MA 13: Magnonics 1

Time: Tuesday 9:30–12:30 Location: H43

MA 13.1 Tue 9:30 H43

Topology induced spin-wave modes in curved surfaces — •Michael Vogel[1], Tim Mewes[2], and Claudia Mewes[2] — [1]Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Kassel, Germany — [2]Department of Physics and Astronomy, University of Alabama, Tuscaloosa, USA

Extending the research of magnetization dynamics from planar two-dimensional structures into the third dimension [1] promises rich physics from theoretically predicted fast domain wall velocities beyond the walker breakdown [2] to Cherenkov-like effects for magnons[3]. Here we investigate the effects of curvature in soft-magnetic hemispheres by means of micromagnetic simulation. The resonant spin-wave spectrum is calculated for different geometries and the power-spectral density is evaluated. The interplay of the local curvature and the external field gives rise to new spin-wave modes at relatively high frequencies located a the edge of the three-dimensional objects.

1. R. Kandori et al., J. Phys. D Appl. Phys. J. Phys. D Appl. Phys. 49, 45 (2016). 2. M. Yan, A. Kákay, S. Gliga, R. Hertel, Phys. Rev. Lett. 104, 057201 (2010). 3. M. Yan, A. Kákay, C. Andreas, R. Hertel, Phys. Rev. B - Condens. Matter Mater. Phys. 88, 20412 (2013).

MA 13.2 Tue 9:45 H43

Propagating Spin-Wave Spectroscopy Studies in a Millikelvin Temperature Environment — •David Schmoll, Sebastian Knauer, Rostyslav Serha, Qi Wang, and Andrii Chumak — University of Vienna, Faculty of Physics, Boltzmanngasse 5, A-1090 Vienna, Austria

Technological advancements in the access to millikelvin temperatures, combined with high-frequency microwave technology, allow first steps towards the investigation of individual magnons, as the corresponding quasi-particles of spin waves, in the field of quantum magnonics. Such experiments require millikelvin base temperatures, to ensure a thermal magnon-free system. We measured spin-wave propagation for external bias magnetic fields in the range of 300 mT to -300 mT at room temperature and at a base temperature of 45 mK. The results were obtained in a cryogenic propagating spin-wave spectroscopy setup, comprising a dilution refrigerator, a 9-1-1 T vector magnet, and a 65 GHz-rated VNA measurement system. The spin-wave transmission was measured in a 70 mm × 2 mm × 5.65 μm yttrium-iron-garnet (YIG) film on a 500 μm-thick gadolinium-gallium-garnet (GGG) substrate in the Magnetostatic Surface Spin-Wave Configuration (MSSW), using a microstrip antenna PCB. The demonstration of spin-wave propagation at cryogenic temperatures, provides the technical capabilities and the platform for future investigations of individual magnons. Moreover, direct optical access to the dilution refrigerator allows millikelvin experiments in the field of hybrid opto-magnonic quantum systems.

MA 13.3 Tue 10:00 H43

Finite-element micromagnetic modeling of spin-wave propagation with the open-source package TetraX — •Lukas Körber[1,2], Gwendolyn Quasebarth[1,2], Alexander Hempel[1,2], Andreas Otto[2], Jürgen Fassbender[1,2], and Attila Kákay[1] — [1]Helmholtz-Zentrum Dresden - Rossendorf, Dresden Germany — [2]Fakultät Physik, Technische Universität Dresden

We present a finite-element-method (FEM) dynamic-matrix approach to efficiently calculate the dispersion and spatial mode profiles of spin waves propagating in waveguides with arbitrary cross section, where the equilibrium magnetization is invariant along the propagation direction. This is achieved by solving numerically a linearized version of the equation of motion of the magnetization only in a single cross section of the waveguide at hand. To compute the dipolar field, we present an extension of the well-known Fredkin-Koehler method to plane waves. The presented dynamic-matrix approach is implemented within our recently published open-source micromagnetic modeling package TetraX [1] which aims to provide user friendly and versatile FEM workflows for the magnonics community (not only for magnonics community, but FEM simulations in general), covering several classes of sample geometries and, in the near future, also antiferromagnets. As a brief introduction, this talk will include a short live-demo of TetraX.

