MA 14: Spin Dynamics / Spin Torque I

Time: Wednesday 9:30–12:45 Location: H10

Invited Talk MA 14.1 Wed 9:30 H10

Ultrafast spin-orbit excitations in ferromagnets probed by fs x-ray pulses — •Hermann A. Dürr — Helmholtz Zentrum Berlin, BESSY II, Germany — SLAC, Stanford University, USA

Polarized soft x-rays have been used over the past 20 years to obtain fascinating new insights into nanoscale magnetism. The separation of spin and orbital magnetic moments, for instance, enabled detailed insights into the interplay of exchange and spin-orbit interactions at the atomic level. The now available polarized soft x-ray pulses with only 100 fs duration allow us to observe the magnetic interactions at work in real time. The ultimate goal of such studies is to understand how spins may be manipulated by ultrashort magnetic field, spin polarized current or light pulses. In this talk I will focus on fs laser induced magnetization dynamics in 3d transition metals, 4f systems and their alloys. Using fs x-ray pulses from the BESSY II femtoslicing facility I will show how fs excitation of the electronic system modifies the spin-orbit interaction enabling ultrafast angular momentum transfer between spin, orbital and lattice degrees of freedom.

MA 14.2 Wed 10:00 H10

Element-specific Study of the Ultrafast Magnetization Switching on GdFeCo — •Ilie Radu[1,2], Kadir Vahaplar[1], Alexey Kimel[1], Christian Stamm[2], Torsten Kachel[2], Niko Pontius[2], Hermann Duerr[2], Arata Tsukamoto[3], Andrei Kirilyuk[1], and Theo Rasing[1] — [1]IMM/SSI, Radboud University Nijmegen, The Netherlands — [2]Helmholtz-Zentrum Berlin, BESSY II, Germany — [3]College of Science and Technology, Nihon University, Chiba, Japan

Recent time-resolved magneto-optical studies of GdFeCo performed in the visible spectral range have demonstrated the intriguing possibility of all-optical magnetization reversal with 40 fs laser pulses. So far, a complete understanding of the switching mechanism and of the involved elementary processes is still lacking. Here, we report on time-resolved X-ray magnetic circular dichroism (TRXMCD) studies of the fs laser-induced magnetization switching of the ferrimagnetic GdFeCo alloy. We trigger the magnetization switching by fs laser heating the material across its magnetization compensation temperature using linearly polarized laser pulses. The subsequent magnetization dynamics is probed with 10 ps X-ray pulses by TRXMCD measured at the absorption edges of Fe and Gd. TRXMCD data reveal an intricate transient magnetization dynamics: A rapid demagnetization accompanied by the onset of the magnetization switching and subsequently the full development of the magnetization reversed state on a few 100 ps.

Funding from European Union through UltraMagnetron Program is gratefully acknowledged.

MA 14.3 Wed 10:15 H10

Magnetisation dynamics of ferrimagnets close to the compensation point — •Ulrich Nowak[1], Thomas Ostler[2], Denise Hinzke[1], Stefan Gerlach[1], and Roy W. Chantrell[2] — [1]Universität Konstanz, 78457 Konstanz — [2]University of York, York YO10 5DD, U. K.

Recently it was demonstrated that a circularly polarised laser pulse in the 100 femtosecond range is able to reverse the magnetisation of the ferrimagnet GdFeCo [1,2]. It was concluded that the laser pulse leads to a combined magnetic field and heat pulse, resulting in the magnetisation switching [3]. However, so far this so-called opto-magnetic writing was only successfully demonstrated for the above class of materials. The reason for this restriction is not clear though it was speculated that the special properties of a ferrimagnet close to its compensation point could be relevant.

Therefore we investigate the dynamics of a ferrimagnet close to its angular momentum compensation point by means of computer simulations. We solve the stochastic Landau-Lifshitz-Gilbert equation for a generic, atomistic model of a ferrimagnet. The temperature dependence of the precession frequency as well as the effective damping constant is investigated. The results are compared with earlier analytical results as well as recent experiments [5].

[1] A. V. Kimel et al., Nature 435, 655 (2005) [2] C. D. Stanciu et al., Phys. Rev. Lett. 99, 047601 (2007) [3] K. Vahaplar et al., Phys. Rev. Lett. 103, 117201 (2009) [4] N. Kazantseva et al., Europhys. Lett. 86, 27006 (2009) [5] C. D. Stanciu et al., Phys. Rev. B, 73, 220402 (2006).

