MA 7: Spin-Dynamics/ Spin-Torque II

Time: Monday 15:15–19:15 Location: HSZ 04

MA 7.1 Mon 15:15 HSZ 04

Phase-locking of dc current-driven vortex motion to an external signal — •Ronald Lehndorff[1,2], Daniel E. Bürgler[1], Zbigniew J. Celinski[2], and Claus M. Schneider[1] — [1]Institut für Festkörperforschung und JARA-FIT, Forschungszentrum Jülich GmbH, D-52425 Jülich — [2]Center for Magnetism and Magnetic Nanostructures, University of Colorado at Colorado Springs, CO, USA

The dynamics of magnetic vortices under the influence of magnetic fields and spin-transfer torque has recently been of great interest [1,2]. The gyrotropic motion of vortices, which is their lowest excitation mode, enables the realization of vortex-based spin-torque oscillators [3].

We study the vortex dynamics in nanopillars made of 20nm Fe/6nm Ag/2nm Fe. The 20nm thick Fe layer is structured to a circular disk of 230nm diameter. Due to its size and shape it can hold a magnetic vortex or an onion state. We excite both magnetic structures by dc currents and show that the vortex state is advantageous for the operation of a spin-torque oscillator. Additionally, we study the coupling of the vortex' dynamic mode to externally applied electric hf signals of different frequencies and amplitudes. The observed phase-locking is a prerequisite to achieve sufficient output power for applications since it enables the coupling of a large number of spin-torque oscillators.

[1] B. van Waeyenberge, et al., Nature 444, 461 (2006) [2] R. Hertel, et al., Phys. Rev. Lett. 98, 117201 (2007) [3] V.S. Pribiag, et al., Nature 438, 339 (2005)

MA 7.2 Mon 15:30 HSZ 04

Current-induced magnetization dynamics in single magnetic-layer nanopillars — •Sarah Fahrendorf[1,3], Nicolas Müsgens[1,3], Marc Weidenbach[1,3], Matthias Bückins[2,3], Joachim Mayer[2,3], Bernd Beschoten[1,3], and Gernot Güntherodt[1,3] — [1]Physics Institute IIA, RWTH Aachen University, Aachen, Germany — [2]Central Facility for Electron Microscopy, RWTH Aachen University, Aachen, Germany — [3]JARA-Fundamentals of Future Information Technology

The current-induced generation of spin waves in Cu/Co/Cu single magnetic-layer nanopillar devices with asymmetric Cu leads is investigated by means of transport and microwave probes at room temperature. The magnetic field is applied perpendicular to the Co layer. Molecular beam epitaxy is used to deposit the thin film stack in prefabricated nanostencil masks with lateral dimensions below 100 nm. Magneto-transport measurements show peaks and dips in the differential resistance for high negative current densities $j < -2 \cdot 10^8$ A/cm^2 and external magnetic fields above |1.5 kOe|. (Negative current is defined as electron flow from the thin to the thick copper layer.) These nonhysteretic features are due to a continuous change of resistance and can be correlated with measured spin wave excitations. At low fields we measure excitation frequencies which decrease with increasing absolute current, whereas the opposite dependence is found at higher fields.

Work supported by DFG through SPP1133

MA 7.3 Mon 15:45 HSZ 04

Influence of lead material on spin-transfer torque in MgO based tunnel junctions — •Christian Heiliger[1], Asma H. Khalil[1], and Mark D. Stiles[2] — [1]I. Physikalisches Institut, Justus Liebig University Giessen, D-35392, Germany — [2]Center for Nanoscale Science and Technology, National Institute of Standards and Technology, Gaithersburg, MD 20899-6202, USA

We report calculations of the spin-transfer torque in MgO based tunnel junctions using a non-equilibrium Keldysh formalism implemented in the Korringa-Kohn-Rostoker Green's function method [1]. Our calculations for Fe/MgO/Fe tunnel junctions show excellent quantitative agreement of the voltage dependence with experimental observation [2]. In this talk we discuss the influence of other lead materials on the bias dependence of the spin-transfer torque. We show the importance of the Δ_1 band gap in the ferromagnetic materials. In particular, the bias dependence of the spin-transfer torque is changed drastically if the applied bias voltage is larger than the Δ_1 band gap. This work has been supported in part by the NIST-CNST/UMD-NanoCenter Cooperative Agreement.