[1] https://gitlab.hzdr.de/micromagnetic-modeling/tetrax

MA 13.4 Tue 10:15 H43

Magnons in antiferromagnets: tools for transport and processing of information — •Olena Gomonay — 1Institute of Physics, Johannes Gutenberg University Mainz, Staudingerweg 7, 55128 Mainz, Germany

Magnonics as a concept of information processing with magnon spins is a promising alternative to spintronics, which manipulates electron-mediated spin currents. Magnons in antiferromagnets have further advantages of high limiting velocities and long propagation length compared to their ferromagnetic counterparts. Moreover, magnon currents in antiferromagnets, in contrast to ferromagnets, can carry both spin orientations and thus can be used for manipulation of the magnetic states. In my talk I discuss different aspects of magnon-mediated transport in antiferromagnets and possible applications to information processing. I compare two mechanisms of the nonlocal spin transport observed in easy-plane and easy-axis antiferromagnets via spin-polarised eigenmodes and via magnon birefringence. Magnon birefringence effect can be also observed in the multidomain antiferromagnets with the pronounced magnetostriction. Interaction of magnons in such a case results in a paramagnetic downconversion and resonance excitation of different magnon modes. I show further how the spin-polarised magnons can be used for manipulation of the magnetic states in multilayered films.

MA 13.5 Tue 10:30 H43

A bifold theoretical approach to spin transport in 2D easy axis and easy plane antiferromagnets — •Verena Brehm and Alireza Qaiumzadeh — QuSpin, NTNU Trondheim, Norway

Due to their terahertz excitation spectrum and the absence of stray fields, antiferromagnetic insulators are great candidates for magnonic applications [1].

We model an antiferromagnet with homogenous DMI inspired by hematite α-Fe_2O_3, that undergoes two phase transitions: For very low temperatures, there is no magnetization as the Néel vector lies in the plane, which corresponds to an easy axis anisotropy. At the Morin temperature, the Néel vector rotates out of plane, leading to a finite DMI-induced magnetization with the system being in an easy plane phase, until at the Néel temperature magnetic order is lost. Spin transport measurements across the Morin temperature [2] are exciting, since the magnonic modes show an anisotropy-dependent polarization [3], which has an impact on the transported angular momentum [4].

In this talk, we demonstrate both analytically and numerically (micromagnetic simulations [5]), how the magnon polarization impacts the spin transport signal across the Morin transition, in connection to Néel vector dynamics and dispersion relation analysis.

[1] Rezende, White. *Phys. Rev. B* **14** (1976)
[2] Ross et al. *J. Mag. Magn. Mat.* **453** (2022); arXiv:2106.12853
[3] Rezende et al. *J. Appl. Phys.* **126** (2019)
[4] Lebrun, Kl´aui et al. *Nat. Comm.* **11** 6332 (2020)
[5] Lepadatu. *J. Appl. Phys.* **128** 243902 (2020)

MA 13.6 Tue 10:45 H43

Employing magnons for generating multi-qubit entangled states for quantum error correction — Ida Skogvoll[1], Jonas Lidal[1], Jeroen Danon[1], and •Akashdeep Kamra[2,1] — [1]Center for Quantum Spintronics, Norwegian University of Science and Technology, Trondheim, Norway — [2]Condensed Matter Physics Center (IFIMAC) and Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, Madrid, Spain

The ongoing rapid progress towards quantum technologies relies on new hybrid platforms optimized for specific quantum computation and communication tasks, and researchers are striving to achieve such platforms. We study theoretically a spin qubit exchange-coupled to an anisotropic ferromagnet that hosts magnons with a controllable degree of intrinsic squeezing. We find this system to physically realize the quantum Rabi model from the isotropic to the Jaynes-Cummings limit with coupling strengths that can reach the deep-strong regime. We demonstrate that the composite nature of the squeezed magnon enables concurrent excitation of three spin qubits coupled to the same magnet. Thus, three-qubit Greenberger-Horne-Zeilinger and related states needed for implementing Shor's quantum error-correction code can be robustly generated. Our analysis highlights some unique advantages offered by this hybrid platform, and we hope that it will motivate corresponding experimental efforts.

