MA 26: Spin Dynamics / Spin -Torque II

Time: Thursday 14:30–18:45 Location: EB 301

MA 26.1 Thu 14:30 EB 301

Relationship between the asymmetry of inelastic magnon excitation and the spin polarization — Nicolai Urban[1], Tobias Schuh[1], Albert F. Takacs[1], Timofey Balashov[1], Markus Däne[2], Arthur Ernst[2], Patrick Bruno[2], and •Wulf Wulfhekel[1] — [1]Physikalisches Instiut, Universität Karlsruhe (TH), Wolfgang - Gaede Str. 1, 76131 Karlsruhe — [2]MPI für Mikrostukturphysik, Weinweg 2, 06108 Halle

Electrons tunneling between the non-magnetic tip of a scanning tunneling microscope and a ferromagnetic sample can scatter inelastically, creating spin waves in the ferromagnet [1]. These excitations can be created for both tunneling directions, i.e. by hot electrons or holes. We observe a strong asymmetry between these two processes. From the selection rules of the conservation of angular momentum follows that in the forward direction only tunneling minority electrons create spin waves, while in the backward direction only tunneling majority electrons create spin waves. Thus, the probability of spin wave creation for forward/backward tunneling is proportional to the local density of states (LDOS) of minority/majority electrons in the investigated magnetic material.

We examined the excitation asymmetry in bulk Fe(100), and thin Co films on Cu(111) and Cu(100). The experimental results of the asymmetry agree well with theoretical calculations of the spin polarization of the LDOS.

[1] T. Balashov, A. Takács, W. Wulfhekel, J. Kirschner, *Phys. Rev. Lett.* **97** 187201 (2006)

MA 26.2 Thu 14:45 EB 301

Excitation of standing spin waves in antiferromagnetic thin films using hot electrons — •Chunlei Gao[1], Wulf Wulfhekel[1,2], Arthur Ernst[1], Guntram Fischer[3], Wolfram Hergert[3], Patrick Bruno[1], and Jürgen Kirschner[1] — [1]MPI für Mikrostrukturphysik, 06120 Halle — [2]Physikalisches Institut, Universität Karlsruhe, 07131 Karlsruhe — [3]Martin-Luther-Universität Halle-Wittenberg, Fachbereich Physik, 06099 Halle

Standing spin waves confined in face centered tetragonal antiferromagnetic Mn thin films were locally excited by hot electron injection with a STM tip. The dispersion of the spin waves was obtained through measurements of the excitation energies in films of various thicknesses. The damping of the spin waves was extracted from the width of the excitation peaks. Both the experimental dispersion and the damping agree well with neutron scattering results of Ni doped γ-Mn. Further, ab-initio calculations of the spin wave dispersion confirm the experimental results.

MA 26.3 Thu 15:00 EB 301

Direct observation of the excitation phase of microwave excited spin waves — •Thomas Schneider[1], Alexander A. Serga[1], Timo Neumann[1], Burkard Hillebrands[1], and Mikhail P. Kostylev[2] — [1]Fachbereich Physik und Forschungsschwerpunkt Minas, TU Kaiserslautern, Erwin-Schrödinger-Str. 56, 67663 Kaiserslautern, Germany — [2]School of Physics, M013, University of Western Australia, 35 Stirling Highway, Crawle, WA 6009, Australia

We report on phase resolved Brillouin light scattering spectroscopy investigations of the excitation of spin waves by microwave pulses. We observed the phase difference between two counterpropagating waves with antiparallel wavevectors excited by the same microwave current flowing through a microstrip spin-wave antenna (the so called "excitation phase"). Theory predicts that for the backward volume mode (spin-wave propagation parallel to the applied bias field) this excitation phase should be equal to π since they are excited by the out-of-plane component of the microwave field. By measuring the phase accumulation (i.e. the change of phase with propagation distance) we were able to experimentally confirm that value. If one changes the propagation direction to perpendicular to the applied field (Damon-Eshbach mode) while the amplitude of the two waves becomes drastically unsymmetrical our experiments show that the phase becomes symmetrical (excitation phase equals zero). Theoretical analysis confirms this effect.

Financial support by the DFG, the Graduiertenkolleg 792 and the Australian Research Council is gratefully acknowledged.

MA 26.4 Thu 15:15 EB 301

Wave-vector Resolved Brillouin Light Scattering Observation of Parametrically Generated Excitations in a Magnon Gas — •Timo Neumann, Aleksandr Serga, and Burkard Hillebrands — Fachbereich Physik, TU Kaiserslautern, Kaiserslautern, Germany

The parametric pumping technique is a very powerful tool to selectively control the density of a magnon gas.

