MA 43: Magnetization Dynamics II of 3

Time: Thursday 15:00–17:45 Location: H22

MA 43.1 Thu 15:00 H22

Ultrafast spin transport as key to femtosecond demagnetization — •Andrea Eschenlohr[1], Marco Battiato[2], Pablo Maldonado[2], Niko Pontius[1], Torsten Kachel[1], Karsten Holldack[1], Rolf Mitzner[1], Alexander Föhlisch[1], Peter M. Oppeneer[2], and Christian Stamm[1] — [1]Institut für Methoden und Instrumentierung der Forschung mit Synchrotronstrahlung, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Albert-Einstein-Str. 15, 12489 Berlin, Germany — [2]Department of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala, Sweden

Ultrafast demagnetization of ferromagnetic metals is typically triggered by excitation with a femtosecond laser pulse. Here we demonstrate that hot electrons transported into a ferromagnetic layer can induce demagnetization as fast and efficient as direct laser excitation. We investigate a layered structure consisting of a Ni film covered by a Au layer, with the thickness of the Au layer chosen such that the incident laser pulse is completely absorbed. Magnetization dynamics in the buried Ni film is measured with x-ray magnetic circular dichroism in transmission geometry at the BESSY II Femtoslicing source, finding sub-picosecond demagnetization of equal magnitude as in a directly excited Ni film. Simulations show that the observed demagnetization is due to spin-dependent transport of non-equilibrium electrons from the Au layer through the ferromagnetic layer into the substrate.

MA 43.2 Thu 15:15 H22

Ultrafast Demagnetization in Ferromagnets: The Influence of Spin flip Scattering and Exchange Splitting Dynamics — •Benedikt Y. Mueller, Hans C. Schneider, and Bärbel Rethfeld — Technical University Kaiserslautern, Germany

The effect of the ultrafast demagnetization process after a femtosecond laser irradiation has been studied intensively for almost two decades [1,2,3] but a complete microscopic theory is still lacking. As a step towards this goal, we propose and analyze a dynamical Elliott-Yafet-type approach that takes into account the effects of spin-orbit interaction as well as the spin-diagonal scattering mechanisms within a microscopic description. Using the density of states of Nickel in our model [4,5] and, additionally, a *dynamical* splitting between the majority and minority bands, we trace the transient non-equilibrium electron distributions providing an energy-resolved picture of ultrafast magnetization dynamics. We illustrate the importance of the interplay of equilibration of temperatures and chemical potentials between the electrons [6] as well as the changes in the Stoner exchange splitting.

[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] B. Y. Mueller et al., AIP Conf. Proc. 1461, 609 (2012)
[6] B. Y. Mueller et al., New Journal of Physics 13, 123010 (2011)

MA 43.3 Thu 15:30 H22

Spin-flip scattering versus superdiffusive transport in the femtosecond-demagnetization of Nickel — •Oliver Schmitt, Daniel Steil, Sabine Alebrand, Stefan Mathias, Mirko Cinchetti, and Martin Aeschlimann — Department of Physics and Research Center OPTIMAS, TU Kaiserslautern, Germany

The phenomenon of ultrafast demagnetization is currently explained by at least two different theories: Spin-flip dynamics via the Elliott-Yafet (EY)-mechanism [1,2], and superdiffusive spin transport [3]. To disentangle the influence of these two spin relaxation mechanisms on the ultrafast demagnetization process, we have performed studies using the time-resolved magneto-optical Kerr effect (TRMOKE) on Ni samples for different film thicknesses and substrate materials. The obtained results demonstrate a strong thickness dependence of the maximum magnetization quenching as well as a dependence of the demagnetization constant on the substrate material. The applicability of EY and superdiffusive transport is discussed on the basis of the obtained results.

