MA 29: Magnetization Dynamics II

Time: Wednesday 15:00–18:15 Location: HSZ 401

MA 29.1 Wed 15:00 HSZ 401

Damping due to spin-lattice coupling — •Matthias Assmann and Ulrich Nowak — University Konstanz, 78457 Konstanz, Germany

The Landau-Lifshitz-Gilbert equation is often used for modeling spin dynamics on atomistic length scales. This phenomenological approach to relaxation accumulates all dissipative effects in the damping constant α, no matter whether they are due to interactions with the electronic system or the lattice.

In this talk we present an investigation of the influence of direct spin-lattice coupling on magnetic relaxation processes. We perform spin-molecular dynamics simulations, which take into account the spatial as well as the spin degrees of freedom, both of which are coupled appropriately.

Especially we are interested in the temperature dependence of the relaxation processes. As an example the behavior of small nickel clusters in an external magnetic field will be presented, the resulting damping mechanism as well as the Einstein-de Haas effect.

MA 29.2 Wed 15:15 HSZ 401

Comparison of different theories for femtosecond demagnetization — •Karel Carva[1,2], Dominik Legut[3], Marco Battiato[2], and Peter M. Oppeneer[2] — [1]Charles University in Prague, Czech Republic — [2]Uppsala University, Sweden — [3]VSB-Technical University of Ostrava, Czech Republic

Magnetization can be changed by means of very strong laser light on the femtosecond timescale. The Elliott-Yafet electron-phonon spin-flip (EY-SF) scattering has been suggested to be the dominant responsible microscopic mechanism [1]. However, ab initio calculations of EY-SF scattering have found the demagnetization rate to be too low to explain the observed demagnetization, especially for electrons in the thermalized state [2]. A recent publication [3] suggests that a different computational approach must be adopted for EY-SF calculation, which leads to a higher calculated demagnetization rate.

We have calculated the spin-flip Eliashberg function for three ferromagnetic metals Fe, Co and Ni [4]. We consider both thermalized very hot electron distributions, as well as highly non-equilibrium electron distributions that are expected to be present immediately after the fs laser excitation. Based on this we study the difference between the proposed models and the physical relevance of the employed approximations.

[1] B. Koopmans et al., Nature Mater. 9, 259 (2010). [2] K. Carva, M. Battiato, P. M. Oppeneer, Phys. Rev. Lett., 107, 207201 (2011) [3] A.J. Schellekens, B. Koopmans, Phys. Rev. Lett. 110, 217204 (2013) [4] K. Carva et al., Phys. Rev. B 87, 184425 (2013)

MA 29.3 Wed 15:30 HSZ 401

Ultrafast demagnetization after laser irradiation: The influence of reduced exchange splitting — •Christian Illg, Michael Haag, and Manfred Fähnle — Max Planck Institute for Intelligent Systems, Heisenbergstr. 3, 70569 Stuttgart, Germany

Electron-phonon scattering is one possible candidate to explain ultrafast demagnetization after laser irradiation in Ni, Fe or Co [1]. We calculate the demagnetization time and the demagnetization rate with ab-initio density-functional theory and estimate the phase space for scattering which is related to the maximum possible demagnetization. We do this for the ground-state band structure and for band structures with reduced exchange splitting (according to reduced magnetic moments). We find that both demagnetization rate and phase space are too small for reasonable excitations to explain the experimental demagnetization [2].

[1] M. Fähnle, C. Illg, J. Phys.: Condens. Matter **23**, 493201 (2011)
[2] C. Illg, M. Haag, M. Fähnle, Phys. Rev. B, in press (2013)

MA 29.4 Wed 15:45 HSZ 401

Ultrafast demagnetization in transition metals - comparing ab-initio electron-phonon and electron-magnon rates — •Michael Haag, Christian Illg, and Manfred Fähnle — Max Planck Institute for Intelligent Systems, D-70569 Stuttgart, Heisenbergstr. 3, Germany

