MA 9: Spin Excitations/Spin Torque

Time: Monday 15:00–18:45 Location: H 0112

Invited Talk MA 9.1 Mon 15:00 H 0112

Ultra-fast three terminal perpendicular Spin-Orbit MRAM — •Gilles Gaudin[1], Olivier Boulle[1], Murat Cubukcu[1], Marc Drouard[1], Nicolaï Mikuszeit[1], Liliana Buda Prejbeanu[1], Claire Hamelin[1], Ioan Mihai Miron[1], Stéphane Auffret[1], Nathalie Lamard[2], Marie-Claire Cyrille[2], Jürgen Langer[3], Berthold Ocker[3], Kevin Garello[4], Can Onur Avci[4], Manuel Baumgartner[4], Abhijit Ghosh[4], and Pietro Gambardella[4] — [1]Univ. Grenoble Alpes, CNRS, CEA, INAC-SPINTEC, F-38000 Grenoble, France — [2]CEA, LETI, Minatec Campus, F-38000 Grenoble, France — [3]Singulus AG, Kahl, Germany — [4]Department of materials, ETH Zürich, Switzerland

STT-MRAM has been identified as a promising candidate for the non-volatile replacement of L1 and L2 SRAM cache memory technology. However, STT-MRAM suffers from serious reliability and endurance issues due to the rapid aging of the tunnel barrier induced by the high write current density at large speed (~ns for L1 cache) as well as erroneous writing by read current. We present a novel memory concept, named Spin Orbit Torque-MRAM (SOT-MRAM) that combines the advantages of STT and naturally solves these issues. The memory is based on the discovery that a current flowing in the plane of a magnetic multilayer with structural inversion asymmetry, such as Pt/CoAlOx, exerts a torque on the magnetization. This spin orbit torque can induce ultra-fast magnetization switching (<200ps in Pt/Co/AlOx). Micromagnetic simulations reveal that the magnetization reversal proceeds by domain nucleation followed by domain wall propagation.

15 min. break

MA 9.2 Mon 15:45 H 0112

Electron energy loss spectroscopy of spin waves in ultrathin films of cobalt on Cu(111) and W(110) — •Eugen Michel[1,2], Harald Ibach[1,2], and Claus M. Schneider[1,2] — [1]Peter-Grünberg-Institut, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Jülich Aachen Research Alliance, Germany

For ultrathin fcc Co/Cu(100) films the dispersion of standing spin wave modes as function the film thickness was shown to be a sensitive probe for the layer dependence of layer exchange coupling constants [1]. We extend the method to hcp Co films grown on Cu(111) and W(110). In addition to the acoustic spin wave we observe up to two standing spin wave modes in films with thicknesses ranging from 2 to 8 atomic layers and wave vectors between 1.6 - 5 1/nm. We find that the layer-dependent dispersion curves obtained for both substrates are consistent with each other when the island growth of Co on Cu(111) is taken into account. Compared to fcc cobalt films on Cu(100) the standing spin waves have a substantially lower energy, which is consistent with the lower number of nearest neighbor interactions between subsequent layers. The results are discussed within the framework of a Heisenberg model with modified coupling constants at surface and interface.

[1] J. Rajeswari et al., Phys. Rev. Lett. 112, (12), pp 127202 (2014)

MA 9.3 Mon 16:00 H 0112

Direct and inverse spin-orbit torques from first principles — •Frank Freimuth, Stefan Blugel, and Yuriy Mokrousov — Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Ferromagnetic (FM) layers asymmetrically sandwiched between non-magnetic (NM) layers can be switched by spin-orbit torques (SOTs) [1,2]. Conversely, an electric current can be induced by magnetization dynamics due to the inverse SOT (ISOT) [3]. We discuss exact relationships between SOTs and ISOTs. Based on DFT calculations [4] we study (I)SOTs in NM/FM thin films for various choices of NM (Pt, W, Ta, Ir, Au) and FM (Co, Fe, Mn). Resolving torques and spin-fluxes on the atomic scale allows us to differentiate between local and non-local contributions. An important contribution to the ISOT is the conversion of pumped spin current into charge current via the inverse spin Hall effect (ISHE). We investigate the spatial decay of the spin current pumped into NM via the ferromagnetic resonance (FMR) of the FM layer, its conversion into a charge current and its contribution to the Gilbert damping. We show that this ISHE-driven charge current is accompanied by a phase-shifted contribution originating in the interfacial spin-orbit coupling. Finally, we investigate (I)SOTs at finite frequencies and find that they can be very well approximated by the zero-frequency (I)SOTs in the GHz regime.