I. C. Skogvoll, J. Lidal, J. Danon, and A. Kamra, Phys. Rev. Applied 16, 064008 (2021).

MA 13.7 Tue 11:00 H43

Long-range quantum entanglement between two distant ferromagnets mediated by dipol-dipol interaction — •Dennis Wuhrer, Niklas Rohling, and Wolfgang Belzig — Universität Konstanz, D-78457 Konstanz, Germany

Recently the quantum states of an antiferromagnet in the spin wave approximation have been identified as two-mode squeezed sublattice-magnon states. The massive sublattice entanglement leads to a nontrivial structure of the two-mode squeezed vacuum in the magnetic Brillouin Zone.

Further the entanglement in synthetic antiferromagnets became of interest. It can be tuned by an applied magnetic field, but an extraction of squeezing parameters is difficult. In this talk we regard a system consisting of two distant 2D ferromagnets coupled via dipol-dipol interaction. The Bogoliubov transformation will be interpreted in terms of inter-/intra-layer squeezing and hybridisation parameters. Using the logarithmic negativity we derive an analytic formula to quantify the degree of entanglement for which we investigate the distance dependence due to the long-range interaction. Using the distance and an external field the entanglement can be manipulated from zero to large values and maintained over large distances. The prospect to transfer massive entanglement over large distances is discussed.

MA 13.8 Tue 11:15 H43

Control of the Magnon Bose-Einstein Condensation by the Spin Hall Effect — •Michael Schneider[1], David Breitbach[1], Alexander A. Serga[1], Andrei N. Slavin[2], Vasyl S. Tyberkevich[2], Björn Heinz[1], Bert Lägel[1], Carsten Dubs[3], Philipp Pirro[1], Burkard Hillebrands[1], and Andrii V. Chumak[4] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, D-67663 Kaiserslautern, Germany — [2]Department of Physics, Oakland University, Rochester, Michigan 48326, USA — [3]INNOVENT e.V. Technologieentwicklung, D-07745 Jena, Germany — [4]Faculty of Physics, University of Vienna, A-1090 Vienna, Austria

Generally, magnon Bose-Einstein condensation (BEC) is achieved by increasing the particle density. Previously, it was shown that the rapid cooling of yttrium-iron garnet/Pt nanostructures, preheated by an electric current passed through the Pt layer, leads to an imbalance between the magnon and the phonon system. Consequently, magnon BEC is triggered by the excess of magnons.

We report on the additional contribution of the spin Hall effect (SHE), generating a spin current in the Pt layer. Depending on the orientation of the electric current and the applied field, the SHE injects or annihilates magnons. We find that the SHE contribution prevents or promotes the rapid-cooling induced magnon BEC, changing the BEC threshold by -8% to +6% depending on the current polarity. These results demonstrate a new method for controlling macroscopic quantum states and pave the way for its application in spintronic devices.

MA 13.9 Tue 11:30 H43

Confinement of Bose-Einstein magnon condensates in adjustable complex magnetization landscapes — •Matthias R. Schweizer, Alexander J.E. Kreil, Georg von Freymann, Alexander A. Serga, and Burkard Hillebrands — Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Kaiserslautern, Germany

We demonstrate the capability to control a room-temperature magnon Bose–Einstein condensate (BEC) by spatial modulation of the saturation magnetization. We use laser heating in combination with a phase-based wavefront modulation technique to create adjustable temperature patterns in an yttrium-iron-garnet film. The increase in temperature leads to a decrease of the local saturation magnetization and in turn to the modification of the corresponding BEC frequency. Over time, a phase accumulation between different BEC-areas arizes, leading to phase-driven magnon supercurrents.

