MA 11: Posters Magnetism III

Topics: Magnonics (11.1-11.16), Terahertz Spintronics (11.17-11.23), Spintronics (other effects) (11.24-11.26), Spin Transport and Orbitronics, Spin-Hall Effects (11.27-11.32), Cooperative Phenomena: Spin Structures and Magnetic Phase Transitions (11.33-11.34)

Time: Wednesday 13:30–16:30 Location: P

MA 11.1 Wed 13:30 P

Formation of magnon polarons in ferromagnetic nanogratings — •Felix Godejohann[1], Alexey Scherbakov[1,2], Serhii Kukhtaruk[1,3], Alexander Poddubny[2], Dmytro Yaremkevych[1], Mu Wang[5], Achim Nadzeyka[4], Dmitri Yakovlev[1,2], Andrew Rushforth[5], Andrey Akimov[5], and Manfred Bayer[1,2] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44227 Dortmund, Germany — [2]Ioffe Inst., RAS, St. Petersburg, Russia — [3]Dept. of Theo. Phys., V.E. Lashkaryov Inst. of Semiconductor Phys., Kyiv, Ukraine — [4]Raith GmbH, 44263 Dortmund, Germany — [5]School of Phys. and Astronomy, Univ. of Nottingham, UK

In our time-resolved experiments with ferromagnetic nanogratings (NGs), the formation of coherent magnon polarons is confirmed by direct evidence of the avoided crossing effect, as well as by several bright indirect manifestations. The NGs have been produced by focused ion beam milling into a 105 nm-thick Fe0.81Ga0.19 film. They have a lateral period of 200 nm and consist of parallel grooves of 100 nm width and 7-21 nm depth milled along the [100]-crystallographic direction. We perform transient magneto-optical measurements in a conventional pump-probe scheme with micron spatial resolution, where the femtosecond pump pulse excites the NGs, while the probe pulse serves to detect coherent lattice and magnetic responses. Using an external magnetic field, the magnon modes can be brought into resonance with the localized phonon modes of the NG resulting in the formation of magnon polarons, where the coupling strength is determined by the spatial overlap of the interacting modes.

MA 11.2 Wed 13:30 P

Topological magnon-polaron in a two-dimensional ferromagnet — •Gyungchoon Go, Se Kwon Kim, and Kyung-Jin Lee — Department of Physics, KAIST, Daejeon 34141, Republic of Korea

We theoretically investigate the topological aspects of the magnon-phonon hybrid excitation in a simple two-dimensional (2D) square-lattice ferromagnet with perpendicular magnetic anisotropy. In our 2D model, the Berry curvature we find requires neither a special spin asymmetry such as the DM interaction nor a special lattice symmetry: Our 2D model description is applicable for general thin-film ferromagnets. We show that even without such long-range dipolar interaction, DM interaction, or special lattice symmetry, the nontrivial topology of a magnon-phonon hybrid can emerge by taking account of the well-known magnetoelastic interaction originates from the magnetocrystalline anisotropy. Because the magnetocrystalline anisotropy is ubiquitous in ferromagnetic thin-film structures, our result does not rely on specific preconditions and thus is quite generic. Furthermore, we show that the topological structures of the magnon-polaron bands can be manipulated by effective magnetic fields via topological phase transition. We uncover the origin of the nontrivial topological bands by mapping our model to the well-known two-band model for topological insulators, where the Chern numbers are read by counting the number of topological textures, called skyrmions, of a certain vector in momentum space. In this picture, the magnon-phonon hybridization induces the chiral texture of the momentum space vector. As an experimental probe for our theory, we propose the thermal Hall conductivity.

MA 11.3 Wed 13:30 P

Magnetization Dynamics in Hybrid Ferromagnetic Systems — •Misbah Yaqoob[1,2,3], Lukas Liensberger[1,2], Luis Flake[1,2], David Weffling[3], Vitaliy Vasyuchka[3], Matthias Althammer[1,2], Rudolf Gross[1,2], and Mathias Weiler[1,3] — [1]Walther-Meißner-Institut, Garching, Germany — [2]Physik- Department, TU München, Germany — [3]Fachbereich Physik, TU Kaiserslautern, Germany

Thin film heterostructures consisting of several magnetically ordered layers are a promising platform for magnon spintronics because they can host complex magnetic textures, hybrid spin dynamics and spin torques [1,2].

We have investigated the magnetization dynamics of purely metallic ferromagnetic thin film multilayers and insulating magnet/metallic magnet thin film hybrid systems using broadband ferromagnetic resonance (FMR) and microfocused frequency-resolved magneto-optic Kerr effect (μFR-MOKE) at room temperature. With FMR, we find that the anisotropy of all-metallic systems can be tuned from $\mu_0 M_{\mathrm{eff}} \approx 300\,\mathrm{mT}$ to $\mu_0 M_{\mathrm{eff}} \approx 0$ by varying the number of multilayer repeats without affecting magnetic damping. We extract the spinwave dispersion using μFR-MOKE and find μm scale spinwave propagation lengths and group velocities in the order of 10 km/s. We compare these findings to those obtained in hybrid metallic ferromagnet/insulating yttrium iron garnet thin film heterostructures.

