MA 35: Spin-Dynamics / Spin-Torque IV

Time: Thursday 15:15–19:30 Location: HSZ 04

MA 35.1 Thu 15:15 HSZ 04

Ultrafast Demagnetization of Lanthanide-Doped Permalloy Thin Films Studied with Time-Resolved Magneto-Optics — •Ilie Radu[1,2], Matthias Kiessling[1], Georg Woltersdorf[1], Alexey Melnikov[3], Uwe Bovensiepen[3], Jan-Ulrich Thiele[4], and Christian Back[1] — [1]Regensburg University, Regensburg, Germany — [2]BESSY GmbH, Berlin, Germany — [3]Free University Berlin, Berlin, Germany — [4]Hitachi Global Storage, San Jose, CA, USA

The fs laser-induced magnetization dynamics of Permalloy thin films doped with Ho and Gd impurities is investigated by time-resolved magneto-optical Kerr effect. Varying the Ho concentration from 0% to 8% we observe a gradual change of the demagnetization time constant from approximately 60 fs to about 150 fs. In contrast, concentrations of Gd up to 15% do not affect the time scale of the demagnetization process. These results are at variance with recent theoretical work [1], that proposes a laser-induced demagnetization mechanism based on impurity- or phonon-assisted spin-flip scattering. We propose a demagnetization mechanism which relies on the strong magnetic inertia of the rare-earth dopant within the framework of the so-called slow relaxing impurity model [2,3].

[1] B. Koopmans et al., PRL 95, 267207 (2005); [2] J.H. van Vleck and R. Orbach, PRL 11, 65 (1963); [3] G. Woltersdorf et al., arXiv:0802.3206v2

MA 35.2 Thu 15:30 HSZ 04

Femtosecond Dynamics of Spin and Orbital Angular Momentum in Nickel — •Christian Stamm, Niko Pontius, Karsten Holldack, Torsten Quast, Torsten Kachel, Marko Wietstruk, Rolf Mitzner, and Hermann A. Dürr — Elektronenspeicherring BESSY II, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, 12489 Berlin

At the BESSY femtoslicing source we measure x-ray magnetic circular dichroism (XMCD) with 100 fs time resolution [1,2]. By virtue of the XMCD sum rules, we find that the spin and orbital momenta in a thin nickel film are quenched with a time constant of 150 fs upon excitation with a fs laser pulse. This represents the first unambiguous proof that the total electronic angular momentum is transferred to the lattice on the same ultrafast time scale. The quenching of orbital angular momentum also is a serious constraint for models of angular momentum dissipation.

[1] S. Khan et al., Phys. Rev. Lett. 97, 074801 (2006).
[2] C. Stamm et al., Nature Mater. 6, 740 (2007).

MA 35.3 Thu 15:45 HSZ 04

Demagnetization processes on ultrashort timescales revisited — •Jakob Walowski[1], Andreas Mann[1], Henning Ulrichs[1], Benjamin Lenk[1], Markus Münzenberg[1], Unai Atxitia[2], and Oksana Fesenko[2] — [1]I. Physikalisches Institut, Universität Göttingen, Germany — [2]Instituto de Ciencia de Materiales de Madrid (CSIC), Spain

All-optical pump-probe experiments give an insight into magnetization dynamics on ultrashort timescales. Femtosecond pulses generated by a Ti:Sa laser are used to trigger magnetization dynamics. Having an optical penetration depth of up to 15 nm the deposited energy is highest for of the topmost layers. A two-temperature type model including the electron heating after excitation and the equilibration with the phonon system, describes the dynamics. Within this process two timescales are of interest, first the demagnetization within the first $150-200$ fs and second the magnetization recovery which takes place on the timescale of $1-20$ ps after excitation. On the first timescale the characteristic slowing down of the demagnetization was revisited, since it is a fingerprint of the correlation effect from incoherent spin-waves occuring at high pump fluencies. The connection between the electron temperatures in the magnetic system is established by a Langevin field term in the modeling of this process. For the modeling an atomistic level description using Landau-Lifshitz-Bloch equations is applied. We find a scaling behavior of the total demagnetization as a function of the pump fluency ($10-50\,\mathrm{mJ/cm^2}$) and the thickness of the magnetic layer ($d_{\mathrm{Ni}} = 10-40$ nm). Support by the DFG within the priority program SPP 1133 is gratefully acknowledged.

