, Faradayweg 4-6, 14195 Berlin, Germany

We excite ferromagnetic iron thin films with sub-picosecond terahertz (THz) pulses covering the spectrum from 0.5 to 2 THz. Measurement of the magnetooptical Kerr effect (MOKE) by optical probe pulses (duration of 10 fs, center wavelength 800 nm) provides access to the time evolution of the sample magnetization. The different contributions to the magnetization dynamics are disentangled by comparing measurements with opposite THz field polarities and with different equilibrium sample magnetization. In particular, we discuss the contributions of ultrafast demagnetization and THz Zeeman torque.

The results shown here were obtained in close collaboration with the research groups of E. Beaurepaire , M. Kläui and M. Münzenberg.

MA 23.3 Tue 10:00 HSZ 403

Ultrafast excitation of coherent magnons by circularly and linearly polarized light pulses in antiferromagnetic NiO — •Christian Tzschaschel[1], Ryugo Iida[2], Tsutomu Shimura[2], Hiroaki Ueda[3], Stefan Günther[1], Takuya Satoh[2,4], and Manfred Fiebig[1] — [1]ETH Zürich, Switzerland — [2]The University of Tokyo, Japan — [3]Kyoto University, Japan — [4]Kyushu University, Japan

NiO is rapidly gaining importance in the field of antiferromagnetic magnonics. In this talk, we clarify the mechanism of ultrafast optical magnon excitation in antiferromagnetic NiO. We employed time-resolved optical two-color pump-probe measurements to study the coherent non-thermal spin dynamics. By near-infrared pumping and probing along the optical axis, we avoid the detrimental influence of birefringence. Thus, we are able to determine the mechanism behind the ultrafast optical magnon generation with linearly and circularly polarized light. For this purpose, we employ a phenomenological theory under consideration of the crystallographic and magnetic point group symmetries. Based on this new approach, we are able to describe the dynamic magneto-optical properties of NiO and derive expressions for the optically induced magnetization via the inverse Faraday effect as well as the inverse Cotton-Mouton effect. Our experimental and theoretical results are in striking agreement. This not only allows us to discriminate between the two effects, but also to extract information about the antiferromagnetic domain distribution. Moreover, we find that magnon generation via the inverse Cotton-Mouton effect is more than 30 times more efficient in NiO than via the inverse Faraday effect.

MA 23.4 Tue 10:15 HSZ 403

Ultrafast structural and magnetization dynamics of the Skyrmion crystal GaV_4S_8 — •Evgeniia Slivina[1], Prashant Padmanabhan[1], Rolf B. Versteeg[1], Sándor Bordács[2], István Kézsmárki[2], and Paul H. M. van Loosdrecht[1] — [1]II. Physikalisches Institut, Universität zu Köln, Zülpicher Straße 77, D-50937 Köln, Germany — [2]Department of Physics, Budapest University of Technology and Economics and MTA-BME Lendület Magneto-optical Spectroscopy Research Group, 1111 Budapest, Hungary

GaV_4S_8 is a lacunar spinel, notable for its unusual para-to-ferroelectric phase transition and the emergence of novel magnetic ground states below the Néel temperature. One of the latter - the Néel Skyrmion - was recently observed, but to date, little is known about the coherent control of magnetic excitations in this material. Here, we employ time-resolved magneto-optical Kerr effect spectroscopy to demonstrate the coherent excitation of Néel-type Skyrmions and other magnetic ground states in GaV_4S_8. In addition, we measure the time-resolved differential reflectivity and coherent phonon dynamics to elucidate the Jahn-teller induced para-to-ferroelectric phase transition in this material.