[1] B. Koopmans, G. Malinowski, F. Dalla Longa, D. Steiauf, M. Fähnle, T. Roth, M. Cinchetti and M. Aeschlimann, NMat **9**(3): 259-265 **(2010)**
[2] T. Roth, A. J. Schellekens, S. Alebrand, O. Schmitt, D. Steil, B. Koopmans, M. Cinchetti, and M. Aeschlimann, PRX **2**, 021006 **(2012)**
[3] M. Battiato, K. Carva, and P. M. Oppeneer, PRB **86**, 024404 **(2012)**

MA 43.4 Thu 15:45 H22

Unified theory of ultrafast femtosecond and picosecond spin dynamics in the three-center magnetic cluster Ni_3Na_2 — •Georgios Lefkidis[1], Hongping Xiang[1,2], and Wolfgang Hübner[1] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Department of Physics and Astronomy, California State University, Northridge, USA

Using *ab initio* quantum chemistry, varying the interatomic distances, and including spin-orbit coupling and a static external magnetic field, we investigate the laser-induced, ultrafast magnetic switching in Ni_3Na_2 [1,2]. Our studies yield a very accurate bond-length sensor based on spin dynamics, as well as a unified picture of subpicosecond, laser-induced and picosecond, phonon-induced spin-flip processes.

Specifically we find that the geometric distortions lead to magnetic phases in the cluster, in which the strongly localized spins exhibit different orientations and hence respond differently to laser pulses. At the critical interatomic distances the spins undergo a sudden reorientation (spin-phonon scattering). This scattering is indirect and mediated through an energetically higher-lying electronic state.

Finally, to completely unify the laser-induced and the phonon-induced processes we calculate their longitudinal and transverse relaxation times and draw an analogy to classical precessional switching.

[1] H. P. Xiang, G. Lefkidis, and W. Hübner, Phys. Rev. B **86**, 134402 (2012)
[2] H. P. Xiang, G. Lefkidis, and W. Hübner, J. Supercond. Nov. Magn. (in press) (2012)

MA 43.5 Thu 16:00 H22

The lattice response of femtosecond laser excited Nickel investigated by time-resolved electron diffraction — •Carla Streubühr, Ping Zhou, Thorsten Brazda, Frank Meyer-zu Heringdorf, Michael Horn-von Hoegen, Dietrich von der Linde, and Uwe Bovensiepen — Universität Duisburg-Essen

In ultrafast magnetization dynamics of ferromagnets like Ni the lattice response to the femtosecond laser excitation is essential [1]. Here we report on an experimental study of the lattice dynamics driven by laser excitation in 20 nm thick Nickel single-crystalline films using time resolved transmission electron diffraction. The electron diffraction patterns of the freestanding Ni (001) films were recorded as function of delay time between optical pump ($h\nu$ = 1.5 eV) and electron probe (E_kin = 30 keV).

The integrated intensity of all diffraction spots decreased after the laser excitation. Our analysis indicates that the observed decrease does not scale with the scattering vector which is inconsistent with the Debye-Waller effect resulting from lattice heating. Furthermore, the diffraction intensity drop was proportional to the intensity of the laser pulse rather than the laser fluence. Both observations indicate a higher order lattice excitation by the laser and argue against the excitation by electron-phonon scattering. Possible alternative excitation mechanisms will be discussed.

[1] B. Koopmans et al, Nature Materials **9**, 259 (2010)

MA 43.6 Thu 16:15 H22

Theory of Thermal Magnetization Switching in Rare-Earth-based Ferrimagnets — •Sönke Wienholdt[1], Denise Hinzke[1], Karel Carva[2], Peter Oppeneer[3], and Ulrich Nowak[1] — [1]University of Konstanz, Germany — [2]Charles University in Prague, Czech Republic — [3]Uppsala University, Sweden

