MA 8: Magnonics

Time: Monday 15:00–18:45 Location: H52

MA 8.1 Mon 15:00 H52

Integrated magnonic half-adder — •Qi Wang[1], Roman Verba[2], Thomas Brächer[1], Philipp Pirro[1], and Andrii Chumak[1] — [1]Fachbereich Physik, Technische Universität Kaiserslautern, Kaiserslautern, Germany — [2]Institute of Magnetism, Kyiv 03680, Ukraine

Spin waves and their quanta, magnons, open up a promising branch of high-speed and low-power information processing. Several important milestones were achieved recently in the realization of separate magnonic data processing units. Nevertheless, the realization of an integrated magnonic circuit consisting of at least two logic gates and suitable for further integration is still an unresolved challenge. Here we demonstrate such an integrated circuit. We show a magnonic half-adder using micromagnetic simulations. The magnonic half-adder has a strikingly simple design, consisting of two components only. The first one is a linear directional coupler that combines two inputs in a planar fashion. The second one is a nonlinear directional coupler in which the coupling strength is strongly dependent on the input power and which perform simultaneously a XOR and an AND logic operation. All information is carried and controlled exclusively by magnons in the circuit.

MA 8.2 Mon 15:15 H52

Efficient Magnonic Spin Transport in Insulating Antiferromagnetic Thin Films — •Andrew Ross[1,2], Romain Lebrun[1], Scott Bender[3], Joel Cramer[1,2], Asaf Kay[4], David Ellis[4], Daniel Grave[4], Lorenzo Baldrati[1], Alireza Qaiumzedah[5], Arne Brataas[5], Anvar Rothschild[4], Rembert Duine[3,5,6], and Mathias Kläui[1,2,5] — [1]Johannes Gutenberg University Mainz, Germany — [2]Graduate School of Excellence MAINZ, Germany — [3]Utrecht University, The Netherlands — [4]Technion-Israel Institute of Technology, Israel — [5]QuSpin, Norwegian University of Science and Technology, Norway — [6]Eindhoven University of Technology, The Netherlands

Antiferromagnet (AF) insulators benefit from unparalleled stability in external fields, magnetisation dynamics at THz frequencies, a lack of stray fields and have been shown to exhibit low Gilbert damping, which enables efficient long-range propagation of magnons[1] as recently demonstrated[2]. Here we investigate the underlying mechanisms behind magnon transport in AF thin films. We find that efficient spin transport is possible across μm distances in nm thick thin films, contrary to previous studies reporting only nm spin-diffusion lengths in AF thin films[3]. By XMLD imaging of the AF domains we demonstrate the role of magnetic correlation in the propagation of magnons. We achieve efficient control over the AF system and establish the possibility to propagate long-distance spin-waves in AF thin films. [1] Chumak et al., Nature Phys. 11, 6 (2015), [2] Lebrun et al., Nature 561 (2018), [3] Cramer et al., J. Phys. D: Appl. Phys. 51, 14 (2018)

MA 8.3 Mon 15:30 H52

Phase-resolved imaging of non-linear spin-wave excitation at low magnetic bias field — •Rouven Dreyer, Lea Apel, Niklas Liebing, 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 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) excitation in $Ni_{80}Fe_{20}$ microstructures using time-resolved table-top magneto-optical microscopy. We have developed 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 arbitrary frequencies. In this way we detect the parametrically excited NLSWs at 3/2 ω of the excitation frequency in space and time directly. The corresponding wave vectors obtained from the two dimensional Fourier transformation of the observed spin-wave pattern at 3/2 ω and higher harmonics are in agreement with the theoretical 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 [cond-mat.mes-hall] (2018)

MA 8.4 Mon 15:45 H52

Magnon Bose-Einstein condensation in a wide temperature range — •Laura Mihalceanu, Dmytro A. Bozhko, Vitaliy I. Vasyuchka, Alexander A. Serga, and Burkard Hillebrands — Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

Today, magnon Bose-Einstein condensates (BEC) and supercurrents are experimentally confirmed phenomena, which exist on a macroscopic scale in parametrically driven spin systems at room-temperature. Allowing for a charge-free information transport and being, thus, free from ohmic heating these macroscopic quantum phenomena pave the path towards more efficient computing technologies. Specifically, they possess the potential for low power consumption information transfer and processing of phase-encoded data by nanometer-sized devices at GHz and THz frequencies. Temperature-dependent experiments provide valuable information about the magnon BEC as its lifetime, threshold, and coherency. Prior, we studied the relaxation behavior of parametrically injected magnons with wavenumbers ranging up to 6×10^5 rad cm^{-1} from 20K to 340K by means of the conventional microwave technique. Here, we incorporate the Brillouin Light Scattering (BLS) spectroscopy via the direct detection of condensed magnons at the bottom of the spin-wave spectrum. This allows us to investigate the magnon BEC formation, as well as magnon supercurrents in a wide range of temperatures. By comparing the microwave results with those of the BLS measurements, we reveal a correlation between the damping of the parametric magnons and the BEC formation.

