MA 45: Magnonics I

Time: Thursday 9:30–13:00 Location: HSZ 401

MA 45.1 Thu 9:30 HSZ 401

Propagation of coherent spin waves in individual nano-sized yttrium iron garnet magnonic conduits — •B. Heinz[1,2], T. Brächer[1], M. Schneider[1], Q. Wang[1], B. Lägel[3], A. M. Friedel[1], D. Breitbach[1], S. Steinert[1], T. Meyer[4], M. Kewenig[1], C. Dubs[5], P. Pirro[1], and A. V. Chumak[1,6] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Germany — [3]Nano Structuring Center, TU Kaiserslautern, Germany — [4]THATec Innovation GmbH, Germany — [5]INNOVENT e.V., Technologieentwicklung Jena, Germany — [6]Faculty of Physics, University of Vienna, Austria

Modern-days CMOS-based computation technology is reaching fundamental limitations. A promising path to overcome these limitations is the emerging field of magnonics which utilizes spin waves for data transport. However, the feasibility of this technology essentially relies on the scalability to the nanoscale and a proof that coherent spin waves can propagate in these structures. Here, we present a study of the spin-wave dynamics in individual yttrium iron garnet (YIG) magnonic conduits with lateral dimensions down to 50 nm. Space and time resolved micro-focused Brillouin-Light-Scattering spectroscopy is used to directly measure the spin-wave decay length and group velocity. Thereby, the first experimental proof of propagating spin waves in individual nano-sized YIG conduits is demonstrated. We acknowledge funding by ERC Starting Grant 678309 MagnonCircuits, DFG Grant DU 1427/2-1 and the Graduate School Material Science in Mainz.

MA 45.2 Thu 9:45 HSZ 401

Realization of a nanoscale magnonic directional coupler for all-magnon circuits — •Qi Wang[1], Martin Kewenig[1], Michael Schneider[1], Roman Verba[2], Björn Heinz[1,3], Moritz Geilen[1], Morteza Mohseni[1], Bert Lägel[4], Florin Ciubotaru[5], Christoph Adelmann[5], Carsten Dubs[6], Sorin Cotofana[7], Thomas Brächer[1], Philipp Pirro[1], and Andrii Chumak[1,8] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Kaiserslautern, Germany — [2]Institute of Magnetism, Kyiv, Ukraine — [3]Graduate School Materials Science in Mainz, Mainz, Germany — [4]Nano Structuring Center, Technische Universität Kaiserslautern, Kaiserslautern, Germany — [5]Imec, Leuven, Belgium — [6]INNOVENT e.V., Technologieentwicklung, Jena, Germany — [7]Department of Quantum and Computer Engineering, Delft University of Technology, Delft, The Netherlands — [8]Faculty of Physics, University of Vienna, Vienna, Austria

Magnonics is a promising alternative in view of beyond-Moore computing in which information is carried by magnons instead of electrons. However, the major challenge in magnon-based computing is the transition from a single logic unit to an integrated circuit. Here, we report a nanoscale directional coupler fabricated from an 85 nm thick Yttrium Ion Garnet film, which consists of two coupled waveguides with a width of 350 nm separated by a gap of 320 nm. The directional coupler can be used as a universal unit for all-magnon circuits, working as a multiplexer, a AND gate and an XOR gate. These functions are demonstrated by Brillouin light scattering spectroscopy.

MA 45.3 Thu 10:00 HSZ 401

Investigation of spin wave focusing by a magnetic field gradient — •Philipp Geyer[1], Rouven Dreyer[1], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Von-Danckelmann-Platz 3, 06120 Halle (Saale), Germany — [2]Interdisziplinäres Zentrum für Materialwissenschaften, Martin-Luther-Universität Halle-Wittenberg, Nanotechnikum Weinberg, 06120 Halle (Saale), Germany

Magnonics is a promising field to realize low energy information transmission and processing. It has been shown experimentally, that spin waves passing through a lateral thickness variation in a magnetic thin film obey snell's law [1]. So, a spatial change of the dispersion parameters like film thickness [2] or magnetic field can be used to deflect and focus a plane spin wave. We show that a magnetic field gradient can be induced using the demagnetizing field of a localized, lateral confinement inside an YIG film. Already a simple rectangular constriction can be used to create a spin wave interference pattern, which focuses the incident spin wave and remain stable when changing the external magnetic field or excitation frequency. It should be noted that the intensity at the focus is higher than at the position of the lens which was not observed in past experiments. The lens shape was first investigated using micromagnetic simulations with MuMax3. The fabricated lenses and their performance were characterized with spatially and time resolved magneto-optical Kerr microscopy (TR-MOKE) measurements.