[1] Klingler et al. Phys. Rev. Lett. 120, 127201 (2018)
[2]Flacke et al. arXiv:2102.11117 (2021)

MA 11.4 Wed 13:30 P

Amplification of Propagating Spin Waves by Rapid Cooling — •David Breitbach[1], Michael Schneider[1], Bert Lägel[1], Carsten Dubs[2], Andrei N. Slavin[3], Vasyl Tyberkevych[3], Philipp Pirro[1], Burkard Hillebrands[1], and Andrii Chumak[4] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Kaiserslautern, Germany — [2]Innovent e.V. Technologieentwicklung, Jena, Germany — [3]Department of Physics, Oakland University, Rochester, MI, United States — [4]Faculty of Physics, University of Vienna, Vienna, Austria

Recently, the formation of a magnon Bose-Einstein Condensate (BEC) triggered by the rapid cooling of magnonic nano-structures has been reported [1]. A rapid decrease of the phonon temperature achieved after heating with an applied DC pulse in a nano-sized YIG|Pt sample leads to a non-equilibrium between the phonon and the magnon system. This results in a redistribution of magnons to the lowest frequencies of the spectrum and, finally, to the formation of a BEC. Building on this mechanism, we show the coherent amplification of externally excited, propagating spin waves in a YIG-waveguide using time-resolved BLS microscopy. This amplification is maximal when the spin-wave packet propagates through the Pt-region during the process of rapid cooling. This study shows the applicability of the rapid cooling mechanism to compensate for the intrinsic damping in spintronic devices and also gives insight into new physics, namely the interaction of a prepared coherent state with a magnon BEC. [1] M. Schneider, et. al., Nat. Nanotechnol. 15, 457-461 (2020)

MA 11.5 Wed 13:30 P

Theory of quantum entanglement and the structure of two-mode squeezed antiferromagnetic magnon vacuum — •Dennis Wuhrer, Niklas Rohling, and Wolfgang Belzig — Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany

Recent investigations of the quantum properties of an antiferromagnet in the spin wave approximation have identified the eigenstates as two-mode squeezed sublattice states. The uniform squeezed vacuum and one-magnon states were shown to display a massive sublattice entanglement. Here we expand this investigation and study the squeezing properties of all sublattice Fock states throughout the magnetic Brillouin zone.

We derive the full statistics of the sublattice magnon number with wave number $\vec{k}$ in the ground state and show that magnons are created in pairs with opposite wave vectors, hence, resulting in entanglement of both modes. To quantify the degree of entanglement we apply the Duan-Giedke-Cirac-Zoller inequality and show that it can be violated for all modes. The degree of entanglement decrease towards the corners of the Brillouin zone. We relate the entanglement to measurable correlations of components of the Néel and the magnetization vectors, thus, allowing to experimentally test the quantum nature of the squeezed vacuum.

The distinct k-space structure of the probabilites shows that the squeezed vacuum has a nonuniform shape that is revealed through the $\vec{k}$-dependent correlators for the magnetization and the Néel vectors.

MA 11.6 Wed 13:30 P

Combined tr-MOKE, BLS and THZ-radiation setup for the

investigation of magnetization dynamics on different time scales — •Akira Lentfert[1], Benjamin Stadtmüller[1], Martin Aeschlimann[1], Georg von Freymann[1,2], and Philipp Pirro[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern — [2]Fraunhofer Institute for Industrial Mathematics ITWM

Two separate models commonly describe spin and magnetization dynamics on different time scales. Systems in the sub-picosecond regime in ultrafast demagnetization processes are dominated by single-particle excitations. Here, a femtosecond laser pulse induces a loss of the magnetic order, which can be observed with time-resolved pump-probe spectroscopy based on the magneto-optical Kerr effect (tr-MOKE). In the nanosecond time scale, dynamics are described by collective excitations in terms of spin waves. However, due to the nature of the measurement technique mentioned above, it is impossible to detect incoherent collective dynamics. Therefore, the role of spin-waves up to the THz regime on ultrashort time scales could not be studied sufficiently. In this work, a combined setup of tr-MOKE with Brillouin-Light-Scattering spectroscopy (BLS) is presented, which allows the simultaneous investigation of magnetization dynamics on different time scales, from 1 ns down to 10 fs. Furthermore, using electromagnetic THz radiation to excite spin waves in this frequency regime resonantly gives further insight into the magneto-optical interactions. This research has been supported by DFG (TRR 173: Spin+X).

MA 11.7 Wed 13:30 P

Influence of Spatial Confinement on Spin-Wave Frequency Combs — •Christopher Heins[1], Tobias Hula[1,2], Katrin Schultheiss[1], Francisco Goncalves[1], Lukas Körber[1,3], Mauricio Bejarano[1,3], Luis Flacke[4,5], Lukas Liensberger[4,5], Aleksandr Buzdakov[1], Attila Kákay[1], Mathias Weiler[4,5,6], Jürgen Fassbender[1,3], and Helmut Schultheiss[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]TU Chemnitz, Germany — [3]TU Dresden, Germany — [4]Walther-Meißner-Institut, Garching, Germany — [5]TU München, Germany — [6]TU Kaiserslautern, Germany

Recently, it has been shown that four-magnon scattering in a stripe-shaped magnonic waveguide can be stimulated and utilized to generate spin wave frequency combs [1].

Here, we demonstrate that by restricting possible eigenstates via a two-dimensional spatial confinement the stimulated four-magnon scattering can be enhanced and a single RF excitation leads to the spontaneous formation of a frequency comb. We determine the frequency spacing of the spin wave modes in a $Co_{25}Fe_{75}$ rectangular microconduit with micromagnetic simulations and explore the formation of spin-wave frequency combs experimentally by means of micro-focused Brillouin light scattering. Further, we show that the spontaneously generated frequency comb can be resonantly amplified by a second RF excitation.

The authors acknowledge financial support from the Deutsche Forschungsgemeinschaft within program SCHU 2922/1-1.