MA 23.5 Tue 10:30 HSZ 403

Picosecond time-evolution of Cu_2OSeO_3's helimagnetic order parameter after photoexcitation studied by time-resolved spontaneous Raman spectroscopy — •Rolf B. Versteeg[1], Jingyi Zhu[1], Christoph Boguschewski[1], Petra Becker[2], and Paul H.M. van Loosdrecht[1] — [1]II. Physikalisches Institut, Universität zu Köln, Cologne, Germany — [2]Abteilung Kristallographie, Institut für Geologie und Mineralogie, Cologne, Germany

Time-resolved Raman spectroscopy is a seldom used tool in the investigation of picosecond magnetization dynamics. This is mostly due to a combination of the low inelastic light scattering rate, and the restrictions on time-resolution, and needed spectral resolution. A successful realization of such an experiment would however lead to valuable insights into symmetry changes after optical perturbation, quasiparticle population statistics, and excitation energy changes on ultrafast timescales.

Here, we present the ultrafast dynamics of helimagnetic order in the chiral magnet Cu_2OSeO_3 studied by time-resolved picosecond spontaneous Raman spectroscopy. This material has attracted significant research interest due to the presence of a Skyrmion lattice phase. The ground state of this material consists of helimagnetically ordered $S = 1$ spin clusters, which are composed of 3-up-1-down Cu $S = 1/2$ spins. The magnetic excitations within the spin-cluster are Raman-active, and serve as a probe for helimagnetic order. We show that after photoexcitation the helimagnetic order "melts" through spin-lattice relaxation on typical timescales of $\sim 100\,$ps.

15 min. break

MA 23.6 Tue 11:00 HSZ 403

Off-resonant excitation of Co films by intense single-cycle THz pulses: computer simulations and experiments — •Andreas Donges[1], Mostafa Shalaby[2], Carlo Vicario[2], Karel Carva[3], Peter M. Oppeneer[4], Christoph P. Hauri[2], and Ulrich Nowak[1] — [1]Universität Konstanz, DE-78457 Konstanz, Germany — [2]SwissFEL, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland — [3]Charles University, CZ-12116 Praha 2, Czech Republic — [4]Uppsala University, SE-75120 Uppsala, Sweden

It was recently demonstrated that THz radiation is an efficient tool to coherently excite ferro- [1] and antiferromagnets [2] on the sub-ps time scale. With the availability of more intense THz sources, there is experimental evidence that the excitation of the magnetization becomes incoherent–an effect that is not understood yet. We performed multiscale modeling simulations, starting from ab-initio calculations of the Heisenberg exchange constants for the spin Hamiltonian of Co. We further used the stochastic Landau-Lifshitz-Gilbert equation in combination with an extended two-temperature model, to compute the spin dynamics response to a THz bullet. The results are compared to our THz pump–NIR MOKE probe measurements, for fluences up to $90\,\mathrm{mJ/cm^2}$. From our findings we conclude that the coherent oscillations are caused by a direct coupling of the spins to the Zeeman field of the THz pulse, whereas the incoherent dynamics is due to the electric field which affects the spins indirectly, via heating of the electrons.

[1] C. Vicario, et al., *Nature Photonics*, **7**, 720-723 (2013).
[2] T. Kampfrath, et al., *Nature Photonics*, **5**, 31-34 (2011).

MA 23.7 Tue 11:15 HSZ 403

Relativistic theory of magnetic inertia in ultrafast spin dynamics — •Ritwik Mondal, Marco Berritta, Ashis K. Nandy, and Peter M. Oppeneer — Department of Physics and Astronomy, Uppsala University, Sweden

The influence of possible magnetic inertia effects has recently drawn attention in ultrafast magnetization dynamics and switching[1]. Here we derive rigorously a theory of inertia in the Landau-Lifshitz-Gilbert equation on the basis of the Dirac-Kohn-Sham framework. Using the Foldy-Wouthuysen transformation up to the order of $1/c^4$ gives the 2^{nd} order time-derivative of magnetization in the dynamical equation of motion. Thus, the inertia damping is a higher order spin-orbit coupling effect, as compared to the Gilbert damping[2]. It is therefore expected to play a role only on ultrashort timescales (sub-picoseconds)[3]. We also show that the Gilbert damping and *intrinsic* inertia damping are related to one another[4] through the imaginary and real parts of the magnetic susceptibility tensor respectively.

