MA 15: Magnetization / Demagnetization Dynamics I

Time: Tuesday 9:30–13:00 Location: H 1012

Topical Talk MA 15.1 Tue 9:30 H 1012

Probing the timescale of exchange interaction in a ferromagnetic alloy — •Stefan Mathias — University of Kaiserslautern and Research Center OPTIMAS — JILA, University of Colorado and NIST

Rapid progress in ultrafast X-ray science worldwide, both in high-harmonic generation (HHG) and X-ray free-electron laser sources, has paved the way for a completely new generation of experiments investigating ultrafast magnetic processes in complex materials with ultrahigh time-resolution and element-specificity. In the presented work, we use extreme ultraviolet (XUV) pulses from a femtosecond HHG as an element-specific probe of ultrafast, optically driven, demagnetization in a ferromagnetic alloy (Permalloy). We show that on femtosecond timescales, the demagnetization dynamics of the constituent elements Fe and Ni in Permalloy are delayed with respect to each other, despite the strong exchange coupling that aligns their magnetic moments in thermodynamic equilibrium. We can further enhance this effect by lowering the exchange energy by diluting the Permalloy with Cu. Our measurement explores the consequences of the fundamental exchange interaction on femtosecond magnetic dynamics in strongly coupled 3d-ferromagnetic systems, showing that distinct magnetization dynamics of the individual elements can be observed on timescales corresponding to the characteristic exchange time.

MA 15.2 Tue 10:00 H 1012

Ultrafast Demagnetization in Ferromagnetic Materials — •Benedikt Y. Mueller, Tobias Roth, Mirko Cinchetti, Martin Aeschlimann, and Bärbel Rethfeld — Department of Physics and Optimas Research Center, University of Kaiserslautern, Germany

Ultrafast demagnetization due to laser irradiation has been studied for more than two decades [1,2,3]. Up to now, no theory explains the large variety of effects on equal footing microscopically. In our model we apply a kinetic approach based on a combination of the Stoner model and the Boltzmann equation [4]. This results in a spin-resolved Boltzmann equation considering three reservoirs: up-electrons, down-electrons and the phononic system. The coupling between these reservoirs is described by electron-electron and electron-phonon collisions whereby spin-flips are realized by Elliott-Yafet type spin-flip scattering. In this spirit, we trace nonequilibrium electrons during and after laser irradiation and additionally this provides a dynamical description for magnetism. We show the solution of the spin-resolved Boltzmann equation for the example of Nickel by implementing the density of states [5] into our model. As a result of our effective two band model, the demagnetization is driven by the equilibration process of the electron temperatures and the chemical potentials of up and down electrons.

[1] E. Beaurepaire et al., Phys. Rev. Lett. 76, 4250 (1996)
[2] J. Hohlfeld et al., Phys. Rev. Lett. 78, 25 (1997)
[3] B. Koopmans et al., Nature Materials 9, 3 (2010)
[4] B. Rethfeld et al., Phys. Rev. B 65, 214303 (2002)
[5] Z. Lin et al., Phys. Rev. B 77, 075133 (2008)

MA 15.3 Tue 10:15 H 1012

Theoretical study of the time evolution of magnetization induced via the ultrafast inverse Faraday effect — •Daria Popova, Andreas Bringer, and Stefan Blügel — Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Ultrafast optical control of the magnetic state of a medium is a subject that attracts much scientific interest. Manipulation of the magnetic order by light on sub-picosecond time scales can be realized by the inverse Faraday effect (IFE) [1]. In these experiments circularly polarized high-intensity laser pulses with the length of several tens of femtoseconds are used to excite the magnetic system of the sample. The important principles of this effect are still unclear.

We describe the IFE via the stimulated Raman-like scattering process, which was suggested to be responsible for the magnetization reversal by light [2]. We show [3] that a system is brought to a new magnetic state after the action of a femtosecond circularly polarized laser pulse due to this process. We solve the time-dependent Schrödinger equation to model the IFE in atoms coupled with the exchange interaction in a crystal field environment. We study the time evolution of the magnetization during the action of light and magnetic oscillations, which are excited in the system.

We are thankful for the support by the FANTOMAS project.

[1] A. Kimel *et al.*, Nature **435**, 655 (2005).
[2] F. Hansteen *et al.*, Phys. Rev. B **73**, 014421 (2006).
[3] D. Popova, A. Bringer, S. Blügel, accepted to Phys. Rev. B.

