MA 27: Spin currents and spin torques

Time: Wednesday 9:30–12:45 Location: EB 407

MA 27.1 Wed 9:30 EB 407

Spin pumping in ferrimagnets: Bridging ferro- and antiferromagnets — •Akashdeep Kamra and Wolfgang Belzig — Department of Physics, University of Konstanz, Germany

A combination of novel technological and fundamental physics prospects has sparked a huge interest in pure spin transport in magnets, starting with ferromagnets and spreading to antiferro- and ferrimagnets. We present a theoretical study of spin transport across a ferrimagnet/non-magnetic conductor interface, when a magnetic eigenmode is driven into a coherent state. Our model continuously encompasses systems from ferromagnets to antiferromagnets, thereby allowing analytical results for the full range of materials within a unified description. It further allows arbitrary (disordered and asymmetric) interfaces. The obtained spin current expression includes intra- as well as cross-sublattice terms. We find that the cross-sublattice terms, disregarded in previous studies, play an important role and result in qualitative changes to our understanding of spin pumping in antiferromagnets. The dc current is found to be sensitive to the asymmetry in interfacial coupling between the two sublattice magnetizations and the mobile electrons, especially for antiferromagnets.

References:

[1] A. Kamra and W. Belzig, Spin pumping and shot noise in ferrimagnets: bridging ferro- and antiferromagnets, Phys. Rev. Lett. 119, 197201 (2017).

[2] A. Kamra, U. Agrawal, and W. Belzig, Noninteger-spin magnonic excitations in untextured magnets, Phys. Rev. B 96, 020411 (R) (2017).

MA 27.2 Wed 9:45 EB 407

Magnon spin valve effect in a multilayer insulator spintronics system — •Joel Cramer[1,2], Felix Fuhrmann[1], Ulrike Ritzmann[1,3], Eiji Saitoh[4], Ulrich Nowak[3], and Mathias Kläui[1,2] — [1]für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany — [2]Graduate School of Excellence Materials Science in Mainz, 55128 Mainz, Germany — [3]Fachbereich Physik, Universität Konstanz, 78457 Konstanz, Germany — [4]WPI Advanced Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan

Magnon-based spintronic applications are a promising alternative to charge-driven devices regarding information transport and processing [1]. We report on ferromagnetic resonance spin pumping measurements in a magnonic spin valve device consisting of magnetic yttrium iron garnet (YIG)/CoO/Co multilayers. By means of microwaves and external magnetic fields YIG is brought into ferromagnetic resonance, thus emitting a pure spin current through the sample stack. The spin current propagates through the antiferromagnetic CoO and is detected in the Co layer via the inverse spin Hall effect [2]. The CoO furthermore enhances the Co coercive field, such that switching between a parallel or antiparallel alignment of the YIG and Co magnetization at the YIG resonance field is enabled. For parallel and antiparallel alignment we observe a very different amplitude of the detected magnonic spin current signal, resulting in a spin valve effect amplitude of 120% [3]. [1] Chumak *et al.*, Nat. Phys. **11**, 453 (2015) [2] Miao *et al.*, Phys. Rev. Lett. **111**, 066602 (2013) [3] Cramer *et al.*, arxiv:1706.07592

MA 27.3 Wed 10:00 EB 407

Enhancement of the Spin Pumping Effect by Two-Magnon Confluence Process in YIG-Pt Bilayers. — •Timo B. Noack, Vitaliy I. Vasyuchka, Dymitro A. Bozhko, Burkard Hillebrands, and Alexander A. Serga — TU Kaiserslautern, Kaiserslautern, Deutschland

Magnon spin currents are seen as a promising alternative to electrical charge currents for the transport and processing of information. Besides magnon-based elements operating with analogous and digital data, the field of modern magnon spintronics crucially depends on the progress in developing of effective converters between the magnon subsystem and the electron-carried spin and charge currents. This task is especially challenging in a case of short-wavelength exchange magnons, which application is promising for the miniaturization of magnonic devices. In Platinum (Pt) covered magnetic insulators such as Yttrium Iron Garnet (YIG, $Y_3Fe_5O_{12}$) films, combined action of the inverse spin-Hall effect (iSHE) and the spin-pumping (SP) effect constitutes an important mechanism allowing for the detection of this kind of magnons: Here, we present our studies on the efficiency of spin pumping in in-plane magnetized Pt-covered YIG films of different thicknesses. In our time-resolved field-dependent measurements of the iSHE-voltage, it has been found that at the given pumping frequency of $f_p = 14.449$ GHz a clearly visible sharp voltage peak appears at a bias magnetic field of approximately 1 kOe. This peak can be related to the confluence of two parametrically excited magnons with frequencies $f_p/2$ and wavevectors k_p into one magnon (f_p, $2k_p$).

