MA 27: Magnetization / Demagnetization Dynamics I

Time: Wednesday 9:30–13:00 Location: EB 301

MA 27.1 Wed 9:30 EB 301

Towards probing ultrafast magnetization dynamics with a table top XMCD setup — •Felix Willems[1], C T L Smeenk[2], Clemens von Korff Schmising[1], Oleg Kornilov[2], Marc Vrakking[2], and Stefan Eisebitt[1] — [1]TU Berlin, 10623 Berlin — [2]Max-Born-Institut, 12489 Berlin

The understanding of ultrafast demagnetization dynamics is of high interest for future applications such as ultrafast magnetic switches and magnetic data storage. Up today there is evidence that two mechanisms (spin-flips [1] and spin transport [2,3]) drive the magnetic dynamics on the femtosecond time scale. In order to isolate the two mechanisms, we need an experimental setup that provides ultrafast time resolution, a well-defined magnetic contrast and element specific sensitivity. We have set up a HHG source that generates circularly polarized x-rays in the energy range of the M-edges of transition metals (40-70 eV) using a four mirror reflection-polariser. We report on first measurements exploiting x-ray magnetic circular dichroism to measure transient magnetisation changes in tailored thin film multilayer sample systems. The advantage of our approach lies in the simultaneous quantitative probing of magnetization of different elements in the sample, enabling us to determine the timing of the dynamics in the adjacent layers with sub 40 fs accuracy. We expect to quantify transport of spin-polarized electrons between the layers vs. dynamics caused by electron-phonon spin flip processes and report on first experiments towards this goal. [1] Koopmans et al., Nat. Mat. 9, 259 (2010) [2] Battiato et al., PRL 105, 027203 (2010) [3] Pfau et al., Nat.Comm. 3, 1100 (2012)

MA 27.2 Wed 9:45 EB 301

Movement of magnetic domain walls induced by single femtosecond laser pulses — •Oliver Sandig[1], Yasser Shokr[1], Bin Zhang[1], Jan Vogel[2], Florian Kronast[3], and Wolfgang Kuch[1] — [1]Institut für Experimentalphysik, Freie Universität Berlin, 14195 Berlin, Germany — [2]CNRS, Institut Néel, 38042 Grenoble, France — [3]Helmholtz-Zentrum Berlin für Materialien und Energie, 12489 Berlin, Germany

Controlling the movement of magnetic domain walls (DW) on ultrashort timescales is important to realize novel applications such as racetrack memories. Magnetic interactions between domain walls, magnetic anisotropy, and coupling between different layers may influence the DW motion. To explore the possibilities of ultra-short laser pulses as a means for ultrafast manipulation of DW's, we carried out lateral- and element-resolved x-ray magnetic circular dichroism (XMCD) photoelectron emission microscopy (PEEM) experiments at BESSY II. The experiments focused on the influence of laser pulses with a wavelength of 800 nm and a duration of 60 fs on the magnetic domains in single-crystalline Co/Cu/Ni trilayers on Cu(001). We observe that even single laser pulses can induce significant depinning and motion of domain walls. This can be considered as a laser-induced variant of thermal domain wall fluctuation, which in the quasi-static case leads to thermal melting of magnetic domains. The experiment shows that single laser pulses can switch individual magnetic domains, without demagnetizing the whole sample.

Funding by the DFG (Ku 1115/11-1) is gratefully acknowledged.