MA 15.4 Tue 10:30 H 1012

Momentum dependent ultrafast electrondynamics in antiferromagnetic $EuFe_2As_2$ — Laurenz Rettig[1,2], Rocio Cortés[1,3], Setti Thirupathaiah[4], Philipp Gegenwart[5], HiraleS. Jeevan[5], Martin Wolf[3], Jörg Fink[4], and •Uwe Bovensiepen[1,2] — [1]Freie Universität Berlin, FachbereichPhysik — [2]Universität Duisburg-Essen,Fakultät für Physik — [3]Fritz-Haber-Institut der MPG — [4]IFW Dresden — [5]UnversitätGöttingen, I. Physikalisches Institut

The response and relaxation dynamics of magnetically ordered materials upon optical excitation is highly interesting from a scientific and an application point of view. Up to now most studies have focussed on ferro- or ferrimagnetic ordered materials. Fe pnictides are metallic, present antiferromagnetic order below the Néel temperature T_N, and become superconducting upon doping. Here, we present results obtained for antiferromagnetic $EuFe_2As_2$ by femtosecond time- and angle-resolved photoelectron spectroscopy. Employing the momentum-sensitivity of the technique we separate the electron-phonon mediated relaxation from transient changes of the magnetic order. We assign the relaxation time of 200 fs observed at 30 K in a single particle region of the electronic band structure at $k_{||} = 0.25$ Å^{-1} to relaxation mediated by e-ph scattering. Antiferromagnetic order is established by backfolding bands from X to Γ. Relaxation monitored at Γ occurs with a time constant of 800 fs and is assigned to the transient magnetic order. The merging of these different times for $T > T_N$ evidences our conclusion.

This work was supported by the DFG through SPP 1458 and the Alexander von Humboldt Foundation.

MA 15.5 Tue 10:45 H 1012

Ultrafast element specific demagnetisation dynamics of Fe and Ni in FeNi Alloys — •Denise Hinzke[1], Unai Atxitia[2], Oksana Chubykalo-Fesenko[2], Karel Carva[3], Peter Openeer[3], and Ulrich Nowak[1] — [1]Universität Konstanz, 78457 Konstanz, Germany — [2]Instituto de Ciencia de Materiales de Madrid, 28049 Madrid, Spain — [3]Uppsala University, 75120 Uppsala, Sweden

Since the first observation of the quenching of magnetisation in Ni on the sub-ps timescales [1], ultrafast demagnetisation was intensively studied, both experimentally and theoretically. Recently, element-specific techniques were used to observe the element-resolved dynamics after optical excitation on fs timescales [2,3]. In order to get an deeper insight of the underlying mechanism we perform atomistic spin model simulations of fcc Permalloy.

We model FeNi using a classical spin Hamiltonian with exchange integrals constructed on the basis of spin density functional theory. Langevin dynamics simulation, i. e. simulations of the stochastic Landau-Lifshitz-Gilbert equation of motion are performed. The differences of the dynamics of Fe and Ni sublattices on the fs timescale is investigated for different model assumptions such as temperature and damping and compared with the dynamics gained in the framework of a two sublattices Landau-Lifshitz-Bloch equation of motion.

[1] E. Beaurepaire et al., Phys. Rev. Lett. **76**, 4250 (1996). [2] C. La-O-Vorakiat et al., Phys. Rev. Lett. **103**, 257402 (2009). [3] I. Radu et al., Nature **472**, 205 (2011). Funding from EC collaborative project FP 7 (FemtoSpin) and the CAP Konstanz is acknowledged.

MA 15.6 Tue 11:00 H 1012

The influence of electron-phonon-scattering on the ultrafast demagnetization of ferromagnetic metals — •Sven Essert[1] and Hans Christian Schneider[2] — [1]Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany — [2]Technische Universität Kaiserslautern, 67653 Kaiserslautern, Germany

The demagnetization of ferromagnetic metals after the irradiation with a femtosecond light pulse is believed to be decisively influenced by an Elliott-Yafet type process, i.e., by spin-flip scattering in a band structure which is spin-mixed due to spin-orbit coupling. There have been different proposals for the underlying scattering mechanism, e.g.,

electron-phonon-, electron-electron- or electron-impurity-scattering.

We numerically investigate the contribution of electron-phonon-scattering to the Elliott-Yafet demagnetization scenario in a fixed band structure by calculating the carrier-dynamics using ab-initio data. With realistic parameters for the laser excitation, we find a magnetization change which is far smaller than the one observed in experiment.

We also show via an energy argument, that the simple picture of scattering in a fixed band structure is insufficient to describe the experimentally observed strong demagnetization. This result is not limited to electron-phonon-scattering but is also valid for most other scattering mechanisms. We conclude that a realistic model that tries to explain the demagnetization in terms of an Elliott-Yafet process should include a dynamical change of the magnetic order beyond a redistribution of carriers in a fixed band structure.

