MA 22: Magnetization Dynamics I

Time: Wednesday 9:30–12:45 Location: HSZ 401

MA 22.1 Wed 9:30 HSZ 401

Pump-probe-experiments on individual atomic-scale superparamagnets — •Jan Hermenau, Andreas Sonntag, Johannes Friedlein, Stefan Krause, and Roland Wiesendanger — Institute of Applied Physics, University of Hamburg, Germany

In our experiments we investigate the fast thermal magnetization reversal of uniaxial atomic-scale magnets [1] using an all electrical pump-probe-scheme [2] implemented in a spin-polarized scanning tunneling microscopy setup.

During the pump-pulse, a temporal population asymmetry of the two magnetization directions is induced due to spin-transfer torque generated by a high spin-polarized tunnel current pulse. After a given time a small current pulse is used to probe the state of the magnet. From the thermal decay of the induced population asymmetry the intrinsic switching rate can be determined. In contrast to pump-probe experiments of Loth et al. the switching between two degenerate ground states can be investigated in absence of a magnetic field.

In our experiments we determine the switching rates of individual magnets at different temperatures. For temperature intervals of 22 K switching rates ranging over eight orders of magnitude are observed on a single magnet. The experiments reveal a deviation of the high switching rates from the predictions of the Néel-Brown-law. This is discussed in terms of multi-droplet nucleation und domain wall propagation.

[1] S. Krause *et al.*, Phys. Rev. Lett. **103**, 127202 (2009)
[2] S. Loth *et al.*, Nature Physics **6**, 340 (2010)

MA 22.2 Wed 9:45 HSZ 401

Ultrafast magnetic and structural dynamics in antiferromagnetic Europium-Telluride — •Christoph Trabant[1,2,3,6], Niko Pontius[1], Karsten Holldack[1], Enrico Schierle[1], Eugen Weschke[1], Torsten Kachel[1], Rolf Mitzner[1], Martin Beye[1], Gunther Springholz[4], Georgi Dakovski[5], Joshua J Turner[5], Stefan Möller[5], Tianhan Wang[5], Alex Gray[5], Markus Hantschmann[5,1], Hermann Dürr[5], Michael Minitti[5], W.S. Lee[5], Yi-De Chuang[5], Zuman Hussain[5], Z.X. Shen[5], Matias Bargheer[3], Daniel Schick[3], Alexander Föhlisch[1,3], and Christian Schüssler-Langeheine[1] — [1]Helmholtz-Zentrum Berlin — [2]II. Physikalisches Institut, Universität zu Köln — [3]Institut für Physik und Astronomie, Universität Potsdam — [4]Institute of Semiconductor and Solid State Physics, Johannes Kepler Universität Linz, Austria — [5]SLAC RSXS collaboration, USA — [6]present address: Institut für Experimentalphysik, FU Berlin

Laser-induced magnetic dynamics is generally assumed to occur much faster than structural effects induced by the same laser pulse. In order to verify that, we studied both dynamics in a metallic 4f AFM EuTe thin film. The dynamics were mapped using the strong resonant x-ray scattering signal of the AFM (001/2) superstructure and (001) structural reflection. Here we report that the loss of antiferromagnetic order precedes structural changes on ultrafast timescales followed by strain wave dominated dynamics. The optical pump xray probe measurements have been performed in one experiment at the SXR-beamline of LCLS. Supported by the BMBF through contract 05K10PK2.

