MA 17: Spin Dynamics / Spin Torque II

Time: Wednesday 14:00–18:30 Location: H10

Invited Talk MA 17.1 Wed 14:00 H10

Current-induced magnetization dynamics — •Mathias Kläui — Fachbereich Physik, Universität Konstanz, 78457 Konstanz

When combining transport with magnetic materials on the nanoscale, a range of exciting and novel phenomena emerge. While magnetoresistance effects have been widely studied, the reciprocal spin transfer torque effect that leads to current-induced domain wall motion, has become the focus of intense research in the last few years [1]. In current-induced domain wall motion (CIDM), due to a spin torque effect, electrons transfer angular momentum and thereby push a domain wall with velocities $>$ 100m/s. We have comprehensively investigated this effect using magnetotransport and dynamic imaging techniques based on synchrotron light sources and we have observed that this interaction is strongly dependent on the wall spin structure [2-4]. To understand the underlying mechanisms, we have separated the effects of the adiabatic and non-adiabatic spin torque terms from parasitic Oersted field effects and we have developed a robust measure of the non-adiabaticity parameter. Dynamic imaging shows that AC currents can excite non-linear domain wall oscillations and we determine the oscillatory eigenmodes and quantitatively map the asymmetric and even non-linear potential, which can be engineered by applying external fields [5]. [1] M. Kläui, Topical Review in J. Phys: Condens. Matter 20, 313001 (2008);[2] M. Kläui et al., PRL 94, 106601 (2005), PRL 95, 26601 (2005);[3] O. Boulle et al., PRL 101, 216601 (2008);[4] L. Heyne et al., PRL 100, 66603 (2008);[5] D. Bedau et al., PRL 99, 146601 (2007); PRL 101, 256602 (2008)

Invited Talk MA 17.2 Wed 14:30 H10

Ultrafast switching of magnetic vortex cores – The role of the internal energy — •Riccardo Hertel — Institut für Festkörperforschung IFF-9, Forschungszentrum Jülich GmbH, Leo-Brandt-Str., D-52425 Jülich

The recently discovered dynamic switching of magnetic vortex cores can be regarded as the most complex fundamental micromagnetic switching process. It is mediated by the rapid formation and annihilation of vortex-antivortex pairs. The first observation of this core switching was obtained by varying the amplitude of an external field tuned at the gyrotropic resonance frequency [1]. This switching route is rather slow, since it requires several nanoseconds to resonantly excite a vortex from the equilibrium state up to the switching threshold. Alternatively, an ultrafast route has been proposed based on single, short field [2] or electric current [3,4] pulses which can switch the core within a few tens of picoseconds. In spite of these differences in switching times, simulations show that the micromagnetic process of the core reversal is the same for both routes. With our finite-element code we studied the role of the internal energy in these processes. We find that the vortex core always switches at well-defined energy thresholds. Careful analysis of the mesh-size dependence of the computed values shows that the critical switching energy is in agreement with the analytic value for the formation energy of a vortex-antivortex pair. [1] B. Van Waeyenberge et al., Nature 444, 461 (2006) [2] R. Hertel et al., Phys. Rev. Lett. 98, 117201 (2007) [3] K. Yamada et al., Nature Mater. 6, 270-273 (2007) [4] Y. Liu et al., Appl. Phys. Lett. 91, 112501 (2007)

MA 17.3 Wed 15:00 H10

Dynamics of massless magnetic domain walls in cylindrical Permalloy nanowires — •Ming Yan, Attila Kákay, Sebastian Gliga, and Riccardo Hertel — Institut für Festkörperforschung, IFF-9, Forschungszentrum Jülich, D-52425 Jülich

It is well known that there exists an upper limit to the velocity of magnetic domain walls (DWs) driven by an external force. This is related to the accumulation of energy or, in other words, the increase of effective mass of the DW during its motion. We have found that DWs formed in cylindrical nanowires can be effectively massless, such that their velocity is not limited by these effects [1]. Driven by a magnetic field or a spin polarized electric current, this DW-type propagates along a characteristic spiraling path. Owing to the cylindrical symmetry of the wire, the DW maintains its configuration during its motion, thereby avoiding the accumulation of energy. This type of DW may have important implications in fundamental studies and for applications, especially in the case of current-driven DW motion. We show that the spin polarization rate of the current can be directly determined by measuring the DW velocity. Moreover, the rotational motion of the DW can be used to measure the non-adiabatic spin transfer torque parameter. The smooth linear motion of the DW provides a possibility to achieve precisely controlled DW motion, which is essential for race-track memories [2].