[1] S. Essert and H.C. Schneider, arXiv:1108.4454 (2011)

15 min. break

MA 15.7 Tue 11:30 H 1012

Ab-initio investigation of the Elliott-Yafet electron-phonon mechanism in laser-induced ultrafast demagnetization — Karel Carva[1,2], Marco Battiato[1], and •Peter M. Oppeneer[1] — [1]Uppsala University, S-75120 Uppsala, Sweden — [2]Charles University, CZ-12116 Prague, Czech Republic

The spin-flip Eliashberg function is calculated from first principles for ferromagnetic Ni to accurately establish the contribution of Elliott-Yafet electron-phonon spin-flip scattering to Ni's femtosecond laser-driven demagnetization. This is used to compute the spin-flip probability and demagnetization rate for laser-created thermalized as well as non-equilibrium electron distributions /1/. Increased spin-flip probabilities are found for thermalized electrons, but the induced demagnetization rate is extremely small. A larger electron-phonon mediated demagnetization rate is obtained for *non-equilibrium* electron distributions, but its contribution is too small to account for the observed femtosecond demagnetization.

/1/ K. Carva, M. Battiato, P.M. Oppeneer, Phys. Rev. Lett. **107**, 207201 (2011).

MA 15.8 Tue 11:45 H 1012

Ultrafast lattice dynamics in FeRh during a laser-induced magnetic phase transition — •Florian Quirin, Michael Vattilana, Uladzimir Shymanovich, Abd-Elmonien El-Kamhawy, Matthieu Nicoul, Alexander Tarasevitch, Dietrich von der Linde, and Klaus Sokolowski-Tinten — Universität Duisburg-Essen, Duisburg, Germany

FeRh exhibits an anti-ferromagnetic to ferromagnetic phase transition upon heating to temperatures above 353 K, which is accompanied by an iso-structural increase in volume of about 1%. Recent results of time-resolved magneto-optical experiments gave indication that after intense optical excitation ferromagnetic order starts to build up on sub-ps time-scales [1,2]. We have used time-resolved X-ray diffraction with fs X-ray pulses from a laser-produced plasma to directly follow the lattice response of FeRh after optical excitation. From experimental data obtained at different starting temperatures below and above the phase transition temperature we have to conclude that the fast changes of the magnetic properties do not lead to the corresponding structural changes as under equilibrium conditions.

1 G. Ju, J. Hohlfeld, B. Bergman, R. J. M. van deVeerdonk, O. N. Mryasov, J.-Y. Kim, X. Wu, D. Weller, and B. Koopmans, Phys. Rev. Lett. 93, 197403 (2004).

2 J.-U. Thiele, M. Buess, and C. H. Back, Appl. Phys. Lett. 85, 2857 (2004).

MA 15.9 Tue 12:00 H 1012

Ab-initio calculation of the demagnetization time in Ni after fs laser pulse excitation — •Christian Illg[1], Bernd Meyer[2], and Manfred Fähnle[1] — [1]Max-Planck-Institut für Intelligente Systeme, Heisenbergstr. 3, 70569 Stuttgart — [2]Interdisziplinäres Zentrum für Molekulare Materialien und Computer-Chemie-Centrum, Universität Erlangen-Nürnberg

It is believed that an ultimate time limit for the macroscopic manipulation of the magnetization is achieved by exposing a ferromagnetic film to an intense sub-100 fs pulse of laser light [1]. The result of this exposure is a demagnetization within few 100 fs for Ni, e.g., and a subsequent remagnetization on a longer time scale. Since the first experiments by Beaurepaire et al. in 1996 [2] a lot of research activities have been done but the underlying mechanisms are still not clarified.

We calculate the demagnetization time T_1 within the Elliott-Yafet theory which we have generalized for ferromagnets [3]. In order to calculate electron-phonon scattering rates, we use realistic electronic states which we calculate with the ab-initio spin-density-functional theory, and realistic phonon states obtained from a force-constant approach with force constants from ab-initio calculations. We present first results for the demagnetization time T_1 within the generalized Elliott-Yafet theory for Ni.