MA 22.3 Wed 10:00 HSZ 401

The role of spin-lattice coupling in the ultrafast demagnetization of GdTb alloys — •Andrea Eschenlohr[1,2], Muhammad Sultan[1], Alexey Melnikov[3], Nicolas Bergeard[1], Jens Wieczorek[1], Torsten Kachel[2], Christian Stamm[2], and Uwe Bovensiepen[1] — [1]Universität Duisburg-Essen — [2]Helmholtz Zentrum Berlin — [3]Fritz-Haber-Institut der MPG, Berlin

$Gd_{1-x}Tb_x$ shows a two-step demagnetization after femtosecond (fs) laser excitation typical for rare earths [Wietstruk et al., PRL **106**, 127401 (2011)]. With fs time-resolved magneto-optical Kerr effect measurements we see that the time constant τ_1 of the first step is not correlated to x, while the rate $\gamma_2 = 1/\tau_2$ of the second step increases linearly with x. We therefore assign the first demagnetization step to the non-equilibrium dynamics of the $5d$ electrons, while the second step, which occurs under quasi-equilibrium conditions after electron-phonon equilibration, is dominated by the strong spin-lattice coupling of Tb given by the spin-orbit coupling of its $4f$ shell with $L = 3$. Complementary fs time-resolved x-ray magnetic circular dichroism measurements show a shared τ_2 of Gd and Tb in $Gd_{0.6}Tb_{0.4}$, but a transient difference in their magnitude of demagnetization. We attribute this to an increased spin-lattice coupling of Gd in $Gd_{0.6}Tb_{0.4}$, compared to pure Gd, via $5d$-$5d$ interatomic exchange coupling to neighboring Tb atoms. This coupling however has a limited efficiency, which explains the transient difference.

We acknowledge funding from BMBF Grant 05K10PG2 Femtospex and the DAAD-HEC Pakistan.

MA 22.4 Wed 10:15 HSZ 401

The Janus face of Gadolinium: different timescales for itinerant and localized magnetism — •Björn Frietsch[1,2], Robert Carley[1,2], Martin Teichmann[1,2], John Bowlan[1,2], and Martin Weinelt[1,2] — [1]Freie Universität Berlin, Fachbereich Physik, Arnimallee 14, 14195 Berlin, Germany — [2]Max Born Institut, Max-Born-Straße 2a, 12489 Berlin, Germany

We present results of experiments from ultrafast laser-driven magnetization dynamics on the rare-earth local-moment ferromagnet Gadolinium. We use high order harmonic radiation to perform time- and angle-resolved photoemission spectroscopy [1].

With this technique it was possible to map the non-equilibrium band structure after excitation of the ferromagnet by a short infrared laser pulse and simultaneously follow the magnetic evolution of the 4f core level using magnetic linear dichroism.

The magnetization dynamics of the valence electrons and the 4f spins are strikingly different. While we observe subpicosecond demagnetization of the valence electronic system [2], the 4f core level exhibits a time constant of about 13ps.

[1] B. Frietsch, R. Carley, K. Döbrich, C. Gahl, M. Teichmann, O. Schwarzkopf, P. Wernet, and M. Weinelt Rev. Sci. Instrum. 84, 075106 (2013)

[2] R. Carley, K. Döbrich, B. Frietsch, C. Gahl, M. Teichmann, O. Schwarzkopf, P. Wernet, and M. Weinelt Phys. Rev. Lett. 109, 057401 (2012)

MA 22.5 Wed 10:30 HSZ 401

Switching dynamics of two-sublattice magnets — •Sönke Wienholdt[1], Denise Hinzke[1], Karel Carva[2,3], Peter Oppeneer[2], and Uli Nowak[1] — [1]University of Konstanz, Germany — [2]Uppsala University, Sweden — [3]Charles University in Prague, Czech Republic

It has been demonstrated recently that linearly polarized light can trigger a thermally driven switching in ferrimagnetic GdFeCo compounds [1,2] via a so called "ferromagnetic-like state", where the rare-earth (RE) and transition metal sublattice magnetizations are aligned parallel on a ps time scale. The ultra-short time scale of the laser pulse and the high electron temperatures following the excitation lead to non-equilibrium processes where longitudinal magnetization dynamics becomes pronounced [2-4]. Recently, we have shown [5] that the thermally driven spin-switching of RE-based ferrimagnets can be well described on the basis of an orbital-resolved spin model, distinguishing electrons in d and f orbitals. In this talk we will show with atomistic spin model simulations that even after having reached the transient ferromagnetic-like state, the system does not necessarily switch. Recently this has also been observed experimentally with element specific measurements on TbFeCo [6]. We acknowledge funding by the European Comission via the Collaborative Project FEMTOSPIN.