MA 8.5 Mon 16:00 H52

Second sound in magnon Bose-Einstein condensate — •Halyna Yu. Musiienko-Shmarova[1], Dmytro A. Bozhko[1], Alexander J.E. Kreil[1], Alexander A. Serga[1], Anna Pomyalov[2], Victor S. L'vov[2], and Burkard Hillebrands[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Department of Chemical and Biological Physics, Weizmann Institute of Science, Rehovot 76100, Israel

A macroscopic collective motion of a quantum condensate is commonly associated with phenomena such as superconductivity and superfluidity, often generalized by the term supercurrent. A quantum condensate supports also another type of motion – second sound. Second sound can be considered as a flow of elementary excitations of various types, which can propagate in a continuous medium with an almost linear dispersion law in the long-wavelength limit. Here, this refers to Bogoliubov waves with oscillations of both the amplitude and the phase of the Bose-Einstein Condensate's (BEC) wave function. We discovered a Bogoliubov wave, magnon second sound, in a magnon BEC prepared by microwave parametric pumping in a room-temperature yttrium iron garnet film. Furthermore, we demonstrate a transition from the supercurrent-type to the second-sound-type motion of the magnon BEC. Financial support from the ERC Advanced Grant "SuperMagnonics" is acknowledged.

MA 8.6 Mon 16:15 H52

Free standing 3D yttrium iron garnet nanobridges with very low Gilbert damping fabricated by room temperature laser deposition. — •Philip Trempler[1], Christoph Hauser[1], Philipp Geyer[1], Rouven Dreyer[1], Frank Heyroth[2], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Germany — [2]Interdisziplinäres Zentrum für Materialwissenschaften, MLU Halle-Wittenberg, Germany

We have fabricated YIG nanobridges by electron beam lithography and room temperature laser deposition with subsequent recrystallization [1]. The structures are monocrystalline except for a single defect in the center of the span. In ferromagnetic resonance the linewidth is 140 *T at 8 GHz and the Gilbert damping can be as low as 2x10-4. Investigations with spatially and time resolved magneto-optic Kerr effect (TR-MOKE) show various resonant magnon modes in the 3D nanobridges. Additionally inductively detected FMR was performed on single YIG bridges confirming the low damping which is in the

range typically known for high quality PLD grown YIG thin films. This makes these YIG bridges perfect candidates for more complex spintronic devices where coupling of magnons and mechanical oscillations is utilized [2]. By coupling these excitations to Qubits the structures may ultimately be used in transmons for quantum information processing [3].

[1] Heyroth, F., et al., arXiv:1802.03176 (2018)
[2] Tabuchi, Yutaka, et al, Phys. Rev. Lett. 113.8 (2014)
[3] Zhang, Xufeng, et al., Phys. Rev. Lett. 113.15 (2014)

MA 8.7 Mon 16:30 H52

Construction and investigation of spin wave lenses — •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, just by excitation of the spin lattice and not by moving electrons. 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 controlled change of the dispersion parameters like film thickness or magnetic field can be used to focus a plane spin wave [2]. We present two different types of spin wave lenses that are realized by lateral patterning of thin film Yttrium-Iron-Garnet (YIG) fabricated by room temperature pulsed laser deposition and subsequent annealing [3]. Both types of lenses are designed for spin waves in Damon-Eshbach geometry. We investigate their functionality by micromagnetic simulations with mumax3 [4] and experimentally with spatially and time resolved magneto-optical Kerr effect (TR-MOKE) and ferromagnetic resonance (FMR) measurements.

