MA 19: Spin Dynamics / Spin Torque I

Time: Wednesday 14:00–18:45 Location: EB 301

MA 19.1 Wed 14:00 EB 301

Current-induced magnetization switching of thermally stable nanoislands — •Stefan Krause[1], Gabriela Herzog[1], Roland Wiesendanger[1], and Matthias Bode[2] — [1]Institute of Applied Physics, University of Hamburg, Germany — [2]Center for Nanoscale Materials, Argonne National Laboratory, USA

Recently is has been shown that spin-polarized scanning tunneling microscopy (SP-STM) serves as a tool to manipulate the switching behavior of uniaxial superparamagnetic nanoislands [1]. Besides its scientific relevance to investigate the details of current-induced magnetization switching (CIMS), this technique opens perspectives for future data storage technologies based on SP-STM. However, for such an application it is essential to switch nanoislands which show a stable magnetization over up to ten years. Hence, the current-induced spin-torque must be the only driving force for reversal, whereas the magnetization of every single data bit has to be stable against thermal agitation.

Iron monolayer nanoislands consisting of 50 to 150 atoms on a W(110) surface exhibit a monodomain magnetization state. In our latest experiments on CIMS at low temperature ($T = 31\,\mathrm{K}$), individual quasistable nanoislands have been addressed and switched using a magnetic SP-STM tip. Using manually initiated pulses of high spin-polarized current we show how SP-STM can be used as a tool to switch the magnetization of quasistable magnetic nanoislands, thereby demonstrating the general capability of SP-STM to manipulate magnetism at ultimate resolution.

[1] S. Krause *et al.*, Science **317**, 1537 (2007).

MA 19.2 Wed 14:15 EB 301

Influence of Fe thickness on spin transfer torque in Fe/MgO/Fe — •Christian Heiliger[1,2] and Mark D. Stiles[1] — [1]Center for Nanoscale Science and Technology, National Institute of Standards and Technology, Gaithersburg, MD 20899-6202 — [2]Maryland NanoCenter, University of Maryland, College Park, MD, 20742

We report calculations of the spin transfer torque in Fe/MgO/Fe tunnel junctions using a non-equilibrium Keldysh formalism implemented in the Korringa-Kohn-Rostoker Green's function method [1]. For the coherent interfaces achievable for this lattice matched system, the Fe layers are half metallic with respect to the Δ_1 states at the Brillouin zone center. This property causes the high tunnelling magnetoresistance measured in Fe/MgO/Fe tunnel junctions [2]. Our calculations show that it also leads to strong localization of the spin transfer torque to the interface. Due to the restriction of the spin transfer torque to the interface, the in-plane torque per current is independent of the Fe layer thickness for more than three monolayers of Fe. 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. (in press); arXiv:0711.2082.

[2] C. Heiliger, P. Zahn, I. Mertig, Materials Today 9, 46 (2006).

MA 19.3 Wed 14:30 EB 301

Spin-torque driven excitations in strongly antiferromagnetically coupled Co/Cu/Co bilayer nanostructures. — •Eva Maynicke[1], Marc Weidenbach[1], Nicolas Müsgens[1], Coen Smits[1], Bernd Beschoten[1], Matthias Bückins[2], Joachim Mayer[2], and Gernot Güntherot[1] — [1]II Physikalisches Institut A, RWTH Aachen, 52056 Aachen, and Virtual Institute for Spinelectronics (VISel) — [2]Gemeinschaftslabor für Elektronenmikroskopie, RWTH Aachen, 52065 Aachen

We investigate the current-induced switching behaviour and high frequency dynamics in MBE grown Co/Cu/Co nanopillars with lateral dimensions below 100 nm by means of transport and microwave probes at room temperature.

In contrast to previous studies we observe a two-step magnetic reversal in field-sweep measurements at low current densities with an intermediate stable state between parallel and antiparallel alignment. The intermediate state is most stable in samples with strong antiferromagnetic coupling between both Co layers as tested by systematic variations of the Cu spacer layer thickness.

Near the critical field for magnetic switching into this intermediate state we observe pronounced dips in the differential resistance at negative currents. In this regime we detect microwave emission with broad spectral features extending from 50 MHz to 4 GHz. Surprisingly, there is no frequency shift with current or magnetic field.