MA 14.4 Wed 10:30 H10

Element resolved magnetisation dynamics in $Fe_{1-x}Ni_x$ thin films — •Stefan Buschhorn, Frank Brüssing, Benjamin Glaubitz, Radu Abrudan, and Hartmut Zabel — Experimentalphysik IV, Ruhr-Universität Bochum

X-Ray Resonant Magnetic Scattering (XRMS) in combination with pump-probe techniques is a unique tool in order to directly observe element-resolved magnetisation dynamics. We present a time resolved setup with a time resolution of less than 100ps, using a magnetic field pulse excitation. The sample is mounted on a stripline and the reflected signal is averaged over many excitations in a delay scan with respect to the synchrotron flash. The experiments were done using the ALICE diffractometer [1]. We present results on the precessional dynamics of a Py sample in a temperature range from 80...350K, showing that both Fe and Ni precess in phase within the given resolution (see also [2]). There is no discernable change in temperature over the temperature range studied. In addition, we followed the frequency dependence of the precession as a function of alloy composition for a set of $Fe_{1-x}Ni_x$ thin films in order to reveal possible variations around the invar region.

This work was supported by BMBF under contracts 05KS7PC1 and 05ES3xBA/5. St. Buschhorn is fellow of the Ruhr-University Research School.

[1] J. Grabis, *et.al.*, Rev. Sci. Inst. **74**, 4048 (2003)
[2] W. Bailey, *et.al.*, Phys. Rev. B **70**, 172403 (2004)

MA 14.5 Wed 10:45 H10

Ultrafast and Element-Selective Demagnetization Dynamics probed at the M Absorption Edges employing a table-top High-Harmonic Soft X-ray Source — •Patrik Grychtol[1], Chan La-O-Vorakiat[4], Roman Adam[1], Stefan Mathias[2,4], Mark Siemens[4], Justin Shaw[3], Hans Nembach[3], Thomas Silva[3], Martin Aeschlimann[2], Claus M. Schneider[1], Henry Kapteyn[4], and Margaret Murnane[4] — [1]Insitut für Festkörperforschung, IFF-9, Forschungszentrum Jülich, Jülich — [2]Technische Universität Kaiserslautern und Forschungszentrum OPTIMAS, Kaiserslautern — [3]Electromagnetics Division, National Institute of Standards and Technology, Boulder, Colorado — [4]Department of Physics and JILA, University of Colorado, Boulder, Colorado

Employing tabletop soft X-ray sources based on ultrafast laser amplifier for probing magnetic materials promises to combine element-selectivity with a spatial and temporal resolution on the nanometer and femtosecond scales for studying magnetism at fundamental limits. In our T-MOKE experiment where coherent X-ray pulses were reflected off a magnetized Ni80Fe20 grating, large changes in the reflected intensity of up to 6% at the M absorption edges of Fe and Ni were observed upon magnetization reversal. We demonstrate that femtosecond soft X-ray pulses from high harmonic generation can probe the Ni80Fe20 demagnetization in the femtosecond range element-selectively. Ultrafast demagnetization induced by a femtosecond laser pump pulse can be observed at both edges pointing towards a tight exchange coupling of the respective magnetic moments.

MA 14.6 Wed 11:00 H10

Electron-phonon contribution to the ultrafast demagnetization of ferromagnetic metals — •Sven Essert, Michael Krauss, and Hans Christian Schneider — TU Kaiserslautern, 67653 Kaiserslautern, Germany

The Elliott-Yafet (EY)-mechanism is arguably the most promising candidate to explain the light-induced ultrafast demagnetization dynamics in ferromagnetic transition metals on time scales on the order of 100 fs. By numerically solving dynamical equations for spin and energy-resolved electronic distribution functions and including electron-electron interactions at the level of Boltzmann scattering integrals, we were able to show [1] that an EY-like mechanism based on electron-electron scattering has the potential to explain time-resolved magneto-optical Kerr effect measurements on thin magnetic cobalt and nickel films, without reference to a "phononic spin bath". In this contribution, we include the electron-phonon interaction as an additional scattering mechanism in our approach. We compare our numerical results for cobalt and nickel with other approaches, which assume

electron-phonon scattering as the spin-diagonal scattering process underlying the demagnetization. [2]