[1] F. Freimuth et al., PRB **90**, 174423 (2014)
[2] F. Freimuth et al., J. Phys.: Condens. Matter **26**, 104202 (2014)
[3] F. Freimuth et al., arXiv:1406.3866 [4] www.flapw.de

MA 9.4 Mon 16:15 H 0112

Domain wall motion in temperature gradients caused by maximization of entropy — •Frank Schlickeiser, Ulrike Ritzmann, Unai Atxitia, Denise Hinzke, and Ulrich Nowak — University Konstanz, 78457 Konstanz, Germany

A theoretical understanding of thermally driven domain wall (DW) motion is of great interest, since it potentially opens the door for new ways to control and manipulate domain structures in spintronic devices. Based on the Landau Lifshitz Bloch equation [1], we present an analytical calculation of the DW velocity as well as the Walker threshold, where we find, that the domain wall is mainly driven by the temperature dependence of the exchange stiffness [2,3]. Additionally we show that the effect of the entropic torques should be larger than the angular momentum transfer from the magnon current [4,5]. Since our argument on thermodynamic principles, mainly the maximization of entropy, is rather general, it should not be restricted to transverse domain walls in ferromagnets only. Therefore, we will also discuss its applicability for different magnetic systems as antiferromagnets, where we expect the DW to move to hotter regions as well. We acknowledge financial support by the DFG through SFB 767. References: [1] D. A. Garanin, Phys. Rev. B 55, 3050 (1997), [2] D. Hinzke and U. Nowak, Phys. Rev. Lett. 107, 027205 (2011), [3] F. Schlickeiser, et al., Phys. Rev. Lett. 113, 097201 (2014), [4] W. Jiang et al., Phys. Rev. Lett. 110, 177202 (2013), [5] D. A. Kovalev et al., Europhys. Lett. 97, 67002 (2012).

MA 9.5 Mon 16:30 H 0112

Probing the linear relation of interfacial Dzyaloshinskii-Moriya interaction and Heisenberg exchange — Hans Nembach[1], Justin Shaw[1], •Mathias Weiler[1,2], Emilie Jué[1], and Thomas Silva[1] — [1]National Institute of Standards and Technology, Boulder, CO, USA — [2]Walther-Meißner-Institut, Garching, Germany

The exchange interaction is the fundamental quantum-mechanical mechanism responsible for ferromagnetism. While the symmetric Heisenberg exchange favors the parallel alignment of spins, the anti-symmetric Dzyaloshinskii-Moriya interaction (DMI) is responsible for chiral magnetic ordering. Moriya calculated that the DMI and Heisenberg exchange interactions should be proportional to each other in the bulk solid, hematite. Up to now, this theoretically predicted proportionality was untested. Here, we use optical spin-wave spectroscopy (Brillouin light scattering) to determine the DMI-induced asymmetric shift of the spin-wave dispersion for thermal Damon-Eshbach spin waves in a series of $Ni_{80}Fe_{20}$/Pt thin film bilayer samples [1]. This allows us to directly extract the magnitude and direction of the interfacial DMI. We compare the extracted DMI to the independently measured Heisenberg exchange integral. The $Ni_{80}Fe_{20}$-thickness-dependencies of both the microscopic symmetric- and antisymmetric-exchange are identical, as was originally proposed by Moriya for a bulk system. This allows to predict the influence of the DMI on spin-orbit torque applications.

[1] Nembach et al. arXiv:1410.6243

MA 9.6 Mon 16:45 H 0112

Interfacial Dzyaloshinskii-Moriya interaction in Ta\CoFeB\MgO nanowires — •R. Lo Conte[1,2], E. Martinez[3], A. Hrabec[4], A. Lamperti[5], T. Schulz[1], L. Nasi[6], L. Lazzarini[6], B. Ocker[7], C. H. Marrows[4], T. A. Moore[4], and M. Kläui[1,2] — [1]Johannes Gutenberg Universität-Mainz, Mainz, Germany — [2]Graduate School of Excellence Materials Science in Mainz, Mainz, Germany — [3]Universidad de Salamanca, Salamanca, Spain — [4]University of Leeds, Leeds LS2 9JT, U.K. — [5]Laboratorio MDM, IMM-CNR, Agrate Brianza, Italy — [6]IMEM-CNR, Parma, Italy — [7]Singulus Technologies, Kahl am Main, Germany

We use domain wall motion due to spin orbit torques to quantify the Dzyaloshinskii-Moriya interaction (DMI) at the Ta\CoFeB interface in out-of-plane magnetized nanostructures with structural inversion asymmetry [1]. Current-induced domain wall motion (CIDWM) experiments were carried out in Ta\Co20Fe60B20\MgO nanowires and the DW motion is imaged by differential Kerr microscopy technique. We find that the velocity of the DW is strongly affected by the presence of a longitudinal magnetic field, resulting in a different velocity for the up-down and down-up domain walls at fixed current density and magnetic field. Such results are interpreted by the spin-Hall effect-torque model, where the chirality of the domain walls is fixed by the DMI at the [heavy metal]\ferromagnet interface. The DMI is found to depend on the B diffusion to the Ta interface, which is a consequence of the annealing process used to obtain the desired perpendicular magnetic anisotropy. [1] R. Lo Conte et al., arXiv: 1409.3753 (2014).

