MA 35: Magnetization / Demagnetization Dynamics II

Time: Wednesday 15:00–18:45 Location: EB 301

MA 35.1 Wed 15:00 EB 301

***Ab initio* calculations of laser-induced magnetism in materials** — •Marco Berritta[1], Ritwik Mondal[1], Karel Carva[1,2], and Peter M. Oppeneer[1] — [1]Uppsala University, Uppsala, Sweden — [2]Charles University, Prague, Czech Republic

An intensive femtosecond laser pulse can induce a short-lived magnetization in materials through the inverse Faraday effect. This effect can be described quantum-mechanically as a quadratic order response to the perturbing circularly polarized laser pulse. The magnitude of the light-imparted opto-magnetic field is thus far unknown; speculatively, it could be responsible for the recently demonstrated all-optical switching in magnetic recording materials [1]. We report *ab initio* calculations of the light-induced magnetization in typical ferromagnetic materials, Fe, Ni, and FePt. Results of full quantum quadratic response calculations are compared with results based on classical electron gas theory by Pitaevskii and an extension within the Drude-Lorentz theory. Support from the EU (under grant No. 281043, FemtoSpin) is acknowledged.

[1] C.-H. Lambert *et al.*, *All-optical control of ferromagnetic thin films and nanostructures.* Science **345**, 1337 (2014).

MA 35.2 Wed 15:15 EB 301

Element-specific investigation of photo-induced ultrafast demagnetization with light in the visible spectral range — •David Weder, Felix Willems, Oliver Gückstock, Clemens von Korff Schmising, and Stefan Eisebitt — Technische Universität Berlin

A promising approach to control magnetic properties and their subpicosecond dynamics is photo-induced ultrafast demagnetization which was measured for the first time in 1996 [Beaurepaire1996]. But even after almost 20 years of research the theoretically background about the fundamental microscopic processes has remained unclear. Several competing models describing the underlying mechanisms of laser-induced "femtomagnetism" have been put forward, one of which focuses on spin-polarized superdiffusive electron transport [Battiato2012]. Here, an ultrashort laser pulse triggers non-equilibrium superdiffusive electrons and gives rise to ultrafast transfer of magnetization on a nanometer length scale.

We have established a time-resolved, high-repetition, low-noise optical Kerr setup with micrometer spatial and 100 fs temporal resolution for ultrafast magnetic spectroscopy [KorffSchmising2014]. By nonlinear interaction of the light pulses in a photonic crystal fiber we generate a femtosecond white light continuum which allows us to disentangle the distinct ultrafast transient response of 3d-4f metallic magnetic multilayers and alloys (e.g. CoTb) [Khorsand2013]. We present first results on element specific magnetization dynamics in engineered sample geometries and discuss the influence of spin-polarized electron transport.

MA 35.3 Wed 15:30 EB 301

Electron kinetics in ultrafast magnetization dynamics — •Benedikt Y. Mueller[1], Bärbel Rethfeld[2], and Manfred Fähnle[1] — [1]Max-Planck-Institute for Intelligent Systems, Heisenbergstrasse 3, 70569 Stuttgart, Germany — [2]Technical University of Kaiserslautern, Germany

When a ferromagnetic metal is excited by an ultrashort laser pulse, a demagnetization within less than one picosecond is observed [1]. Up to now, no microscopic theory explains the large variety of this effect [1-3] on equal footing. As a step towards this goal, we investigate the ultrafast demagnetization by a kinetic approach, applying Boltzmann collision integrals [4-8] to trace the dynamics of the electrons [6,7]. For Nickel, we investigate the contribution of electron-electron and electron-phonon spin-flip scattering to the total demagnetization effect. Moreover, we illustrate the thermalization and relaxation processes after laser irradiation. As a result, we find that a dynamic electron band structure is essential for describing ultrafast demagnetization [6].