[1] Hula et al., arXiv:2104.11491 (2021)

MA 11.8 Wed 13:30 P

Magnon condensates in 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

In this study, we demonstrate the potential to control a magnon condensate by spatial modulation of the saturation magnetization.
As shown in previous studies, a magnon condensate can be created via parallel parametric pumping in a stripline-resonator. We use a 458 nm laser in combination with a phase-based wavefront modulation technique to create confined temperature patterns in an yttrium-iron-garnet film of 5 μm thickness, which result in a decrease of the local saturation magnetization and in modify the local frequency of the condensate. The magnon density is measured by means of k-vector-resolved Brillouin-light-scattering-spectroscopy. We provide evidence of strong, directed magnon accumulation by magnon supercurrents [1] and anomalous decay behavior for several distances between heated positions.
Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - TRR 173 - 268565370.
[1] *D. A. Bozhko et al.*, Nat Commun **10**, 2460 (2019)

MA 11.9 Wed 13:30 P

Parametric pumping in out-of-plane magnetized ferrite films towards magnon Bose-Einstein condensation — •Andra Pirktina, Timo B. Noack, Vitaliy I. Vasyuchka, Alexander Serga, and Burkard Hillebrands — Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

The Bose–Einstein condensate (BEC) in a parametrically overpopulated gas of spin-wave quanta—magnons—manifests itself as a spontaneous formation of a coherent spin wave state at the energy minimum of the magnon spectrum. Magnon BECs, which are observed at gigahertz frequencies in tangentially magnetized yttrium iron garnet (YIG) films even at room temperature, can be used as signal sources for microwave applications and as information carriers in wave and quantum computing. However, due to the wavelength of the order of a few micrometers, the magnon BEC is detected mainly by the Brillouin light scattering spectroscopy, which is hardly applicable to real devices.

Here, we report on the spontaneous BEC formation in the out-of-plane magnetization geometry, where the magnon spectrum has a minimum at zero wavenumber, and the BEC frequency coincides with the ferromagnetic resonance frequency. In this case, the BEC was detected as a microwave electromagnetic signal by an inductive microstrip antenna. A small signal line width of 1.4 MHz was measured after the pump power exceeded the parametric instability threshold by 34 dB.

Funded by the ERC Advanced Grant 694709 SuperMagnonics and by the DFG within TRR 173 – 268565370 (project B04).

MA 11.10 Wed 13:30 P

Electric phase control of magnon currents — •Rostyslav O. Serha, Vitaliy I. Vasyuchka, Alexander A. Serga, and Burkard Hillebrands — Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Kaiserslautern, Germany

New findings of interactions between electric fields and magnons are promising for novel magnonic applications. They would allow the control of the phase of magnon currents by applying a voltage to the magnetic waveguides. In our work, we investigated the influence of a strong electric field on the phase of propagating spin waves in yttrium iron garnet (YIG) films. The experiment was performed in different spin-wave excitation geometries when volume and surface magnetostatic spin waves were excited. With the help of a vector network analyzer, the phase shift of the transmitted wave, which is sensitive to different external influences, was precisely measured. It was found that the phase shift owing to the electric field influence is relatively strong in the case of magnetostatic surface spin waves but is also observable for backward volume magnetostatic waves. By comparing results obtained for different spin-wave geometries, we discuss the physical nature of the observed phase shift, including possible contributions from the magnetoelectric effect in YIG and from the Aharonov-Casher effect. Funding by the ERC Advanced Grant 694709 SuperMagnonics is gratefully acknowledged.

MA 11.11 Wed 13:30 P

Dipolar interactions and spin dynamics in the itinerant ferromagnets Fe and Ni — •Lukas Beddrich[1,2], Steffen Säubert[3,4], Johanna K. Jochum[1], Christian Franz[1,5], and Peter Böni[2] — [1]Research Neutron Source Heinz Maier-Leibnitz (FRM II) | TU München — [2]Physics Department | TU München — [3]Chair for Topology of Correlated Systems (E51) | Physics Department | TU München — [4]Department of Physics | Colorado State University — [5]Jülich Center for Neutron Science (JCNS)

The spin wave dispersion of an isotropic ferromagnet is comprehensively described by the Holstein-Primakoff theory, which takes dipolar interactions into account. The dispersion follows a quadratic form for large q values $E_{SW} \propto q^2$, whereas for small q the dispersion shows linear behavior. This is attributed to the long-range dipolar interaction between the magnetic moments. The subtle influence of these interactions on the magnon spectrum are expressed by the dipolar wave vector q_D. The dipolar interactions are primarily probed for $q \leq q_D$. Utilizing the modern MIEZE method, a neutron resonance spin echo technique, we investigated the spin wave dispersion in iron and the paramagnetic spin fluctuations in nickel at small momentum and energy transfer with high resolution, never achieved before by neutron scattering. The results show excellent agreement with previously conducted triple-axis measurements by Collins et al. in the overlapping q regime, while extending the investigated range of the spin wave dispersion down to a momentum transfer of $q = 0.015A^{-1}$ with unprecedented energy resolution.

MA 11.12 Wed 13:30 P

Integration and characterization of micron-sized YIG structures with very low Gilbert damping on arbitrary substrates — •Philip Trempler[1], Rouven Dreyer[1], Philipp Geyer[1], Georg Woltersdorf[1], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther Universität Halle-Wittenberg, 06099 Halle (Saale), Germany — [2]Interdisziplinäres Zentrum für Materialwissenschaften, Martin-Luther Universität Halle-Wittenberg 06099 Halle (Saale), Germany

We present a process that allows the transfer of monocrystalline yttrium-iron-garnet microstructures onto virtually any kind of substrate. The process is based on a recently developed method that allows the fabrication of freestanding monocrystalline YIG bridges on gadolinium-gallium-garnet. Here, the bridges' spans are detached from the substrate by a dry etching process and immersed in a watery solution. Using drop-casting, the immersed YIG platelets can be transferred onto the substrate of choice, where the structures finally can be reattached and, thus, be integrated into complex devices or experimental geometries. Using time-resolved scanning Kerr microscopy and inductively measured ferromagnetic resonance, we find a ferromagnetic resonance linewidth of 195 μT at room temperature and we were even be able to inductively measure magnon spectra on a single micrometer-sized YIG platelet at a temperature of 5 K. In the future, this approach will allow for types of spin dynamics experiments until now unthinkable.