Recently it was demonstrated that a linearly polarized laser pulse is able to reverse the magnetization in ferrimagnetic GdFeCo on a purely thermal basis within a ps time scale [1,2]. Thermal opto-magnetic switching has so far only been obtained in rare-earth-based ferrimagnets like GdFeCo [1,2]. Hence it is assumed that the antiferromagnetic exchange interaction plays a role. Additionally the substanstially different demagnetization times of rare earths (RE) and transition metals (TM) [3,4] seems to be crucial [1,2]. Nevertheless the general mechanisms, especially the role of the highly non-equilibrium transient ferromagnetic-like state, are still up for debate. We devel-

oped an atomistic multi-band spin model for RE-based ferrimagnets, where we distinguish between d- and f-electrons in the RE [5]. Our numerical results show a transient ferromagnetic-like state of the right magnitude as well as the switching of the sublattices. We explain the origin of this by dissipationless dynamics occuring on a timescale below one ps.

[1] I. Radu et al., Nature 472, 205 (2011) [2] T.A. Ostler et al., Nat. Comm. 3, 666 (2012) [3] B. Koopmans et al., Nat. Mat. 9, 259 (2009) [4] M. Wietstruk et al., Phys Rev Lett. 106, 127401 (2011) [5] S. Wienholdt et al., submitted

MA 43.7 Thu 16:30 H22

Controlling the Competition between Optically Induced Ultrafast Spin-Flip Scattering and Spin Transport in Magnetic Multilayers — •S. Mathias[1], E. Turgut[2], C. La-o-vorakiat[2], J. M. Shaw[3], P. Grychtol[2], H. T. Nembach[3], D. Rudolf[4], R. Adam[4], M. Aeschlimann[1], C. M. Schneider[4], T. J. Silva[3], M. M. Murnane[2], and H. C. Kapteyn[2] — [1]TU Kaiserslautern and Research Center OPTIMAS, 67663 Kaiserslautern, GER — [2]JILA, University of Colorado, Boulder, USA — [3]NIST, Boulder, USA — [4]Peter Grünberg Institut, Research Centre Jülich, 52425, Jülich, GER

The study of ultrafast dynamics in magnetic materials provides rich opportunities for greater fundamental understanding of correlated phenomena in solid-state matter, because many of the basic microscopic mechanisms involved are as-yet unclear and are still being uncovered. Recently, two different possible mechanisms have been proposed to explain ultrafast laser induced magnetization dynamics: spin-flip scattering and superdiffusive spin transport. In this work, we use multilayers of Fe and Ni with different metals and insulators as the spacer material to conclusively show that both optically induced demagnetization, due to spin scattering processes, and spin-currents contribute simultaneously to ultrafast dynamics in magnetic materials. Moreover, we can control the competition between these two processes, and in some cases completely suppress interlayer spin currents as a sample undergoes rapid demagnetization. Finally, by reversing the order of the Fe/Ni layers, we experimentally show that spin-currents are directional in our samples, predominantly flowing from the top to the bottom layer.

MA 43.8 Thu 16:45 H22

Spin-lattice dynamics under conservation of angular momentum — •Matthias Assmann and Ulrich Nowak — University Konstanz, 78457 Konstanz, Germany

On ultrafast time scales conservation laws can enforce strong constraints onto the magnetization dynamics. These restrictions cannot be described by the Landau-Lifshitz-Gilbert equation with its dissipative dynamics. In this talk a set of coupled microscopic equations of motion for the spin and lattice dynamics is proposed, which include a direct coupling between spins and lattice, so that energy and angular momentum can be transferred between these subsystems. For the coupling between lattice and spin degrees of freedom a two-site anisotropy arising from spin-orbit coupling is considered as well as magnetic dipole-dipole interaction. Both of these coupling terms allow for a dynamics, which obey all conservation laws, including the conservation of total angular momentum. For the numerical treatment in our simulations new sympletic algorithms are used. As a test the Einstein-De Haas effect is reproduced as well as the Barnett effect. Furthermore, heat dissipation from the magnetic subsystem into the lattice is investigated in film geometries.