[1] Beaurepaire et al., Phys. Rev. Lett. 76, 4250 (1996)
[2] Roth et al., Phys. Rev. X 2, 021006 (2012)
[3] Koopmans, B. et al., Nature Materials 9, 259 (2010)
[4] Rethfeld et al., Phys. Rev. B 65, 214303 (2002)
[5] Mueller and Rethfeld, Phys. Rev. B 87, 035139 (2013)
[6] Mueller et al., Phys. Rev. Lett. 111, 167204 (2013)
[7] Illg et al., Phys. Rev. B 88, 214404 (2013)
[8] Essert and Schneider, Phys. Rev. B 84, 224405 (2011)

MA 35.4 Wed 15:45 EB 301

Transfer of angular momentum from the electrons to the lattice during ultrafast demagnetization — •Thodoris Tsatsoulis, Michael Haag, Christian Illg, and Manfred Faehnle — Max-Planck-Institute for Intelligent Systems, Heisenbergstrasse 3, 70569 Stuttgart, Germany

After irradiation of a magnetic film with a femtosecond (fs) optical laser pulse there is an ultrafast demagnetization of the film on a timescale of few 100 fs. For a theoretical explanation it is often assumed (see [1] and references therein) that the electrons excited by the beam are scattered at phonons and that thereby in systems with spin-orbit coupling the spin- and orbital-angular momentum of these electrons, which are related to magnetic moments, change. In all these theories only the change of the electronic magnetic moment is calculated explicitly, whereas it is implicitly assumed that the lattice acts as a perfect sink for the angular momentum. The reason is that for the construction of the electron-phonon scattering operator the lattice dynamics is represented in terms of linearly polarized phonons, which do not have a well-defined angular momentum. Therefore the change of the angular momentum of the lattice cannot be calculated from the change of the phononic occupation numbers. We calculate the modification of the angular momentum of the lattice explicitly by representing the lattice dynamics in terms of the magnetoelastic eigenmodes of a ferromagnetic system which carry a well-defined angular momentum [2], respectively.

[1] C.Illg, M. Haag and M. Faehnle, Phys. Rev. B 88, 214404 (2013).
[2] L. Zhang and Q. Niu, Phys. Rev. Letters 112, 085503 (2014).

MA 35.5 Wed 16:00 EB 301

Spin oscillations triggered by strongly correlated t_{2g} electrons at the timescale of electron-electron interactions — •Malte Behrmann and Frank Lechermann — I. Institut für Theoretische Physik, Universität Hamburg, 20355 Hamburg, Germany

Laser-induced ultrafast (fs) magnetization experiments in antiferromagnets have recently attracted large attention, paving the road for inherently fast spin dynamics in the THz regime without invoking stray fields. The technical importance is emphasized by the rising new research field of antiferromagnetic (AFM) spintronics, where superexchange-dominated strongly correlated compounds provide an interesting materials playground. Then an intriguing question is, whether the Coulomb interaction may be a key to control AFM order on ultrafast timescales. Therefore we here study (de)magnetization processes in a time-dependent multi-orbital Hubbard model, focusing on t_{2g} electrons in a wider doping range. We reveal novel filling-dependent stable/transient spin oscillations via interaction quenches from the antiferro- or paramagnetic state. Non-equilibrium ultrafast spin-orientation effects in prominent correlated transition-metal oxides are therefrom predicted, which could be detected by THz emission spectroscopy.

MA 35.6 Wed 16:15 EB 301

Ultrafast changes in crystal field during the demagnetization of antiferromagnetic Cr2O3 — •Vera Giulia Sala[1], Timothy Miller[1], Stefano Dal Conte[2], Valérie Véniard[3], Giulio Cerullo[2], and Simon Wall[1] — [1]ICFO - The Institute of Photonic Sciences, Av. Carl Friedrich Gauss 3, 08860 Castelldefels, Spain — [2]Politecnico di Milano, Piazza L. da Vinci 32, I-20133 Milano, Italy — [3]École Polytechnique, 91128 Palaiseau cedex, France

While magnetization dynamics in ferro- and ferri-magnetic materials has received significant experimental attention, dynamics in antiferromagnetic systems has been less studied. This is because most optical techniques used to probe magnetism require a net magnetic moment for a signal to be observed, but antiferromagnets have no net magnetization. To overcome this issue we use time-resolved resonant second harmonic spectroscopy which is sensitive to the magnetic order in the room temperature antiferromagnet Cr2O3. Exciting the system with visible light causes charge transfer excitations which modify both the magnetic state and the resonance condition of the second harmonic process. By performing polarization analysis we can separate the dy-

namics of the magnetic state and the crystal field which sets the resonant conditions. By tuning the pump wavelength, we can control how strongly we drive the crystal field and find that the crystal field contribution can be reduced whilst still demagnetizing the system by the same amount. This opens the way to more efficient control of the magnetic state, where energy is coupled more selectively into the magnetic system than other degrees of freedom.