Here we report on the identification of the wave vectors of parametrically generated magnons in a ferrite film.

Using Brillouin Light Scattering (BLS) spectroscopy with wave vector resolution we have studied the process of parametric interaction between an electromagnetic field and the spin wave subsystem of an yttrium iron garnet film in order to unambiguously identify the spectral positions of the generated groups of magnons. Moreover, the process of energy transfer from the overheated areas was investigated.

To achieve this, the possibility to retrieve information about the wave vectors was implemented in an existing BLS-setup by means of spatial selection of the scattered light. Advantages and shortcomings of different methods of such a selection procedure are discussed.

Financial support by the MATCOR Graduate Program is acknowledged gratefully.

MA 26.5 Thu 15:30 EB 301

Non-resonant parametric restoration of microwave spin-wave signals in YIG films — •Sebastian Schäfer, Andrii V. Chumak, Alexander A. Serga, and Burkard Hillebrands — FB Physik and FSP MINAS, TU Kaiserslautern, 67663 Kaiserslautern, Germany

We report on the storage and restoration of spin-wave pulses in a thin Yttrium-iron-garnet (YIG) film. A Damon-Eshbach (DE) type spin-wave pulse is irradiated by a microstrip antenna and excites perpendicular standing spin-wave modes (PSSW), existing due to the finite thickness of the film. Those modes are excited, where the crossing of DE and PSSW dispersions leads to a hybridization of both groups of magnons. After the DE pulse has left the area of interest, energy is provided to the magnonic system with the means of parallel parametric pumping. Here we focus on the dependence of the characteristics of recovered traveling spin-wave pulses on the intensity of the input microwave spin-wave signal for the non-resonant case where the pumping frequency does not match exactly twice the carrier frequency of the original DE mode. This enables the investigation of spectral characteristics of the input microwave spin-wave signal and is a basic step in order to understand the influence of the thermal bath and increasing of the thermal noise for the interaction between the magnon system and a parametric pumping field. Financial Support by the DFG within the SFB/TRR 49 is gratefully acknowledged.

MA 26.6 Thu 15:45 EB 301

Storage and parametrically stimulated recovery of microwave signal using standing spin-wave modes of a magnetic film — •Alexander Serga[1], Andrii Chumak[1,2], Alexander André[1], Gennadiy Melkov[2], Andrei Slavin[3], Sergej Demokritov[4], and Burkard Hillebrands[1] — [1]FB Physik and FSP MINAS, TU Kaiserslautern, Germany — [2]Taras Shevchenko University of Kiev, Ukraine — [3]Oakland University, Rochester, MI, USA — [4]Institut für Angewandte Physik, Westfälische Wilhelms-Universität Münster, Germany

Microwave signals stored for a long time in the form of standing spin-wave (SW) modes of the ferrite film were recovered by parametric pumping. The experiment was performed on an in-plane magnetized yttrium-iron-garnet film. The microwave signal was carried by a packet of surface spin waves that propagate transversely to the bias magnetic field. Near the points of hybridization between the lowest SW mode and the higher-order exchange-dominated SW modes this packet partially transforms into standing thickness modes of the film. A pumping pulse having a carrier frequency close to twice the frequency of one of the standing modes recovers the packet of propagated waves. The time of recovery, duration, and power of the recovered pulse signal were controlled by the pumping power. We propose a theory of non-stationary parametric amplification of the standing modes on the background of the thermal magnon bath, which provides a good qualitative explanation of the experimental results. The work was supported by the DFG, by the Ukrainian Fund for Fundamental Research, by the U.S. Army Research Office, and by the Oakland University Foundation.

MA 26.7 Thu 16:00 EB 301

Propagation, Dispersion and Interference of Spin Waves in Ferromagnetic Thin Films — Korbinian Perzlmaier, •Wolfgang Scheibenzuber, Frank Hoffmann, Georg Woltersdorf, and Christian H. Back — Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Universitätsstr. 31, 93040 Regensburg

The propagation and interference of spin waves has been observed in 20 nm thick $Ni_{80}Fe_{20}$ films by time and space resolved scanning Kerr microscopy. The sample is a continuous thin film with a CPS (coplanar stripline) patterned along one edge of the sample. Using cw (continuous wave) or pulsed microwave excitation, the phase velocities, group velocities, and dispersion relations have been determined in two geometries of an externally applied magnetic in plane bias field, namely the DE (Damon Eshbach) and MSBV (Magneto Static Backward Volume) geometries. Analytical calculations based on the linearized LLG (Landau Lifshitz Gilbert) equation reproduce the experimental findings.