[1] M. Krauß, T. Roth, S. Alebrand, D. Steil, M. Cinchetti, M. Aeschlimann, and H. C. Schneider, Phys. Rev. B **80**, 180407(R) (2009)
[2] D. Steiauf and M. Fähnle, Phys. Rev. B **79**, 140401(R) (2009)

MA 14.7 Wed 11:15 H10

Extension of Yafet's theory of spin relaxation to ferromagnets — •Christian Illg[1], Daniel Steiauf[2], and Manfred Fähnle[1] — [1]Max-Planck-Institut für Metallforschung, Heisenbergstraße 3, 70569 Stuttgart, Germany — [2]Materials Department, University of California, Santa Barbara, CA 93106-5050, USA

By making use of Kramer's degeneracy of the electronic states in a nonmagnetic material, Yafet [1] has derived an expression for the longitudinal spin relaxation time T_1 due to scattering of electrons at phonons in the presence of spin-orbit coupling, using rate equations near the equilibrium state and Fermi's golden rule for the scattering rates. This expression involves the properties of electronic and phononic states and the matrix elements for the scattering. In a ferromagnet, Kramer's degeneracy does not hold and then the electronic dispersion and density of states become spin-dependent. Moreover, the symmetry of the scattering matrix element changes. It is shown that an analogous (yet more complicated) expression for T_1 can be derived for ferromagnets when taking into account the conservation of the total number of electrons. This expression can be used as a starting point for the ab-initio calculation of T_1, and this quantity is required for an interpretation of the ultrafast demagnetization of ferromagnets after excitation with a femtosecond laser pulse.

[1] Y. Yafet, in *Solid State Physics* (Eds.: F. Seitz and D. Turnbull, Academic, New York, 1963), Vol. 14.

MA 14.8 Wed 11:30 H10

Theoretical investigation of ultrafast laser-induced magnetization dynamics in small quantum mechanical systems — •Daria Popova, Andreas Bringer, and Stefan Blügel — Institut für Festkörperforschung & Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany

Ultrafast optical control of the magnetic state of a medium is presently a subject of intense research. It is of importance for the development of novel concepts for high-speed magnetic recording and information processing. A series of experiments has revealed direct optical control on magnetization via inverse Faraday effect [1]. In these experiments femtosecond circularly polarized high-intensity laser pulses are used to excite the sample. Laser induced spin dynamics are investigated using the pump-probe technique. An open question is the evolution of the orbital momentum transferred from light to the medium, which defines the fundamental time limit on magnetic switching. In order to get insight into the magnetization dynamics we treat small quantum mechanical systems. In our work we begin from the investigation of a hydrogen atom excited by a femtosecond gauss-shaped polarized laser pulse. The connection between light and spin are introduced due to the spin-orbit coupling of the excited level. Solving the time-dependent Schroedinger equation using the Volterra iteration method we study the temporal behavior of spin and orbital momentum during and after the application of the pump and probe laser pulses. We are thankful for the financial support of the FANTOMAS project.

[1] A. V. Kimel et al., Nature **435**, 655 (2005)

MA 14.9 Wed 11:45 H10

Modelling of ultrafast laser-induced demagnetization — •Benedikt Müller, Mirko Cinchetti, Tobias Roth, Martin Aeschlimann, and Bärbel Rethfeld — University of Kaiserslautern, Germany

Experiments with ultrashort laser pulses irradiating ferromagnetic transition metals show a demagnetization on femtosecond timescale [1]. Despite the numerous experimental efforts, still no complete microscopic understanding of ultrafast magnetization dynamics have been achieved. In order to describe the microscopic processes we apply the Boltzmann equation including electrons and phonons which characterize a solid [2]. The model can be extended for a ferromagnetic material: We consider electrons with spin up and down separately and allow coupling between both reservoirs. Including this, we are able to describe changes in the magnetization by incorporating the spin dependence into the Boltzmann equation. With this model we describe the temporal evolution of a ferromagnetic material which is strongly excited by an ultrashort laser pulse.