[1] J. Stigloher et al., Phys. Rev. Lett. 117, 037204 (2016) [2] J. Toedt et al., Scientific Reports 6, 33169 (2016)

MA 45.4 Thu 10:15 HSZ 401

Dynamic Unidirectional Magnetic Anisotropy due to Chiral Magnetic Coupling — •Nicolas Josten[1], Benjamin Zingsem[1], Thomas Feggeler[1], Ralf Meckenstock[1], Detlef Spoddig[1], Marina Spasova[1], Ke Chai[2], Iliya Radulov[3], Zi-An Li[2], Oliver Gutfleisch[3], and Michael Farle[1] — [1]Faculty of Physics and Center for Nanointegration (CENIDE), University Duisburg Essen, Duisburg, 47057, Germany — [2]Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China — [3]Department of Material- and Geosciences, Functional Materials, Technical University Darmstadt, Germany

Non-centrosymmetric crystal structures like cubic FeGe show an antisymmetric exchange often denoted as Dzyaloshinskii-Moriya interaction (DMI). In addition to static spin structures like helices or skyrmions DMI leads to a shift of the dispersion curve. We investigated the dynamic magnetic properties of millimeter and micrometer sized polycrystalline FeGe samples using resonator-based X-band and K-band ferromagnetic resonance (FMR). The measurements reveal unidirectional anisotropy [1], i.e. a change of the resonance position of up to 30 mT after inversion of the magnetic field direction. This difference is present at all investigated temperatures (80K - 280K), frequencies and sample sizes.

[1] N. Josten et al., Dynamic unidirectional anisotropy in cubic FeGe with antisymmetric spin-spin-coupling, submitted to Scientific Reports.

MA 45.5 Thu 10:30 HSZ 401

Reflection-less width-modulated magnonic crystals — •Pascal Frey[1], Aleksei A. Nikitin[2], Alexey B. Ustinov[2], Florin Ciubotaru[3], Andrii V. Chumak[4], Burkard Hillebrands[1], and Alexander A. Serga[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Department of Physical Electronics and Technology, St. Petersburg Electrotechnical University, 197376 St. Petersburg, Russia — [3]imec, B-3001 Leuven, Belgium — [4]Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria

Magnonic crystals receive a lot of attention in spintronics, due to their great potential for information processing technologies. The main features of these crystals are the presence of bandgaps in the spin-wave spectra. The bandgaps are formed due to Bragg reflections from the artificially created periodic structures. In this work, we studied spin-wave propagation in longitudinally magnetized width-modulated yttrium-iron-garnet waveguides by means of both Brillouin light scattering and microwave spectroscopies. Short pulses (30 ns) of backward volume magnetostatic spin waves were excited, close to the ferromagnetic resonance frequency, and their propagation was visualized and measured, both in pass and rejection frequency bands. We found, that the width-modulated magnonic crystal, shows a new underlying mechanism, where no back reflection of the spin-wave pulse is observed. Such a reflection-less magnonic crystal is a promising candidate for the realization of frequency selective or multi-component devices.

15 min. break.

MA 45.6 Thu 11:00 HSZ 401

Frequency multiplication effects in thin ferromagnetic layers detected by diamond nitrogen-vacancy center microscopy — •Chris Körner, Rouven Dreyer, Niklas Liebing, and Georg Woltersdorf — Martin Luther University Halle-Wittenberg, 06120 Halle, Germany

In thin ferromagnetic layers inhomogeneous magnetic properties can lead to frequency multiplication effects generating high harmonics of the rf driving field close to ferromagnetic resonance. Scanning time-resolved Kerr microscopy is employed to spatially resolve those high harmonics as well as parametric excitations [1]. Since the spatial frequency of the magnetic response increases at higher harmonics, the diffraction limited resolution of the microscope leads to an averaging of the Kerr response within the laser spot. Hence, a more local probing technique is required to resolve magnetization dynamics. Because of their extremely small size and strong response to magnetic fields, Nitrogen-vacancy defect centers in diamond offer an ideal method to detect fields locally. The optical detection of magnetic resonance (ODMR) is a double-resonant technique to locally probe magnetic fields with the help of those defect centers [2]. It allows for the detection of up to the 25th harmonic of the rf excitation frequency generated by the precessing magnetic moments in a Permalloy film at low magnetic bias fields as well as parametric excitations at large driving amplitudes.