The BEC is created by microwave parametric pumping and probed by Brillouin light scattering spectroscopy. We observe a strong magnon accumulation effect caused by magnon supercurrents for several distances between heated regions. This accumulation effect manifests in the confinement of the magnon BEC, which exhibits an enhanced lifetime due to the continuous influx of magnons. The experimental results are supported by a numerical model, based on the hydrodynamic approximation of the Gross–Pitaevskii equation.

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MA 13.10 Tue 11:45 H43

New magnetostatic modes in biaxial magnets — •Yue Sun[1,2], Changmin Lee[2], Linda Ye[3], Shingo Toyoda[1,2], Veronika Sunko[1,2], Joseph Checkelsky[4], and Joseph Orenstein[1,2] — [1]University of California, Berkeley, Berkeley, California, USA — [2]Lawrence Berkeley National Laboratory, Berkeley, California, USA — [3]Stanford University, Stanford, California, USA — [4]Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

Easy-plane antiferromagnets have been demonstrated to have long-distance magnon propagation and flexible control of ultrafast magnetic dynamics. However, exact XY systems are rare, and it is common to have a small in-plane crystalline easy-axis, which leads to the great interest in biaxial magnets. Spin superfluidity has been predicted in biaxial antiferromagnet in an applied magnetic field. Here, we discover new magnetostatic modes in both biaxial ferromagnet and antiferromagnet, where the interesting biaxial anisotropy opens new ranges for magnon frequency. We observe the new magnetostatic modes in biaxial ferromagnet $\mathrm{Fe_3Sn_2}$, and the prediction of the magnetostatic modes in biaxial antiferromagnet matches with the experimental observations in CrSBr. Comparing to the spin wave induced by the exchange interaction, the magnetostatic modes dominate in the long wavelength limit and offer a unique possibility to observe magnon Bose-Einstein condensation in biaxial antiferromagnet.

MA 13.11 Tue 12:00 H43

Features of magnon spectra in conductive altermagnet: ab initio calculations — •Alberto Marmodoro[1], Ondřej Šipr[1,2], and Tomas Jungwirth[1] — [1]Institute of Physics (FZU) of the Czech Academy of Sciences, Prague, Czech Republic — [2]New Technologies Research Centre, University of West Bohemia, Pilsen, Czech Republic

Altermagnets [1] are materials with zero net magnetization, alike traditional antiferromagnets, as well as a characteristic alternation of spin polarization for the electronic structure in reciprocal space, due to the relative orientation for anisotropic crystal field effects on different magnetic sublattices in direct space. This may have significant implications for possible spintronics and nano-electronics applications. We report on ongoing work for the ab initio study of transverse magnon excitations in the case of the conducting, colinear antiferromagnetic altermagnet material RuO2

[1] arXiv 2105.05820v2

MA 13.12 Tue 12:15 H43

Beating Fabry-Pérot interference pattern in a magnonic scattering junction in the graphene quantum Hall ferromagnet — •Jonathan Atteia[1,2], François Parmentier[3], Preden Roulleau[3], and Mark-Oliver Goerbig[2] — [1]Faculty of Physics, University of Duisburg-Essen, 47057 Duisburg, Germany — [2]Laboratoire de Physique des Solides, Université Paris Saclay, CNRS UMR 8502, F-91405 Orsay Cedex, France — [3]SPEC, CEA, CNRS, Université Paris-Saclay, CEA Saclay, F-91191 Gif sur Yvette Cedex, France

At filling factor $\nu = 0, \pm 1$, the ground state of graphene is a particular SU(4) ferromagnet which hosts a rich phase diagram along with several spin, pseudospin or “entanglement” magnon modes. Motivated by recent experiments, we study a $\nu = -1|0|-1$ Fabry-Pérot magnonic junction. If the ground state at $\nu = 0$ is spin polarized, there exist two spin modes which interfere and create a beating pattern, while pseudospin modes are reflected. The same scenario occurs for pseudospin magnon if the $\nu = 0$ ground state is pseudospin polarized. The observation of such an interference pattern would provide information on the low-energy anisotropies and thus on the ground state.