15 min. break

MA 35.7 Wed 16:45 EB 301

Sublattice Magnetization Orientation Dependence of All-Optical Magnetic Switching in Tb-Fe Thin Films — •Alexander Hassdenteufel[1], Christian Schubert[1,2], Johannes Schmidt[3,4], Peter Richter[1], Dietrich R. T. Zahn[1], Georgeta Salvan[1], Manfred Helm[3,4], Rudolf Bratschitsch[5], and Manfred Albrecht[2] — [1]Institute of Physics, Technische Universität Chemnitz, D-09107 Chemnitz, Germany — [2]Institute of Physics, University of Augsburg, D-86159 Augsburg, Germany — [3]Helmholtz Zentrum Dresden Rossendorf, P.O. Box 510119, D-01314 Dresden, Germany — [4]Technische Universität Dresden, D-01062 Dresden, Germany — [5]Institute of Physics, University of Münster, D-48149 Münster, Germany

All-optical switching (AOS), first witnessed with GdFeCo [1], attracted growing attention for future data storage devices as well as from the fundamentals point of view. Here we demonstrate that the direction of AOS in rare-earth transition-metal (RE-TM) alloy Tb-Fe thin films depends on the orientation of the sublattice magnetization and not on the direction of the resulting net magnetization[2]. This finding of the sublattice dependence of AOS contributes to the understanding of switching in RE-TM multilayered thin films [3] and heterostructures [4]. [1] C. D. Stanciu et al. Phys. Rev. Lett 99, 047601 (2007). [2] A. Hassdenteufel et al. Appl. Phys. Lett. 105, 112403 (2014). [3] S. Mangin et al. Nature Mater. 13, 286-292 (2014). [4] C. Schubert et al. Appl. Phys. Lett. 104, 082406 (2014).

MA 35.8 Wed 17:00 EB 301

Ultrafast Spin dynamics in tunnel-magneto resistance junctions — •Jakob Walowski[1], Marvin von der Ehe[1], Ulrike Martens[1], Vladyslav Zbarsky[1,2], Markus Münzenberg[1], Andy Thomas[3], Jia Zhang[4], Christian Franz[4], Michael Czerner[4], and Christain Heiliger[4] — [1]Institut für Physik, Ernst-Moritz-Arndt Universität, Greifswald, Germany — [2]Fakultät für Physik, Georg-August Universität, Göttingen, Germany — [3]CSMD, Physics Department, Bielefeld University, Germany — [4]I. Physikalisches Institut, Justus Liebig Universität, Gießen

We investigate the spin transport and ultrafast spin dynamics in the magnetic layers of tunnel-magneto resistance junctions (MTJs) with out-of-plane magnetic anisotropy PMA. Both effects are induced by the excitation of the electron and spin system by ultra-short laser pulses.

The processes causing the spin dynamics and the spin transport depend on the properties of the magnetic electrodes and the tunnel barrier. Therefore the thickness of the CoFeB electrodes is varied within the range of permendicular magnetic anisotropy from 0.9 nm up to 1.3 nm. By studying the ultrafast dynamics, we disentangle the mechanisms and processes causing spin transfer between the electrodes through the tunnel barrier on femtosecond time scales.

Financial funding by the DFG SPP 1538 SpinCaT is acknowledged.