[1] M. Cinchetti et al., PRL 97, 177201 (2006)
[2] B. Rethfeld et al., PRB 65, 214303 (2002)

MA 14.10 Wed 12:00 H10

Enhanced Spin-Orbit Interaction During Ultrafast Demagnetization of Nickel — •Christian Stamm, Niko Pontius, Torsten Kachel, Marko Wietstruk, and Hermann A. Dürr — Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Elektronenspeicherring BESSY II, Albert-Einstein-Str. 15, 12489 Berlin

Time-resolved x-ray absorption spectroscopy (XAS) allows for a detailed view of microscopic processes during ultrafast demagnetization following a laser pump pulse. Previously we have shown that both spin and orbital angular momentum are quenched within a few 100 fs, utilizing the x-ray magnetic circular dichroism (XMCD) sum rules [1]. In addition, XAS is able to measure the spin-orbit interaction by quantifying the absorption ratio between the spin-orbit split L3, L2 absorption edges, the so-called branching ratio [2]. We find an increase of the spin-orbit coupling just after laser excitation, which persists during the demagnetization process. This is the first experimental demonstration of laser-enhanced spin-orbit interaction.

[1] C. Stamm et al., Nature Mater. 6, 740 (2007).
[2] G. van der Laan, B. T. Thole, Phys. Rev. Lett. 60, 1977 (1988).

MA 14.11 Wed 12:15 H10

Fluence and temperature dependent studies of femtosecond magnetism — •Oliver Schmitt, Tobias Roth, Daniel Steil, Sabine Alebrand, Mirko Cinchetti, and Martin Aeschlimann — Department of Physics and Research Center OPTIMAS, TU Kaiserslautern, Germany

We exploit the time-resolved magneto-optical Kerr effect (TRMOKE) to gain access to the physics underlying ultrafast spin-dynamics. In this contribution, external parameters like the pump pulse fluence and the ambient temperature are deliberately varied over a wide range. The won results for a thin nickel film demonstrate a strong temperature dependence on the maximum quenching q of the magnetization as well as on the demagnetization constant τ_m and the relaxation back to the initial state. The Elliott-Yafet (EY) spin-flip mechanism is the most promising candidate to explain the ultrafast loss of magnetic order. Experimental results are discussed behind the background of the two recent models for ultrafast demagnetization based on EY scattering [1,2].

[1] B. Koopmans, G. Malinowski, F. Dalla Longa, D. Steiauf, M. Fähnle, T. Roth, M. Cinchetti and M. Aeschlimann, *Nature Mater.*, accepted
[2] M. Krauß, T. Roth, S. Alebrand, D. Steil, M. Cinchetti, M. Aeschlimann and H. C. Schneider, *PRB* **80**, 180407(R) (2009)

MA 14.12 Wed 12:30 H10

Probing half-metalicity of $Co_2Fe_xMn_{1-x}Si$ Heusler films in all-optical pump-probe experiments — •Jakob Walowski[1,2], Andreas Mann[1], Markus Münzenberg[1], Shigemi Mizukami[3], Takahide Kubota[2], Mikihiko Oogane[2], Hiroshi Naganuma[2], Yasuo Ando[2], and Terunobu Miyazaki[3] — [1]I. Physikalisches Institut, Universität Göttingen, Germany — [2]Department of Applied Physics, Graduate School of Engineering, Tohoku University, Sendai, Japan — [3]WPI-AIMR, Tohoku University, Sendai, Japan

Half metals are a promising candidate as spin injectors for spintronic devices, because of a high spin polarization at Fermi level and low Gilbert damping α. All-optical TRMOKE enables us to determine the degree of spin polarization by exciting the electrons above the Fermi level and probing the demagnetization time τ_m. Because of a band gap for minority electrons at Fermi level, Elliott-Yafet scattering processes are blocked, τ_m increases to the ps regime. From the increased τ_m the degree of spin polarization and thus a half-metallic behavior can be concluded. A second time scale τ_α , which describes the decline of magnetization precession (∼1 ns) started by an anisotropy change during the excitation allows the determination of α. We studied magnetization dynamics on both timescales in epitaxial $Co_2Fe_xMn_{1-x}Si$ samples by systematically increasing the Fe content in steps of 0.2. The samples reveal a spin polarization around 80% and $\alpha < 0.01$. Both parameters are sensitive to the quality of the sample structure.

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