[1] I. Radu et al., Nature 472, 205 (2011). [2] T. A. Ostler et al., Nat. Commun. 3, 666 (2012). [3] N. Kazantseva et al., Europhys. Lett. 81, 27004 (2008). [4] J. H. Mentink et al., Phys. Rev. Lett. 108, 057202 (2012). [5] S. Wienholdt et al., Phys. Rev. B 88, 020406(R) (2013). [6] A. R. Khorsand et al., Phys. Rev. Lett. 110, 107205 (2013).

MA 22.6 Wed 10:45 HSZ 401

Ultrafast Spin dynamics in multicenter Nickel complexes — •Debapriya Chaudhuri, Georgios Lefkidis, and Wolfgang Hübner — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, 67653 Kaiserslautern, Germany

We present ultrafast logic elements in molecular systems with active magnetic centers using *ab initio* theory and show the possibility of coherent spin manipulation [1]. The processes are investigated in Ni_n (n = 2,3,4) clusters where spin localization, spin-flip, spin-transferability and demagnetization are discussed with respect to their geometries.

We investigate laser-induced, spin-dynamics scenarios on Ni_2 at various interatomic distances. High-fidelity spin-switching is possible within 500 fs with the Λ-process. At each bond length the dimer responds to a specially optimized pulse. Strong correlations are observed and new rules-of-thumb are derived. In case the Λ-process fails, switching is achieved through the M-process that includes more intermediate states with higher occupations. Ni_4 [2] is a good cluster of interest due to its flexibility in achieving local spin-flips and spin-transfers between magnetic centers which occur within 350 fs. Inclusion of higher multiplicities such as quintets in the excited states provides an insight to the phenomena such as reversible global spin-switch and irreversible demagnetization scenarios within 350-400 fs.

[1] G. Lefkidis, G. P.Zhang, and W. Hübner, Phys. Rev. Lett. **103**, 217401 (2009).
[2] M. H. Ghatee, and Leila Pakdel, Int. J. Quantum Chem. **113**, 1549 (2013).

15 min. break

MA 22.7 Wed 11:15 HSZ 401

Equilibration of Electron Temperatures and Chemical Potentials during Ultrafast Magnetization Dynamics — •Benedikt Y. Mueller and Baerbel Rethfeld — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany

Exciting a ferromagnetic nickel film with an ultrashort laser pulse leads to a quenching of the magnetization on a subpicosecond timescale [1]. Since this discovery, several models for the microscopic mechanism have been proposed, for instance, spin-flip scattering [2,3,4] and superdiffusive transport [5]. Today it seems that both processes contribute to the demagnetization, depending on the sample properties. Easy-to-handle models are essential to predict dynamic properties of systems with increasing complexity. Exploiting insights from our analysis of the spin-resolved Boltzmann equation [2,4] we set up a model governed by the equilibration of temperatures and chemical potentials of spin-up and spin-down electrons. This opens the possibility to describe transport effects in parallel with spin-flip processes and allows for analytical predictions of the demagnetization dynamics.

[1] Beaurepaire et al., PRL 76, 4250 (1996)
[2] Mueller et al., PRL 111, 167204 (2013)
[3] Koopmans et al., NMAT 9, 259 (2010)
[4] Essert et al., PRB 84, 224405 (2011)
[5] Battiato et al., PRL 105, 027203 (2010)

