MA 23: Magnetization / Demagnetization Dynamics II

Time: Wednesday 9:30–13:00 Location: H 1012

Invited Talk MA 23.1 Wed 9:30 H 1012

Uncovering the Ultrafast Angular Momentum Transfer on the Nanoscale in GdFeCo — •A. Scherz[1], C. Graves[1,2], A.H. Reid[1], B. Wu[1,2], T. Wang[1,2], S. de Jong[2], K. Vahaplar[3], I. Radu[3], M. Messerschmidt[4], R. Coffee[4], M. Bionta[4], R. Hartmann[5], N. Kimmel[5], S. Epp[5], A. Tsukamoto[6], J. Turner[4], W.F. Schlotter[4], Y. Acremann[7], A. Kimel[3], A. Kirilyuk[3], J. Stöhr[1,4], T. Rasing[3], and H. Dürr[1] — [1]Stanford Inst. for Material and Energy Science, California — [2]Stanford University, California — [3]Radboud University Nijmegen, Netherlands — [4]LCLS, SLAC Nat. Acc. Lab., California — [5]ASG-MPG, CFEL Hamburg, Germany — [6]Nihon University, Japan — [7]ETH Zürich, Switzerland

The ultrafast control of electron spins is of both fundamental scientific and technological interest. Recent experiments have shown that femtosecond laser excitation can act as a stimulus to switch the direction of the magnetization in ferrimagnetic GdFeCo, called all-optical switching. However, how angular momentum is transferred to result in a switched state remains unknown. To further understand this mechanism, we used the fs x-ray pulses at the x-ray free electron laser facility, LCLS, to study the all-optical magnetization switching of GdFeCo triggered by fs laser excitation using time-, element- and spatially-resolved x-ray resonant magnetic scattering. We present here the first-ever measurement of the fs magnetic response in GdFeCo with spatial resolution down to 10nm. Our results reveal drastically different behaviors on the nanoscale as compared to the bulk and provide insight into the angular momentum transfer channels.

MA 23.2 Wed 10:00 H 1012

Bending spin waves around the corner — •Katrin Vogt[1,2], Helmut Schultheiss[3], Shikha Jain[3], Axel Hoffmann[3], and Burkard Hillebrands[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, D-67663 Kaiserslautern, Germany — [2]Graduate School of Excellence Material Science in Mainz, Staudinger Weg 9, D-55128 Mainz, Germany — [3]Materials Science Division, Argonne National Laboratory, Argonne, IL 60439

The guidance of spin waves in more complicated geometries than simple waveguide strips is a challenge in realizing magnonic devices. Especially in metallic magnetic materials like Permalloy ($Ni_{81}Fe_{19}$), where the length scales are of interest for applications, it will be inevitable to find means how to accomplish truly two-dimensional spin-wave propagation.

Using Brillouin light scattering microscopy, we have studied the propagation of spin waves in Permalloy microstrips exhibiting a smooth bend. We will discuss the use of a direct current flowing through a gold wire underneath the Permalloy to provide a local magnetic field and maintain a transverse magnetization around the bend of the waveguide. We will demonstrate how spin-wave propagation around the bend is improved compared to the case of an externally applied magnetic field which generates strong inhomogeneities in the internal magnetization distribution and prevents any spin-wave propagation around the bend.

Financial support by the Carl-Zeiss-Stiftung is gratefully acknowledged.

MA 23.3 Wed 10:15 H 1012

Mode selective parametric excitation of spin waves in a $Ni_{81}Fe_{19}$ microstripe — •Thomas Braecher[1,2], Philipp Pirro[1], Björn Obry[1], Alexander A. Serga[1], Britta Leven[1], and Burkard Hillebrands[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler-Straße 47 67663 Kaiserslautern, Germany

Due to their potential application in logic devices and microwave signal processing spin-wave excitations have been intensively studied. However, experiments in microstructured systems remain a challenge since the spin-wave lifetime in commonly used materials like Permalloy ($Ni_{81}Fe_{19}$) is restricted to a few nanoseconds. We present the experimental observation of parallel parametric amplification of selected thermal spin-wave modes in a transversally magnetized $Ni_{81}Fe_{19}$ microstripe. By employing Brillouin light scattering microscopy we identify the dominant group, i.e. the spin-wave mode that is preferentially amplified. We show that due to the existing spin-wave quantization in the system it is possible to select one specific mode to be parametrically excited by changing the bias magnetic field. This gives access to transversal spin-wave eigenmodes of the stripe, promising the ability to amplify externally excited propagating spin waves that carry information, and also to modes localized at the stripe edges. This work was recently published in Applied Physics Letters (Appl. Phys. Lett. **99**, 162501 (2011)).