Further on, we report on the interference of propagating spin waves in continuous ferromagnetic films.

MA 26.8 Thu 16:15 EB 301

Crosstalk of dipolar spin-wave modes in thin Nickel films — •Benjamin Lenk, Marija Djordjevic, Jakob Walowski, Gerrit Eilers, and Markus Münzenberg — IV. Physikalisches Institut, Universität Göttingen

The relaxation mechanisms in thin Nickel films are investigated with all optical pump-probe experiments. Laser pulses with a duration of $60fs$ from a Ti:Sa mode-coupled laser system are used for optical excitation (pump pulse) as well as observation of the subsequent magnetic relaxation taking place in the pico- and nanosecond regime (probe pulse). The relaxation spectra, i.e. the time dependent magnetization curves $M(t)$, are recorded using the time-resolved magneto-optical Kerr effect (TRMOKE). Numerical analysis yields the relaxation frequencies for all layer thicknesses ranging from $40nm$ to $220nm$ on a wedge sample.

Different modes are observed that can be attributed to i) uniform precession of the spins ii) exchange-dominated perpendicular standing spin waves as well as iii) dipole-dominated surface modes. By applying an external field $0mT \leq \mu_0 H \leq 150mT$ dispersion relations $\omega(H)$ are determined for the different modes at each layer thickness. The experimental results are compared to theoretical equations derived from the Landau-Lifschitz-Gilbert equation of motion. Good agreement is seen with partly strong deviations at points of mode crossing.

Research is supported by *DFG Schwerpunkt SPP 1133: "Ultrafast magnetization processes"*.

15 Min. Session Break

MA 26.9 Thu 16:45 EB 301

Determination of the magnon dispersion of ferromagnets on the nanometer scale — •Nicolai Urban, Timofey Balashov, Albert F. Takacs, and Wulf Wulfhekel — Physikalisches Institut, Universität Karlsruhe (TH), Wolfgang Gaede Str. 1, 76131 Karlsruhe

We studied the dispersion of magnons in thin ferromagnetic Co films on Cu(100) using inelastic tunneling spectroscopy at 4K. By an interaction between the tunneling electrons and the spin-polarized electron sea of the films, magnons can be excited. Due to the finite thickness of the films, a series of standing magnons quantized perpendicular to the plane evolves. From the film thickness and the order of the standing mode, the magnon momenta can be determined while the energy is given by the position of the extrema in the inelastic tunneling spectra. The obtained dispersion curve agrees well with neutron scattering data and with ab-initio calculations within the whole Brillouin zone [1]. This experimental method allows to determine excitation energies and magnon dispersions of magnetic materials on the nanometer scale.

[1] M. Pajda et al., Phys. Rev. B. **64**, 174402 (2001).

MA 26.10 Thu 17:00 EB 301

Femtosecond magnetization dynamics of iron films after laser excitation — •Stefan Polei, Xuan Truong Nguyen, Armin Kleibert, and Karl-Heinz Meiwes-Broer — Institut für Physik, Universität Rostock, 18051 Rostock, Germany

In 1996 Beaurepaire et al. [1] demonstrated a femtosecond demagnetization of a ferromagnetic sample after excitation with ultrashort laser pulses. The observed time scale was approx. 100 times shorter than expected from theory of magnetization dynamics. Thus, this pioneering experiment has attracted much attention by researchers worldwide. Despite its enormous potential for applications, a full microscopic understanding is still lacking. Thus, great efforts are made to get insight into the fundamental physical processes which lead to a rapid loss followed by a slower recovery of the magnetization within the first picoseconds.

In this contribution we present recent pump-probe experiments on thin iron films. Our setup relies on a Ti-Saphire-laser followed by a multipath amplifier providing pulses of 35fs with up to 2.5mJ at 800nm and a repetition rate of 1kHz. The magnetization dynamics is investigated observing the magneto-optical Kerr-rotation in the longitudinal geometry. Time-dependent hysteresis loops obtained by varying the pump-probe delay give insight into the magnetization dynamics.