References:

[1] M. Yan, A. Kákay, S. Gliga, and R. Hertel, submitted.

[2] S. S. Parkin, M. Hayashi, and L. Thomas, Science 320, 190 (2008).

MA 17.4 Wed 15:15 H10

Dynamics of domain walls in thin films with out-of-plane magnetization — •Benjamin Krüger[1], Imam Makhfudz[2], Oleg Tchernyshyov[2], and Daniela Pfannkuche[1] — [1]I. Institut für Theoretische Physik, Universität Hamburg — [2]Department of Physics and Astronomy, Johns Hopkins University

The possibility that domain walls can be shifted by a spin-polarized current flowing through the wall or by magnetic fields is important for memory and spintronic devices. While for small wires the dynamics of the wall is well described by a model in which the wall moves as a quasi particle[1,2,3] this model has to fail for broader wires and magnetic films where the current or field may be inhomogeneous.

We investigate the dynamics of domain walls in a thin magnetic film with a strong easy-axis anisotropy that favors the out-of-plane direction. It is found that the dominance of the gyrotropic force over the viscous one makes the dynamics of Bloch walls rather unusual. By distorting the wall it is possible to excite waves that propagate with different speed in the two directions along the wall. From these results one finds that the star-shaped gyrational trajectory of a magnetic bubble in a magnetic disc[4] is a result of superposition of two waves with the same wavenumber and different frequencies running in opposite directions along the wall that surrounds the bubble.

[1] W. Döring Z. Naturforsch. 3a, 373 (1948)

[2] L. Thomas et al. Nature 443, 197 (2006)

[3] L. Bocklage et al. Phys. Rev. Lett. 103, 197204 (2009)

[4] C. Moutafis et al. Phys. Rev. B 79, 224429 (2009)

MA 17.5 Wed 15:30 H10

Field and current driven depinning of domain walls in V-shaped nanowires — •Sebastian Hankemeier, Björn Beyersdorff, Robert Frömter, and Hans Peter Oepen — Universität Hamburg, Institut für Angewandte Physik, Jungiusstr. 11, 20355 Hamburg, Germany

We have studied the depinning behaviour of domain walls in V-shaped nanowires. In our geometry, the angle between the two arms of the Permalloy wire is 170°, width and thickness are 350 nm and 18 nm, respectively. At the intersection of the two arms, domain walls can be easily nucleated by an external field, which is aligned parallel to the mirror axis of the V-shaped wire. The electrical resistivity is measured to reveal the existence of a domain wall within the wire via the anisotropic magnetoresistance (AMR). The depinning behaviour of the domain wall has been investigated by measuring the AMR in dependence of strength and orientation of the external magnetic field. When cooling the nanowire, the DC current density can be increased up to $4 \cdot 10^{12} \frac{\mathrm{A}}{\mathrm{m}^2}$ without destroying the wire [1]. Beyond a DC current density of $1 \cdot 10^{11} \frac{\mathrm{A}}{\mathrm{m}^2}$, the current affects the depinning field of a domain wall via Joule heating, Oersted field and the spin torque effect. We demonstrate a procedure that allows a separation of these effects to study their individual influences on the depinning field of the domain wall. This work is supported by DFG, SFB 668.

[1] S. Hankemeier, K. Sachse, Y. Stark, R. Frömter, and H. P. Oepen, Appl. Phys. Lett. **92**, 242503 (2008).

MA 17.6 Wed 15:45 H10

Tailoring laser-induced domain wall pinning — •Philipp Möhrke[1], Jeroen Franken[2,1], Jan Rhensius[1,3], Jan-Ulrich Thiele[4], Ursula J. Gibson[5], Laura J. Heyderman[3], Ulrich Rüdiger[1], and Mathias Kläui[1] — [1]Universität Konstanz, Fachbereich Physik, Universitätsstraße 10, 78457 Konstanz, Germany — [2]Department of Applied Physics, University of Technology, Einhoven, Netherlands — [3]Paul Scherrer Institut, 5232 Villingen PSI, Switzerland — [4]Hitachi Global Storage, San Jose, CA, USA — [5]Thayer School

of Engineering, Dartmouth Colege, Hanover, NH, USA

The generation of spin-currents due to temperature gradients was predicted from theoretical calculations and measured in experiment (spin Seebeck effect). This topic has attracted interest lately, but so far no influence of such spin-currents on domain wall (DW) motion has been reported.