Work supported by DFG through SPP1133.

MA 19.4 Wed 14:45 EB 301

Spin-current induced magnetic excitations in single magnetic layer nanopillars — •Marc Weidenbach[1], Eva Maynicke[1], Nicolas Müsgens[1], Coen Smits[1], Bernd Beschoten[1], Matthias Bückins[2], Joachim Mayer[2], and Gernot Güntherodt[1] — [1]II Physikalisches Institut A, RWTH Aachen, 52056 Aachen, and Virtual Institute for Spinelectronics (VISel) — [2]Gemeinschaftslabor für Elektronenmikroskopie, RWTH Aachen, 52065 Aachen

We investigate current-induced spin-wave excitations in Cu/Co/Cu single magnetic layer nanopillar devices with asymmetric Cu leads by means of transport and microwave probes at room temperature.

The thin film stack is deposited by MBE in prefabricated nanostencil masks with lateral dimensions below 100 nm. At high current densities we observe narrow excitations (bandwidth $\sim$ 100 MHz) and higher harmonics for magnetic fields perpendicular to the layers. The frequency increases with increasing current and magnetic field, which indicates an out-of plane precessional mode as found in bilayer systems (e.g., Kiselev et al., PRL 93, 036601(2004)).

Furthermore we observe frequency jumps as a function of both current and magnetic field, which might originate from transitions between different localized nonlinear spin-wave modes.

Work supported by DFG through SPP1133.

MA 19.5 Wed 15:00 EB 301

Investigation of spin-wave radiation and current controlled three-magnon-scattering in spin-torque nanocontact devices — •Helmut Schultheiss[1], Xavier Janssens[2], Sven Cornelissen[2], Maarten van Kampen[2], Sebastian Hermsdörfer[1], Britta Leven[1], Andrei N. Slavin[3], Liesbet Lagae[2], and Burkard Hillebrands[1] — [1]Fachbereich Physik and FSP MINAS, TU Kaiserslautern, 67663 Kaiserslautern, Germany — [2]IMEC, Kapeldreef 75, Leuven, Belgium — [3]Oakland University, Rochester, Michigan, USA

The magnetization dynamics of spin torque oscillators are of large interest for the fundamental understanding of the interaction between a spin polarized current and a magnetic thin film. Here we report on Brillouin light scattering microscopy investigations of the magnetization dynamics in spin-torque nanocontacts under the influence of an applied ac and dc current. The spin-wave radiation patterns are studied for several applied microwave frequencies. Strong nonlinear effects are observed and discussed within the framework of three-magnon-scattering. Intriguing is the shift of the power threshold for these nonlinear processes when a dc current is applied. Depending on the dc current direction the threshold and efficiency of the three-magnon-scattering can be strongly enhanced or reduced. This is a clear evidence that the internal damping due to magnon scattering can be tuned by a dc current. Support by the DFG within the SPP 1133 and by the EC-MRTN SPINSWITCH (MRTN-CT-2006-035327) and EC-Dynamax (IST-033749) is acknowledged. MvK acknowledges the IWT Flanders for financial support.

MA 19.6 Wed 15:15 EB 301

Real-time soft X-ray microscopy of current-induced domain-wall oscillations — •Lars Bocklage[1], René Eiselt[1], Markus Bolte[1], Benjamin Krüger[2], Peter Fischer[3], Ulrich Merkt[1], and Guido Meier[1] — [1]Institut für Angewandte Physik, Universität Hamburg — [2]I. Institut für Theoretische Physik, Universität Hamburg — [3]Center for X-Ray Optics, LBNL, USA