MA 35.4 Thu 16:00 HSZ 04

Absolute measurements of the excitation amplitude at ferromagnetic resonance — •P. Majchrak[1], G. Woltersdorf[1], T. Martin[1], T. Kachel[2], C. Stamm[2], H. Dürr[2], and C. H. Back[1] — [1]Institut für Exp. und Angewandte Physik, Uni Regensburg, 93040 Regensburg — [2]BESSY, Albert-Einstein-Straße 15, 12489 Berlin

Using X-ray magnetic circular dichroism (XMCD) we directly measure the transversal components of the precessing magnetization in a thin film under cw microwave excitation (phase locked to the X-ray flashes). The real and imaginary parts of the rf-magnetic susceptibility are obtained by adjusting the phase between exciting microwave signal and the X-ray flashes to 0° and 90°, respectively. Measurements at different angles between the sample plane and the X-ray beam allow to determine the in and out-of-plane rf magnetization components and thereby the ellipticity of the precession. Since the signal is calibrated by XMCD hysteresis loops the excursion angle can be evaluated. At large microwave fields the susceptibility becomes nonlinear due to the decrease of the effective magnetization and the excitation of parametric spin waves (Suhl instability). We measure the precession angle and the ellipticity as function of rf power up to the nonlinear regime. XMCD also allows for an element specific and therefore layer sensitive investigation of the magnetization dynamics. Optic and acoustic modes are observed in an interlayer exchange coupled sample $Co_{90}Fe_{10}/Ru/Ni_{80}Fe_{20}$. From the phase difference between the precessing magnetizations of both layers the coupling energy is determined.

MA 35.5 Thu 16:15 HSZ 04

Experimental check of the Elliott-Yafet model in laser-induced ultrafast demagnetization — •Tobias Roth[1], Daniel Steil[1], Sabine Alebrand[1], Bert Koopmans[2], Grégory Malinowski[2], Francesco Dalla Longa[2], Daniel Steiauf[3], Manfred Fähnle[3], Mirko Cinchetti[1], and Martin Aeschlimann[1] — [1]Department of Physics and Research Center OPTIMAS, TU Kaiserslautern, Germany — [2]Department of Applied Physics, center for NanoMaterials (cNM), Eindhoven University of Technology, The Netherlands — [3]Max-Planck-Institut für Metallforschung Stuttgart, Germany

The deep interest in the area of femtosecond magnetism results both from the very fundamental physical question about the involved interactions between light, spin, and matter and from the fact that magnetization dynamics on an ultrafast time scale may serve as a potential candidate for the future of data processing. In 2005 B. Koopmans et al. proposed an Elliott-Yafet (EY) type spin-flip process to be the responsible mechanism for the observed loss in magnetic order [1,2]. The model is based on electron-phonon or electron-impurity interaction whereby each scattering event carries a spin-flip probability to end up in a changed spin state. In this contribution we present time resolved magnetooptical Kerr measurements in the high perturbation regime that check the validity of the EY type spin-flip process by changing external key parameters. The results will be discussed behind the background of the model's predictions. [1] B. Koopmans et al., PRL 95 267207 (2005) [2] M. Cinchetti et al., PRL 97 177201 (2006)

MA 35.6 Thu 16:30 HSZ 04

Ab-initio calculations on the Elliott-Yafet mechanism for the discussion of femtosecond magnetization dynamics — •Daniel Steiauf and Manfred Fähnle — Max-Planck-Institut für Metallforschung, Heisenbergstr. 3, 70569 Stuttgart

Ultrashort laser pulses are able to reduce the magnetization of ferromagnetic metals such as Ni. Thereby, angular momentum is transferred from the spin system faster than a picosecond, however, not into the electronic orbital moments, as shown by recent experiments. Thus the lattice has to be involved. The Elliott-Yafet [1,2] mechanism, a spin-orbit mediated spin-flip scattering of an electron at a phonon, is one possible, however questioned, candidate to explain the ultrafast demagnetization after fs laser excitation. The doubts have arisen as the value of the Elliott-Yafet spin-mixing parameter of Ni has not been known and has been assumed to be similar to the one of Cu which is very small. We present ab-initio calculations of the spin-mixing within the density functional electron theory for various alkali, transition and rare earth metals. The spin mixing of the electronic system is induced by spin-orbit coupling as well, and is a measure for the strength of the spin-flip scattering.