15 min. break

MA 9.7 Mon 17:15 H 0112

Spin-transfer torque effects in the dynamic forced response of the magnetization of nanoscale ferromagnets in superimposed ac and dc bias fields in the presence of thermal agitation — •William Coffey[1], Yuri Kalmykov[2], Sergey Titov[3], Declan Byrne[1], and Jean Wegrowe[4] — [1]Department of Electronic and Electrical Engineering, Trinity College, Dublin 2, Ireland — [2]Université de Perpignan Via Domitia, Laboratoire de Mathématiques et Physique, F-66860, Perpignan, France — [3]Kotelnikov Institute of Radio Engineering and Electronics of the Russian Academy of Sciences, Vvedenskii Square 1, Fryazino, Moscow Region, 141120, Russia — [4]Laboratoire des Solides Irradiés, Ecole Polytechnique, 91128 Palaiseau Cedex, France

Spin-transfer torque (STT) effects on the stationary forced response of nanoscale ferromagnets driven by an ac magnetic field of arbitrary strength in the presence of thermal fluctuations are investigated via the generic nanopillar model of a spin-torque device. The STT effects are treated via the magnetic Langevin equation generalized to include the Slonczewski STT term thereby extending the statistical moment method to the forced response. Hence, the dynamic susceptibilities, frequency-dependent dc magnetization, dynamic hysteresis loops, etc. are evaluated for arbitrary ac field direction, strength and spin polarization, highlighting STT effects on both the low-frequency thermal relaxation processes and the high-frequency ferromagnetic resonance, demonstrating a pronounced dependence of such characteristics on the spin polarization current, allowing interpretation of STT experiments.

MA 9.8 Mon 17:30 H 0112

Lifetime of high-energy magnons in ultrathin FePd(001) films — •Huajun Qin[1], Khalil Zakeri Lori[1], Arthur Ernst[1,2], Leonid M. Sandratskii[1], Pawel Buczek[1], Alberto Marmodoro[1], Tzu-Hung Chuang[1], Yu Zhang[1], and Jürgen Kirschner[1,3] — [1]Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, 06120 Halle, Germany — [2]Wilhelm Ostwald Institut für Physikalische und Theoretische Chemie, Universität Leipzig, Linnéstr. 2, 04103 Leipzig, Germany — [3]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06120 Halle, Germany

The lifetime of high-energy magnons in itinerant ferromagnets is very short due to their decay into the single-particle Stoner excitations. This damping mechanism is commonly referred to as Landau damping.

We present the results of our investigations of magnons' lifetime in ultrathin FePd(001) alloy films grown on Pd(001), obtained by means of spin polarized electron energy loss spectroscopy. It is observed that the magnons' lifetime in ultrathin FePd alloy films is rather long compared to the one in Fe films grown on other substrates [1]. First-principles calculations revealed that the long magnons' lifetime has its origin in the peculiar electronic hybridizations between Fe and Pd atoms. These electronic hybridizations lead to the suppression of the relaxation channels of high-energy magnons and result in a long magnons' lifetime. We anticipate that the long lifetime of magnons in FePd films makes them as good candidates for terahertz magnonics.

[1] Y. Zhang, T.-H. Chuang, Kh. Zakeri, and J. Kirschner, PRL **109**, 087203 (2012).

MA 9.9 Mon 17:45 H 0112

Spin-orbit torques in $L1_0$-FePt/Pt thin films driven by electrical and thermal currents — •Guillaume Géranton, Frank Freimuth, Stefan Blügel, and Yuriy Mokrousov — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Using the linear response formalism for the spin-orbit torque (SOT) we compute from first principles the SOT in a system of two layers of $L1_0$-FePt(001) deposited on an fcc Pt(001) substrate of varying thickness [1]. We predict SOTs of the same order of magnitude than the ones computed in Co/Pt thin films [2]. Moreover, the good matching of the lattice constants of Pt and $L1_0$-FePt(001) allows these films to be grown epitaxially. The comparison of theory with experiment would therefore be simplified and fruitful to understand the underlying mechanisms that contribute to SOTs in thin films. Taking the system at hand as an example, we also compute the values of the thermal spin-orbit torque (T-SOT). We predict that the gradients of temperature that can be experimentally created in this type of systems will cause a detectable torque on the magnetization.

We gratefully acknowledge funding under the HGF-YIG programme VH-NG-513 and SPP 1538 of DPG.