[1] Beaurepaire et al., PRL **76**, 4250 (1996)

MA 26.11 Thu 17:15 EB 301

Spatio-temporal magnetic imaging with a femtosecond laser Kerr microscope — •Thomas Eimüller, Jie Li, Min-Sang Lee, Wei He, and Björn Redeker — Nachwuchsgruppe Magnetische Mikroskopie, Ruhr-Universität Bochum, D-44780 Bochum

We report on first results obtained with our new femtosecond laser scanning Kerr microscope. The abilities of the instrument to study magnetization dynamics with a temporal resolution below 100 fs and a lateral resolution in the sub-micrometer regime is demonstrated in all-optical two-colour pump-probe experiments. In a wedged Fe/Gd sample we record the dynamic polar MOKE signal both as a function of the film thickness gradient and as a function the delay time. The resulting spatio-temporal images reveal how the demagnetization process and the induced spin precession change as a function of the film thickness. The high lateral resolution is furthermore used to study the the reversal and magnetization dynamics of lithographically structured Co/Pt systems as a function of different geometrical shapes and different sizes of the elements.

Financial support by the DFG via project SFB491-N1 is gratefully acknowledged.

MA 26.12 Thu 17:30 EB 301

Ultrafast magnetization dynamics in Gd studied by time-resolved XMCD — •Marko Wietstruk[1], Torsten Kachel[1], Niko Pontius[1], Christian Stamm[1], Hermann A. Dürr[1], Wolfgang Eberhardt[1], Alexey Melnikov[2], Uwe Bovensiepen[2], Cornelius Gahl[3], and Martin Weinelt[2,3] — [1]BESSY GmbH, Berlin — [2]FU Berlin, FB Physik — [3]MBI Berlin

In order to improve heat assisted magnetic recording techniques, the understanding of ultrafast magnetization processes especially the flow of energy and angular momentum is essential. The demagnetization of a thin gadolinium film has been investigated in the .1 to 100 ps regime after excitation of the 5d6s valence electrons by a 100 fs IR laser pulse.

The measurements were done at the fs-slicing facility at BESSY in low-α and slicing mode. Using circularly polarized synchrotron radiation we measured X-ray magnetic circular dichroism (XMCD) at the Gd $M_{4,5}$ absorption edges, a method which provides access to the 4f spin and orbital momentum.

The measurements show that the demagnetization process is divided into two steps. First, a 'fast' demagnetization occurs with a reduction of the sample magnetization by 20% within the first ps after excitation. This is followed by a further magnetization decrease within 100ps. While the latter time scale corroborates earlier observations [1] and is assigned to spin-lattice relaxation, the sub-ps component suggests ultrafast demagnetization via the exchange interaction between the 5d6s valence and the 4f core electrons.

[1] A. Vaterlaus *et.al.*, Phys. Rev. Lett. 67, 3314 - 3317 (1991)

MA 26.13 Thu 17:45 EB 301

Ultrafast dynamics in optically excited nickel nanodiscs — •Georg Müller[1], Gerrit Eilers[1], Zhao Wang[1], Malte Scherff[1], Ran Ji[2], Kornelius Nielsch[2], and Markus Münzenberg[1] — [1]IV. Phys. Institute, Georg-August-University, Friedrich-Hund-Platz 1, D-37077 Göttingen — [2]Max Planck Institute of Microstructure Physics, Weinberg 2, D-06120 Halle

The temporal change in the Kerr angle of an in-plane magnetized nano patterned nickel wedge structure as the response to a fs laser pulse is investigated. The examined structure consists of an array of discs with a diameter of 185 nm and a separation of 280 nm, whose thickness is varied from 4 to 40 nm, and is prepared by optical interference lithography. The traced Kerr signal dynamics comprises a wealth of different modes which can be mostly attributed to reflectivity changes of the film due to the generation of surface acoustic waves or even magnetoelastic coupling. Nevertheless, one mode is clearly identified to be of pure magnetic origin. The theoretical mode spectrum of a single nanodisc obtained by micromagnetic simulations shows that the experimentally excited mode is of end mode type. A comparison between the theoretically and experimentally determined dependence of the frequency on the structure thickness allows to derive an approximate expression for the dipole interaction between the discs in the patterned film.

Research is supported by the DFG priority program 1133 'Ultrafast Magnetization Processes'.