MA 22.8 Wed 11:30 HSZ 401

Ultrafast demagnetisation dynamics in Cu-doped Permalloy — •Sadashivaiah Sakshath[1], Oliver Schmitt[1], Daniel Steil[1], Moritz Barkowski[1], Sabine Alebrand[1], Ute Bierbrauer[1], Emrah Turgut[2], Patrik Grychtol[2], Justin Shaw[3], Roman Adam[4], Chan La-O-Vorakiat[2], Hans T. Nembach[3], Claus M. Schneider[4], Margaret M. Murnane[2], Henry C. Kapteyn[2], Thomas J. Silva[3], Stefan Mathias[1], and Martin Aeschlimann[1] — [1]TU Kaiserslautern, Germany — [2]JILA, University of Colorado, USA — [3]NIST, Boulder, USA — [4]Forschungszentrum Jülich, Germany

Permalloy doped with Copper presents itself as an interesting system for investigations of ultrafast demagnetisation dynamics as the exchange interaction is tuned [1]. Here, we perform fluence dependent TR-MOKE measurements for different Copper concentrations. In pure Permalloy, where exchange coupling is strong, and the Curie temperature is high, the demagnetisation time constant (τ_m) increases monotonously as the magnetization is quenched. These dynamics gradually change with increasing copper concentration. First, the total demagnetization times become slower, and second we observe a drastic reduction of τ_m at high quenching values, similar to the predictions of the M3TM model [2]. The influence of varying exchange coupling on the measured ultrafast demagnetization rates is discussed.

[1] S. Mathias *et al.*, PNAS **109**, 4792 (2012)
[2] B. Koopmans *et al.*, Nature Materials **9**, 259 (2010)

MA 22.9 Wed 11:45 HSZ 401

Thickness dependent ultrafast magnetization dynamics in Co/Cu(100) films — •Jens Wieczorek, Nicolas Bergeard, Andrea Eschenlohr, Alexander Tarasevitch, Boris Weidtmann, Andreas Duvenbeck, and Uwe Bovensiepen — Universität Duisburg-Essen, Fakultät für Physik, Germany

To disentangle the local and non-local contributions in femtosecond laser induced demagnetization [1,2,3], we measure the variation of the magneto optical Kerr rotation and ellipticity of Co/Cu(100) films at thicknesses 2 nm $< d <$ 20 nm. We find an increasing quenching of the magnetization and a shift of the time delay of maximum demagnetization to longer delay times with increasing film thickness. Both effects result from a competition between light absorption in cobalt and energy transport to copper. Due to the high thermal conductivity copper acts in our investigated sample as an energy sink. For thicker films the transport to the substrate is decreased due to lower heat conductivity in cobalt and the energy remains longer in Co. This results in a higher excess electron energy density and a reduced cooling, so that the sample can demagnetize longer and stronger. This behavior is also seen in three temperature model [3] simulations, which include different heat conductivity in Co and the Cu substrate. This shows the importance of energy transport to a conducting substrate in magnetization dynamics. We acknowledge support by the DFG through SFB616 and the Mercator Research Center Ruhr through Projekt 2011-0003. [1]Battiato et al., PRL **105**, 027203 (2010); [2]Melnikov et al., PRL **107**, 076601 (2011); [3]Koopmans et al., Nat. Mat. **9**, 259 (2010).

MA 22.10 Wed 12:00 HSZ 401

Spin transfer in Au/Fe/MgO(001) structures by optically excited hot carrier transport — •Alexandr Alekhin[1], Damian Bürstel[2], Tim O. Wehling[3], Detlef Diesing[2], Ivan Rungger[4], Maria Stamenova[4], Stefano Sanvito[4], Uwe Bovensiepen[5], and Alexey Melnikov[1] — [1]Fritz-Haber-Institut der MPG, Abt. Phys. Chemie — [2]Universität Duisburg-Essen, Institut für Phys. Chemie — [3]Universität Bremen, Theor. Phys. Institut — [4]Trinity College Dublin, School of Physics and CRANN — [5]Universität Duisburg-Essen, Fakultät für Physik