[1] M. Fähnle, C. Illg, J. Phys.: Condens. Matter **23**, 493201 (2011)
[2] E. Beaurepaire et al., Phys. Rev. Lett. **76**, 4250 (1996)
[3] D. Steiauf, C. Illg, M. Fähnle, J. Magn. Magn. Mater. **322**, L5 (2010)

MA 15.10 Tue 12:15 H 1012

Ultrafast and Distinct Spin Dynamics in Magnetic Alloys — •Ilie Radu[1,2], Christian Stamm[2], Andrea Eschenlohr[2], Kadir Vahaplar[1], Torsten Kachel[2], Niko Pontius[2], Rolf Mitzner[2], Karsten Holldack[2], Alexander Föhlisch[2], Florin Radu[2], Richard Evans[3], Thomas Ostler[3], Johan Mentink[1], Roy Chantrell[3], Arata Tsukamoto[4], Akiyoshi Itoh[4], Andrei Kirilyuk[1], Alexey Kimel[1], and Theo Rasing[1] — [1]Radboud University Nijmegen, The Netherlands — [2]Helmholtz-Zentrum Berlin, BESSY II, Germany — [3]University of York, United Kingdom — [4]Nihon University, Japan

Recent time-resolved XMCD investigations of magnetization reversal in ferrimagnetic GdFeCo alloy have shown [1] the intriguing possibility of manipulating the magnetic order on the ultrafast timescales pertinent to the exchange interaction. In particular, we have demonstrated that the antiferromagnetically coupled Fe and Gd sublattices had very distinct demagnetization times and reversed via a transient ferromagnetic state. Here we report on a systematic study of femtosecond laser-induced spin dynamics in several ferromagnetic and ferrimagnetic alloys and reveal that such distinct spin dynamics in magnetic alloys is a general phenomenon [2]. We demonstrate that the demagnetization of the constituent magnetic sublattices evolves on significantly different timescales which depend on their elemental magnetic moments and exchange interaction. Funding through EU UltraMagnetron program is acknowledged. [1] I. Radu et al., Nature 472, 205 (2011) [2] I. Radu et al., submitted (2011)

MA 15.11 Tue 12:30 H 1012

Ultrafast Demagnetization by a Laser-Generated Hot Electron Pulse — •Christian Stamm, Andrea Eschenlohr, Niko Pontius, and Torsten Kachel — Helmholtz-Zentrum Berlin für Materialien und Energie, Albert-Einstein-Str. 15, 12489 Berlin, Germany

Ultrafast demagnetization usually is triggered by a fs laser pulse. Here we demonstrate that a pulse of hot electrons is equally capable of causing a sizeable ultrafast demagnetization. We use a fs laser pulse to generate hot electrons in a 30 nm thick Au layer on top of a 15 nm Ni film. The laser pulse energy is absorbed to 90% in the Au, and hot electrons traveling from Au into the Ni film cause its magnetization to decrease down to 20% of the original value. The demagnetization time of the Au/Ni sample is slightly slower than the one of a Ni reference, but still in the fs range. This is in accordance with a superdiffusive transport mechanism for the hot electrons.

MA 15.12 Tue 12:45 H 1012

Magnetization Dynamics in FeCuNi and FeRuNi Multilayers - Influence of the Spacer Layer — •Roman Adam[1], Dennis Rudolf[1], Chan La-O-Vorakiat[2], Patrik Grychtol[1], Bastian Heller[1], Emrah Turgut[2], Stefan Mathias[3], Moritz Plötzing[1], Zbigniew Celinski[4], Justin Shaw[5], Hans Nembach[5], Tom J. Silva[5], Martin Aeschlimann[3], Henry Kapteyn[2], Margaret Murnane[2], and Claus M. Schneider[1] — [1]1Peter Grünberg Institut, PGI-6, Forschungszentrum Jülich, 52425, Jülich, Germany — [2]Department of Physics and JILA, University of Colorado, Boulder, CO, USA — [3]TU Kaiserslautern und Forschungszentrum OPTIMAS, Kaiserslautern, Germany — [4]Center for Magnetism and Magnetic Nanostructures, UCCS, Colorado Springs, CO 80918, USA — [5]Electromagnetics Division, NIST, Boulder, CO, USA

We performed time-resolved pump-probe measurements on Ni/Ru/Fe and Ni/Cu/Fe multilayers, testing magnetization dynamics on the femtosecond time scale using either visible or extreme ultraviolet (XUV) radiation, as a probe. In the latter experiments, laser-generated XUV radiation was tuned to the M absorption edges of Fe (53eV) and Ni

(67eV). By exploiting strong signal enhancement at these resonance conditions, we obtained a clear element- and layer-selective magnetic contrast upon magnetization reversal of magnetic layers comprising the multilayers. Our measurements demonstrate that laser-based high-harmonic experiments employing XUV wavelengths can yield layer-selective information about the magnetization, contributing to detailed understanding of femtosecond switching in magnetic multilayers.