[1] J. Stigloher et al., Phys. Rev. Lett. 117, 037204 (2016) [2] J. Toedt et al., Scientific Reports 6, 33169 (2016) [3] C. Hauser et al., Scientific Reports 6, 20827 (2016) [4] A. Vansteenkiste et al., AIP Advances 4, 107133 (2014)

MA 8.8 Mon 16:45 H52

Unidirectional spin wave propagation in a magnetic bilayer system — •Moritz Geilen[1], Matías Grassi[2], Morteza Mohseni[1], Yves Henry[2], Thomas Brächer[1], Damien Louis[2], Michel Hehn[3], Matthieu Bailleul[2], Burkard Hillebrands[1], and Philipp Pirro[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Institut de Physique et Chimie des Matériaux de Strasbourg, CNRS and Université de Strasbourg, Strasbourg, France — [3]Institut Jean Lamour, Université de Lorraine, UMR 7198 CNRS, 54506 Vandoeuvre-lés-Nancy, France

We present the realization of a magnonic diode based on a magnetic bilayer system, which allows spin wave propagation effectively only in one direction. Spin waves traveling perpendicular to the static magnetization intrinsically show a non-reciprocal propagation. But as long as both surfaces of the film are equal and the film itself has homogenous material parameters across its thickness, the frequencies of counter-propagating spin waves are degenerate. This symmetry is broken in a magnetic bilayer system leading to a frequency shift between counter-propagating spin waves with the same wavelength, while leaving the good propagation characteristics of the materials unharmed. This non-reciprocal behaviour is studied in a CoFeB/Py bilayer film using wave-vector resolved Brillouin light scattering spectroscopy (BLS) and micromagnetic simulations. The spin wave propagation in the microstructured device is measured using BLS microscopy. It reveals unidirectional spin-wave propagation in a wide frequency range.

15 min. break

MA 8.9 Mon 17:15 H52

Magnonic crystals on atomic length scales — Huajun Qin[1,2], Sergey Tsurkan[1], Arthur Ernst[3,4], and •Khalil Zakeri Lori[1] — [1]Heisenberg Spin-dynamics Group, Physikalisches Institut, Karlsruhe Institute of Technology, Wolfgang-Gaede-Str. 1, D-76131 Karlsruhe, Germany — [2]NanoSpin, Department of Applied Physics, Aalto University School of Science, FI-00076 Aalto, Finland — [3]Institute for Theroretical Physics, Johannes Kepler University,Altenberger Str. 69, 4040 Linz, Austria — [4]Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, D-06120 Halle, Germany

We discuss the possibility of designing atomic-scale magnonic crystals for operation in terahertz regime. Utilizing spin-polarized high-resolution electron energy-loss spectroscopy we investigate ferromagnetic multilayers composed of alternating layers of Fe and Co grown on different substrates. We show that in such atomically designed multilayers one can efficiently excite different magnon modes associated with the quantum confinement in the third dimension i.e., the direction perpendicular to the layers. We demonstrate experimentally that the magnonic band structure in these materials exhibits bands of allowed magnon states as well as forbidden gaps. The band structure can be tuned by changing the materials combination and the number of atomic layers. The work has been supported by the Deutsche Forschungsgemeinschaft (DFG) through the Heisenberg Programme ZA 902/3-1 and the DFG grant ZA 902/4-1.

MA 8.10 Mon 17:30 H52

Spin waves in disordered film and bulk samples — Pawel Buczek[1], •Martin Hoffmann[2], Wulf Wulfhekel[3], Khalil Zakeri[4], and Arthur Ernst[2,5] — [1]Fakultät Technik und Informatik, Hochschule für Angewandte Wissenschaften Hamburg, Germany — [2]Institute for Theoretical Physics, Johannes Kepler University Linz, Austria — [3]Physikalisches Institut, Karlsruhe Institute of Technology, Germany — [4]Heisenberg Spin-dynamics Group, Physikalisches Institut, Karlsruhe Institute of Technology, Germany — [5]Max Planck Institute of Microstructure Physics, Halle, Germany

In many studied materials and mixed compounds, the magnetic response and in particular the energy spectrum of magnons will be strongly influenced by different kinds of disorder. Thin films might consist of islands or alloys might form solid solutions. Hence, we need to take into account disorder as well, in order to describe magnons theoretically. We will present briefly the underlying theory of our two complementary approaches based on a Heisenberg model. The included effective interaction between magnetic moments entering the Heisenberg model can be obtained from first-principles using a self-consistent Green function method within the density functional theory. We demonstrate the application of both methods on experimentally relevant material systems: 3ML Co/Cu(001), 1ML Fe/Pd(001), and Fe-Co alloys. Taking into account the disorder improves a lot the agreement between the spin-polarized electron energy loss spectroscopy measurements and the theoretical results.