In 1996 Beaurepaire [1] found that a thin ferromagnetic Ni film, which is excited by a fs laser pulse, exhibits an ultrafast demagnetization on 100fs timescale. Despite years of fruitful research the underlying mechanisms remain unclear. Many mechanisms have been suggested including electron-phonon, and electron-magnon spin flips. Carpene [2] suggested that electron-magnon scattering can describe the demagnetization, because in presence of spin-orbit coupling, where spin- is transferred to orbital-angular momentum, which is rapidly quenched by the crystal field. Since the angular momentum is conserved [3] it has to be transferred to the lattice to allow the demagnetization. However Illg [4] could prove that rates and available phase space of electron-phonon coupling alone are too small to explain the demagnetization. We calculate the electron-magnon rates to check whether a combined process of electron-magnon and electron-phonon scatterings explains ultrafast demagnetization. In addition Carpene's assumption is checked by calculating the transferred orbital angular momentum rate.

[1] E. Beaurepaire, et al., Phys. Rev. Lett. 76, 4250 (1996)
[2] E. Carpene, et al., Phys. Rev. B 78, 174422 (2008)
[3] M. Fähnle, et al., J. Magn. Magn. Mater. 347, 45 (2013)
[4] C. Illg, M. Haag, M. Fähnle, Phys. Rev. B. accepted

MA 29.5 Wed 16:00 HSZ 401

Ultrafast relaxation dynamics of majority and minority electrons in ferromagnetic metals — Benedikt Y. Mueller, Mirko Cinchetti, Martin Aeschlimann, Hans Christian Schneider, and •Baerbel Rethfeld — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany

It is experimentally well established that irradiating ferromagnetic films with an ultrashort laser pulse leads to a quenching of the magnetization on a subpicosecond timescale [1]. Currently, Elliott-Yafet like spin-flip processes [2,3,4] as well as superdiffusive transport [5] are discussed to cause this effect. Recently, we have shown that the Elliott-Yafet process, including its possibility during electron–electron collisions [3], can quantitatively reproduce ultrafast magnetization dynamics [4]. This is due to a feedback effect: The interplay of the equilibration of chemical potentials and temperatures and a dynamical exchange splitting increases the demagnetization considerably. In this talk we show additional insights how distinct collision processes influence magnetization dynamics. The Boltzmann description allows to switch separate collisions on and off, identifying their microscopic role on the dynamics. We further present the development of transient spin-resolved temperatures, chemical potentials and electronic energies.

[1] Beaurepaire et al., PRL 76, 4250 (1996)
[2] Koopmans et al., NMAT 9, 259 (2010)
[3] Krauss et al., PRB 80, 180407(R) (2009)
[4] Mueller et al., PRL 111, 167204 (2013)
[5] Battiato et al., PRL 105, 027203 (2010)

15 min. break

MA 29.6 Wed 16:30 HSZ 401

***Ab initio* study of relativistic effects in femtosecond magneto-optics** — Ritwik Mondal[1], Karel Carva[1,2], and •Peter M. Oppeneer[1] — [1]Uppsala University, Uppsala, Sweden — [2]Charles University, Prague, Czech Republic

Excitation of a metallic ferromagnet such as Ni with an intensive femtosecond laser-pulse causes an ultrafast demagnetization within approximately 300 fs. It has been proposed that the ultrafast demagnetization, which is measured in femtosecond magneto-optical experiments, could be due to relativistic light-induced processes: either direct light-induced spin-flip processes or coherent relativistic quantum electrodynamics [1,2] (see also [3]). We perform an *ab initio* investigation of the influence of these relativistic effects on the magneto-optical response of Ni. To this end, we compute, first, the influence of relativistic spin-flip transitions, and second, develop a response theory formulation of the additional appearing ultra-relativistic terms in the Foldy-Wouthuysen transformed Dirac Hamiltonian due to the electromagnetic field. This allows us to draw conclusions on the amount of demagnetization that could be achieved by these mechanisms. Financial support from the EU (under grant No. 281043, FemtoSpin) is acknowledged. [1] J.-Y. Bigot, M. Vomir, E. Beaurepaire, Nature

Phys. **5**, 515 (2009). [2] G.P. Zhang, W. Hübner, G. Lefkidis, Y. Bai, T.F. George, Nature Phys. **5**, 499 (2009). [3] K. Carva, M. Battiatio, P.M. Oppeneer, Nature Phys. **7**, 665 (2011).