We first probe the effect of the current-induced heating on the magnetic and magneto-optical properties of Permalloy nanowires with increasing current density using a dynamic Kerr-microscope. Furthermore the creation of tunable pinning sites by local laser-induced heating, which could be explained by spin-currents, is shown for higher laser powers. We find that the laser spot focused onto the wire can act as a flexible pinning site for a DW. As part of the power is absorbed by the sample, it is heated locally and a strong thermal gradient is created. The field or current required to depin the DW from the spot increases with laser power so that the pinning strength can be tuned by adjusting the laser.

MA 17.7 Wed 16:00 H10

Ultrafast all-optical switching of magnetic domains using circular polarized laser light — •Alexander Hassdenteufel, Daniel Steil, Sabine Alebrand, Mirko Cinchetti, and Martin Aeschlimann — Department of Physics and Research Center OPTIMAS, TU Kaiserslautern, Germany

Magnetic switching is typically a continuous process that can be described as a damped precession of the magnetization in an external magnetic field. This process takes typically up to 1 ns. Recently it has been shown that it is possible to achieve magnetic switching within 100 fs [1,2]. This process is induced by circularly polarized ultrashort laser pulses, where the direction of this opto-magnetic switching is determined only by the helicity of light. In this contribution, the femtosecond laser-induced reversal mechanism of GdFeCo thin films is investigated by static and time-resolved magneto-optical Faraday measurements. In particular, we studied the dependence of the writing threshold on the laser duration and bandwidth by using chirped laser pulses with different durations from 0,1 ps to 1,5 ps as well as by modifying the pulses with a slit. This work was supported by the European project ULTRAMAGNETRON.

[1] Kimel, A. V. et. al. Nature **435**, 2005, 655-657
[2] Stanciu, *PRL* **99**, 047601 (2007)

MA 17.8 Wed 16:15 H10

Dependence of Magnetic Domain-Wall Motion on a Fast Changing Current — •Lars Bocklage[1], Benjamin Krüger[2], Hauke Langner[1], Toru Matsuyama[1], Markus Bolte[1], Ulrich Merkt[1], Daniela Pfannkuche[2], and Guido Meier[1] — [1]Institut für Angewandte Physik, Universität Hamburg, Jungiusstrasse 11, 20355 Hamburg, Germany — [2]I. Institut für Theoretische Physik, Universität Hamburg, Jungiusstrasse 9, 20355 Hamburg, Germany

Domain walls in magnetic nanowires can be moved by an electrical current. Using resonant excitations the temporal shape of the current strongly influences the dynamics of the wall [1]. Theoretically it was predicted that the time derivative of the current density also affects the wall motion [2,3]. We observe a dependence of the depinning probability of a vortex wall on the rise time of current pulses in permalloy nanowires [4]. The characteristic time scale in which the rise time affects the depinning probability is in the order of some nanoseconds. An analytical description shows that a strong force acts on the domain wall for short rise times which arises from the time derivative of the current. The damping time of the domain wall, that is independent of the pinning potential, is the scaling time on which the force of the time derivative of the current gets significant. [1] L. Thomas et al., Nature 443, 197 (2006)

[2] B. Krueger et al., Phys. Rev. B 75, 054421 (2007)
[3] T. Suzuki et al., J. Appl. Phys. 103, 113913 (2008)
[4] L. Bocklage et al., Phys. Rev. Lett. 103, 197204 (2009)

MA 17.9 Wed 16:30 H10

Different Walker fields in the same nanostripe: The influence of slanted edges on the domain wall dynamics — •Sascha Glathe, Matthias Zeisberger, and Roland Mattheis — IPHT Jena, Albert-Einstein-Str. 9, 07745 Jena

The Walker field is the key parameter describing field driven domain wall (DW) dynamics. We analyzed the Walker field in giant magnetoresistance (GMR) nanostripes by means of time resolved resistance measurements. With this technique we are able to determine the Walker field strength directly by evaluating the obtained single shot measurements. The 160*45*45000 nm^3 (sense layer thickness was 20 nm) GMR nanostripe was deposited by dc magnetron sputtering and structured via photolithography and Ar ion etching under tilt. Therefore the nanostripes have slanted edges in the cross section. This geometrical feature breaks the symmetry between a moving head-to-head and a tail-to-tail DW, respectively, giving rise to different Walker field strengths in the same sample. This difference is explained by means of the different stray field contribution appearing for both configurations and is confirmed by micromagnetic simulations.

