MA 6: Ultrafast magnetism I

Time: Monday 9:30–12:45 Location: EB 407

MA 6.1 Mon 9:30 EB 407

Manipulation of magnetic order in antiferromagnets — •Fabian Mertens, Marc Terschanski, Stefano Ponzoni, Davide Bossini, and Mirko Cinchetti — Experimentelle Physik VI, TU Dortmund, Otto-Hahn-Straße 4, 44227 Dortmund, Germany

The spin dynamics in antiferromagnetic materials is intrinsically fast compared to other magnetic materials, making antiferromagnets interesting for possible future applications like faster data storage. In this talk, we present the magneto-optical setup that was recently built in our group to study the ultrafast optical manipulation of the magnetic order in antiferromagnets. The setup is based on a femtosecond laser with repetition rates of up to 1 MHz, coupled to two optical parametic amplifiers (OPA) for the independent tuning of the pump and the probe beam to photon energies between 0.5 eV up to 3.5 eV. The problem of single pulse detection at high repetition rates was solved by a home-built balanced photodetector. We will present the characterization of the home-built detector and the first experimental results optained with the setup.

MA 6.2 Mon 9:45 EB 407

Optically induced symmetry breaking in multiferroic h-$YMnO_3$ probed by second harmonic generation — •Christian Tzschaschel[1], Mads Weber[1], Manfred Fiebig[1], and Takuya Satoh[2,3] — [1]ETH Zürich, Switzerland — [2]The University of Tokyo, Japan — [3]Kyushu University, Japan

Recent advances in antiferromagnetic spintronics demand for a better understanding of the order-parameter dynamics on ultrafast time scales. Here, we demonstrate an optically induced coherent modulation of the antiferromagnetic (AFM) order parameter in the multiferroic phase of hexagonal $YMnO_3$. We employ optical second harmonic generation (SHG) as a highly symmetry sensitive probe that couples directly to the AFM order. Exploiting the inverse Faraday effect (IFE), we optically induce a spin precession, which transiently reduces the symmetry of the magnetic lattice from $\underline{6}m\underline{m}$ to 3. Probing the symmetry of the magnetic lattice by SHG, we observe a periodic anisotropy modulation. The periodicity corresponds to a magnon mode in $YMnO_3$. This is further verified by simultaneous measurements of the transiently occuring Faraday rotation. The observed SHG modulation and the Faraday rotation can be described by a combined model of the microscopic spin system with a phenomenological description of the IFE. This model furthermore allows us to directly extract the basal plane spin rotation angle from the SHG data – a quantity that is hardly accessible by established magneto-optical techniques.

MA 6.3 Mon 10:00 EB 407

Ultrafast dynamics of Néel vector in aniferromagnetic thin films detected with optical pump probe spectroscopy — •Vladimir Grigorev[1,2], Alexey Sapozhnik[1,2], Stanislav Bodnar[1], Martin Jordn[1], and Jure Demsar[1,2] — [1]Institute of Physics, Johannes Gutenberg-University Mainz, Mainz, Germany — [2]Graduate School of Excellence, Materials Science in Mainz (MAINZ), Mainz, Germany

Determination of the Néel vector in an antiferromagnetic (AFM) thin film is not trivial and usually requires large-scale facilities. Recently a novel method was demonstrated, utilizing the modulation aspect of the optical pump-probe technique [P. Saidl, et al., Nature Photonics 11, 91-97 (2017)]. We applied this method to determine the Néel vector in the c-axis oriented Mn2Au thin films. Analysis of angular dependence of the pump induced polarization rotation clearly suggests the Néel vector to be pointing along the <110> crystallographic direction, in agreement with recent experimental studies on bulk samples and theoretical calculations. Moreover, following the time evolution of the angular dependent polarization rotation, we were able to resolve the photoinduced rotation of the Néel vector and its recovery on the 100 picosecond timescale. The observed photoinduced rotation proceeds on the 5 ps timescale, which is in a good agreement with the characteristic time of strain induced expansion of the thin film. This suggests a strong coupling of the magnetic order to crystal lattice.