Financial support by the DFG and MAINZ is gratefully acknowledged.

MA 23.4 Wed 10:30 H 1012

Micromagnetic study of magnonic band gaps in waveguides with a periodic variation of the saturation magnetization — •Florin Ciubotaru, Andrii V. Chumak, Björn Obry, Alexander A. Serga, and Burkard Hillebrands — FB Physikand Landesforschungszentrum OPTIMAS, TU Kaiserslautern, 67663 Kaiserslautern, Germany

Spin wave propagation in micro-sized magnonic crystals (MCs) is intensively studied due to their potential technological application for signal processing in spintronic devices. Here we report on micromagnetic simulations [1] of the spin wave propagation in a MC realized as a permalloy waveguide with a periodical variation of its saturation magnetization. In real structures the variation of magnetization can be achieved by using an ion implantation technique. The 2 μm-wide waveguide of 40 nm thickness is magnetized transversal to its long axis. The MC lattice constant is equal to 1 μm. The spin-wave transmission characteristics have been studied as a function of the width of the implanted areas and of the level of the magnetization variation M/M_0. Frequency band gaps were clearly observed. The dependences of the depth, width and the position in frequency and space of the rejection band gaps on the above parameters are referred in our studies. The role of the higher order spin-wave width modes on the MC properties is discussed as well. Support from DFG (grant SE-1771/1-2) is gratefully acknowledged. [1] OOMMF open code, M. J. Donahue, and D. G. Porter, Report NISTIR 6376, NIST, Gaithersburg, MD (1999).

MA 23.5 Wed 10:45 H 1012

Magnon magnetometry of non-linear spin-wave excitations — •Hans G. Bauer[1], Georg Woltersdorf[1], Peter Majchrak[1], Thorsten Kachel[2], and Christian H. Back[1] — [1]Department of Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Helmholtz-Zentrum Berlin, Albert-Einstein-Strasse 15, 12489 Berlin, Germany

The understanding of non-linear magnetization dynamics is essential for the operation of many spintronics devices. In particular it is important to understand the flow of angular momentum.

We study experimentally a very simple and relevant system, a thin ferromagnetic film. Time resolved X-ray magnetic circular dichroism experiments allow us to determine precisely the number of magnons in a Permalloy sample. In doing so we show that commonly used models for non-linear resonance are actually not applicable at low bias fields.

A simple non-linear model allows us to find the threshold and associated critical modes that agree well with our experimental findings and with micro-magnetic simulations. Other non-linear properties such as the wave-vector dependent non-linear frequency shift and frequency-locking to half-integer multiples of the driving frequency are also discussed.

Our model is also applicable to 1st and 2nd order Suhl instability processes, demonstrating its general character.

MA 23.6 Wed 11:00 H 1012

Magnetic Anisotropy and Damping of Rare-Earth Doped Permalloy — •Christoph Zollitsch[1], Fredrik Hocke[1], Mathias Weiler[1], Rudolf Gross[1,2], Georg Woltersdorf[3], Jahn-Ulrich Thiele[4], Sebastian T.B. Goennenwein[1], and Hans Huebl[1] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching — [2]Physik-Department, Technische Universität München, Garching — [3]Physik-Department, Universität Regensburg, Regensburg — [4]Seagate Technology, Fremont, CA, USA

Understanding and engineering the magnetization damping of magnetic materials is of considerable interest both from a fundamental physics perspective and for applications. Of particular importance are low damping materials such as Permalloy ($Ni_{80}Fe_{20}$) and Yttrium Iron Garnet. We study the temperature dependent behavior of the ferromagnetic resonance (FMR) of $Ni_{80}Fe_{20}$ doped with 1at.% Ho. At room-temperature the FMR dispersion is not altered by the dopant. The latter only leads to an increased damping with respect to the undoped $Ni_{80}Fe_{20}$ as expected in the frame of the slow relaxation mechanism [1]. At around 100 K the FMR is suppressed due to the efficient damping by the Ho dopant. In the temperature regime below 100 K which was previously not studied, the dispersion shifts to higher frequencies by 14 GHz, while the damping reduces to its initial magnitude. This is attributed to an increase in the magnetic moment of Ho in combination with its thermal population.