MA 29.7 Wed 16:45 HSZ 401

Ultrafast electrical control of the exchange interaction — •Johan H. Mentink and Martin Eckstein — Max Planck Research Department for Structural Dynamics, University of Hamburg-CFEL, 22607 Hamburg, Germany

Ultrafast magnetism is concerned with the dynamics of magnetic materials on a timescale of their intrinsic magnetic interactions [1]. The strongest of them is the exchange interaction, which determines the ordering of microscopic spins. In many situations the ultrafast dynamics of magnetization can conveniently be described using (quasi) equilibrium models in which only the (effective) temperature and the magnetization depend on time, leaving the exchange interaction essentially unchanged. Nevertheless, since the exchange interaction is determined by the interactions between the electrons, it can potentially be controlled with electric fields. In this contribution we demonstrate theoretically that ultrafast electrical control of the exchange interactions is indeed possible by studying the Hubbard model out of equilibrium in the regime relevant to Mott insulators and charge-transfer insulators. Furthermore, we show that such ultrafast modification of the exchange interaction can experimentally be detected by measuring the spin resonances that are excited by it.

[1] J. Stöhr and H.C. Siegmann, Magnetism: from fundamentals to nanoscale dynamics, (Springer-Verlag, Berlin Heidelberg 2006).

MA 29.8 Wed 17:00 HSZ 401

Microscopic electronic configurations during ultrafast magnetisation dynamics — Inka Locht[1], Igor Di Marco[1], Silvano Garnerone[2], Raghuveer Chimata[1], Anna Delin[1], Olle Eriksson[1], and •Marco Battiato[1,3] — [1]Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden — [2]Institute for Quantum Computing, University of Waterloo, Waterloo, Canada — [3]Institute of Solid State Physics, Vienna University of Technology, Vienna, Austria

Recent experiments [1,2] have shown the new possibility of generating an increase of magnetisation in Fe upon direct injection of spin from a neighbouring layer. This reopens the unsolved question about the microscopical configuration after ultrafast magnetisation dynamics, requiring an answer that addresses both dynamics on equal footing.

We provide a model for the description of the electronic and magnetic configurations of ferromagnetic Fe undergoing both ultrafast decrease and increase of magnetization. The model is based on the assumption that after the the ultrafast magnetization change is complete the system has achieved a local thermodynamic equilibrium. With statistical arguments it is possible to show that the magnetic configurations in the case of reduced or increased magnetic moment are qualitatively different. The predicted magnetic configurations are then used to compute T-MOKE spectra at the 3p (M) absorption edges which are in excellent agreement with the existing experiments.

[1] Rudolf et al., Nat. Commun. 3, 1037 (2012) [2] Turgut et al., Phys. Rev. Lett. 110, 197201 (2013)

MA 29.9 Wed 17:15 HSZ 401

Gilbert damping tensor within the breathing Fermi surface model: anisotropy and non-locality — •Danny Thonig[1,2] and Jürgen Henk[2] — [1]Max Planck Institute of Microstructure Physics, Halle, Germany — [2]Martin Luther University Halle-Wittenberg, Halle, Germany

An essential property of magnetic devices is the relaxation rate in magnetic switching which depends strongly on the damping in the magnetization dynamics. The latter enters the Landau-Lifshitz-Gilbert equation as Gilbert damping α and is commonly taken as a phenomenological parameter. Recent experiments predict, however, a complicated behavior of dissipation in low-dimensional systems, which is hardly to explain by a local scalar α. This mismatch calls for a theoretical understanding based on *ab initio* results.

We apply the breathing Fermi surface model [1] in the framework of a renormalized Green function tight-binding approach. Slater-Koster parameters were obtained by genetic-algorithm optimization with respect to first-principles results. Magnetic as well as structural disorder are treated by the coherent potential approximation. The results are non-local Gilbert tensors $\boldsymbol{\alpha}_{ij}$ which depend on the electron, spin and phonon temperatures as well as on the directions of the local magnetic moments.

Our approach is applied to the bulk and to surfaces of Stoner magnets. The non-local tensorial behavior of the damping leads to significant differences with respect to the conventional local scalar treatment.