MA 11.13 Wed 13:30 P

Local and nonlocal spin Seebeck effect in lateral Pt-Cr_2O_3-Pt devices at low temperatures — •Prasanta Muduli[1], Richard Schlitz[1], Tobias Kosub[2], René Hübner[2], Artur Erbe[2], Denys Makarov[2], and Sebastian T. B. Goennenwein[1] — [1]Institut für Festköper- und Materialphysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universiät Dresden, 01062 Dresden, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf e.V., Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany

We have studied thermally driven magnon spin transport (spin Seebeck effect, SSE) in heterostructures of antiferromagnetic α-Cr_2O_3 and Pt at low temperatures. Monitoring the amplitude of the local and nonlocal SSE signals as a function of temperature, we found that both decrease with increasing temperature and disappear above 100 K and 20 K, respectively. Additionally, both SSE signals show a tendency to saturate at low temperatures. The nonlocal SSE signal decays exponentially for intermediate injector-detector separation, consistent with magnon spin current transport in the relaxation regime. We estimate the magnon relaxation length of our α-Cr_2O_3 films to be around 500 nm at 3 K. This short magnon relaxation length along with the strong temperature dependence of the SSE signal indicates that temperature-dependent inelastic magnon scattering processes play an important role in the intermediate range magnon transport. Our observation is relevant to low-dissipation antiferromagnetic magnon memory and logic devices involving thermal magnon generation and transport.

MA 11.14 Wed 13:30 P

Nonlinear relaxation of quantized propagating magnons in nanodevices — •Morteza Mohseni[1], Qi Wang[2], Björn Heinz[1], Michael Schneider[1], Felix Kohl[1], Carsten Dubs[3], Andrii V. Chumak[2], and Philipp Pirro[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria — [3]INNOVENT e.V., Technologieentwicklung, Prüssingstraße 27B, 07745 Jena, Germany

The use of spin waves and their quanta, the magnons, opens many opportunities in designing novel data processing units. Relaxation of linear spin waves is well described by viscous Gilbert damping processes. However, for strong excitations, nonlinear damping processes such as the decay via magnon-magnon interactions emerge and trigger additional relaxation channels. Such nonlinear dynamics are essential for the generation of magnon Bose-Einstein condensates, although their characteristics are not well investigated in magnonic nanostructures. We investigate the nonlinear relaxation of strongly generated spin waves in yttrium iron garnet nanodevices. We show that the nonlinear magnon relaxation in this highly quantized system possesses intermodal features, i.e., magnons scatter to other quantized modes through a cascade of scattering events. A further discussion of the phenomenon in the regime of its fundamental limitations is given.

MA 11.15 Wed 13:30 P

Mode selective excitation of spin waves — •Takuya Taniguchi and Christian Back — Technische Universität München

In a magnetic stripe, spin waves have eigenmodes which are energetically separated due to the geometry of the device. However, it has been difficult to selectively excite one eigenmode of spin wave. In this work, we performed micromagnetic simulation to study spin wave propagation in a T-shaped device and found that the spin wave mode in the device is controllable by varying the resonant frequency and the device structure.

MA 11.16 Wed 13:30 P

Spin-wave frequency combs — •Tobias Hula[1,2], Katrin Schultheiss[1], Francisco Goncalves[1], Lukas Körber[1,3], Mauricio Bejarano[1,3], Matthew Copus[4], Luis Flacke[5,6], Lukas Liensberger[5,6], Aleksandr Buzdakov[1], Attila Kakay[1], Mathias Weiler[5,6,7], Robert Camley[5], Jürgen Fassbender[1,3], and Helmut Schultheiss[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]TU Chemnitz, Chemnitz, Germany — [3]TU Dresden, Dresden, Germany — [4]Center for Magnetism and Magnetic Nanostructures, University of Colorado, USA — [5]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, Germany — [6]TU München, Munich, Germany — [7]TU Kaiserslautern, Kaiserslautern, Germany

We present experimental observations on the generation of a spin wave frequency comb in a low damping Co25Fe75 conduit measured using Brillouin light scattering microscopy. By driving the magnetization to large precession angles, nonlinear interactions such as four magnon scattering can be observed. When applying two RF signals with tunable frequencies and amplitudes to our microstructure, we can actively control the final states populated by these scattering processes. Our results show the generation of a frequency comb, consisting of several spin wave modes with adjustable frequency spacing and amplitude. Our observations are in qualitative agreement with micromagnetic simulations. We acknowledge financial support from the DFG within programs SCHU 2922/1-1, WE5386/4-1 and WE5386/5-1. K. S. acknowledges funding within the Helmholtz Postdoc Programme.

MA 11.17 Wed 13:30 P

Identification and characterization of plastics using THz-spectroscopy — •Tobias Kleinke, Finn-Frederik Stiewe, Ulrike Martens, Jakob Walowski, and Markus Münzenberg — Institute of Physics, University Greifswald, Germany

THz-spectroscopy is an attractive tool for scientific research, especially in life science, offering non-destructive interaction with matter due to its low photon energies [1]. Current research investigates the impact of plastic nanoparticles on cell tissue in several aspects, because those particles are highly abundant in the environment and also enter the human body potentially causing harmful interactions [2]. THz spectroscopy offers the opportunity to discover and study the influence of microplastics in living human cells.

Our project aims to identify and characterize different types of plastics in the human body or even in cells. Therefore it is necessary to set up a database with THz-spectra of the most abundant polymers. We analyze transmission spectra of several plastics with a commercial THz spectrometer (bandwidth from 0.1 to 6 THz) and identified specific absorption peaks for the individual studied materials. Furthermore, by determining the refractive index and the absorption coefficient, specific polymers can be characterized and identified.

Funding by BMBF: MetaZik PlasMark-T (FKZ:03Z22C511) is acknowledged.

[1] W. Shi et al., Journal of Biophysics, Vol. 14, 2021 [2] A. Ragusa et al., Environment International, Vol. 146, 2021

MA 11.18 Wed 13:30 P

THz-2D Scanning Spectroscopy — •Finn-Frederik Stiewe, Tobias Kleinke, Tristan Winkel, Ulrike Martens, Jakob Walowski, Christian Denker, and Markus Münzenberg — Institute of Physics, University Greifswald, Germany

THz-spectroscopy offers attractive imaging capabilities for scientific research, especially in life science. Its low photon energies lead to non-destructive interaction with matter [1,2]. However, wavelengths above 100 μm principally limit its spatial resolution by diffraction. Near-field-imaging using spintronic emitters offers the most feasible approach to overcome this restriction. In our study, we investigate THz-pulses generated by fs-laser-excitations in CoFeB/Pt heterostructures, based on spin currents together with a LT-GaAs Auston switch as detector.