Novel concepts for high density and ultrafast magnetic storage devices suggest domain walls (DW) or vortices in nanostructures to store information. Spin-polarized currents exerting a torque on the local magnetization can move these magnetization configurations [1,2]. Magnetic soft X-ray microscopy allows to image changes in the DW structures upon spin current injection with a spatial resolution down to 15 nm [3]. Spin dynamics can be imaged by a stroboscopic pump-probe measurement scheme at a temporal resolution below 100 ps. We have prepared vortex DWs in a restoring potential in permalloy nanostructures and displaced the vortex from its equilibrium position by injecting nanosec-

ond current pulses. The displacement holds while the pulse is applied, afterwards the DW starts a free oscillation with strong damping. The frequency, the damping constant, and the confining potential of our samples is calculated within a harmonic oscillator model.
This work was supported by the DPG via SFB 668 and GRK 1286 as well as by the DOE via Contract No. DE-AC02-05-CH11231.
[1] S. Zhang and Z. Li, Phys. Rev. Lett. 93, 127204 (2004).
[2] G. Meier et al., Phys. Rev. Lett. 98, 187202 (2007).
[3] D. H. Kim et al., J. Appl. Phys. 99, 08H303 (2006).

MA 19.7 Wed 15:30 EB 301

Homodyne Detection of Domain Wall Oscillations — Daniel Bedau[1], Mathias Klaeui[1], Stefan Krzyk[1], •Katarzyna Buchta[1], Ulrich Ruediger[1], G. Faini[2], and L. Vila[2] — [1]Department of Physics, University of Konstanz, Germany — [2]CNRS, Phynano Team, Laboratoire de Photonique et de Nanostructures, Route de Nozay, France

Laterally confined magnetic domain walls behave like quasiparticles moving in an external potential well created by a mechanical constriction or a pinning defect. Spin torque effects allow to displace the domain wall quasiparticle electrically, by injecting an ac current the domain can be excited to resonate inside the potential well. As the domain wall oscillates, the resistance of the magnetic structure is modulated due to the anisotropic magnetoresistance in phase with the domain wall position. If the quasiparticle happens to be excited at the resonance frequency, the varying resistance will rectify the injected high frequency current and a DC voltage is developed across the structure. Using this technique we determined the resonance frequency of the domain wall. At resonance we observed a reduction of the depinning field of the domain wall for currents as low as 2×10^{10} A/m^2, allowing us to determine the resonance frequency by a second method. The domain wall resonance frequency was measured for different external magnetic fields and was found to be proportional to the external field. By measuring the mean value of the resistance during excitation we identified the oscillation of the domain wall to be confined close to the potential minimum without a large-scale displacement.

MA 19.8 Wed 15:45 EB 301

Direct observation of the Walker breakdown process during domain wall (dw) propagation in Permalloy nanowires — •Sascha Glathe and Roland Mattheis — IPHTJena e.V., A.-Einstein-Str.9, D-07745 Jena

The Walker breakdown process determines the field driven dw movement in nanowires above a critical magnetic field Hw. Until now there are only some simulations adressing this process, mainly in ideal structures. An adequate experimental verification is not offered yet.

We explored the dw propagation in 150 nm wide, 15 nm thick permalloy films, which are the sense layer of GMR stacks. The dw movement was examined due to time resolved measurements of GMR stack resistance. During the dw motion we find periods of steady dw movement and periods where the dw stops. These time domains are in the order of some ns and are repeated alternately. We attribute this behaviour of the dw to the Walker breakdown process. Thus we provided a direct experimental evidence of the Walker breakdown process.

MA 19.9 Wed 16:00 EB 301

Spin waves in curved $Ni_{81}Fe_{19}$ nanowires in the presence of domain walls — •Christian W. Sandweg, Sebastian J. Hermsdörfer, Helmut Schultheiss, P.Andreas Beck, Britta Leven, and Burkard Hillebrands — FB Physik and FSP MINAS, TU Kaiserslautern, Erwin-Schrödinger-Str. 56, 67663 Kaiserslautern, Germany

We present a study of spin-wave properties in curved $Ni_{81}Fe_{19}$ nanowires in the presence of domain walls. The spin-wave spectra are detected with a lateral resolution of 300 nm employing Brillouin light scattering microscopy. The elements are prepared using a combination of EBL and MBE. The structure dimensions are a radius of 10 μm, a width of 500 nm and a thickness of 10 nm. A protrusion with a radius of 250 nm acts as artificial domain wall pinning site. In the absence of a domain wall we observe typical spin wave quantization effects due to the lateral confinement in radial direction. In contrast, in the presence of a domain wall the quantized wave profile is distorted in the vicinity of the domain wall due to the variation of the internal magnetic field. The domain structure was investigated by Lorentz microscopy in collaboration with the group of John Chapman, Glasgow university. First results on artificially excited spin waves as well as their decay length in $Ni_{81}Fe_{19}$ are presented. Technical support by the Nano+Bio Center of the TU Kaiserslautern and financial support by the DFG within SPP1133, the EU-MRTN SPINSWITCH (MRTN-CT-2006-035327) and the NEDO grant No 2004IT093 is acknowledged.