[1] G. Woltersdorf, et al., Phys. Rev. Lett. **102**, 257602 (2009)

15 min. break

MA 23.7 Wed 11:30 H 1012

Spindynamics of individual permalloy nanowires — •Nathalie Reckers[1], Zheng Duan[2], Ilya Krivorotov[2], Michael Farle[1], and Jürgen Lindner[1] — [1]Fakultät für Physik und Center for Nanointegration Duisburg-Essen, Universität Duisburg-Essen, 47048 Duisburg, Germany — [2]Department of Physics and Astronomy, University of California, Irvine, USA

Nanostructured single wires (600 nm* 80 μm* 20 nm) composed of Permalloy are investigated by dc electrically detected ferromagnetic resonance in a frequency range of 4-16 GHz at ambient temperature [1]. It is demonstrated that the quasi uniform mode and other localized spinwave modes in a single nanowire can be detected with high sensitivity in different measurement geometries, the external magnetic field being applied along easy and hard direction of the wire. Based on these multi-frequency measurements we observe that in nanostructured finite elements deviations to the widely employed Kittel-resonance equation are present. Examples will be discussed.

Financial support by DFG, SFB 491 is acknowledged.

[1] N. Mecking, Y. Y. Gui and C.-M. Hu, Phys. Rev. B, 224430, (2007)

MA 23.8 Wed 11:45 H 1012

Rotational Doppler Effect in Magnetic Resonance — •Sergi Lendínez[1], Eugene Chudnovsky[2], and Javier Tejada[1] — [1]Departament de Física Fonamental, Facultat de Física, Universitat de Barcelona, Barcelona, Spain — [2]Physics Department, Lehman College, The City University of New York, New York, U.S.A.

The Doppler Effect consists of a shift on the frequency received by an observer which is moving with respect to the source of the radiation. Commonly, linear Doppler is observed. In this case, an observer moving at relative velocity v will perceive a frequency shifted by v/c: $f' = f(1 \pm v/c)$, where the plus (minus) sign is for an observer moving towards (backwards) the source. However, the Doppler Effect can also be observed at rotations of the body. In particular, if a solid rotates with an angular velocity Ω in the field of a circularly polarized electromagnetic wave, in its rotating frame the frequency of the wave will be shifted by $\omega' = \omega \pm \Omega$, where the plus (minus) sign is for a rotation in the opposite (same) direction of the circular polarization.

In the case of a rotating object with a resonant frequency, one would firstly think that the frequency will be shifted by Ω. However, a mechanical rotation of a system of charges is equivalent to a magnetic field, hence it must be checked whether the resonant frequency is affected by this magnetic field. Resonant frequencies of LC circuits are insensitive to magnetic fields, and the frequency will by shifted by Ω as expected. On the contrary, frequencies based upon magnetic resonance will be sensitive to this magnetic field, so the frequency shift may not be Ω.

MA 23.9 Wed 12:00 H 1012

Towards atomistic tight-binding spin dynamics — •S. Rossen[1,2], P. Mavropoulos[1], T. Schena[1], S. Blügel[1], and Th. Rasing[2] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Institute for Molecules and Materials, Radboud Universiteit Nijmegen, 6525 AJ Nijmegen, The Netherlands

This work is motivated by the increasing interest in atomistic magnetization dynamics [1]. Until now, the computational approaches are mainly based on model Hamiltonians of the magnetic system. Here we will present a method based on the adiabatic approximation in which the electronic structure is recalculated within the tight-binding approximation during the time evolution, so that the transverse and longitudinal magnetic as well as charge degrees of freedom are coupled [2]. The torques acting on the magnetic moments are obtained self-consistently using constraining fields [3]. It is then possible to describe the magnetization dynamics of a strongly non-equilibrium magnetic state. We will show model calculations of such dynamics where we mainly focus on the integration of the Landau-Lifshitz equation with torques calculated by means of the tight-binding method. The presented results are compared with those of a classical Heisenberg model.

[1] A. Kirilyuk et al., Rev. Mod. Phys. **82**, 2731 (2010).

[2] V. P. Antropov et al., Phys. Rev. B **54**, 1019 (1996).

[3] L. M. Small and V. Heine, J. Phys. F: Met. Phys. **14**, 3041 (1984).