[1] G. Géranton, F. Freimuth, S. Blügel, Y. Mokrousov (2014), arXiv:1409.1767

[2] F. Freimuth, S. Blügel, Y. Mokrousov, PRB **90**, 174423 (2014)

MA 9.10 Mon 18:00 H 0112

Current-induced spin torque resonance of a magnetic insulator — •Michael Schreier[1,2], Takahiro Chiba[3], Arthur Niedermayr[1,2], Johannes Lotze[1,2], Hans Huebl[1,4], Stephan Geprägs[1], Saburo Takahashi[3], Gerrit E. W. Bauer[3,5,6], Rudolf Gross[1,2,4], and Sebastian T. B. Goennenwein[1,4] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, DE — [2]Physik-Department, TU München, Garching, DE — [3]Institute for Materials Research, Tohoku University, Sendai, JP — [4]Nanosystems Initiative Munich, DE — [5]WPI Advanced Institute for Materials Research, Tohoku University, Sendai, JP — [6]Kavli Institute of NanoScience, Delft University of Technology, Delft, NL

We report the observation of spin transfer torque induced ferromagnetic resonance in the ferromagnetic insulator yttrium iron garnet (YIG). An alternating current at gigahertz frequencies in the Pt layer of a YIG/Pt sample generates Oersted and effective anti damping (spin transfer) torque fields inducing ferromagnetic resonance in the YIG. This can be observed as DC spin pumping and spin Hall magnetoresistance rectification voltages. To disentangle the two excitation and detection processes we investigate YIG layers of different thickness, which impacts the magnitude of the effective damping torque field. In ultrathin yttrium iron garnet films the magnitude of the spin transfer torque actuated magnetization dynamics is substantially enhanced and dominates that generated by the Oersted field. We discuss the determination of spurious effects and present a quantitative analysis. Support by the DFG through SPP1538 is gratefully acknowledged.

MA 9.11 Mon 18:15 H 0112

Magnetic excitations in Co films on Ir(001) and Rh(001) substrates: The role of interfacial electronic hybridization — •Ying-Jiun Chen[1], Khalil Zakeri Lori[1], Arthur Ernst[1], Huajun Qin[1], Tzu-Hung Chuang[1], Yang Meng[1], and Jürgen Kirschner[1,2] — [1]Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, 06120 Halle, Germany — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06120 Halle, Germany

The hybridization between the electronic states of an ultrathin magnetic film and the substrate is a notable effect, which modifies the magnetic properties of the film. In order to address this effect we have investigated the magnetic properties and high-energy magnetic excitations in ultrathin Co films, with a thickness of 1-2 monolayer (ML), grown on Ir(001) and Rh(001). The magneto-optical Kerr effect measurements revealed that the magnetic easy axis for both systems is lying in the film plane. It was found that the in-plane magnetic anisotropy energy of the Co films grown on the Ir(001) surface is rather large, compared to the one of the Co films on Rh(001). The high-energy magnetic excitations were investigated by means of spin-polarized electron energy loss spectroscopy. It was observed that the magnon dispersion relation for both Co/Ir(001) and Co/Rh(001) systems is nearly the same. Combined with first-principles calculations, we discuss how the interfacial hybridization of the Co_{3d}-Ir_{5d} and Co_{3d}-Rh_{4d} electronic states influences the magnetic anisotropy energy and high-energy magnetic excitations in these systems.

MA 9.12 Mon 18:30 H 0112

Vortex Core Motion driven by Thermal Spin Transfer Torque — •Michael Vogel[1], Jean-Yves Chauleau[1], Claudia Mewes[2], Tim Mewes[2], and Christian Back[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Regensburg, Germany — [2]MINT Center / Depeartment of Physics and Astronomy, University of Alabama, Tuscaloosa, AL, USA

The dynamical properties of spin caloric devices play a key role in their design and functionality. Especially the estimation of the required temperature gradients is essential for a successful development of new spin caloritronic applications and experiments. We report on theoretical investigations of magnetic vortex motion driven by thermal spin transfer torque for static and time dependent temperature gradients. The magnetization dynamic of the vortex core is well described by the Landau-Lifshitz-Gilbert equation including the adiabatic and non-adiabatic spin transfer torque term [S. Zhang and Z. Li, Phys. Rev. Lett 93, 127204 (2004)]. Using the Onsager relations within a three current model [S.D. Brechet, and J.-P. Ansermet, Phys. Status Solidi RRL 5, No. 12, 423*425 (2011); K.M.D. Hals, A. Brataas, and G.E.W. Bauer, Solid State Com. 150, 461465 (2010)] one can write the involved current density as a spin polarization factor times a current density derived from the temperature gradient which is determined by experimental measurements in combination with finite element calculations. We report on the dynamic behavior of such systems and the importance of the interplay of the spatial and temporal shape of the heat gradient in combination with the geometry of the magnetic structure.