[1] C. Heiliger, M. Czerner, B. Yu. Yavorsky, I. Mertig, M. D. Stiles, J. Appl. Phys. **103**, 07A709 (2008)
[2] C. Heiliger and M.D. Stiles, Phys. Rev. Lett. **100**, 186805 (2008)

MA 7.4 Mon 16:00 HSZ 04

Impact of lateral size of nanopillars on spin wave spectra in magnetic tunnel junctions — •Annerose Helmer[1], Sven Cornelissen[2,3], Thibaut Devolder[1], Joo-Von Kim[1], Paul Crozat[1], Maaike Op de Beeck[2], Liesbet Lagae[2,4], and Claude Chappert[1] — [1]Institut d´ Electronique Fondamentale, CNRS UMR 8622, Bât. 220, Université Paris-Sud 11, 91405 Orsay, France — [2]IMEC, NextNS, Kapeldreef 75, 3001 Leuven, Belgium — [3]ESAT, KU Leuven, Leuven, Belgium — [4]Natuurkunde en Sterrenkunde, KU Leuven, Leuven, Belgium

As dynamic eigenexcitations of a magnetic system, thermally excited spin waves constitute an excellent probe for the intrinsic magnetic properties of nanopillar devices, such as MRAM. In particular, they provide information on the spatial orientation of the magnetization in the different layers of the pillar. We have studied spin wave spectra (mode frequency versus magnetic field) in rectangular shaped nanopillars of lateral dimensions 50 x 100, 75 x 140, and 100 x 200 nm2, patterned from MgO-based magnetic tunnel junctions, which were deposited at Singulus Technologies AG. The devices were subjected to inplane magnetic fields either along the long edge (easy axis) or the short edge (hard axis) of the rectangle. For both field directions the spectra become more complex with larger lateral pillar sizes: the number of modes increases, their relative intensity changes, while the spectra become progressively deformed - phenomena, which can be explained by the formation of edge domains. Moreover, there is clear evidence that not even for the smallest pillar size the magnetization is uniform.

MA 7.5 Mon 16:15 HSZ 04

Spin-torque shot noise — •Jacek Swiebodzinski[1], Alexander L. Chudnovskiy[1], and Alex Kamenev[2] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Jungiusstraße 9, D-20355 Hamburg, Germany — [2]Department of Physics, University of Minnesota, Minneapolis, Minnesota 55455, USA

The role of spin shot noise in magnetization dynamics, though being the dominant contribution to magnetization noise at low temperatures, remains largely unexplored yet. We propose a stochastic version of the Landau-Lifshitz-Gilbert equation taking into account both, thermal and nonequilibrium sources of noise and apply this equation to a system consisting of a free ferromagnetic layer in contact with a fixed ferromagnet. We derive the noise correlator in the magnetic tunnel junction setup using the Keldysh technique. We solve the corresponding Fokker-Planck equations and show that the spin shot noise yields to the experimentally observed nonmonotonic dependence of the precession spectrum linewidth on the current.

MA 7.6 Mon 16:30 HSZ 04

Influence of microwave irradiation on the spin current induced precession — •Nathalie Reckers[1], Julien Cucchiara[2], Stéphane Mangin[2], Ralf Meckenstock[1], Horst Zähres[1], Günter Dumpich[1], and Jürgen Lindner[1] — [1]Universität Duisburg-Essen, Standort Duisburg, Institut für Physik und CeNIDE, AG-Farle, Lotharstr. 1, 47048 Duisburg, Germany — [2]Nancy-Université, Laboratoire de Physique des Matériaux, CNRS, Boîte Postal 239, 54506 Vandoeuvre les Nancy, France

Nano-structured magnetic pillars composed of multi-layers containing a free layer and a fixed layer are investigated for their magnetoresistance behaviour. Measurements were conducted using a fixed alternating current in the μA range and a variable direct current in the mA range. The measurements can be esplained in the framework of spin-torque effects. For high direct currents a precession of the magnetization is observed. By increasing the direct current the range of the precession is shifted to higher magnetic fields. Moreover, the influence of an irradiated microwave in the GHz-range on the precession is investigated. For this purpose a fixed direct current is chosen while the microwave frequency is varied.