The spatial resolution is tested by applying a 2D scanning technique with motorized stages allowing scanning steps in the sub-micrometer range. For this purpose, the spintronic emitter is directly evaporated on a gold-test pattern separated by a several hundred nanometer thick insulating spacer layer. Moving these structures with respect to the THz wave generation spot allows for resolution determination using the knife-edge method. We observe a THz beam FWHM of 4.86 *0.37 μm at 1 THz by using near-field imaging, which are in the dimension of the laser spot. Due to its simplicity, our technical approach offers a large potential for wide-ranging applications.

Funding by: MetaZIK PlasMark-T (FKZ:03Z22C511), BMBF

[1] A. G. Davies et al., Materials Today, Vol. 11 (2008) 18. [2] A. Y. Pawar et al., Drug Invention Today, Vol. 5 (2013).

MA 11.19 Wed 13:30 P

Spin-Hall-Angle measurements on magnetic heterostructures using THz-spectroscopy — •Tristan Winkel, Finn-Frederik Stiewe, Tobias Kleinke, Ulrike Martens, Jakob Walowski, and Markus Münzenberg — Institute of Physics, University Greifswald, Germany

Spin Hall angle measurements are important for spin device design. The data is used to build optimized spin Hall nano-oscillators for the fabrication of a neuromorphic computer chip [1]. THz spectroscopy provides effective means to measure spin Hall angles. In our study, we investigate THz pulses generated by fs laser excitations in magnetic heterostructures based on spin currents, together with an LT-GaAs Auston switch as a detector. The magnetic heterostructures consist of a CoFeB layer and a heavy metal layer. From the THz measurement, we can extrapolate the spin Hall angle of the heavy metal. Our technical approach offers great potential for wide-ranging applications due to its simplicity.

[1] M. Zahedinejad et al., Appl. Phys. Lett. 112, 132404 (2018)

Funding by: EU Horizon 2020, Spinage

MA 11.20 Wed 13:30 P

Microstructured spintronic terahertz emitters — •Rieke von Seggern[1], Christopher Rathje[1], Leon Gräper[1], Nina Meyer[2], Markus Münzenberg[2], and Sascha Schäfer[1] — [1]Institute of Physics, University of Oldenburg, Germany — [2]2Institute of Physics, University of Greifswald, Germany

In recent years, spintronic terahertz (THz) emitters have become a well-established source for strong single-cycle THz pulses [1]. In those metallic multilayer systems, an optically induced spin-polarized current pulse is converted into a transverse charge current, resulting in a broadband emission of THz radiation. In this work, we investigate different strategies for coupling the transverse current to micro-resonators on, or in close proximity, to the THz emitter surface and their influence on the detected THz spectrum. Various designs of resonator arrays were fabricated by electron beam lithography with expected resonance frequencies in the range of 0.5-4 THz. The resonances are visible as a decreased spectral THz amplitude at the corresponding resonance frequencies. A transition from a field- to a current-coupled regime is identified for decreasing distance between the resonator and the emitter, and compared to numerical modelling based on finite-element simulations.

[1] Seifert et al., Nat. Photonics 10, 483-488 (2016)

MA 11.21 Wed 13:30 P

Nutation resonance in antiferromagnets — •Ritwik Mondal[1,2], Levente Rózsa[3], Sebastian Grossenbach[3], and Ulrich Nowak[3] — [1]Institute of Physics of the Czech Academy of Sciences, Prague 6, Czech Republic — [2]Department of Physics and Astronomy, Uppsala University, Sweden — [3]Fachbereich Physik, Universität Konstanz, DE-78457 Konstanz, Germany

At ultrafast timescales, an additional spin torque term has to be supplemented within Landau-Lifshitz-Gilbert spin dynamics, to account for magnetic inertial dynamics causing spin nutation [1]. The experimental observation of the nutation resonance has only been achieved very recently [2]. In this work, we compare the effect of spin nutation in ferromagnets, antiferromagnets and ferrimagnets using linear response theory [3]. We identify the precession and nutation resonance peaks, and demonstrate that the precession resonance frequencies are reduced by the spin nutation, while the lifetime of the excitations is enhanced. We find the interplay between precession and nutation resonances to be more prominent in antiferromagnets compared to the ferromagnets, where the timescale of the exchange-driven sublattice dynamics is comparable to inertial relaxation times. Consequently, antiferromagnetic resonance techniques should be better suited for the search for intrinsic inertial spin dynamics on ultrafast timescales than ferromagnetic resonance [3].

[1] M.-C. Ciornei, J. M. Rubí, and J.-E. Wegrowe, Phys. Rev. B **83**, 020410(R) (2011) [2] K. Neeraj *et al.*, Nature Phys. **17**, 245 (2021) [3] R. Mondal *et al.* Phys. Rev. B **103**, 104404 (2021)

MA 11.22 Wed 13:30 P

Spintronic THz emitters tuned with Ta and modified interface qualities — •Laura Scheuer[1], Dominik Sokoluk[2], Garik Torosyan[3], René Beigang[1], Marco Rahm[2], and Evangelos Papaioannou[4] — [1]Fachbereich Physik and Landesforschungszentrum Optimas, TUK, Kaiserslautern, Germany — [2]Fachbereich Elektrotechnik, TUK, Kaiserslautern, Germany — [3]Photonic Center Kaiserslautern, Kaiserslautern, Germany — [4]Institut of Physics, MLU, Halle-Wittenberg, Germany

THz emission from metallic thin film multilayers interlinked the field of ultrafast spintronics and the field of THz optics, raising new fascinating research subjects. In principle, the THz pulse is generated by a spin current. This spin current is excited in a ferromagnetic layer by a fs laser pulse and diffuses into the adjacent layers. Usually their material is chosen to have a high spin-orbit coupling to provide a strong spin-to-charge conversion via the spin-Hall effect, resulting in a transient charge current. These accelerated electrons emit a radiation in the THz range.