15 Min. Session Break

MA 19.10 Wed 16:30 EB 301

Nanowires for high DC current applications — •Sebastian Hankemeier, Konrad Sachse, Yuliya Stark, Matthias Scholz, Germar Hoffmann, Robert Frömter, and Hans Peter Oepen — Universität Hamburg, Germany

For a more detailed investigation of current induced domain wall movement in nanowires by spin torque effect, it is essential to have maximum control of the external experimental parameters, i.e. the current density and the wire temperature. Additional, to study the forces that act on the walls, it is desirable to perform experiments with DC currents large enough to move the domain walls.

In this talk we present the realization of Permalloy nanowires which sustain current densities larger $4\cdot10^{12}A/m^2$. The wires are made from $20nm$ thick Permalloy, evaporated on diamond, with a width of $1\mu m$ and a length of $25\mu m$. While applying current densities beyond $10^{11}A/m^2$, we observe ohmic heating of the wires, which causes annealing effects. This effect can be used to improve the specific resistance of the wire near to the values of bulk material. The experiments are performed under HV conditions to prevent oxidation and cooling with liquid nitrogen is necessary for heat dissipation. The temperature of the wire, which depends on the applied current, has been evaluated utilizing the change in wire-resistance and estimated by heat transfer calculations.

MA 19.11 Wed 16:45 EB 301

Selective Vortex Core Switching by Applying Rotating Magnetic Fields — Michael Curcic[1], •Bartel Van Waeyenberge[1,2], Kang Wei Chou[1], Arne Vansteenkiste[2], Markus Weigand[1], Vitalij Sackmann[1], Aleksander Puzic[1], Hermann Stoll[1], Georg Woltersdorf[3], Tolek Tyliszczak[4], Christian H. Back[3], and Gisela Schütz[1] — [1]Max-Planck-Institut für Metallforschung, Stuttgart, Germany, — [2]Departement of Subatomic and Radiation Physics, Ghent University, Gent, Belgium — [3]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Regensburg, Germany — [4]Advanced Light Source, LBNL, Berkeley, USA

We report on the experimental observation of the switching of the vortex core polarization in sub-micron sized ferromagnetic Landau structures caused by rotating magnetic fields.

In contrast to linear field pulses which toggle the vortex core from its up to the down position or vice versa, rotating magnetic fields allow for a selective vortex core switching either to its up or to its down position depending on the sense of field rotation.

The experiments were performed on 500 nm wide, 50 nm thick Permalloy Landau structures. They were imaged by time-resolved scanning transmission X-ray microscopy (STXM, BL. 11.0.2, ALS Berkeley). Defined thresholds were observed for the field amplitudes needed to switch the vortex core. Surprisingly, the threshold for the CW rotating field and CCW rotating field differed significantly. Possible explanations for this 'symmetry breaking' will be discussed.

MA 19.12 Wed 17:00 EB 301

The influence of non centric holes on the magnetization dynamics of Landau structures — •Sebastian Wintz[1], Karsten Kuepper[1], Matthias Buess[2], Joerg Raabe[2], Christoph Quitmann[2], Chavkat Akhmadaliev[1], Lothar Bischoff[1], and Juergen Fassbender[1] — [1]FZ Dresden-Rossendorf, Bautzner Landstr. 128, D-01328 Dresden, Germany — [2]Swiss Light Source, Paul Scherrer Institut, CH-5232 Villigen, Switzerland