[1] R. J. Elliott, Phys. Rev. 96, 266 (1954).
[2] Y. Yafet, in "Solid State Physics", F. Seitz and D. Turnbull (eds.) (Academic, New York, 1963), Vol. 14

MA 35.7 Thu 16:45 HSZ 04

Calculation of ultrafast demagnetization following laser excitation — •Sabine Alebrand, Michael Krauss, Tobias Roth, Daniel Steil, Mirko Cinchetti, Hans Christian Schneider, and Martin Aeschlimann — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Erwin-Schrödinger-Straße 46, 67663 Kaiserslautern, Germany

In this presentation, we investigate a model for optically induced ultrafast magnetization dynamics in ferromagnets. In our approach we include electron-electron (and electron-phonon) scattering processes and a simplified spin-split electronic band structure. In this model, Elliott-Yafet type spin-flip scattering between electrons, and electrons and phonons leads to the demagnetization after optically excitation. The total spin-polarization dynamics can be compared with experiments, such as time resolved magneto optical Kerr measurements. For magnetic metals, such as Co and Ni, we find that calculated fluence dependence of the demagnetization dynamics reproduces experimental trends.

MA 35.8 Thu 17:00 HSZ 04

Laser-induced quenching of the spin polarization in 3d-ferromagnets studied by time and spin resolved photoemission — •Alexander Weber — Universität Regensburg

In the field of ultrafast magnetization dynamics most progress was achieved by all optical measurements. With optical measurements no direct access to the spin polarization is possible. In order to gain direct insight into the time evolution of the spin polarization after excitation with a fs laser pulse a time and spin-resolved pump probe experiment is applied to measure the quenching of spin polarization in 3d-ferromagnets on a fs timescale. In our experiment the spin polarization of the photoexcited electrons of 8ML Fe/W(110) and 8ML Co/W(110) is measured directly with a Mott-detector. Three different timescales could be distinguished, a fast quenching of spin polarization, a fast remagnetization, and a slow remagnetization. The measured data fit well to a heat-diffusion expanded three temperature model. The fit yields demagnetization times of 0.8 ps and 0.3 ps for Co and Fe, respectively. The qualitative and quantitative accordance to Kerr measurements is discussed.

15 min. break

MA 35.9 Thu 17:30 HSZ 04

Anisotropic and nonlocal damping in near-adiabatic magnetization dynamics — •Jonas Seib, Daniel Steiauf, and Manfred Fähnle — Max-Planck-Institut für Metallforschung, Heisenbergstr. 3, 70569 Stuttgart

Recently, a Gilbert type equation of motion was derived by the combination of the phenomenological breathing Fermi surface model and the ab-initio density functional electron theory [1]. This equation is valid on the near-adiabatic time scale. The Gilbert damping scalar is replaced by an anisotropic damping matrix for the case of collinear magnetization. In the case of noncollinear systems, nonlocal damping matrices lead to a nonlocal equation of motion on the atomic length scale.
We show, from the viewpoint of theory, to what extent a FMR (ferromagnetic resonance) experiment can give insight to anisotropic damping parameters in collinear systems. Additionally, we present results for damping parameters in noncollinear systems, which lead to a much stronger damping than in the collinear case.

[1] D. Steiauf, J. Seib, and M. Fähnle, Phys. Rev. B **78**, 020410(R) (2008).

MA 35.10 Thu 17:45 HSZ 04

Magnetization Dynamics of Co-based Heusler Alloys — •Daniel Steil, Tobias Roth, Sabine Alebrand, Mirko Cinchetti, and Martin Aeschlimann — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, 67663 Kaiserslautern, Germany

For more than a decade now the microscopic mechanisms responsible for ultrafast magnetization dynamics after strong optical excitation have been investigated. Today the most likely candidates for this process seem to be Elliott-Yafet-type spin-flip processes [1,2]. To give a strong experimental proof for the above assumption, it would be necessary to compare the dynamics of different magnetic materials, while ideally changing only a single parameter of the system. In this context, Heusler alloys serve as a nearly ideal test system for probing the microscopic mechanism driving magnetization dynamics due to their special properties. In particular, many Co-based Heusler alloys have been predicted to be half metallic ferromagnets, exhibiting a minority spin band gap at the Fermi level (E_F). Moreover, in the quaternary alloy $Co_2Mn_{1-x}Fe_xSi$ (CMFS), the size and position of the band gap with respect to E_F can be tuned by changing the Fe content x [3]. This allows drawing direct conclusions about the influence of the band structure on magnetization dynamics. In this talk we will present the results of time-resolved MOKE experiments on CFMS and compare them to the results from Co and other Co-based Heusler alloys.