MA 43.9 Thu 17:00 H22

Temperature Dependence of Nutation in Magnetic Nanostructures — •Danny Böttcher[1,2] and Jürgen Henk[2] — [1]Max Planck Institute of Microstructure Physics, Halle, Germany — [2]Martin Luther University Halle-Wittenberg, Halle, Germany

The dynamics of magnetic moments in nanostructures is closely linked to that of gyroscopes. The Landau-Lifshitz-Gilbert equation describes precession and relaxation but does not include nutation. Both precession and relaxation have been observed in experiments, in contrast to nutation. We have extended the atomistic Landau-Lifshitz-Gilbert equation as well as the Landau-Lifshitz-Miyazaki-Seki equation, that specifies the temperature in strong time correlated systems, by a nutation term. This allows us to study the significance of nutation in magnetization dynamics of nanostructures: for a single magnetic moment, a chain of Fe atoms, Co islands on Cu(111) as well as finite temperature. We find that nutation is significant at low-coordination sites and on the timescale of about 100 fs in systems with low time correlation at finite temperatures; its observation challenges todays experimental techniques.

MA 43.10 Thu 17:15 H22

Statistical moment equations for stochastic spin dynamics in phase space: a uniaxial paramagnet subjected to a dc bias field of arbitrary orientation — •William Coffey[1], Yuri Kalmykov[2], and Sergey Titov[3] — [1]Department of Electronic and Electrical Engineering, Trinity College, Dublin 2, Ireland — [2]LAMP, University of Perpignan Via Domitia, 52, Ave. Paul Alduy, 66860 Perpignan, France — [3]Kotelnikov Institute of Radio Engineering and Electronics RAS, Vvedenskii Sq. 1, Fryazino, Moscow reg., 141190, Russian Federation

Spin dynamics in a dissipative environment are treated via the evolution (master) equation for spin orientations in the phase space in the weak spin-bath coupling and high temperature limits. The explicit solution is written for an arbitrary spin Hamiltonian as a finite series of spherical harmonics analogous to the (infinite) Fourier series representation of the classical case governed by the Fokker-Planck equation. Therefore, the expansion coefficients, i.e., the statistical averages of the spherical harmonics may be determined from a differential-recurrence relation yielding the stochastic spin dynamics for arbitrary spin number S. For large S the differential-recurrence relations reduce to those generated by the Fokker-Planck equation. Thus the spin dynamics may be treated in a manner transparently linking to the classical representations, providing quantum corrections to classical averages. The method is illustrated via the magnetization relaxation of a uniaxial paramagnet with a dc field applied at an arbitrary angle to the easy axis.

MA 43.11 Thu 17:30 H22

Phonon mediated Bose-Einstein magnon condensation — •Peter Clausen[1], Dmytro A. Bozhko[1,2], Andrii V. Chumak[1], Alexander A. Serga[1], Gennadii A. Melkov[2], and Burkard Hillebrands[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Germany — [2]Faculty of Radiophysics, Taras Shevchenko National University of Kyiv, Ukraine

We report on the first observation of a magneto-elastic magnon (MEM) mode populated due to the thermalization of a parametrically driven magnon gas. The gas behavior is investigated by time- and wavevector-resolved Brillouin light scattering (BLS) spectroscopy in an yttrium iron garnet (YIG) film. Two peaks of the magnon density with very similar energies but different wavevectors are observed near the bottom of the magnon spectrum. The magnons with the lower wavevector are identified as a Bose-Einstein magnon condensate (BEC) and the others with an approximately two-times larger wavevector as the MEM mode.

Our investigations show that the MEM mode starts to be visible at pumping powers at least ten times smaller than the threshold of the BEC formation. Furthermore, in contrast to the BEC peak, the width of the MEM mode peak is practically independent from the magnon density. The population characteristic of the MEM mode can be understood as a result of a phonon induced coupling of high magnon modes, and thus the formation of an effective transfer channel of the thermalized magnons to the bottom of the spin-wave spectrum.

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