Magnetic vortex cores are attracted and can be trapped by artificial defects. If more than one of such defects are created a switching between different vortex core trapped states, which might serve as discrete levels in a multivalent memory device, can be achieved. Up to now a number of studies of circular vortex structures comprising holes has been reported, e. g. [1,2,3]. We report the imaging of the magnetic excitation spectrum in presence of holes, fabricated by focussed ion beam milling, in the magnetic domains and domain walls of Landau structures by means of x-ray magnetic circular dichroism photoemission electron microscopy (XMCD-PEEM). Due to the very high lateral and temporal resolution the magnetization dynamics and the corresponding Eigen modes, which are characteristic for the vortex-hole interaction, are investigated in detail. The experimental results are compared to micromagnetic simulations.

[1] M. Rahm et al., Appl. Phys. Lett. **85**, 1553 (2004).
[2] T. Uhlig et al., Phys. Rev. Lett. **95**, 237205 (2005).
[3] F. Hoffmann et al., Phys. Rev. B **76**, 014416 (2007).

MA 19.13 Wed 17:15 EB 301

Harmonic oscillator model for current and field-driven vortices and antivortices

— •Benjamin Krüger[1], André Drews[2], Markus Bolte[2], Ulrich Merkt[2], Daniela Pfannkuche[1], and Guido Meier[2] — [1]1. Institut für Theoretische Physik, Universität Hamburg, 20355 Hamburg, Germany — [2]Institut für Angewandte Physik, Universität Hamburg, 20355 Hamburg, Germany

We investigate the gyroscopic motion of current- and field-driven magnetic vortices and antivortices in micro- or nanostructured thin-film elements by analytical calculations and by micromagnetic simulations [1]. Starting from micromagnetic equations of motion we derive an analytical expression for the current- and Oersted-field driven trajectory of the vortex and antivortex. For small harmonic excitations the vortex and antivortex cores perform an elliptical rotation around their equilibrium positions. Our analytical model allows to calculate the amplitude and the phase of the current- and Oersted-field driven gyration. The global phase of the rotation and the ratio between the semi-axes are determined by the frequency and the amplitudes of the field and the spin torque. The accordance between analytical and numerical approaches is very good. Even though the influence of the Oersted field on the trajectories of a vortex or antivortex is small, the phase of the rotation is significantly changed. Thus, the model can give an estimate of the Oersted-field's contribution in spin-torque experiments.

[1] B. Krüger, A. Drews, M. Bolte, U. Merkt, D. Pfannkuche, and G. Meier, Phys. Rev. B, accepted.

MA 19.14 Wed 17:30 EB 301

Amplification and suppression of magnetic antivortex motion

— •André Drews[1], Stellan Bohlens[2], Benjamin Krüger[2], Markus Bolte[1], and Guido Meier[1] — [1]Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg — [2]I. Institut für Theoretische Physik, Universität Hamburg

We investigate numerically the response of an antivortex to excitation by alternating currents and magnetic fields using micromagnetic simulations. The phase between antivortex deflection and excitation in case of an electrical current depends on the polarization and in case of magnetic field additionally on the chirality. The chirality of an antivortex can be changed by a rotation of the sample with respect to the driving force. The dynamical characteristics of antivortices can be identified with a harmonic oscillator model as it has been recently shown for the vortex state theoretically as well as experimentally. Excitation in a superposition of an electrical current and a magnetic field can lead to an enhancement or to an entire suppression of the amplitude of the antivortex gyration. For example, for an antivortex with positive polarization an angle of 0 or π occurs between magnetic field and current excitation with chiralities $c = 0$ and $c = 2$, respectively. This leads in case of $c = 0$ to an enhancement and in case of $c = 2$ to a quenching of the gyration. In experiments this chirality-dependent amplitude of the gyration can be used to distinguish between current and Oersted field driven antivortex core motion.