MA 17.10 Wed 16:45 H10

Ion-milled permalloy nanowires sputtered on heated substrates for current-induced domain-wall depinning — •Gesche Nahrwold[1], Sedat Dogan[1], Lars Bocklage[1], Toru Matsuyama[1], Guido Meier[1], Ulrich Merkt[1], Kouta Kondou[2], Gen Yamada[2], and Teruo Ono[2] — [1]Institut für Angewandte Physik, Jungiusstr. 11, 20355 Hamburg — [2]Institute for Chemical Research, Kyoto University, Kyoto 611-0011, Japan

Current-induced domain-wall motion is a subject of wide interest, most prominently represented by the race-track memory invented by S. Parkin [1]. In order to investigate reliable devices it is crucial to optimize the material properties of permalloy [2], which is commonly used for the fabrication of nanowires for domain-wall depinning. By sputtering permalloy on heated substrates the specific resistance is significantly decreased while keeping other relevant characteristics, such as crystal structure, magnetic properties, crystallite size, and material composition at desired levels. For sample preparation with this material a subtractive process is needed as due to the high temperatures during deposition lift-off is impossible. We have fabricated curved wires by subtractive ion-milling of permalloy films sputtered on substrates heated to 300 °C. Current-induced domain-wall experiments yield low depinning fields and a reliable depinning process. [1] S. S. P. Parkin et al., Science **320**, 190 (2008), [2] G. Nahrwold et al., J. Appl. Phys. **105**, 07D511 (2009)

15 min. break

MA 17.11 Wed 17:15 H10

Vortex dynamics in arrays of dipolar coupled ferromagnetic disks — •Andreas Vogel[1], André Drews[1,2], Markus Bolte[1,2], and Guido Meier[1] — [1]Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg, Jungiusstrasse 11, 20355 Hamburg, Germany — [2]AB Technische Informatik Systeme, Department Informatik, Universität Hamburg, Vogt-Kölln-Strasse 30, 22527 Hamburg, Germany

Vortices trapped in small ferromagnetic structures are of intense scientific interest because of their sub-nanosecond dynamics and potential technological applications as ultra-fast and high density digital storage elements [1-2]. We study the influence of the magnetostatic interaction on the vortex dynamics in arrays of ferromagnetic disks by means of a broadband ferromagnetic-resonance setup using a vector-network analyzer. Transmission spectra reveal a strong dependence of the frequency of resonant circular vortex-core motion on the inter-element distance within the array. For decreasing distance, a considerable broadening of the absorption peak is observed following a sixth-order power law, known from the Van der Waals type interaction. The experimental data are in accordance with analytical and numerical calculations using the rigid vortex model [3-4]. Additionally, micromagnetic simulations give a deeper insight into the observed phenomena.

[1] T. Shinjo et al., Science 289, 930 (2000);
[2] R. P. Cowburn et al., Phys. Rev. Lett. 83, 1042 (1999);
[3] J. Shibata et al., Phys. Rev. B 67, 224404 (2003);
[4] J. Shibata and Y. Otani, Phys. Rev. B 70, 012404 (2004).

MA 17.12 Wed 17:30 H10

Experimental Proof for the Vortex-Antivortex Mediated Vortex Core Reversal — •Hermann Stoll[1], Arne Vansteenkiste[2], Bartel Van Waeyenberge[2], Markus Weigand[1], Michael Curcic[1], Matthias Kammerer[1], Matthias Noske[1], Georg Woltersdorf[3], Kang Wei Chou[4], Tolek Tyliszczak[4], Christian H. Back[3], and Gisela Schütz[1] — [1]MPI für Metallforschung, Stuttgart — [2]Ghent University, Belgium — [3]Universität Regensburg — [4]Advanced Light Source, LBNL, Berkeley, CA, USA

The reversal of the vortex core polarization via excitation of vortex gyration was discovered experimentally by time-resolved X-ray microscopy [1]. A model was suggested based on dynamic vortex-antivortex (VA) creation and annihilation [1]. Meanwhile this model is generally accepted for vortex core switching. However, in all experiments so far the vortex core polarization was only determined 'before' and 'after' the vortex core reversal and the evidence for the VA model is only indirect, by comparing the experimental parameters with micromagnetic simulations. No direct support for the VA model has been given so far. We present experimental data supporting the VA model directly. Time-resolved imaging of the out-of-plane vortex core magnetization has given a direct proof for the initial step, the deformation of the vortex core [2]. A region with opposite magnetization becomes visible at sufficiently high excitation power when the vortex is gyrating fast and its velocity is approaching the critical velocity.