[1] V. Kamberský. Cz. Journal of Physics B, **34** (1984) 1111

MA 29.10 Wed 17:30 HSZ 401

Supermagnonic Bloch point propagation in cylindrical nanowires — •Christian Andreas[1,2], Attila Kákay[1], and Riccardo Hertel[2] — [1]Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich GmbH, D-52428 Jülich, Germany — [2]Institut de Physique et Chimie des Matériaux de Strasbourg, Université de Strasbourg, CNRS UMR 7504, Strasbourg, France

Bloch points (BPs) [1,2] are micromagnetic singularities that can play a decisive role in magnetic switching processes. The archetypal example is a soft-magnetic cylinder [3], where a BP resides in the center of a vortex domain wall (VDW). Micromagnetic theory is not capable to treat BPs and their dynamics correctly, as they represent topological defects and singularities. We used our multiscale-multimodel code [4] that combines an atomistic Heisenberg model with a finite element micromagnetic algorithm to trace Bloch points and to study the dynamics of VDWs driven by an external magnetic field. The results show that, owing to the high stability of VDWs, the combination of BP and VDW can smoothly propagate at supermagnonic velocities above 1000 m/s when it is driven by fields of only a few mT. We further find a limiting BP/VDW propagation velocity that remains unchanged for a broad range of magnetic field values; a feature that could be advantageous for domain-wall based magnetic storage or logic devices.

[1] E. Feldtkeller, Z. Angew. Phys. 19, 530 (1965)
[2] W. Döring, J. Appl. Phys. 39, 1006 (1968)
[3] A. Arrott *et al.*, IEEE Trans. Mag. 15, 1228 (1979)
[4] C. Andreas, A. Kákay, R. Hertel, arXiv:1311.1617 [cond-mat] (2013)

MA 29.11 Wed 17:45 HSZ 401

Energy dissipation of moved magnetic vortices — •Martin Magiera — Fakultät für Physik, Universität Duisburg-Essen

A two-dimensional easy-plane ferromagnetic substrate, interacting with a dipolar tip which is magnetized perpendicularly with respect to the easy plane is studied numerically by solving the Landau-Lifshitz Gilbert equation. The dipolar tip stabilizes a vortex structure which is dragged through the system and dissipates energy [EPL **100**, 27004 (2012)]. Based on Thiele's equation, an analytical expression for the energy dissipation for the limiting case of a vanishing scanning velocity as well as its validity are discussed [EPL **103**, 57004 (2013)]. A magnetic friction number is defined which represents a general criterion for the validity of Thiele's equation and quantifies the degree of nonlinearity in the response of a driven spin configuration.

MA 29.12 Wed 18:00 HSZ 401

ON THE KRAMERS VERY LOW DAMPING ESCAPE RATE FOR POINT PARTICLES AND CLASSICAL SPINS — •William T. Coffey[1], William J. Dowling[2], Yuri P. Kalmykov[3], and Serguey V. Titov[4] — [1]Department of Electronic and Electrical Engineering, Trinity College, Dublin 2, Ireland — [2]Department of Electronic and Electrical Engineering, Trinity College, Dublin 2, Ireland — [3]University of Perpignan, Perpignan, France — [4]Kotelnikov Institute of Radio Engineering and Electronics, RAS, Russia

The seminal Kramers result for the very low dissipation (VLD) escape rate of point particles from a potential well is rigorously derived by writing following Stratonovich, the Langevin equation (LE) in energy (slow) and configuration (fast) variables which now contain a multiplicative noise term. The corresponding Fokker-Planck equation (FPE) in configuration-energy space may then be written via the Kramers-Moyal expansion merely by calculating the drift and diffusion coefficients from the LE given the Stratonovich interpretation. The configuration-energy LE method may be transparently generalized following transformations given very recently by Dunn et al. [T. Dunn et al., in Fluctuating Nonlinear Oscillators, Ed. by M.I. Dykman, Oxford University Press, Oxford, 2012], to the stochastic motion of classical spins executing Stoner-Wohlfarth orbits in nonaxially symmetric anisotropy-Zeeman potentials which is governed by the Landau-Lifshitz-Gilbert equation yielding an exact expression for the VLD mean first passage time whence the Kramers VLD rate for spins.