Our recent experiments concentrate on materials different from our well-studied Fe/Pt-bilayers: Firstly, as Ta is a material with high spin-orbit coupling and a spin-Hall angle opposite to Pt's, we did not only replace Pt in bilayers but also added Ta as a second non-magnetic layer. Additionally we extended our investigations regarding the role of the interface to interfaces 'dusted' with Au and Cu, meaning they are grown thin enough not to form a whole monolayer.

MA 11.23 Wed 13:30 P

Modulation of Terahertz radiation by current confinement in patterned Ferromagnetic Emitters — •Bikash Das Mohapatra[1], Evangelos Th. Papaioannou[1], Reza Rouzegar[3], Tobias Kampfrath[3], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Von-Danckelmann-Platz 3, D-06120 Halle, Germany — [2]Interdisziplinäres Zentrum für Meterialwissenschaften, Martin-Luther-Universität Halle-Wittenberg, Heinrich-Damerow-Straße 4, D-06120 Halle, Germany — [3]Department of Physical Chemistry, Fritz Haber Institute, Faradayweg 4-6, 14195 Berlin, Germany

Spintronic Ferromagnetic Emitters are novel sources for generation of THz radiation. Various studies have shown the generation of ultrafast transverse charge current from spin current by the Inverse Spin Hall Effect resulting in THz electromagnetic pulses. We have fabricated THz emitters into arrays of geometrical structures using Sputter deposition and e-beam lithography. The structures were micron or sub-micron sized squares and rectangles. Upon fs laser irradiation these emitters show an emission spectrum which is different than for large area reference emitters. We suggest that the confinement[1] results in local charge accumulation that creates additional currents that counteract the initial inverse spin Hall effect.

[1] Z. Jin et al., "Terahertz Radiation Modulated by Confinement of Picosecond Current Based on Patterned Ferromagnetic Heterostructures ", Phys. Stat. Sol. 13, 1900057 (2019).

MA 11.24 Wed 13:30 P

Strain effect in the anomalous Hall effect of SrRuO3 thin films : a first principles study — •Kartik Samanta[1], Marjana Ležaić[2], Stefan Blügel[2], and Yuriy Mokrousov[2] — [1]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [2]Peter Grunberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

We investigate the effect of strain-induced oxygen octahedral distortion in the electronic structure and anomalous Hall response of the ferromagnetic SrRuO3(SRO) ultra-thin films by virtue of density functional theory calculations. We find a strong deformation of the oxygen octahedra (RuO6) with an increasing amount of substrate induced compressive strain. Our Berry curvature calculations predict a positive value of the anomalous Hall conductivity of +76 S/cm at -1.7% strain, whereas it is found to be negative (-156 S/cm) at -0.47% strain. We attribute the observed behavior of the anomalous Hall effect to the nodal point dynamics in the electronic structure arising in response to tailoring the oxygen octahedral distortion driven by the substrate induced strain. Our calculation of the strain-mediated anomalous Hall conductivity as a function of reduced magnetization obtained by scaling down the magnitude of the exchange field inside Ru atoms, shows a good qualitative agreement with experimental observations, which indicates a strong impact of longitudinal thermal fluctuations of Ru spin moments on the anomalous Hall effect in this system.

MA 11.25 Wed 13:30 P

Anisotropy of $4f$ states in $3d$-$4f$ single molecular magnets — Andreas Rauguth[1], Ahmed Alhassanat[1], Hebatalla Elnaggar[3], Angeliki A. Athanasopoulou[1], Chen Luo[2], Hanjo Ryll[2], Florin Radu[2], Torge Mashoff[1], Frank M.F. de Groot[3], Eva Rentschler[1], and •Hans-Joachim Elmers[1] — [1]Johannes Gutenberg-Universität Mainz, Mainz, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany — [3]University Utrecht, Utrecht, Netherlands

Using X-ray magnetic circular dichroism, we determined element-specific magnetic moments in $3d$-$4f$ metallacrown single molecular magnets at low temperature (7 K) and large field (7 Tesla). The magnetic moment of the molecule is dominated by the rare earth moment revealing a large contribution of orbital moment. Angular-dependent spectra on oriented molecules in single crystals allow to disentangle magnetic and orbital anisotropies. X-ray natural linear dichroism reveals the anisotropic charge distribution of the rare earth $4f$ state in the tetragonal crystal field despite the small $4f$ crystal field splitting. The angular dependence of the spin and orbital magnetic moments are compared to theory using multiplet calculations. We determined magnetic anisotropies from the angular dependence of the orbital magnetic moment.

MA 11.26 Wed 13:30 P

Numerical dynamic study of two coupled vortex-based spin transfer oscillator — •Abbass Hamadeh[1], Milan Ender[1], Vitally Lomakin[2], and Philipp Pirro[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Kaiserslautern, Germany — [2]Center for Magnetic Research, University of California at San Diego, La Jolla, CA, USA.

The magnetic vortex state in nano-magnetic structures is a subject of intensive research since it offers many applications. To gain key insight into engineering and manipulating the vortex core (VC) orientation reversal, it is crucial to fully understand their coupled dynamics. For this purpose, we have studied micromagnetically the auto-oscillating modes in a spin-transfer vortex oscillator with vortices in two coupled thin and thick layers for different applied magnetic fields and currents. We find that for the anti-parallel vortex polarity configurations, a region with downward/upward magnetization appears at the inner side of the vortex core resembling a deformation of the vortex profile. This deformation, induced by the vortex core's accelerating motion, breaks the lateral magnetization symmetry between the two layers of the oscillator. Our results reveal the origin of the signal measured experimentally [N. Locatelli et al., Appl. Phys. Lett. 98, 062501 (2011)] for a system based on two coupled vortices and provide key insights into engineering the vortex core orientation using DC currents.