MA 35.9 Wed 17:15 EB 301

Ultrafast Electron Spin Dynamics at the Fermi Level in Fe3O4 Thin Films — C Cacho[1], M Battiato[2], J-M Mariot[3], •M C Richter[4], O Heckmann[4], F Parmigiani[5], H Ebert[6], J Minar[6], and K Hricovini[4] — [1]Central Laser Facility, STFC, RAL, Harwell, United Kingdom — [2]Institute of Solid State Physics, Vienna University of Technology, Austria — [3]LCP-MR, Univ. Paris 6/CNRS, France — [4]LPMS, Univ. de Cergy-Pontoise, France — [5]Elettra - Sincrotrone Trieste, Italy — [6]LMU Münich, Germany

Magnetite, Fe3O4 (FO), belongs to the family of half-metals characterized by an insulating gap for one spin state resulting in a fully spin-polarised transport at the Fermi level, which attracts a high interest for spintronic devices. In spite of intensive theoretical and experimental studies, the magnetic and electronic properties of FO remain controversial. We studied the demagnetisation process in FO by spin- and time-resolved pump-probe photoemission experiments using the third harmonic (4.65 eV) of a Ti-Saphire laser with a repetition rate of 250 kHz. For the maximum of the photoexcitation we observe a clear reduction of the spin polarisation in a region of ~200 meV around the Fermi level. At higher binding energy no variation is observed up to a 1000 fs delay indicating that the spin polarisation reduction observed comes from the electron dynamics and not from the demagnetization. The Boltzmann equation for out-of-equilibrium dynamics combined with the calculated spin-resolved electronic density-of-states fully describes the decay of the excited electrons as well as the variation of the spin polarisation.

MA 35.10 Wed 17:30 EB 301

Competition between ultrafast spin transport and spin-flip scattering investigated by complex femtosecond time-resolved MOKE — Jens Wieczorek[1], •Andrea Eschenlohr[1], Boris Weidtmann[1], Malte Rösner[2], Andreas Duvenbeck[1], Nicolas Bergeard[1], Alexander Tarasevitch[1], Tim O. Wehling[2], and Uwe Bovensiepen[1] — [1]Faculty of Physics and Center for Nanointegration (CENIDE), University of Duisburg-Essen — [2]Institute for Theoretical Physics, University of Bremen, and Bremen Center for Computational Materials Science

We analyze femtosecond laser-induced magnetization dynamics of epitaxial Co/Cu(001) films via ultrafast changes in the polarization rotation and ellipticity of the complex magneto-optical Kerr effect (MOKE). By exploiting the effective depth sensitivity of this experimental method, we conclude on a time- and depth-dependent magnetization profile, which is qualitatively different for ultrafast spin transport and spin-flip scattering. We find that before hot electron thermalization (<100 fs) the ultrafast demagnetization of Co/Cu(001) is dominated by spin-dependent transport, while local spin-flip processes govern the magnetization dynamics after thermalization.

We acknowledge funding from the DFG through SFB 616, the BMBF through Grant 05K10PG2 FemtospeX, and the Mercator Research Center Ruhr through Grant PR-2011-0003.

MA 35.11 Wed 17:45 EB 301

Interplay of spin scattering and spin transport in the complex demagnetization of Ni — •Oliver Schmitt, Moritz Barkowski, Sakshath S, Daniel Steil, Mirko Cinchetti, Stefan Mathias, and Martin Aeschlimann — Department of Physics and Research Center OPTIMAS, TU Kaiserslautern, 67663 Kaiserslautern, Germany

We use femtosecond time-resolved MOKE to study ultrafast demagnetization in a variety of different Ni films. With this approach, we aim to investigate and quantify the interplay of spin-flipping and spin-transport in the demagnetization process [1][2]. To exclude one of each possible channel, we performed measurements on Ni films that are fabricated into various different multilayer compositions. For our investigations, we than extended our MOKE setup by an advanced Kerr method, which enables us to measure a distinct depth or layer of the sample system [3].