Spin transfer induced by ultrashort laser pulses is of great importance in light of recent advances in spintronics and attempts to control magnetization on femtosecond (fs) time scales. Using 14 fs laser pulses in pump-probe experiments performed on the epitaxial Au/Fe/MgO(001) structures, we pump the Fe film to excite and inject spin-polarized hot carriers (HC) into the Au layer and probe the Au side of the samples to monitor transient bulk spin polarization (SP) by the magneto-optical Kerr effect (MOKE) and transient SP at the Au surface by the magneto-induced second harmonic generation (mSHG). Analyze of the transient MOKE and mSHG signals as functions of Au thickness let us study evolution of the HC packet and the spin current pulse and evaluate that the velocity of the ballistic fraction of the HC packet equals to 1.19 nm/fs which is close to the ballistic velocity of minority electrons in Au. Varying Fe thickness, we demonstrate the possibility to manipulate the ballistic fraction of the HC packet. DFG (ME 3570/1, Sfb 616) and EU 7-th framework program (CRONOS) are acknowledged.

MA 22.11 Wed 12:15 HSZ 401

Time-resolved MOKE in Au/Fe/MgO(001) structures: hot carrier transport and response of transiently magnetized Au — Alexandr Alekhin[1], Damian Bürstel[2], Detlef Diesing[2], Tim O. Wehling[3], Ivan Rungger[4], Maria Stamenova[4], Stefano Sanvito[4], Markus Münzenberg[5], Uwe Bovensiepen[6], and •Alexey Melnikov[1] — [1]Fritz-Haber-Institut der MPG, Abt. Phys. Chemie — [2]Universität Duisburg-Essen, Institut für Phys. Chemie — [3]Universität Bremen, Theor. Phys. Institut — [4]Trinity College Dublin, School of Physics and CRANN — [5]Universität Göttingen, I. Phys. Institut — [6]Universität Duisburg-Essen, Fakultät für Physik

Ultrafast spin dynamics (SD) is the key for development of faster data storage and spintronics devices. In metals with highly mobile hot carriers (HC) SD is essentially non-local and determined by the transport of spin-polarized HC. Therefore we consider the effect of HC transport being superimposed onto SD originating from the spin-lattice interaction. We investigate this non-locality of optically excited SD in Au/Fe/MgO(001) structures observing magneto-optical Kerr effect (MOKE) with 20 fs time resolution. Exciting the Fe layer and probing either the Fe or Au sides of the sample, we demonstrate the crucial role of spin-polarized HC transport in ultrafast SD and reveal a sizable contribution of transiently magnetized Au into the MOKE signal. Finally, we propose a technique for the definition of magneto-optical constants of non-magnetic materials based on spin polarized HC transport and estimate the magneto-optical constant of Au. DFG (ME 3570/1, Sfb 616) and EU 7-th framework program (CRONOS) are acknowledged.

MA 22.12 Wed 12:30 HSZ 401

Spin-resolved photoelectron spectroscopy using femtosecond extreme ultraviolet light pulses — •Moritz Plötzing, Roman Adam, Christian Weier, Lukasz Plucinski, and Claus M. Schnei-

DER — Peter Grünberg Institut (PGI-6), Research Center Jülich, 52425 Jülich, Germany

The ongoing discussion about the physical mechanism responsible for femtosecond magnetization dynamics raise the demand for new experimental techniques capable of accessing fundamental properties of ferromagnetic materials, *e.g.* by investigating the ultrafast evolution of the spin-resolved band structure. Our work focusses on a combination of highly efficient spin detection in a photoemission spectroscopy (PES) experiment and a femtosecond laser-driven extreme ultraviolet (XUV) light source. Using the ultrashort XUV pulses, we measured spin-resolved PES spectra of thin Co films grown *in-situ* on Cu(100). By a comparison of these results with spectra obtained using a continuous-wave He discharge lamp, we identified important differences due to the excitation with the XUV source. Furthermore, we found that the spectra measured using the pulsed XUV source allow the extraction of important magnetic properties including the exchange splitting. The necessary acquisition times are fully suited for time-resolved experiments employing a pump-probe scheme.