MA 27.3 Wed 10:00 EB 301

Laser-induced ultrafast demagnetization of Co_2MnGa Heusler alloy probed by femtosecond XMCD in reflection geometry — •Sergej Solopow[1], Alexander Kronenberg[2], Martin Jourdan[2], Loic Le Guyader[1], Niko Pontius[1], Torsten Kachel[1], Hans-Joachim Elmers[2], Ilie Radu[1], and Alexander Föhlisch[1] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Albert-Einstein-Strasse 15, 12489 Berlin, Germany — [2]Institut für Physik Johannes Gutenberg Universität, Staudingerweg 7, 55128 Meinz, Germany

Being equally a science- and technologically-driven topic, the research on ultrafast demagnetization dynamics has witnessed an intense activity over the past decades. However, its microscopic origin remains highly elusive and equally debated. In this context, the half-metallic Heusler alloys are particularly interesting due to their peculiar band structure i.e. they are metallic for majority electrons while exhibiting a band gap for the minority ones. Here we report on ultrafast demagnetization investigations of the Co_2MnGa alloy using time-resolved XMCD in reflection geometry at the slicing facility of BESSY II Berlin. Upon tuning the pumping wavelength from visible to near-IR we were able to photo-excite k-specific and spin-selective electronic states and thus to trigger a band structure-specific demagnetization dynamics. The subsequent optical and magnetic responses of the alloy have been recorded for both Co and Mn elements, showing an intriguingly fast dynamics.

MA 27.4 Wed 10:15 EB 301

Constant spin polarization of the Gd(0001) surface state during laser-induced ultrafast demagnetization — •Beatrice Andres[1], Marko Wietstruk[1], Cornelius Gahl[1], Jürgen Kirschner[2], and Martin Weinelt[1] — [1]Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin — [2]Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, 06120 Halle

Yet, there is no theory that is capable to completely describe the dynamics in the electronic structure during laser-induced ultrafast demagnetization. However, recent approaches can reproduce the observed electronic binding energies on Gd [1] by assuming a disordering either of the $4f$ [2] or the $5d$ spin orientation [3] after laser irradiation.

To test the validity of these models, we perform spin- and time-resolved photoemission spectroscopy on Gd/W(110) with our amplified Ti:Sa laser system. Using $4\,mJ/cm^2$ of the fundamental (1.5 eV) as pump and the 4th harmonic (6 eV) as probe pulse, we directly measure the spin polarization and binding energy of the majority surface-state.

We observe a shift in binding energy that is in accordance with the decreasing exchange splitting of the $5d$ bands in Ref. [1]. In parallel, the spin polarization remains constant before spins and lattice equilibrate after several tens of picoseconds. This is in clear contrast to thermal heating where the surface state's spin polarization decreases, while the exchange splitting remains finite even above the Curie temperature.

[1] Robert Carley *et al.*, Phys. Rev. Lett. **109**, 057401 (2012)
[2] Leonid M. Sandratskii, Phys. Rev. B **90**, 184406 (2014)
[3] Björn Frietsch *et al.*, submitted, (2014)

MA 27.5 Wed 10:30 EB 301

Ultrafast Generation of Magnetic Ordering in a First Order Phase Transition — •Robert Carley[1], Sebastian Carron[6], Tyler Chase[4], Bruce Clemens[4], Georgi Dakovski[6], Eric Fullerton[5], Patrick Granitzka[4], Alexander Gray[3], Stefan Günther[2], Daniel Higley[4], Manuel Izquierdo[1], Emmanuelle Jal[3], Loic Le Guyader[7], Joel Li[4], Serguei Molodtsov[1], Mike Minitti[6], Ankush Mitra[6], Alexander Reid[3], William Schlotter[6], Vojtech Uhlir[5], Joachim Stöhr[3], Hermann Dürr[3], Christian Back[2], and Andreas Scherz[1] — [1]European XFEL, Hamburg, Germany — [2]Universität Regensburg, Germany — [3]SIMES, Stanford, California, USA — [4]Stanford University, California, USA — [5]University of California San Diego, USA — [6]LCLS, Stanford, California, USA — [7]HZB, Berlin, Germany

We report on recent experimental studies of the laser-driven antiferromagnetic (AFM) to ferromagnetic (FM) phase transition in FeRh using the time-, element-, and spatially resolving technique of resonant x-ray diffraction (tr-RXD) at the Fe L3 edge. FeRh undergoes a prototypical first order phase transition where the magnetization is the order parameter. The AFM to FM transition is accompanied by an isotropic lattice expansion. Time-resolved magneto-optical Kerr effect measurements suggest FM generation on sub-picosecond time scales, indicating an electronic process. In contrast, monitoring the lattice with time-resolved hard x-ray diffraction reveals nucleation and growth of FM regions on 10ps time-scales. This work aims to establish if the electronic system or the lattice drives the phase transition.