[1] R. Dreyer et al. ArXiv:1803.04943 (2018)
[2] C. S. Wolfe et al. ArXiv 1512.05418v2 (2016)

MA 45.7 Thu 11:15 HSZ 401

Probing magnetic excitation by spin-polarized scanning tunneling microscopy — •Hung-Hsiang Yang[1,2], Masayuki Hamada[1], Yasuo Yoshida[1], and Yukio Hasegawa[1] — [1]Institute for Solid State Physics, 5-1-5, Kashiwa-no-ha, Kashiwa, Chiba 277-8581, Japan — [2]Physikalisches Institut, Karlsruhe Institute of Technology, Wolfgang-Gaede-Str. 1, Karlsruhe, 76131, Germany

Magnetic excitation due to inelastic electron scattering plays a crucial role in spintronics devices concerning the spin lifetime of polarized electrons and the amount of spin transfer torque for switching magnetic configurations in magnetic tunnel junctions. One of the fundamental processes is magnon creation, which occurs when injected hot electrons induce spin-flip scattering of the magnetic material. To image and address the magnetic origin of the excitations, we have performed low-temperature spin-polarized inelastic electron tunneling spectroscopy (IETS) on double layer Mn thin films formed on W(110) substrate. The atomically-thin magnetic layer exhibits a homogeneous spin spiral with antiferromagnetic coupling, which provides a good reference for spin-polarized scanning tunneling microscopy (STM). Characteristic peak-dip feature in IETS, as well as its correlation with the spin spiral, are acquired. Additionally, we have observed contrast reversal in the IETS intensity when the tip magnetization direction is flipped, indicating that the excitation is spin-dependent and thus presumably due to magnon creation. The spatial distribution of the magnon excitation and its energy dependence will be discussed in the presentation.

MA 45.8 Thu 11:30 HSZ 401

Non-standing spin-waves in confined micron-sized structures imaged with time-resolved STXM — •Santa Pile[1], Taddäus Schaffers[1], Sven Stienen[2], Martin Buchner[1], Sebastian Wintz[3], Sina Mayr[4], Johannes Förster[3], Verena Ney[1], Rysard Narkowicz[2], Kilian Lenz[2], Markus Weigand[5], Jürgen Lindner[2], and Andreas Ney[1] — [1]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, 4040 Linz, Austria — [2]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [3]Max Planck Institute for Intelligent Systems, Stuttgart, Germany — [4]Paul Scherrer Institute, Villigen PSI, Switzerland — [5]Helmholtz-Zentrum Berlin, Berlin, Germany

The STXM-FMR setup enables the visualization of the high frequency magnetization dynamics in the GHz regime with a high lateral resolution of nominally 35 nm and a time resolution of 17.4 ps [1]. In this contribution we present the results for the magnetic $Ni_{80}Fe_{20}$ micron-sized stripes with dimensions: 5x1x0.03 μm^3. For FMR and STXM-FMR measurements a static magnetic field was applied in the plane of the stripes. Both FMR and STXM-FMR measurements confirm that quasi-uniform and spin-wave modes can be excited in the samples. With increasing the static magnetic field it is possible to observe the transition from one mode to another and also a superposition of the modes in-between the FMR signals, when a non-standing character of the spin-waves is visible. Financial support by the Austrian Science Fund (FWF), Project No. I-3050 is gratefully acknowledged.

[1] T. Schaffers et al., Nanomaterials 9, 940 (2019).

MA 45.9 Thu 11:45 HSZ 401

Detection of magnons in thin ferromagnetic films by ferromagnetic resonance measurements — •Sergej Andreev, Julian Braun, Elke Scheer, and Torsten Pietsch — Physics Department, University of Konstanz, 78457 Konstanz, Germany

We report measurements of the ferromagnetic resonance (FMR) of thin ferromagnetic films and bilayers of Ni, Co, Py and NiCo by FMR measurements in a broadband resonator from 2 to 40 GHz with an applied magnetic field in plane at 4 K and deduce their spin wave spectra from these data. We obtain information on the magnetization and the Gilbert damping of perpendicular polarized magnons. Superimposed onto the spin wave absorption lines, we observe an amplification of the FMR signal with a Fano resonance shape at distinct frequencies, which are absent without the ferromagnetic fields. We interpret this finding as an enhancement and modification of the resonator properties by the coupling to the ferromagnetic layer.

MA 45.10 Thu 12:00 HSZ 401

Phase-sensitive and Spatially Resolved Detection of Magnetization Dynamics — •Lukas Liensberger[1,2], Luis Flacke[1,2], David Rogerson[1,2], Matthias Althammer[1,2], Rudolf Gross[1,2,3], and Mathias Weiler[1,2] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Germany — [2]Physik-Department, Technische Universität München, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Germany

In the recent years, many advances in utilizing spinwaves and their quanta, magnons, have been made in order to transport and store information. The precise and accurate determination of dynamic magnetic properties like magnetic damping and spinwave propagation length is essential to design magnonic devices. The established broadband ferromagnetic resonance spectroscopy with a vector network analyzer (BMR) is the key technique to determine damping characteristics in unpatterned samples. It however lacks the ability to measure the magnetization dynamics locally and to detect propagating spinwaves with non-zero wavenumber.