MA 6.4 Mon 10:15 EB 407

Computational investigation of ultrafast magnetization dynamics; ferromagnets vs antiferromagnets — •Unai Atxitia[1], Severin Selzer[2], Tobias Birk[2], Marcel Strohmeier[2], and Ulrich Nowak[2] — [1]Department of Physics, Freie Universität Berlin, D-14195 Berlin, Germany — [2]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

The speed of switching between two stable magnetic states has become a major bottleneck for future advancement of magnetic-based information technologies. Magnetization dynamics in antiferromagnets (AFM) are proposed to be considerably faster than their ferromagnetic (FM) counterparts. In FM, thermal effects can drive magnetization dynamics in a wide range of timescales, from femtosecond laser induced subpicosecond magnetic order relaxation to the slower thermally activated magnetic reversal in nanoparticles. Thermally induced magnetization dynamics in AFM are rather unknown. Here, we investigate the differences between AFM and FM in the thermally induced magnetization dynamics by means of computer simulations based in atomistic spin models. First, we investigate the superparamagnetic limit. Surprisingly, we find that in AFM nanoparticles, switching time is faster than in FM, even if the energy barrier is the same. Second, sub-picosecond heat induced demagnetization; in AFM is up to one order of magnitude faster than in FM. Interestingly, the subsequent remagnetization process to the initial state could also be up to two orders of magnitude faster than in FM. These findings have strong implications for ultrafast control of magnetic states in antiferromagnets.

MA 6.5 Mon 10:30 EB 407

Ultrafast magnetization and lattice dynamics: non-thermal effects — •Karel Carva[1], Pablo Maldonado[2], Pavel Balaz[1], and Peter M. Oppeneer[2] — [1]Charles University, DCMP, Ke Karlovu 5, CZ-12116, Prague, Czech Republic — [2]Uppsala University, PO Box 516, 75120 Uppsala, Sweden

Femtosecond lasers allow to observe magnetization dynamics on an unprecedently short timescale. This dynamics is often described employing the three temperature model, without verifying its validity.

Here we study magnetization dynamics with a special emphasis to non-thermal effects. We have calculated electron-phonon scattering rates for systems with a high electronic temperature, and phonon lifetimes due to phonon-phonon scattering. From these we obtain phonon populations that differ sharply from the thermal ones within picoseconds after the pump [1]. This allows us to understand recent experimental observations and disproves the applicability of the model based on one lattice temperature here [2].

Another important consequence of ultrafast demagnetization is the presence of spin currents described by the superdiffusive spin transport model [3]. This is also a non-thermal effect since electrons with energy significantly above the Fermi level play crucial role there. We compare it to its thermal counterpart, the spin-dependent Seebeck effect.

[1] P. Maldonado et al., Phys. Rev. B 96, 174439 (2017)
[2] T. Henighan et al., Phys. Rev. B 93, 22030 (2016)
[3] M. Battiato et al., Phys. Rev. Lett. 105, 027203 (2010)

15 minutes break

MA 6.6 Mon 11:00 EB 407

Ultra-fast control of the magnetic order of materials by laser light — •Sangeeta Sharma[1], John Kay Dewhurst[1], Peter Elliott[1], Sam Shallcross[2], and E. K. U. Gross[1] — [1]Max Planck Inst. of micro structure physics, Halle, Germany — [2]Lehrstuhl fuer Theoretische Festkoerperphysik, Erlangen University, Erlangen, Germany

By creating via pump laser pulse a non-equilibrium distribution of charge on sub-exchange time scales (i.e., faster than the time scale associated with spin flip in the ground state) we demonstrate that a precise control of magnetic structure is possible on ultra-short time scales, including switching of spin order from anti-ferromagnetic (AFM) to transient ferromagnetic (FM). The microscopic physics of this ultrafast spin modulation is dominated by charge flows created by spin-preserving optical excitations, one of the fastest means of manipulating an electronic system by light. We demonstrate this mechanism to be universally applicable to AFM, FM, multilayers and bulk systems, and provide three rules that encapsulate the laser induced early time magnetization dynamics of multi-sub-lattice systems.