[1] Koopmans et al, PRL 95, 267207 (2005) [2] Cinchetti et al, PRL 97, 177201 (2006) [3] Balke et al, PRB 74, 104405 (2006)

MA 35.11 Thu 18:00 HSZ 04

Characterizing half-metallicity via magnetization dynamics on ultrafast timescales — •Andreas Mann[1], Henning Ulrichs[1], Jakob Walowski[1], Markus Münzenberg[1], Jan Schmalhorst[2], Andy Thomas[2], Andreas Hütten[2], and Günter Reiss[2] — [1]I. Physikalisches Institut, Universität Göttingen, Germany — [2]Department of Physics, Universität Bielefeld, Germany

We study the magnetization dynamics of potential half-metals probed by the time-resolved magneto-optical Kerr effect (TRMOKE) using a femtosecond laser pump-probe setup (temporal resolution: $50\,fs$). Half metals are promising candidates for the development of so called 'spintronic' devices, because they possess a minority-spin band gap at the Fermi level and are therefore 100 % spin-polarized. The magnetization dynamics in ferromagnetic metals are generally marked by two characteristic timescales, a short demagnetization time τ_m of several hundred fs and a relaxation time τ_e in the ps range. In the special case of a half metal, the minority-spin band gap blocks the Elliot-Yafet scattering and thus slows down the demagnetization. The enlarged τ_m of a few ps to ns which is governed by anisotropy fluctuations can be measured in our setup and indicates a half-metallic behaviour of the sample. More in detail, our experiments imply that the band gap of a half metal also has a subtle influence on the magnetization dynamics on the ultrafast timescale, evident in a steplike feature. We present an expansion of the three temperature model by Beaurepaire et al.. We gratefully acknowledge the support by the DFG SPP 1133: "Ultrafast magnetization processes".

MA 35.12 Thu 18:15 HSZ 04

Thermally Induced Magnetization Reversal of Fe/W(110) Nanoislands Investigated by SP-STM — •Stefan Krause[1], Gabriela Herzog[1], Luis Berbil-Bautista[2], Matthias Bode[3], and Roland Wiesendanger[1] — [1]Institute of Applied Physics, University of Hamburg, Germany — [2]Materials Science Division, Lawrence Berkeley National Laboratory, USA — [3]Center for Nanoscale Materials, Argonne National Laboratory, USA

Spin-polarized scanning tunneling microscopy (SP-STM) is a well-established tool to investigate not only static but also dynamic magnetic properties of surfaces at lateral resolution down to the atomic scale [1]. Our variable-temperature STM is suitable to investigate the thermal switching behavior of single atomic-scale Fe/W(110) nanoislands over a temperature range between 30 K and 300 K.

Both the attempt frequency as well as the effective activation energy barrier of individual nanoislands can be determined from the Arrhenius-like switching behavior as a function of temperature. An analysis of the data reveals that magnetization reversal takes place via the nucleation and propagation of a domain wall. Furthermore, the attempt frequency is found to vary with island size and shape.

The results will be discussed in terms of domain wall nucleation and diffusion. For atoms at the center and the rim of a nanoisland the exchange stiffness and anisotropy energy contributions are to be quantified and compared to the results of earlier studies on the Fe/W(110) monolayer system.

[1] M. Bode *et al.*, Phys. Rev. Lett. 92, 067201 (2004).

MA 35.13 Thu 18:30 HSZ 04

Thermally assisted magnetisation switching close to the Curie temperature: elliptical and linear reversal — •Denise Hinzke[1], Natalia Kazantseva[2], Roy W. Chantrell[2], and Ulrich Nowak[1] — [1]Universität Konstanz, 78457 Konstanz — [2]University of York,

York YO10 5DD, U. K.

Laser induced magnetic writing processes have been extensively studied recently as a possibility to improve the storage density as well as the writing speed in magnetic data storage. In our work, we focus on magnetisation reversal processes during laser heating in the presence of a magnetic field. This is important for the understanding of the dynamics of writing processes in the pico-second time scale and in relation to Heat Assisted Magnetic Recording. This technique has been proposed as a means of writing information on high anisotropy magnetic media.