MA 19.15 Wed 17:45 EB 301

Dynamic Vortex-Antivortex Interaction in a Single Cross-Tie Wall

— •Karsten Kuepper[1], Matthias Buess[2], Joerg Raabe[2], Christoph Quitmann[2], and Juergen Fassbender[1] — [1]FZ Dresden-Rossendorf, Bautzner Landstr. 128, 01328 Dresden, Germany — [2]Swiss Light Source, Paul Scherrer Institut, CH-5232 Villigen, Switzerland

In a rectangular permalloy platelet one can find a stable micromagnetic configuration comprising two vortices and an antivortex, a so called single cross-tie wall. Such a single cross-tie wall can be understood as being a coupled micromagnetic system with three static solitons. Here we report on its magnetization dynamics including the vortex-antivortex interactions [1]. The spectrum of eigenmodes is investigated as well as the effect of different vortex core orientations. These are important for the magnetization dynamics because they determine the sense of rotation for the gyrotropic motion. Since three cores are present in total $2^3 = 8$ configurations are possible. We find that different types of configurations lead to completely different dynamic behaviors. The origin is the dynamic coupling of the cores which is mediated by the exchange coupling through the adjacent domain walls. This coupling is significant and introduces unexpected effects, such as the quenching of gyrotropic motion for the antivortex in certain core configurations. The vortex dynamics can be used to identify the core configuration, which is not directly accessible to x-ray microscopy because of its limited spatial resolution.

[1] K. Kuepper et al., Phys. Rev. Lett. **99**, 167202 (2007)

MA 19.16 Wed 18:00 EB 301

Dynamic Properties of Patterned Ferromagnetic Thin Films

— •Roman Adam, Riccardo Hertel, and Claus M. Schneider — Institute of Solid State Research, Research Center Jülich, D-52425 Jülich, Germany

We studied dynamic response of ferromagnetic thin film bars to magnetic pulse excitations employing both time-resolved magneto-optic Kerr effect (TR-MOKE) measurements and micromagnetic simulations. The bars with rectangular and hexagonal geometries were patterned on top of coplanar waveguides and oriented with their long axis either parallel, perpendicular or 45° with respect to the external magnetic field. The bars were inserted into weak magnetic field and excited with 10 ps magnetic pulse generated by a photoconducting switch. The time evolution of the magnetization was recorded employing TR-MOKE and compared with micromagnetic simulations. Fourier analysis of the time-resolved signal reveals the presence of oscillatory modes associated with the dynamics in the central part and at the borders of ferromagnetic bars. The observed initial gradual increase of the oscillation amplitude is attributed to the excitation of multiple modes inside the sampled region. A strongly nonlinear dependence of the relaxation time on the static field suggests an even more complex response due to mode interactions.

MA 19.17 Wed 18:15 EB 301

Adjusting ferromagnetic precessional modes in magnetic thin film structures

— •Jeffrey McCord[1], Rainer Kaltofen[1], Manfred Wolf[1], Ingolf Mönch[1], Eckhardt Quandt[2], Rudolf Schäfer[1], and Ludwig Schultz[1] — [1]IFW Dresden — [2]CAU Kiel

By controlled adjustment of the magnetic ground state in square ferromagnetic elements a coupled micromagnetic system with coupled precessional oscillations is generated. The occurrence of the coupled system is associated with domain branching at the element's edges. Dynamic mode-to-mode energy transfer results in a precessional decay time exceeding the natural ferromagnetic material's relaxation time. This reduction in the effective magnetic damping parameter is in contradiction to the consensus that magnetic domain formation leads to a decrease in precessional relaxation time.

MA 19.18 Wed 18:30 EB 301

The role of bandstructure on the ultrafast magnetization dynamics

— •Tobias Roth, Daniel Steil, Mirko Cinchetti, and Martin Aeschlimann — TU Kaiserslautern, Erwin-Schrödinger Str. 46, 67663 Kaiserslautern

Herein we report on the effect of the electronic bandstructure on the spin dynamics. In a comparative study the 3d ferromagnet Co and the Heusler alloy Co_2MgSi, both with strongly deviating bandstructures, were investigated by means of the time resolved MOKE. The focus was put on the ultrafast magnetization dynamics following an optical excitation with a high intensive femtosecond laser pulse. The behaviour of the first ultrafast demagnetization step is similar for both materials. In contrast, the process of thermalization between the participating subsystems is delayed in the case of the Heusler alloy. We ascribe this as a distinct signature of a blocked Elliot-Yafet like scattering due to the bandgap in Co_2MgSi.