MA 27.6 Wed 10:45 EB 301

Ultrafast demagnetization in rare-earth alloys: the role of spin-orbit coupling — •Loic Le Guyader[1], Sergej Solopow[1], Radu Abrudan[1,2], Florin Radu[1], Karsten Holldack[1], Rolf Mitzner[1], Torsten Kachel[1], Niko Pontius[1], Alexander Föhlisch[1], and Ilie Radu[1] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Albert-Einstein-Strasse 15, 12489 Berlin, Germany — [2]Institut für Experimentalphysik/Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany

Understanding the ultrafast demagnetization occurring upon femtosecond laser excitation of a magnetic material is a fundamental problem of modern magnetism and its microscopic origin remains highly elusive and intensely debated. Particularly, the spin-orbit coupling mediating the spin-lattice interaction is one of the key ingredients. An intriguing case of tunable parallel to anti-parallel LS coupling can be realized in rare-earth (RE) alloys. For instance, Gd60Sm40 and Gd60Dy40 alloys have similar absolute S and L, but exhibit opposite LS coupling while displaying the same ferromagnetic ordering temperature of 250 K. They constitute thus an ideal case to investigate the particular role of the LS coupling on the ultrafast demagnetization. Here we report on the properties of such RE thin film alloys using X-ray Magnetic Circular Dichroism (XMCD) with the spin and orbit sum rules at M5,4 edges. Femtosecond time-resolved transmission XMCD measurements performed at the slicing beamline reveal the element-specific demagnetization time constant in these alloys. Funding from European Union through FEMTOSPIN is gratefully acknowledged.

15 min. break

MA 27.7 Wed 11:15 EB 301

Magnetostriction in Dysprosium studied by Ultrafast X-Ray diffraction — •Alexander von Reppert, Jan-Etienne Pudell, Flavio Zamponi, and Matias Bargheer — Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Str. 24-25, 14476 Potsdam, Germany

We use ultrafast x-ray diffraction to study the lattice dynamics of thin film samples of dysprosium across a large temperature range with different magnetic ordering. Dysprosium has a phase transition from a paramagnetic to the antiferromagnetic phase at $T_{\mathrm{Neel}} = 179$ K and becomes ferromagnetic below $T_{\mathrm{C}} = 86$ K. A strong magnetostriction resulting from the RKKY - interaction in dysprosium leads to an anomalous increase of the interatomic distance with decreasing temperature. In our experiments, we study the behaviour of the dysprosium lattice after direct excitation of the electronic system in the dysprosium layer, as well as after an indirect excitation through electron and heat transfer from an excited adjacent yttrium layer. At temperatures below the phase transition hot electrons can not only couple to the phonon system, leading to an expansive stress but also interact with the magnetic system. Exciting the magnetic system affects the lattice potential so that we observe a contraction of the dysprosium lattice on the picosecond timescale on the order of 0.1%, which can be attributed to a partial removal of the repulsive RKKY interaction. From the fluence- and temperature-dependence we can study details of the coupling of electrons, phonons and magnetic excitation to extract relevant timescales.