We investigate the thermally assisted switching analytically within the framework of the Landau-Lifshitz-Bloch equation recently derived by D. Garanin [1]. Close to the Curie temperatures T_c two different reversal modes appear: elliptical as well as linear reversal [2]. The latter one plays a crucial role for the dynamics of the magnetisation reversal close to and especially above T_c. We have calculated the coercive fields and the energy barriers for both reversal modes as well as the minimal switching time and field needed for thermally assisted switching below and above T_c.

[1] D. A. Garanin, Phys.Rev. B 55, 3050 (1997), [2] N. Kazantseva et al, submitted for publication

MA 35.14 Thu 18:45 HSZ 04

Three-dimensional control of the antiferromagnetic order parameter in nickel oxide — •Andrea Rubano[1], Takuya Satoh[2], and Manfred Fiebig[1] — [1]HISKP, University of Bonn, Germany — [2]Institute of Industrial Science, University of Tokyo, Japan

A three-dimensional switching of the antiferromagnetic (AFM) order parameter has been achieved in the exchange-bias compound NiO by means of an intense optical excitation. By controlling the power and pulse length of the pump pulse the AFM order parameter was transiently oriented into the easy(1) axis, the easy(2) axis, or the hard axis direction. The reorientation was evidenced by optical second harmonic generation beating processes. The relation between the pump-pulse parameters and the induced direction of the AFM order parameter was investigated in detail. At constant pump-pulse energy we tuned its temporal duration: "short pulse" ($\approx$ 110 fs) switch the AFM order parameter into the hard axis direction, while longer pulses ($\approx$ 130 fs) set the order parameter along the easy(2) axis. We ascribe the observed phenomenon to the competition between "hot carrier" creation modifying the magnetic anisotropy and electron-electron relaxation processes occurring on the same timescale.

MA 35.15 Thu 19:00 HSZ 04

Magnetization Dynamics in Interlayer Exchange Coupled Magnetic Microstructures — •Alexander Kaiser, Carsten Wiemann, Stefan Cramm, and Claus M. Schneider — Forschungszentrum Jülich, Institut für Festkörperforschung IFF-9 und JARA-FIT, 52425 Jülich, Deutschland

Photoemission Electron Microscopy (PEEM) combined with soft x-rays with variable polarization and a pulsed time structure offered at modern storage rings is a powerful tool for investigating magnetization dynamics with high spatial and temporal resolution. Tuning the photon energy to the absorption edges of the appropriate elements and exploiting the XMCD effect offers the possibility to probe the micromagnetic structure of different layers in magnetic heterostructures independently. Thus the influence of coupling phenomena on the micromagnetic behavior can be studied in magnetic heterostructures.

We have investigated the magnetization dynamics in interlayer exchange coupled CoFe/Cr/NiFe structures for different Cr thicknesses spanning parallel, antiparallel and 90°-coupling of the ferromagnetic layers. The films have been grown epitaxially by MBE on GaAs substrates with Ag buffer layers. We present time-resolved PEEM measurements of the magnetodynamic response on a short magnetic field pulse in both ferromagnetic films. The influence of the interlayer exchange coupling on the magnetodynamic behaviour will be discussed.

This work was supported by the DFG within SFB 491.

MA 35.16 Thu 19:15 HSZ 04

Ultrafast Spin Noise Spectroscopy — •Sebastian Starosielec and Daniel Hägele — AG Spektroskopie der kondensierten Materie, Ruhr-Universität Bochum, D-44801 Bochum, Germany

Optical spin noise spectroscopy based on cw laser probe has proved to be a powerful method for determining e.g. spin lifetimes with only minimally perturbing the electronic system [1]. The accessible frequency range is however limited to typically below 1 GHz by the detection electronics. Here we propose a new scheme based on pairs of fs laser pulses that allows for measuring noise spectra up to 10 THz [2]. Monte-Carlo-simulations including photon shot noise show that smooth spectra can be obtained within a total observation time of only a few seconds. In addition, ultrafast noise spectroscopy can measure broad signals that are centered around zero frequency where traditional Raman- or Brillouin spectroscopy is notoriously difficult or even impossible. We give analytic expressions for the quality of ultrafast spin noise spectra in terms of observation time, photon shot noise, electrical noise, and the spin-noise level. A time-resolved version of noise spectroscopy for detecting noise after a pump event follows naturally from the scheme.

[1] M. Oestreich, M. Römer, R. J. Haug and D. Hägele, Phys. Rev. Lett. **95**, 2166003 (2005).
[2] S. Starosielec and D. Hägele, Appl. Phys. Lett. **93**, 051116 (2008).