MA 6.7 Mon 11:15 EB 407

Localized-spin dynamics from time-dependent correlation functions — •Kai Leckron and Hans Christian Schneider — University of Kaiserslautern, Department of Physics

We present a microscopic method for the calculation of spin dynamics in Heisenberg models with coupling to a phonon bath using time-dependent correlation functions. We discuss the general strategy to truncate the hierarchy of equations of motion and to obtain approximations at a given level of spin correlations. In this talk, we use an approximation scheme that is exact for the case of a three-spin system. The phonons are treated as a bath in this approach, where contributions of higher order are taken into account using a broadening of the bath interactions.

We apply this method to calculate the spin dynamics after an instantaneous switching of local spins in small ferromagnetically and antiferromagnetically coupled Heisenberg systems and we investigate the influence of the broadening on the magnetization dynamics.

MA 6.8 Mon 11:30 EB 407

A micromagnetic model for ultrafast spin current-driven magnon dynamics — •Henning Ulrichs[1] and Ilya Razdolski[2] — [1]I. Physical Institute, Georg-August University of Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany — [2]Physical Chemistry Department, Fritz Haber Institute of the Max Planck Society, Faradayweg 4-6, 14195 Berlin, Germany

Recent experimental reports have demonstrated that optically induced femtosecond spin currents can excite coherent magnon dynamics in the THz frequency range.[1,2] In this talk I will discuss a simple micromagnetic model for this process. The basic ingredient of this practically 1d model is a Slonczewski-like spin-transfer torque term. With this, we can reproduce the salient features of the experiments presented in reference [1]. Furthermore, the model provides insight into the factors which govern the spin wave mode-specific excitation efficiency. Lastly, I will discuss results for a collinear spin injection geometry. Our modelling shows that then, a thermally occupied magnon ensemble can be heated or cooled on fs time-scales. HU acknowledges financial support by the DFG within project A06 of the SFB 1073.

[1] I. Razdolski et al., Nat. Comm. 8, 15007 (2017)

[2] M.L.M. Lalieu, P.L.J. Helgers, and B. Koopmans, Phys. Rev. B, 96, 014417 (2017)

MA 6.9 Mon 11:45 EB 407

Ultrafast magnetization dynamics probed by Lorentz microscopy — •Marcel Möller[1], John H. Gaida[1], Nara Rubiano da Silva[1], Armin Feist[1], Sascha Schäfer[1,2], and Claus Ropers[1] — [1]4th Physical Institute University of Göttingen, Göttingen, Germany — [2]Physical Institute University of Oldenburg, Oldenburg, Germany

Lorentz microscopy is a widely applied technique for the nanoscale mapping of magnetization structures. Its adaptation to time-resolved imaging offers fascinating prospects for studying ultrafast magnetization dynamics. The Göttingen Ultrafast Transmission Electron Microscope (UTEM) is a newly developed instrument, which allows for studies of ultrafast magnetization and demagnetization dynamics induced by radio-frequency currents or optical pulses. This is facilitated with an electron source which can either deliver a continuous electron beam or electron pulses with a duration down to 200 fs at a 0.6 eV spectral width and a sub-nm focal spot size. In this contribution, we investigate the gyrotropic motion of a magnetic vortex confined within a 20 nm thick 2μm x 2μm permalloy nanoisland. Exciting the magnetic vortex with an in-plane spin current near the resonance frequency of 101MHz, we are able to track the gyration of the vortex core with 20 nm resolution. Furthermore, we investigate the response of the vortex to non-periodic excitations. Using a sinusoidal current pulse which only lasts for a few cycles, we can trace the build-up and relaxation of the vortex gyration, which yields the damping and the spectral characteristics of our sample system.