MA 7.7 Mon 16:45 HSZ 04

Spin transfer torque in pillar arrays investigated by ferromagnetic resonance — •Oliver Posth, Günter Dumpich, and Jürgen

Lindner — Fachbereich Physik, Experimentalphysik, AG Farle, Universität Duisburg-Essen, 47048 Duisburg, Germany

It is well known from other studies that a spin polarized current in a ferromagnet exerts a torque on the magnetic moments by spin-momentum transfer. This current can be used to switch the magnetization of one ferromagnetic layer in a ferromagnetic metal / nonmagnetic metal / ferromagnetic metal spin valve device. We investigate the influence of the spin polarized current on the damping in the ferromagnetic layers of the pillar structures directly by means of ferromagnetic resonance (FMR). The pillars are prepared and electrically contacted by high-resolution electron beam lithography (HR-EBL) and electron beam evaporation in a multi-step process. The FMR measurements are carried out on a pillar array, in which all pillars are connected in series, so that we are able to increase the current density to a value being sufficient to observe the effect of the spin transfer torque. The temperature rise due to high current density is avoided by a cooling set-up. An influence of the spin torque effect on the intrinsic damping in the ferromagnet can be observed for in plane orientation as well for out of plane orientation of the magnetic field. The influence of the Oersted-field is estimated in addition. We further investigate the domain structure of the pillars in an applied field by means of micromagnetic calculations. This work is supported by the Deutsche Forschungsgemeinschaft within SFB 491.

MA 7.8 Mon 17:00 HSZ 04

Light-controlled spin switch in linear metallic chains — •Tobias Hartenstein, Georgios Lefkidis, and Wolfgang Hübner — Department of Physics and Research Center OPTIMAS, Kaiserslautern University of Technology, PO Box 3049, 67653 Kaiserslautern, Germany

We present an ab initio theory for ultrafast spin dynamics in highly correlated materials [1], which includes the spin-orbit interaction and the interaction with external magnetic fields. In particular we analyze optically induced spin-switch processes in linear metallic chains with a magnetic center at each end; in particular Fe, Co or Ni atoms separated by Na atoms. The electronic structure of the ground and excited states of these clusters is determined using high-level quantum chemistry methods. We show that the spin density for low-lying triplet states is located at one magnetic center only. Through the influence of a laser pulse, transitions between different many-particle states are induced and local spin-switch processes can take place. For the purpose of ultrafast magnetic switching, we consider Λ-processes with laser pulses optimized by a genetic algorithm [2]. It is shown that local spin switch due to optical electron excitation can occur on a subpicosecond time scale [3].

[1] G. Lefkidis and W. Hübner Phys. Rev. B 76 014418 (2007)
[2] T. Hartenstein, C. Li, G. Lefkidis and W. Hübner J. Phys. D: Appl. Phys. 41 164006 (2008)
[3] T. Hartenstein, G. Lefkidis and W. Hübner J. Phys. D: Appl. Phys. (in press)

15 min. break

MA 7.9 Mon 17:30 HSZ 04

Coherent switching of the vortex core polarization by monopolar magnetic field pulses — •Markus Weigand[1], Michael Curcic[1], Bartel Van Waeyenberge[1], Arne Vansteenkiste[3], Vitalij Sackmann[1], Hermann Stoll[1], Tolek Tyliszczak[2], Georg Woltersdof[4], Christian Back[4], and Gisela Schütz[1] — [1]MPI f. Metallforschung, Stuttgart — [2]ALS, Berkeley, USA — [3]Ghent University, Belgium — [4]Uni. Regensburg

Time-resolved imaging of vortex core reversal in 500nm large Permalloy Landau structures has been achieved by 'pump-and-probe' measurements at a scanning-transmission X-ray microscopy (STXM), combining <100 ps and ~30 nm time and lateral resolution. A fast data aquisition system recorded up to 1000 time frames simultaneously, capturing the entire excitation and relaxation cycle of the vortex core.

The vortex polarization could be switched by in-plane monopolar magnetic pulses as low as 5-15mT, depending on sample geometry. This was achieved by taking advantage of a 'resonance timing' of the rising and falling pulse edges of the excitation field pulse: Provided a correct adjustment of the pulse length, the vortex is accelerated by the rising edge as well as by the falling edge, causing a doubling of the gyration amplitude. When a critical velocity is reached, the vortex core switches.

The excitation and relaxation sequences as shown in our movies and the measured switching thresholds agree well with micromagnetic simulations. Applications for current (spin torque) induced vortex core reversal will be addressed, too.