Here, we establish the micro-focused frequency-resolved magneto-optic Kerr effect (μFR-MOKE), which is essentially a spatially resolved BMR technique with sub-micrometer resolution. We present μFR-MOKE studies of propagating micrometer-scale spinwaves in microstructured ferromagnet/normal metal samples with $Co_{25}Fe_{75}$ as the ferromagnet and compare the μFR-MOKE results to those obtained using established micro-focused Brillouin light scattering. We acknowledge financial support by the DFG via project WE5386/4-1.

MA 45.11 Thu 12:15 HSZ 401

Threshold determination of non-linear spin-wave generation at low magnetic bias field — •Rouven Dreyer, Niklas Liebing, Chris Körner, and Georg Woltersdorf — Martin Luther University Halle-Wittenberg, Institute of Physics, Von-Danckelmann-Platz 3, 06120 Halle (Saale), Germany

Recently it was shown that the prediction of the non-linear spin-wave excitation in the framework of Suhl instability processes is not adequate at low magnetic bias fields. In particular, it was shown by spatially averaged and time-resolved x-ray ferromagnetic resonance spectroscopy that in the low bias field regime non-linear spin waves are excited parametrically at 3/2 of the excitation frequency [1].

Here we demonstrate the 3/2 ω non-linear spin-wave (NLSW) generation in $Ni_{80}Fe_{20}$ microstructures using a novel variant of scanning magneto-optical microscopy which we term super-Nyquist sampling microscopy (SNS-MOKE) [2]. This technique allows for phase-resolved imaging of the sample at multiple arbitrary frequencies. In this way we detect parametrically excited NLSWs at 3/2 of the excitation frequency in space and time directly. For this type of non-linearities we determine the threshold rf-field for different sample geometries and investigate the phase stability of the NLSW generation as a function of rf-field and bias field. The corresponding wave vectors obtained from the 2D-FFT of the observed spatially resolved spin-wave pattern at 3/2 ω above the threshold rf-field are in agreement with the predictions from Bauer et al. [1]. [1] H. G. Bauer et al., Nat. Commun. 6:8274 (2015) [2] R. Dreyer et al., arXiv:1803.04943 (2018)

MA 45.12 Thu 12:30 HSZ 401

Generation and tuning of a spin wave frequency comb — •Tobias Hula[1], Luis Flacke[2,3], Lukas Liensberger[2,3], M Copus[4], Katrin Schultheiss[1], Aleksandr Buzdakov[1], Mathias Weiler[2,3], Robert Camley[4], and Helmut Schultheiss[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Walther-Meißner-Institute, Bayerische Akademie der Wissenschaften, Garching, Germany — [3]Physik-Department, Technische Universität München, Munich, Germany — [4]Center for Magnetism and Magnetic Nanostructures, University of Colorado, Colorado Springs, USA

We present experimental results on the generation of a spin wave frequency comb in a Co25Fe75 wave guide measured by Brillouin light scattering microscopy. By driving the magnetisation at large precession angles, using high RF amplitudes, non-linear four magnon scattering can be observed. When mixing two RF signals with different frequencies and amplitudes, we can actively control the final states that will be populated by this scattering process. Our results show the generation of a frequency comb consisting of several spin waves with tuneable frequency spacing and amplitude. This effect is investigated in different sample geometries, which allow mixing of co-propagating as well as counter-propagating spin waves. Our experimental observations are in qualitative agreement with micromagnetic simulations.

Financial support by the Deutsche Forschungsgemeinschaft within programs SCHU2922/1-1 and WE 5386/4-1 is gratefully acknowledged. K.S. acknowledges funding within the Helmholtz Postdoc Programme.

MA 45.13 Thu 12:45 HSZ 401

Spin wave excitation by surface acoustic waves — •Moritz Geilen[1], Felix Kohl[1], Alexandra Nicoloiu[2], Florin Ciubotaru[3], Christoph Adelmann[3], Alexandru Müller[2], Burkard Hillebrands[1], and Philipp Pirro[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]IMT, Bucharest, Romania — [3]IMEC, Leuven, Belgium

Surface acoustic waves (SAW) are strain waves which are located close to the surface of a medium. They are widely used in bandfilters up to the GHz regime because of their tuneability and narrow bandwidth given by wavevector selection during excitation and detection. Is a magnetic film placed on the surface of the medium an effective field is generated by the magnetoelastic interaction. This field can be used to excite spin waves. We present the investigation on spin wave excitation in a CoFeB microstripe on top of a GaN layer. Both, the SAWs and the spin waves, have been measured by Brillouin light scattering microscopy. With this technique spatially resolved measurements are possible while the signals caused by phonons and magnons can be well separated by the polarization of the scattered light. We found that spin waves can be excited in a wide wavevector regime. We acknowledge the support of the EU under H2020 FET Open Project CHIRON (grant agreement no 692519 2018 - 2021).