[1]A. V. Kimel *et al.*, Nature Phys. **5**, 727 (2009). [2]R. Mondal, M. Berritta and P. M. Oppeneer Phys. Rev. B **94**, 144419 (2016). [3]M.-C. Ciornei, J. M. Rubí and J.-E. Wegrowe, Phys. Rev. B **83**, 020410(R) (2011). [4]M. Fähnle, D. Steiauf and C. Illg, Phys. Rev. B **84**, 172403 (2011).

MA 23.8 Tue 11:30 HSZ 403

Ultrafast Spin Transfer Torque Generated by a Femtosecond Laser Pulse — •Pavel Baláž[1], Martin Žonda[1], Karel Carva[1], Pablo Maldonado[2], and Peter Oppeneer[2] — [1]Department of Condensed Matter Physics, Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, CZ-12116 Prague 2, Czech Republic — [2]Department of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala, Sweden

A phenomenon of laser pulse-induced ultrafast demagnetization of magnetic material on femtosecond time-scale, is connected with number of open questions. Particularly, in transition metals and their alloys featuring spin polarized 3d valence band and conduction 4s band, a laser pulse can excite electrons from the d band into the s one with higher electron mobility. Consequently, the nonequilibrium hot charge carriers migrate away from the laser spot and reduce the local magnetic moment. This process is described by the superdiffusive spin transport model [1], which takes into account scattering of hot electrons on atomic sites leading to nonequilibrium avalanches of excited electrons.

In this work, we study the spin transfer torque and magnetization dynamics induced by a spin current of hot electrons in spin valve consisted of two magnetic layer with perpendicular magnetizations separated by a nonmagnetic one. To this end, we developed a four-channel model of spin transport, which allows us to calculate spin transfer torque and describe magnetization dynamics.

[1] M. Battiato, K. Carva, P. Oppeneer Phys. Rev. Lett. 105, 027203 (2010); Phys. Rev. B 86, 024404 (2012).

MA 23.9 Tue 11:45 HSZ 403

TDDFT simulation of ultrafast demagnetization: Spin Current vs Spin Flips — •Peter Elliott, Kevin Krieger, J. Kay. Dewhurst, Sangeeta Sharma, and E.K.U. Gross — Max-Planck Institute of Microstructure Physics

We apply the ab-initio simulation method of time dependent density functional theory (TDDFT) to shed light on the underlying physics of ultrafast demagnetization in ferromagnetic materials due to intense laser pulses. A key finding of our work is that the spin-orbit interaction (SOI) can be responsible for this ultrafast loss of moment, under the right circumstances. In this work we compare the loss of moment due to 1) spin transport (i.e. transport of the moment from a ferromagnetic layer into a substrate) and 2) SOI demagnetization happening in the magnetic layer itself. For the interfaces we study, we find that both processes contribute equally to the demagnetization of the ferromagnet. Furthermore we predict that if the substrate has strong SOI character (e.g. Pt), there can even be SOI type demagnetization of the moment that was transported into the substrate.

MA 23.10 Tue 12:00 HSZ 403

Monte Carlo simulation of the non-equilibrium spin dynamics — •Johan Briones and Baerbel Rethfeld — Department of Physics and Optimas Research Center, University of Kaiserslautern, Germany

A Monte Carlo simulation model will be developed in order to study the ultrafast demagnetization process due to the interaction of an ultrashort laser pulse with a ferromagnetic material. In this stochastic model, the electron-electron interaction will be considered, as well as spin-dependent inelastic and elastic scattering processes. Furthermore, the magnetization dynamics will be investigated by using a two-bands dynamic model. The model will be first applied to the case of Nickel. The results of this simulation will provide information regarding the time evolution of the electron number, energy distribution, energy dissipation and the quenching of the magnetization.

The long-term perspective of this project is to develop a model that can describe the non-equilibrium transport and its effect on magnetization dynamics.