MA 11.27 Wed 13:30 P

First principles design of Ohmic spin diodes based on quaternary Heusler compounds — •Thorsten Aull, Ersoy Sasioglu, and Ingrid Mertig — Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06099 Halle (Saale) Germany

The Ohmic spin diode is a new concept in spintronics whose operation principle relies on the transport properties of spin-gapless semiconductors (SGSs) and half-metallic magnets (HMMs). [1] Due to the spin-dependent filtering of electrons Ohmic spin diodes exhibit linear current-voltage characteristics in the on-state and zero threshold voltage due to the absence of an energy barrier at the interface between the SGS and HMM electrode. Quaternary Heusler compounds offer a platform to design SGSs and HMMs within the same family and these materials possess high Curie temperatures which makes them favorable for room temperature applications. By applying first-principles DFT calculations combined with the non-equilibriums Green's function method we design four different OSDs using quaternary Heusler compounds. [2] We demonstrate that these diodes exhibit zero threshold voltage and possess linear current-voltage characteristics. Moreover, we reveal that the small leakage currents can be attributed to the overlap of the conduction and valance band edges in opposite spin channels at the Fermi energy in the SGS material.

[1] E. Şaşıoğlu *et al.*, Phys. Rev. Appl. **14**, 014082 (2020)
[2] T. Aull *et al.*, Appl. Phys. Lett. **118**, 052405 (2021)

MA 11.28 Wed 13:30 P

Bipolar Spin Hall Nano-Oscillators — •Toni Hache[1], Yancheng Li[2], Tillmann Weinhold[3], Bernd Scheumann[1], Francisco T. J. Goncalves[1], Olav Hellwig[1,4], Jürgen Fassbender[1,3], and Helmut Schultheiss[1,3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]Johns Hopkins University, United States — [3]Technical University Dresden, Germany — [4]Technical University Chemnitz, Germany

Spin Hall nano-oscillators (SHNO) convert dc currents in microwave oscillations of the magnetization. The frequency can be tuned by external magnetic fields, the applied dc current magnitude or by injection locking if an additional microwave magnetic field is applied to the SHNO. Here, we demonstrate another approach to extend the frequency range of an SHNO by adding a second ferromagnetic layer. An SHNO with a layer stack NiFe/Pt/CoFeB is used. By applying a charge current a pure spin current is generated by the spin Hall effect in the Pt. It has opposite spin polarization at both interfaces being in contact with the ferromagnetic layers. Therefore, only in one of both the Gilbert damping can be compensated by the spin-orbit torque to achieve auto-oscillations. By switching the charge current polarity the spin current polarizations switch as well and the second ferromagnetic material shows auto-oscillations. In this way two frequency ranges can be accessed by switching the applied charge current. The authors acknowledge financial support from the Deutsche Forschungsgemeinschaft within programme SCHU 2922/1-1.

MA 11.29 Wed 13:30 P

Asymmetric modification of the magnetic proximity effect in Pt/Co/Pt trilayers — •Ankan Mukhopadhyay[1], Sarathlal Koyiloth Vayalil[1], Dominik Graulich[2], Imran Ahamed[3], Sonia Francoual[4], Arti Kashyap[3], Timo Kuschel[2], and Anil Kumar P S[1] — [1]Indian Institute of Science, Bangalore, India — [2]Center for Spinelectronic Materials and Devices, Bielefeld University, Germany — [3]Indian Institute of Technology, Mandi, India — [4]Deutsches Elektronen-Synchrotron, Hamburg, Germany

Interfacial spin-orbit coupling in ferromagnet/nonmagnet systems promotes remarkable spin-related phenomena and interactions which simultaneously provide the electrical manipulation of the magnetic moments up to the point of magnetization switching by current-driven domain wall motion. The phenomenon of a nominally paramagnetic material getting spin-polarized in presence of an adjacent ferromagnetic material by the exchange interaction is known as the magnetic proximity effect (MPE). The MPE in the top and bottom Pt layers induced by Co in Ta/Pt/Co/Pt and Ta/Pt/Co/Cu/Pt multilayers has been studied by interface sensitive, element-specific x-ray resonant magnetic reflectivity at the Pt L_3 absorption edge with an in-plane magnetic field. It has been observed that the Ta buffer layer with increasing thickness modifies the bottom Pt growth which in turn reduces the induced magnetic moment in the bottom Pt layer in Ta/Pt/Co/Pt[1], while it decreases in the top Pt layer in Ta/Pt/Co/Cu/Pt if the thickness of the Cu spacer is increased.

[1]A. Mukhopadhyay et al., Phys. Rev. B **102**, 144435 (2020).

MA 11.30 Wed 13:30 P

Magnon transport in YIG/Pt nanostructures with reduced effective magnetization — •Janine Gückelhorn[1,2], Tobias Wimmer[1,2], Manuel Müller[1,2], Stephan Geprägs[1], Hans Hübl[1,2,3], Rudolf Gross[1,2,3], and Matthias Althammer[1,2] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik-Department, Technische Universität München, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), München, Germany

The transport of information via spin waves (magnons) in magnetically ordered insulators provides novel paths for information processing. For applications based on pure magnonic spin currents damping effects resulting in a decrease of the corresponding conductivity, have to be minimized. Here, we investigate the magnon transport through an yttrium iron garnet (YIG) thin film with strongly reduced effective magnetization. Utilizing three-terminal Pt strip devices allow us to manipulate the magnon transport between the two outer strips via an additional charge current applied to the center electrode. Most importantly, above a certain threshold current, where damping compensation via spin torque is reached, the effective magnon conductivity can be enhanced by a factor of up to six. Another major observation is the linear dependence of the threshold current on the applied magnetic field. We attribute these observations to the reduced effective magnetization and the associated nearly circular mangetization precession.

Financial support by the DFG via project AL2110/2-1 and Germany's Excellence Strategy – EXC-2111 – 390814868 is acknowledged.