MA 27.8 Wed 11:30 EB 301

Time-resolved X-ray diffraction on dysprosium thin films — •Azize Koc[1], Matthias Reinhardt[1], Peter Gaal[1,2], Wolfram Leitenberger[3], and Matias Bargheer[1,3] — [1]Helmholtz Zentrum Berlin, BESSY II, Germany — [2]Institute for Nanostructure and Solid State Physics, University of Hamburg, Germany — [3]Institute of Physics and Astronomy, University of Potsdam, Germany

Dysprosium is a rare earth metal with a ferromagnetic (FM) phase below 86K and an antiferromagnetic (AFM) phase with a helical spin structure below 178 K [1].An important property of the antiferromagnetic phase is the negative thermal expansion coefficient due to magnetostrictive forces [2]. To investigate the structural changes and the interactions between electronic, phononic and magnonic degrees of freedom we use time-resolved X-ray diffraction at the XPP-KMC3 beamline at BESSY II.We feed energy into the conduction band electron system by excitation with 250 fs laser pulses at a central wavelength of 1030 nm.The structural response of the Dy thin film is measured with 100 ps time-resolution at temperatures from 100 K to 300 K and at various fluences. Above the AFM phase transition a fast lattice expansion according to the excitation of the phonon occurs (thermal expansion).Below the AFM phase transition a lattice contraction due to the rapid loss of the RKKY interaction is detected.We observe that the phonon system approaches equilibrium by heat conduction faster than 100 ns required to reestablish the antiferromagnetic order of the magnon system. [1] F.J. Darnell,Phys. Rev.,130,5 (1963) [2] M. Doerr, M. Rotter and A.Lindbaum, Adv. in Phy.,54:1, 1-66 (2005)

MA 27.9 Wed 11:45 EB 301

Ultrafast optical tuning of ferromagnetism in EuO via the carrier density — •Manfred Fiebig — Department of Materials, ETH Zürich, Vladimir-Prelog-Weg 4, 8093 Zurich, Switzerland

The interest in manipulating magnetic order by ultrashort laser pulses has thrived since it was observed that such pulses can be used to alter magnetization on a sub-picosecond timescale. In many cases demagnetization by laser heating dominates the dynamics; this is well described by the classic three-temperature model — assuming energy exchange between thermalized reservoirs of electrons, spins, and the lattice. Here we demonstrate a mechanism that allows the magnetic order of a material to be enhanced or attenuated at will. This is possible in systems simultaneously possessing a low, tunable density of conduction band carriers and a high density of magnetic moments. In such systems the thermalization time can be set such that adiabatic processes dominate the photoinduced change of the magnetic order — the three-temperature model is bypassed. In ferromagnetic $Eu_{1-x}Gd_xO$ we thereby demonstrate strengthening as well as weakening of the magnetic order by $\sim$10% and within $\leq$3 ps by optically controlling the magnetic exchange interaction. A theory backing up and expanding our experimental results will be presented.

MA 27.10 Wed 12:00 EB 301

Ultrafast demagnetization of a ferrimagnetic insulator driven by selective phonon excitation — •Sebastian Mährlein[1], Ilie Radu[2], Pablo Maldonado[3], Alexander Paarmann[1], Michael Gensch[4], Alexandra Kalashnikova[5], Roman Pisarev[5], Peter Oppeneer[3], Martin Wolf[1], and Tobias Kampfrath[1] — [1]FHI der MPG, Berlin — [2]HZB, Berlin — [3]Uppsala University, Sweden — [4]HZDR, Dresden — [5]Ioffe Institute, St. Petersburg, Russia

We present a novel pathway for ultrafast demagnetization of spin-ordered solids by resonant excitation of their crystal lattice, while leaving the electronic orbital degrees of freedom in their ground state. More precisely, the oxygen-iron phonon modes (around 19 THz) of the insulating ferrimagnet $Y_3Fe_5O_{12}$ (YIG) are excited using intense THz pump pulses (absorbed fluence 4 mJ/cm^2) from a femtosecond laser source and, complementarily, a free-electron laser. The resulting spin dynamics are magneto-optically probed over a wide range of time scales from 100 fs to 1 ms. We find a quenching of the magnetization by 3 % with a time constant as short as (1.2$\pm$0.2) ps, which recovers very slowly with a time constant on the order of 0.3 ms. The phonon-driven demagnetization observed is surprisingly fast, orders of magnitude faster than spin-lattice relaxation times in YIG. These findings indicate a highly efficient nonequilibrium energy transfer between the optical phonons and spins. Supported by *ab initio* calculations, we discuss possible microscopic mechanisms of the magnetization dynamics observed.