[1] Van Waeyenberge et al., Nature 444 (2006) 461-464
[2] Vansteenkiste et al., Nature Physics 5 (2009) 332-334

MA 17.13 Wed 17:45 H10

Direct imaging of current induced vortex gyration in an asymmetric potential well — •Andre Bisig[1,2], Jan Rhensius[1,3], Matthias Kammerer[2], Michael Curcic[2], Bartel Van Waeyenberge[4], Kang Wei Chou[5], Tolek Tyliszczak[5], Stephen Krzyk[1], Arndt von Bieren[1], Hermann Stoll[2], Gisela Schütz[2], Laura Jane Heyderman[3], and Mathias Kläui[1] — [1]Universität Konstanz, 78457 Konstanz, Germany — [2]Max-Planck-Institut für Metallforschung, 70569 Stuttgart, Germany — [3]Labor für Mikro- und Nanotechnologie, 5232 Villigen PSI, Switzerland — [4]Ghent Univerity, 9000 Ghent, Belgium — [5]Advanced Light Source, 94720 Berkeley LBNL, USA

Employing time-resolved scanning transmission x-ray microscopy (STXM), we investigate the dynamics of a pinned magnetic vortex domain wall in a magnetic nanowire. The gyrotropic motion of the vortex core is imaged in response to an exciting ac current. Using the analytical model of a two-dimensional harmonic oscillator, we determine the resonance frequency of the vortex core gyration by measuring the phase at various excitation frequencies. The elliptical vortex core trajectory at resonance reveals asymmetries in the local potential well that are correlated with the pinning geometry. Furthermore, we can measure the stiffness of the local potential well by determining the eccentricity of the vortex core trajectory at resonance. In the nanowire geometry, where the electrical contacts are placed far away from the area under investigation, Oersted field contributions are minimized.

MA 17.14 Wed 18:00 H10

The Barnett effect in magnetic nanostructures — •Stefan Bretzel[1], Gerrit E. W. Bauer[1], Arne Brataas[2], and Yaroslav Tserkovnyak[3] — [1]Kavli Institute of NanoScience, TU Delft, Lorentzweg 1, 2628CJ Delft, The Netherlands — [2]Department of Physics, Norwegian University for Science and Technology, 7491 Trondheim, Norway — [3]Department of Physics and Astronomy, University of California, Los Angeles, California 90095, USA

The Barnett effect – magnetization induced by mechanical rotation – was discovered at the dawn of quantum mechanics and provided first evidence of the anomalous electron g-factor. We discuss the Barnett effect in the framework of the Landau-Lifshitz-Gilbert equation for magnetic nanostructures, providing theoretical estimates for its observation in different structures and materials. Furthermore, we propose a magnetomechanical device consisting of a sliding domain wall in a rotatable magnetic wire, which relates the Barnett effect with its close relative, the Einstein-de Haas effect via Onsager's reciprocity relations.

MA 17.15 Wed 18:15 H10

Calculation of damping parameter in bulk-Gd — •Jonas Seib and Manfred Fähnle — Max-Planck-Institut für Metallforschung, Heisenbergstr. 3, 70569 Stuttgart

We calculate a damping matrix for the 5d6s-valence magnetic moment in bulk-Gd within the Breathing Fermi Surface model. This model describes the damping in magnetization dynamics caused by the creation of intraband electron-hole pairs in the low temperature limit. It has been shown that the creation of electron-hole pairs is the dominant contribution to damping in 3d transition metals [1]. In an approach similar to the sd-model, we get from the valence moment damping parameter to a damping parameter for the 4f magnetic moment which contributes the main part to the total magnetic moment.

[1] K. Gilmore, Y.U. Idzerda, and M.D. Stiles, Phys. Rev. Lett. **99**, 027204 (2007).