MA 8.11 Mon 17:45 H52

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

We demonstrate that inhomogenous magnetic properties can lead to frequency multiplication effects. Close to ferromagnetic resonance, this effect locally generates high harmonics of the magnetic driving field. In the experiment, we detect multiple harmonics as well as parametric excitations in thin ferromagnetic layers via scanning time-resolved Kerr microscopy (MOKE) [1]. The spatial frequencies of the response of the magnetic system increases at higher harmonics up to the diffraction-limited resolution of the microscope. Nitrogen-vacancy defect centers (NV-centers) in diamond can be used as local probe of magnetic fields. Here we employ a double-resonant optical detection of magnetic resonance (ODMR) in NV-centers in the vicinity of the ferromagnetic layer [2]. The NV-centers represent a highly localized probe for the dynamic magnetic fields produced by the precessing magnetization in the adjacent ferromagnet. By this means, it is possible to locally detect rf-magnetic fields with spatial frequencies beyond the optical diffraction limit of MOKE. We use this method to detect up to the 20th harmonic of the magnetic excitation frequency in Permalloy at low bias fields and frequencies (as low as 100 MHz) as well as parametric excitations at large driving amplitudes.

[1] R. Dreyer et al. arXiv:1803.04943 [cond-mat.mes-hall] (2018)
[2] C. S. Wolfe et al. ArXiv 1512.05418v2 (2016)

MA 8.12 Mon 18:00 H52

Propagating magnetic droplet solitons as moveable nano-scale spin-wave sources — •Morteza Mohseni[1], Thomas Brächer[1], Qi Wang[1], Majid Mohseni[2], Burkard Hillebrands[1], and Philipp Pirro[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany. — [2]Faculty of Physics, Shahid Beheshti University, Evin, Tehran 19839, Iran

Magnetic droplet solitons are strongly nonlinear magnetic nano-objects which can be formed in spin torque nano-oscillators with large perpendicular magnetic anisotropies. The droplet is a localized magnetodynamical soliton which can only be stabilized in the presence of the applied spin transfer torque. However, a propagating droplet can be an attractive information carrier since it can transport energy and momentum at the same time. Here, we propose a simple way to launch droplets in an inhomogeneous waveguide. We use the drift motion of a droplet and we show that in a system with broken translational symmetry, the droplet acquires momentum and starts to propagate. By using numerical simulations, we find that the droplet velocity is tunable via the strength of the broken symmetry and the size of the nano-contact. In addition, we demonstrate that the launched droplet can propagate up to several micrometers in a realistic system with reasonable damping. Finally, we demonstrate how a blowing droplet delivers its momentum to a highly non-reciprocal spin-wave burst. Such a propagating droplet can be used as a moveable spin-wave source in nano-scale magnonic networks.

MA 8.13 Mon 18:15 H52

Control and stimulation of three-magnon scattering in a magnetic vortex — •Lukas Körber[1,2], Katrin Schultheiss[1], Tobias Hula[1,3], Roman Verba[4], Toni Hache[1], and Helmut Schultheiss[1,2] — [1]Helmholtz-Zentrum Dresden - Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstraße 400, 01328 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany — [3]Technische Universität Chemnitz, 09111 Chemnitz, Germany — [4]Institute of Magnetism, National Academy of Sciences of Ukraine, Kyiv 03680, Ukraine

When applying a large enough RF field amplitude, spin waves in a magnetic vortex disk can be forced to decay into two other spin waves via three-magnon scattering. These scattering processes obey certain selection rules. Here, we show that three-magnon scattering in such a system can be stimulated below the usual instability threshold. We further present how this may be integrated into magnonic conduits by coupling the vortex to a adjacent magnon waveguide. The authors acknowledge financial support from the Deutsche Forschungsgemeinschaft within programme SCHU 2922/1-1.

MA 8.14 Mon 18:30 H52

Temporal evolution of magnon-magnonen interactions in a magnetic vortex — •Tobias Hula[1], Katrin Schultheiss[1], Lukas Körber[1,2], Franziska Wehrmann[1], Kai Wagner[1], and Helmut Schultheiss[1,2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany

Brillouin light scattering microscopy measurements on a Permalloy disk magnetized in the vortex state are presented. By applying a homogenous out-of-plane AC field with sufficiently large amplitudes it is possible to drive the spin waves in the nonlinear regime and initiate three- and four-magnon scattering processes.

Time resolved BLS microscopy is used to show that these pumping conditions cause cascades of different types of magnon-magnon interactions. It is shown, that the temporal transition of different scattering mechanisms can be tuned by the excitation frequency and amplitude.

Further, an experimental approach to determine the coupling between directly excited magnons and magnons excited via nonlinear scattering is presented. To rule out unknown parameters like lifetime and thermal population, tr-BLS measurements with two RF sources where performed.