MA 27.11 Wed 12:15 EB 301

Mechanisms of ultrafast phonon-driven demagnetization of a ferrimagnetic insulator — •Pablo Maldonado[1], Sebastian Mährlein[2], Ilie Radu[3], Alex Paarmann[2], Michael Gensch[4], Alexandra M. Kalashnikova[5], Roman V. Pisarev[5], Martin Wolf[2], Tobias Kampfrath[2], and Peter M. Oppeneer[1] — [1]Uppsala University, Sweden — [2]Fritz Haber Institute of the Max Planck Society, Berlin — [3]Helmholtz-Zentrum Berlin BESSY II, Berlin — [4]Helmholtz-Zentrum Dresden-Rossendorf, Dresden — [5]A.F. Ioffe Physical Technical Institute, St. Petersburg, Russia

We observe that the magnetization of the insulating ferrimagnet Y3Fe5O12 (YIG) is quenched following a resonant phonon excitation by a THz electromagnetic pulse. As electronic degrees of freedom are not excited, we expect that the complexity of the subsequent dynamics is considerably reduced as compared to ultrafast demagnetization of ferromagnetic metals. To gain more insight into microscopic processes leading to a phonon-driven demagnetization in YIG, we perform an ab initio study of the electronic structure and phonon modes of the system. We discuss possible microscopic mechanisms leading to ultrafast demagnetization, by considering two fundamental processes that couple lattice and magnetic order: i) direct coupling, where phonons decay into magnons through the spin-orbit coupling, and ii) phonon anharmonicities driving the system into a metastable state in which the structural changes trigger a modification of the orbital angular momenta.

MA 27.12 Wed 12:30 EB 301

Ferromagnetic relaxation in yttrium iron garnet at small wave vectors — •Julian Hüser and Tilmann Kuhn — Institut für Festkörpertheorie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster

Shortly after the discovery of yttrium iron garnet (YIG) in 1956, a lot of investigations have been performed on this unique magnetic material which to the present has the smallest known ferromagnetic resonance line width. Thereby, a problem occured in explaining the very fast thermalization of pumped magnons in recent experiments in the field of Bose-Einstein condensation of magnons. This fast thermalization is typically interpreted as a multi-stage four-magnon scattering process. However, according to the standard derivation, the contribution of the four-magnon scattering to the relaxation of low energy magnons vanishes in the limit of zero wave vector and therefore this process is far too weak in order to account for thermalization at very small wave vectors where the minimal energy state is located.

In this work, we study the intrinsic relaxation mechanisms and present an additional contribution which has been neglected so far. We show that this contribution is strong enough to explain the experimentally observed fast magnon thermalization.

MA 27.13 Wed 12:45 EB 301

Modelling of laser induced magnetization dynamics at very high magnetic fields — •Unai Atxitia — Zukunftskolleg and Department of Physics, Konstanz, Germany

Recently constructed high magnetic field labs connected to femtosecond laser pulse experiments will permit the measurement of the ultrafast magneto-optical properties of magnetic materials, allowing access to yet unexplored regimes of ultrafast non-equilibrium magnetisation dynamics. However, theoretical models of laser induced magnetisation dynamics assume applied magnetic fields as a second order effect, since it is usually very small in comparison to the strong exchange interactions present in ferromagnets. Thus, current models are not capable of adequately describing the magnetisation dynamics in the presence of high magnetic fields. Therefore further theoretical work is necessary in this line. Here, we present the extension to high fields of the widely used Landau-Lifshitz-Bloch equation of magnetisation dynamics. Within this model we compare the magnetisation dynamics induced by a laser pulse at different magnetic fields, from 0 to 50 Tesla. We show that very high magnetic fields can not only quantitatively but also qualitatively change the magnetisation dynamics after the laser pulse. It is expected that the predictions made within this model can be soon experimentally checked.