MA 7.10 Mon 17:45 HSZ 04

A Current Controlled Random-Access Memory Based On Magnetic Vortex Handedness — •Stellan Bohlens[1], Benjamin Krüger[1], André Drews[2], Markus Bolte[2], Guido Meier[2], Ulrich Merkt[2], and Daniela Pfannkuche[1] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Hamburg, Germany — [2]Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg, Hamburg, Germany

We propose a memory element based on a magnetic vortex which is operated simultaneously by a spin-polarized current and a magnetic field. [1] Starting from our recent analytical description of the vortex motion [2,3] we have developed a scheme that allows to transfer the vortex into an unambiguous binary state. This state is defined as the product of chirality and core polarization named the vortex handedness.

The VRAM is non-volatile and the stability requirements for a memory device are fulfilled: the vortex state is stable against temperature and static magnetic fields as long as they remain in the millitesla regime. Foremost, the VRAM is a fast memory concept which needs no reading and no erasing before writing.

[1] S. Bohlens, et al., Appl. Phys. Lett. 93, 142508 (2008)
[2] M. Bolte, et al., Phys. Rev. Lett. 100, 176601 (2008)
[3] B. Krüger, et al., Phys. Rev. B 76, 224426 (2007)

MA 7.11 Mon 18:00 HSZ 04

electrical switching of the magnetic vortex core polarities in a magnetic circular disk — •June-Seo Kim[1], Olivier Boulle[1], Steven Verstoep[1], Mathias Kläui[1], Ulrich Rüdiger[1], and Giancarlo Faini[2] — [1]Fachbereich Physik, Universität Konstanz, Universitätsstr. 10, D-78457 Konstanz, Germany — [2]Phynano team, LPN, Route de Nozay, 91460 Marcoussis, France

The recent discovery that a spin-polarized current can induce magnetization dynamics (DW) without an applied magnetic field has created interest in field-induced oscillations of confined spin structures. Especially, a vortex domain wall in a nanowire pinned at an artificial notch can be driven into large amplitude vortex core oscillations by a high frequency alternative current for very low current density (~109 A/m2) [1]. Here, we have observed the resonance of a single magnetic vortex core in an asymmetric Py disk, which allows a better control of the energy landscape felt by the magnetic vortex core. We have measured variations of the dc voltage (homodyne detection) for some particular resonance frequencies that indicate the resonance excitation of the vortex. The shape of the DC voltage vs. frequency curve can be determined by the relative polarities (pointing up and down) of the vortex. Moreover, the eigen-frequencies of the magnetic vortex cores are changed as a function of the amplitudes and angles of applied fields from which the 3D potential landscape can be ascertained. This work is supported by the EU-RTNs SPINSWITCH (MRTN-CT-2006-035327). [1] D. Bedau, M. Kläui et al., Phys. Rev. Lett. 99, 146601 (2007); Phys. Rev. Lett. 101 (in press 2008)

MA 7.12 Mon 18:15 HSZ 04

Polarization selective switching of magnetic vortices with rotating currents — •Michael Martens[1], Thomas Kamionka[1], Markus Bolte[1], Benjamin Krüger[2], Kang Wei Chou[3], Tolek Tyliszczak[3], Michael Curcic[4], Bartel Van Waeyenberge[4], Hermann Stoll[4], and Guido Meier[1] — [1]Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg, Germany — [2]I. Institut für Theoretische Physik, Universität Hamburg, Germany — [3]Advanced Light Source, LBNL, Berkeley, CA, USA — [4]Max-Planck-Institut für Metallforschung, Stuttgart, Germany

Magnetic vortices in micron-sized disks and squares are interesting objects of research for understanding fundamental field- and current-induced magnetization dynamics and offer new concepts for data storage devices. The selective switching of the vortex-core polarization, i.e the out-of-plane component of the magnetization, by resonant excitation has been shown both theoretically [1] and experimentally [2]. Here we present our experiments on polarization reversal using rotating currents through a permalloy square. The frequency and power dependent excitation is measured systematically by means of time-resolved scanning transmission X-Ray microscopy (STXM). The phase of the gyration with respect to the exciting current yields information about the Oersted-field and the spin-torque driven contribution to the excitation.

In addition we found experimental confirmation of halo-formation near the switching threshold.