MA 6.10 Mon 12:00 EB 407

Nonequilibrium melting of spin and orbital-order in the two-band Hubbard model — •Jiajun Li and Martin Eckstein — Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

We study the dynamics of spin and orbital order after strong non-equilibrium excitation in a two-band Hubbard model, using non-equilibrium dynamical mean field theory. The model features an A-type antiferromagnetic phase with antiferro-orbital ordering in equilibrium. Various charge excitations are created during the strong electric pulse, causing both spin and orbital order to melt dynamically. However, due to strong anisotropy in the hopping of electrons in the ordered phase, the orbital-order defects are easier to create and move than the spin-order defects. Therefore, the antiferromagnetic order typically melts slower than the antiferro-orbital order. In addition, varying Hund's coupling modifies the energy spectrum of the two-electron sector in the local Hilbert space. We demonstrate that this can be utilized to control the relative populations of non-equilibrium excitations and therefore the dynamical melting of order parameters. Our finding reveals the possibility of preparing non-thermal spin and orbital-ordered phases and may lead to a way of simultaneously controlling the order parameters with non-equilibrium techniques.

MA 6.11 Mon 12:15 EB 407

Steering of domain walls in Co/$Fe_{25}Gd_{75}$ bilayers by ultrashort laser pulses — •Yasser A. Shokr[1,2], Mustafa Erkovan[3], Bin Zhang[1], Oliver Sandig[1], Matthias Bernien[1], Ahmet A. Ünal[4], Florian Kronast[4], Umut Parlak[3], Jan Vogel[5], and Wolfgang Kuch[1] — [1]Institut für Experimentalphysik, Freie Universität Berlin, 14195 Berlin, Germany — [2]Faculty of Science, Department of Physics, Helwan University, 17119 Cairo, Egypt — [3]Sakarya University, Nanoscience and Nanoenginering Department, 54187 Sakarya, Turkey — [4]Helmholtz-Zentrum Berlin für Materialien und Energie, 12489 Berlin, Germany — [5]CNRS and Université Grenoble Alpes, Institut Néel, 38042 Grenoble, France

Steering magnetic domain walls by light is of high interest. We present a magnetic domain-imaging study by x-ray magnetic circular dichroism photoelectron emission microscopy on a Co/$Fe_{75}Gd_{25}$ bilayer under exposure to single focused ultrashort (100 fs) infrared laser pulses. Magnetic domain walls experience a force in the gradient of the laser pulses away from the center of the pulse, which can be used to move domain walls in a certain direction. Maximum domain-wall displacements close to 1 μm per laser pulse in zero external field are observed. Quantitative estimates show that electronic spin currents from the spin-dependent Seebeck effect are not strong enough to explain the effect, which we thus attribute to the torque exerted by magnons from the spin Seebeck effect that are reflected at the domain wall. The possibility to steer domain walls by ultrashort laser pulses might open new avenues for writing magnetic information.

MA 6.12 Mon 12:30 EB 407

Laser-induced spin currents in nonhomogeneous magnetic systems — •Pavel Baláž[1,2], Karel Carva[1], Pablo Maldonado[3], and Peter M. Oppeneer[3] — [1]Charles University, Faculty of Mathematics and Physics, Department of Condensed Matter Physics, Ke Karlovu 5, CZ 121 16 Prague, Czech Republic — [2]IT4Innovations Center, VSB-TU Ostrava, 17.listopadu 15, CZ 70833 Ostrava, Czech Republic — [3]Uppsala University, Dept. of Physics and Astronomy, Box 530, S-751 21 Uppsala, Sweden

Laser-induced ultrafast demagnetization of transition metals and their alloys is accompanied by generation of spin current of hot electrons which diffuses along the sample. This process is well described by superdiffusive spin transport, which can be applied to a multilayer structure consisted of ferromagnetic (F) and nonmagnetic (N) metallic layers [1]. Recently, a model of spin transfer torque for a F/N/F trilayer with perpendicular magnetizations has been developed [2].

Here, laser-induced processes in magnetic textures like domain walls shall be studied. First, we shall analyze how ultrafast demagnetization influences the domain wall structure. Second, we shall study how spin currents arise in the vicinity of the spin texture.

[1] M. Battiato, K. Carva, P. Oppeneer Phys. Rev. Lett. 105, 027203 (2010).

[2] P. Baláž, M. Žonda, K. Carva, P. Maldonado, P. M. Oppeneer, arXiv:1710.02083 [cond-mat.mes-hall] (2017).