[1] B. Koopmans et al., Nature Materials 9, 259-265 (2010)
[2] E. Turgut et al., PRL 110, 197201 (2013)
[3] A. J. Schellekens et al., PR B 90, 104429 (2014)

MA 35.12 Wed 18:00 EB 301

Ultrafast demagnetization dynamics in Ni/Ru/FePt/MgO(100) films — •Sadashivaiah Sakshath[1], Oliver Schmitt[1], Moritz Barkowski[1], Patrick Matthes[2], Manfred Albrecht[2,3], Mirko Cinchetti[1], Stefan Mathias[1], and Martin Aeschlimann[1] — [1]Technische Universität Kaiserslautern, Germany — [2]Technische Universität Chemnitz, Germany — [3]Universität Augsburg, Germany

Non-collinear magnetic layers allow us to study the influence of one ferromagnetic layer on the ultrafast dynamics of the non-collinear ferromagnet, primarily due to a spin current through the spacer layer [1,2]. We follow the dynamics of the in-plane magnetized Ni layer, as influenced by the perpendicularly magnetized FePt, using Ni/Ru/FePt/MgO(100) films. By changing the thickness of the Ru layer, we tune the amount of spin currents flowing between the magnetic layers [3]. When the thickness of Ru is low, Ni is observed to demagnetize faster in the non-collinear than in the collinear configuration. At high Ru thickness, the rate of demagnetization is the identical in both configurations, since the ultrafast spin currents do not reach the Ni layer. Additionally, at high Ru thickness, the observed magneto-optic signal shows a transient change of sign.

[1] A. J. Schellekens *et al.*, Nat. Comm. **5**, 4333 (2014)
[2] G-M. Choi *et al.*, Nat. Comm. **5**, 4334 (2014)
[3] E. Turgut *et al.*, Phys. Rev. Lett. **110**, 197201 (2013)

MA 35.13 Wed 18:15 EB 301

The fate of the transient ferromagnetic-like state in ferrimagnetic GdFe alloys — •Ilie Radu[1], Loic LeGuyader[1], Ilya Radzolsky[2], Raja Medapalli[2,3], Christian Stamm[1,4], Torsten Kachel[1], Rolf Mitzner[1], Karsten Holldack[1], Arata Tsukamoto[5], Alexey Kimel[2], and Theo Rasing[2] — [1]Helmholtz-Zentrum Berlin, BESSY II, Germany — [2]Radboud University Nijmegen, Netherlands — [3]University of California, San Diego, USA — [4]ETH Zürich, Switzerland — [5]Nihon University, Chiba, Japan

Recent femtosecond time-resolved XMCD investigations of ferrimagnetic GdFeCo alloys revealed the existence of a transient ferromagnetic state [1] mediating the ultrafast magnetization switching of antiferromagnetically coupled Fe and Gd spins [2]. Here we present a two-fold strategy on the control of the transient state's lifetime and onset by either changing the alloy stoichiometry or upon varying the laser excitation density. Possible implications for the magnetic switching phenomena in ferrimagnetic alloys and heterostructures will be discussed.

We acknowledge funding from European Union through FEMTOSPIN program and from BMBF through FEMTOSPEX grant No. 05K10PG2.

[1] I. Radu et al., Nature 472, 205 (2011) [2] T. Ostler et al., Nature Commun. 3, 666 (2012)

MA 35.14 Wed 18:30 EB 301

Monitoring of spin-polarized hot carrier currents by time-resolved magneto-induced SHG in metallic multi-layers — Alexandr Alekhin[1], Nikita Ilin[1], Damian Bürstel[2], Detlef Diesing[2], Tim O. Wehling[3], Ivan Rungger[4], Maria Stamenova[4], Stefano Sanvito[4], Vladimir Roddatis[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, Institut für Materialphysik — [6]Universität Duisburg-Essen, Fakultät für Physik

In metals, spin dynamics is non-local and determined by the transport of spin-polarized hot carriers (HC). We monitor resulting ultrafast variations of the magnetization in ferro- and the appearance of transient magnetization in paramagnetic layers by time-resolved MOKE. To get deeper insight in complex dynamics of the excited state, we complement MOKE by magneto-induced second harmonic generation (mSHG) which is sensitive to electron and magnetization dynamics at interfaces. In addition, it contains terms proportional (i.e. giving a direct access) to electric and spin currents in the bulk of metallic layers. Analyzing the response of Au/Fe/MgO(001) and Fe/Au/Fe/MgO(001) structures with varying layer thicknesses, we observe contributions from both charge/particle and spin components of HC currents within 300 fs after the excitation. The underlying mechanisms and related details of mSHG diagnostics are discussed. DFG (ME 3570/1, Sfb 616) and EU 7-th framework program (CRONOS) are acknowledged.