[1] S. K. Kim et al., Appl. Phys. Lett. **92**, 022509 (2008).
[2] M. Curcic et al., Phys. Rev. Lett. **101**, 197204 (2008).

MA 7.13 Mon 18:30 HSZ 04

Spin wave mode spectra of continuous and structured amorphous CoFeB films — •Henning Ulrichs, Jakob Walowski, Andreas Mann, Benjamin Lenk, Gerrit Eilers, and Markus Münzenberg — I. Physikalisches Institut, Universität Göttingen

Magnetization dynamics within the GHz-range in amorphous CoFeB thin-films are investigated using all optical pump probe experiments. After a fs-laser pulse excites the film, a second time delayed pulse is utilized to record the time dependent magnetization curve M(t) exploiting the time-resolved magneto-optical Kerr effect (TRMOKE). As an experimental variable a bias magnetic field 0mT$\leq \mu_0$H $\leq$ 150mT in an angle to the samples surface between 0° and 30° is applied. From Fourier transformations mode spectra ω(H) are obtained. By comparison with theoretical dispersion curves different spin wave modes are identified. In the thinnest films (5nm to 25nm) only uniform precession is found. From the magnetization curves of the 25nm sample a very low Landau-Lifshitz-Gilbert damping factor of $\alpha \approx$0.006 is extracted. For thicker films (50nm to 225nm) also Damon-Eshbach modes and perpendicular standing spin waves can be seen. In a second step we structured the surface of a 125nm CoFeB film with a focused ion beam. Two-dimensional cubic lattices of holes having a diameter of 5μm and a lattice constant between 15 and 23μm were fabricated. The distances were chosen close to the wave length of the propagating DE modes. The mode spectra of the structured regions are significantly altered, indicating Blochstates of DE waves forming due to the periodic potential. Research is supported by DFG Schwerpunkt SPP 1133.

MA 7.14 Mon 18:45 HSZ 04

Local control of ultra fast dynamics in magnetic nanoparticles — •Alexander Sukhov[1,2] and Jamal Berakdar[2] — [1]Max-Planck-Institut für Mikrostrukturphysik, Halle/Saale — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Halle/Saale

Using the local control theory [1] and the Landau-Lifshitz-Gilbert equation of magnetization motion for a Stoner nanoparticle we deduce analytical expressions for ultra short magnetic pulses that steer the magnetization to a predefined state. Additionally, we obtain conditions for a monotonic positive change of the polar angle providing thus a magnetization switching. Minimal field amplitudes of the pulses needed for switching upon the polar angle for two angle shifts between the magnetization and the field are achieved. Numerical implementation of the Landau-Lifshitz-Gilbert equation extended for finite temperatures allows for more freedom in variation of pulse form, duration and anisotropy types and approves/supplements the analytical results.

[1] R. Kosloff, A. D. Hammerich and D. J. Tannor, Phys. Rev. Lett. **69**, 2172 (1992).

MA 7.15 Mon 19:00 HSZ 04

Investigating the Spin Dynamics in Nanostructures at Finite Temperature — •David Bauer, Samir Lounis, Phivos Mavropoulos, and Stefan Bluegel — Institut für Festkörperforschung and Institute for Advanced Simulation, Forschungszentrum Jülich, D-52425 Jülich, Germany

Magnetic nanoparticles are promising candidates for future information storage. We developed a spin dynamics code and investigated the dynamics of the magnetization in nanoscale systems on the basis of a classical spin model including Heisenberg exchange, magnetic anisotropy, external magnetic fields and dipole-dipole interaction. The spin-system is coupled to a heatbath through a stochastic force within the Langevin approach [1]. This requires the solution of the stochastic Landau-Lifschitz equations. Thermodynamical properties are shown to be in excellent agreement to those obtained by Monte Carlo simulations. The complexity $\mathcal{O}(n^2)$ of the direct evaluation of the dipolar interaction was reduced to $\mathcal{O}(n \log n)$ by the use of multipole methods. Preliminary results are presented on the switching time of different sized nano-islands which are in agreement to the Arrhenius-Néel-law. This work was supported by the ESF EUROCORES Programme SONS under contract N. ERAS-CT-2003-980409 and the Priority Programme SPP1153 of the DFG grant Bl 444/8-1.

[1] V. P. Antropov, S. V. Tretyakov, and B. N. Harmon, J. Appl. Phys. **81**, 3961 (1997).