MA 11.31 Wed 13:30 P

Agility of spin Hall nano-oscillators — •Francisco Gonçalves[1], Toni Hache[1], Mauricio Bejarano[1,2], Tobias Hula[1,3], Olav Hellwig[1,3], Jürgen Fassbender[1,2], and Helmut Schultheiss[1,2] — [1]HZDR, Institute of Ion Beam Physics and Materials Research, Germany — [2]Technische Universität Dresden, Germany — [3]Institut für Physik, Technische Universität Chemnitz, Germany

Spin Hall nano-oscillators (SHNOs) have the ability to convert a direct current input to magnetisation auto-oscillations (AOs) in the gigahertz regime, by means of spin Hall effect and spin orbit torque [1-2]. We report the temporal response of nano-constriction SHNOs driven by voltage pulses, measured using time-resolved Brillouin light scattering microscopy. The SHNOs consist of a double-disk constriction of NiFe(5 nm)/Pt(7 nm). First, we show how few-nanosecond voltage pulses can efficiently induce AOs. Then, we show how the AOs synchronise to external microwave pulses by means of injection-locking [3]. Our findings suggest that the operation time of processes such as synchronisation and logic using SHNOs can be reduced to the nanosecond timescale and that multi-level microwave outputs can be achieved by combination of voltage and RF pulses. Financial support by the Deutsche Forschungsgemeinschaft is gratefully acknowledged within program SCHU2922/1-1.

[1] A. Manchon et al., Rev. Mod. Phys., vol. 91, p. 035004, Sep 2019. [2] T. Hache et al., Applied Physics Letters, vol. 116, no. 19, p. 192405, May 2020. [3] T. Hache et al., Applied Physics Letters, vol. 114, no. 10, p. 102403, Mar 2019.

MA 11.32 Wed 13:30 P

Monte Carlo simulation of ultrafast nonequilibrium spin and charge transport in iron — •Johan Briones, Hans Christian Schneider, and Bärbel Rethfeld — Department of Physics and Optimas Research Center, TU Kaiserslautern, Germany

Spin transport and spin dynamics after femtosecond laser pulse irradiation of iron (Fe) are studied using a kinetic Monte Carlo model. This model simulates spin dependent dynamics by taking into account elastic electron-lattice scattering, where only the direction of the excited electrons changes, and inelastic electron - electron scattering, where secondary electrons are generated. An analysis of the particle kinetics inside the material shows that a smaller elastic scattering time affects the spin dynamics by leading to a larger spatial spread of electrons in the material, whereas generation of secondary electrons affects the spin transport by increasing the propagation length of homogeneous spin polarization.

MA 11.33 Wed 13:30 P

Magnetic Transitions in Synthetic Antlerite, $Cu_3SO_4(OH)_4$ — •Darren C. Peets[1], Anton A. Kulbakov[1], Quirin Stahl[1], Pavlo Portnichenko[1], Maxim Avdeev[2], Sebastian Gass[3], Laura Teresa Corredor Bohorquez[3], Anja U. B. Wolter[3,4], Manuel Feig[5], Hagen Poddig[6], Inés Puente-Orench[7,8], Jochen Geck[1,4], and Dmytro S. Inosov[1,4] — [1]IFMP, TU Dresden, 01069 Dresden, Germany — [2]ANSTO, Lucas Heights, NSW 2234, Australia — [3]IFW-Dresden, 01069 Dresden, Germany — [4]ct.qmat, TU Dresden, 01069 Dresden, Germany — [5]IEP, TU Bergakademie Freiberg, 09596 Freiberg, Germany — [6]Anorganische Chemie II, TU Dresden, 01069 Dresden, Germany — [7]INMA, CSIC-Universidad de Zaragoza, Zaragoza 50009, Spain — [8]ILL, 38042 Grenoble, France

In frustrated magnetic systems, geometric constraints or the competition amongst interactions introduce extremely high degeneracy and prevent the system from readily selecting a low-temperature ground state. In the mineral antlerite, $Cu_3SO_4(OH)_4$, Cu^{2+} ($S = \frac{1}{2}$) quantum spins populate triangular-lattice three-leg ladders in a novel highly-frustrated quasi-one-dimensional structural motif. We demonstrate that this mineral hosts four distinct magnetically-ordered phases in zero field alone, including an incommensurate phase and a multiple-**q** phase. Multiple-**q** phases are extremely uncommon in centrosymmetric compounds of 3d and lighter elements, and the discovery of such a phase in antlerite opens a new route to finding new materials platforms for exotic magnetic order.

MA 11.34 Wed 13:30 P

Unconventional magnetism in the $RE_3Fe_3Sb_7$ spin system — •Sabrina Palazzese[1,2], Falk Pabst[3], Sumanta Chattopadhyay[1], Shingo Yamamoto[1], Thomas Herrmannsdörfer[1], Denis Gorbunov[1], Eugen Weschke[4], Oleksandr Prokhnenko[4], Hiroyuki Nojiri[5], Thomas Doert[3], Bella Lake[4,6], Joachim Wosnitza[1,2], and Michael Ruck[3] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL), HZDR, Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]Fakultät für Chemie und Lebensmittelchemie, TU Dresden, Germany — [4]Helmholtz-Zentrum Berlin für Materialien und Energie (HZB), Berlin, Germany — [5]Institute for Materials Research, Tohoku University, Sendai, Japan — [6]Institut für Festkörperphysik, TU Berlin, Germany

Here we present a detailed magnetization and electrical-transport study of novel $RE_3Fe_3Sb_7$ compounds. We find a number of spontaneous magnetic phase transitions in a wide temperature range and a pronounced magnetic anisotropy. $RE_3Fe_3Sb_7$ shows an emergent spontaneous magnetization in zero field and a kink in the temperature-dependent resistivity at the spin-reorientation transition SRT. In the ground state, $RE_3Fe_3Sb_7$ displays a large uniaxial magnetic anisotropy that changes to planar at SRT. Our neutron scattering results reveal an unusual antiparallel alignment of Pr and Fe magnetic moments. In addition, XMCD measurements in pulsed magnetic fields up to 28 T indicate a continuous rotation of the Nd moment towards the Fe moment.