MA 26.14 Thu 18:00 EB 301

Laser-Induced Magnetization Dynamics of Holmium-Doped Permalloy Thin Films — •Ilie Radu[1,4], Matthias Kiessling[1], Georg Woltersdorf[1], Alexey Melnikov[2], Uwe Bowensiepen[2], Jan Thiele[3], Martin Wolf[2], and Christian Back[1] — [1]Institut für Experimentelle Physik, Universität Regensburg — [2]Fachbereich Physik, Freie Universität Berlin — [3]Hitachi GST, San Jose Research Center, USA — [4]BESSY GmbH, Berlin

The magnetization response of holmium-doped permalloy thin films after femtosecond laser excitation is studied by time-resolved magneto-optical Kerr effect (TR-MOKE). The investigated system consists of 10 nm Permalloy (Py) films doped with Holmium (Ho) at concentrations ranging from 1% to 8%. Consequently, the magnetization damping parameter changes from 0.008 (pure Py) to 0.2, as deduced from ferromagnetic resonance measurements. Thus, we can investigate the contribution of the impurity-assisted spin-flip scattering to the photo-induced demagnetization process. From the TR-MOKE data we observe: (i) a drop in the transient MOKE signal that evolves within the first hundreds of femtoseconds after optical excitation (ii) a gradual shift to longer pump-probe delays of the minimum position of the transient MOKE signal as the Ho impurity content increases. The results will be discussed along the lines of a recent theoretical model [1] which propose a laser-induced demagnetization mechanism determined by impurity- or/and phonon-mediated spin-flip scattering processes.

[1] B. Koopmans et al., PRL 95, 267207 (2005)

MA 26.15 Thu 18:15 EB 301

Photo-Induced Magnetization Dynamics of FeRh Thin Films Investigated by Time-Resolved X-ray Magnetic Circular Dichroism — •Ilie Radu[1,2], Christian Stamm[2], Torsten Kachel[2], Niko Pontius[2], Paul Ramm[1], Jan Thiele[3], Hermann Dürr[2], and Christian Back[1] — [1]Institut für Experimentelle Physik, Universität Regensburg — [2]BESSY GmbH, Berlin — [3]Hitachi GST, San Jose Research Center, USA

For close to equiatomic composition the FeRh alloy undergoes a first-order phase transition from the antiferromagnetic (AFM) to ferromagnetic (FM) state upon heating above room temperature. We trigger the magnetic phase transition by femtosecond laser excitation and study the subsequent dynamics of the Fe and Rh magnetic moments in an element specific manner using X-ray magnetic circular dichroism (XMCD) as a probing tool. For both elements we observe a gradual growth of ferromagnetic ordering that takes place on a ˜200 ps time scale after optical excitation. On the other hand, once in the FM state, FeRh can be demagnetized on a few picoseconds time interval, the observed dynamics being limited by the width of the X-ray probing pulse (here ˜10 ps). By comparison to the demagnetization dynamics measured on Ni under similar conditions, we retrieve the lower limit of the demagnetization process that evolves on a sub-picosecond time scale. Hence, the AFM-FM phase transition in conjunction with time-resolved XMCD allow us to study at a microscopic level the elementary processes involved in the magnetization growth, demagnetization and re-magnetization phenomena.

MA 26.16 Thu 18:30 EB 301

First-principles study of ultrafast magneto-optical swithing in nickel oxide: Phononic contributions. — •Georgios Lefkidis and Wolfgang Hübner — Dept. of Physics, Kaiserslautern University of Technology, Box 3049, 67653 Kaiserslautern, Germany.

NiO is a good candidate for ultrafast magnetic swiching because of its large spin density, antiferromagnetic order, and clearly separated intragap states. In order to detect and monitor the switching dynamics, we develop a systematic approach to study optical second harmonic generation in NiO, both at the (001) surface and in the bulk [1-2].

We model NiO as a doubly embedded cluster and obtain all intragap d-states of the bulk and the (001) surface with highly correlational quantum chemistry. Then we propagated the states in time under the influence of a static magnetic field and a laser pulse. Switching can be best achieved with linearly polarized light. We also show the importance of including an external magnetic field in order to distinguish spin-up and spin-down states and the necessity of including magnetic-dipole transitions in order to realize the Λ-process in the centrosymmetric bulk [3]. Having already shown the effects of phonons in SHG for the bulk within the frozen phonon approximation [4], we discuss their role as a symmetry-lowering mechanism in the switching scenario and investigate the electronic and lattice temperature effects.

[1] R. Gómez-Abal *et al.*, PRL **92**, 227402 (2004)
[2] G. Lefkidis and W. Hübner, PRL **95**, 077401 (2005)
[3] G. Lefkidis and W. Hübner, PRB **76**, 014418 (2007)
[4] G. Lefkidis and W. Hübner, PRB **74**, 155106 (2006)