MA 23.10 Wed 12:15 H 1012

Lifting the Degeneracy of Spin Wave Resonances in Three-Dimensional Rolled-Up Microtubes — •Felix Balhorn, Cornelius Bausch, Lennart Moldenhauer, Wolfgang Hansen, Detlef Heitmann, and Stefan Mendach — Institut für Angewandte Physik Hamburg, Jungiusstr. 11, 20355 Hamburg

Nowadays, the established methods of nano-sized sensors, integrated circuits or storage devices are mostly based on two-dimensional fabrication technologies. In strong contrast to those planar nanostructures, the concept of self-rolling strained layers [1] holds the opportunity to prepare and study three-dimensional functionalized devices. We recently demonstrated that strained semiconductor/Permalloy layers can be rolled-up into three-dimensional microtubes which exhibit azimuthal spin-wave resonances and act as magnetically tunable filters for the GHz regime [2].

In this talk, the dynamic properties of these structures obtained via broadband-microwave absorption spectroscopy are discussed. We focus here on an experiment where the axis of the rolled-up microtube is oriented parallel to the signal line of our waveguide. The position of the rolling edge is varied with a micromanipulator to optimize the excitation efficiency. A characteristic frequency splitting of resonant modes in external magnetic fields is observed. We gratefully acknowledge support by the DFG via SFB 668, GrK 1286, and by the city of Hamburg via the Cluster of Excellence Nano-Spintronics.

[1] V. Y. Prinz et al., Physica E **6**, 828-831 (2000); [2] F. Balhorn et al., PRL **104**, 037205 (2010)

MA 23.11 Wed 12:30 H 1012

Quasi uniform modes and standing spinwaves in a single Co-Stripe measured by Ferromagnetic Resonance — •Christian Schöppner[1], Sven Stienen[1], Ryszard Narkowicz[2], Dieter Suter[2], Ralf Meckenstock[1], Jürgen Lindner[1], and Michael Farle[1] — [1]University of Duisburg-Essen, CeNIDE, Faculty for Physics, Lotharstr. 1 47057 Duisburg — [2]Technical University Dortmund, Faculty für Physik, Otto-Hahn-Str. 4 44227 Dortmund

Stripe-like magnetic systems of a few micrometer lateral size and few nanometer thickness exhibit quasi-uniform excitations which are influenced by dynamic pinning, modes of standing character and those which are characterized by a pronounced local confinement due to the inhomogeneous demagnetization field. As the sample edges and inhomogeneities in the demagnetization field become important in such systems, it is crucial to rather measure single stripe samples than ensembles. We present results of Ferromagnetic Resonance experiments on one single Co-Stripe of a few micrometer lateral size and 20nm thickness. For the first time measurements were performed using a microresonator [Banholzer et al. Nanotech. 22 (2011)] in an angular dependent way. The angular dependence was conducted over 180 degree with respect to the long axis of the stripe. We used microwave-frequency of 14GHz and external magnetic fields up to 300mT at room temperature. The measured spectra exhibit the mentioned types of spin waves and are in very good agreement with micro magnetic simulations, which will also be discussed. The work is funded by the DFG (LI 1567/3-1)

MA 23.12 Wed 12:45 H 1012

Spin-Wave Interference Patterns: Perfect Imaging with Spin-Waves — •Sebastian Mansfeld, Jesco Topp, Kim Martens, Jan-Niklas Toedt, Daniel Mellem, Wolfgang Hansen, Detlef Heitmann, and Stefan Mendach — Institute of Applied Physics, University of Hamburg, Hamburg, Deutschland

We discuss time resolved scanning Kerr microscopy data showing the diffraction of planar Damon-Eshbach spin waves on a one-dimensional grating, realized by a micrometer sized slit array in a Permalloy film. We observe a unique diffraction pattern behind the grating which produces images of the spin-wave field at the slits [1]. In accordance to superlensing concepts known from optical metamaterials [2, 3], these images are formed due to the anisotropic shape of the isofrequency line in k-space defined by the dispersion law for spin waves. A consequence is that the resolution of the observed image is not limited by the wavelength of the spin wave, as is the case in isotropic media. Instead, the image resolution is limited by the curvature of the isoline in k-space and by the damping of the spin wave. We show that the images can be tuned by manipulating the isoline in k-space via the excitation frequency and the external magnetic field.

We gratefully acknowledge support by the DFG via SFB 668, SFB 508, GrK 1286, and by the City of Hamburg via the Cluster of Excellence Nano-Spintronics.

[1] Mansfeld et al., Physical Review Letters, in press (2011) - arXiv:1108.5883v1; [2] Liu et al., Science **315**, 1686 (2007); [3] Schwaiger et al., Physical Review Letters **102**, 163903 (2009)