MA 27.4 Wed 10:15 EB 407

Collective spin transport in easy-plane systems — •Martin Evers, Pascal Bolz, and Ulrich Nowak — University of Konstanz, D-78457 Konstanz

Spin transport has many aspects. It can occure as a spin polarized current or a magnon flow, moving magnetic textures as domain walls, spin spirals or skyrmions. One specific kind of transport is a collective spin current in an easy-plane magnet, that is called a spin superfluid [1,2]. This transport is predicted to be long-ranged and should also have a protection against dissipation. Within this framework also dissipationless spin transport has been predicted [1,3].

In our work, we study this spin superfluid transport numerically in an atomistic spin model in order to get insight into the possible mechanisms to drive such a supercurrent, to investigate the dissipation and the characteristic length scale of the transport. The systems we study include ferro- and antiferromagnets, as well as spin spirals and different driving mechanisms, such as a time-dependent Dzyloshinskii-Moriya interaction (originating from an electric field in an multiferroic material) [3], an injected spin accumulation and temperature gradients.

[1] J. König et al., Phys. Rev. Lett. **87**, 187202 (2001)
[2] S. Takei et al., Phys. Rev. Lett. **112**, 227201 (2014)
[3] W. Chen et al., Phys. Rev. Lett. **114**, 157203 (2015)

MA 27.5 Wed 10:30 EB 407

Long-distance supercurrent transport in a magnon Bose-Einstein condensate — •Alexander J.E. Kreil, Dmytro A. Bozhko, Alexander A. Serga, and Burkard Hillebrands — Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

Currently, supercurrents in a room-temperature magnon Bose-Einstein condensate (BEC) have been reported [1]. The condensate is created by parametric microwave pumping in a tangentially magnetized yttrium-iron-garnet (YIG) film. We study the condensate by means of time-resolved Brillouin light scattering spectroscopy (BLS). By heating the sample, a spatially variation of the saturation magnetization is induced, which leads to a change of the magnon frequencies across the heated film. Because the magnon condensate is coherent across the entire heated area, a spatial varying phase shift is imprinted into its wavefunction. The spatial phase gradient generates a magnon supercurrent flowing out of the probing point. The earlier evidence of these supercurrents was obtained by an observation of the different relaxation behaviors of the magnon BEC under different heating conditions. By heating the sample with an external heat source, we are able to perform spatially resolved measurements. In this work we are showing the one-dimensional supercurrent transport measured over a large distance whereby travelling magnon density wave packets could be observed.

[1] Bozhko *et al.* Nature Physics **12**, 1057 (2016)

MA 27.6 Wed 10:45 EB 407

Unidirectional angular momentum transport in obliquely magnetized magnetic films — •Dmytro A. Bozhko[1], Halyna Yu. Musiienko-Shmarova[1], Vasyl S. Tyberkevych[2], Andrei N. Slavin[2], Ihor I. Syvorotka[3], Burkard Hillebrands[1], and Alexander A. Serga[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Germany — [2]Department of Physics, Oakland University, USA — [3]Department of Crystal Physics and Technology, SRC "Carat", Ukraine

Thermal spectra of dipole-exchange magnons in an obliquely magnetized yttrium iron garnet (YIG) film were measured in a wide range of wavenumbers using a newly developed wavevector- and angleresolved Brillouin light scattering (BLS) spectrometer. The YIG film of 5.6 μm thickness was grown in the (111) crystallographic plane on a gadolinium-gallium-garnet substrate by liquid-phase epitaxy. The experimentally measured magnon spectra agree well with the results of a theoretical analysis where transverse (thickness) profiles of the magnon modes were calculated. Calculations show that in the case of an in-plane magnetized film the thickness profile of the lowest magnon mode is a *standing* wave demonstrating dipolar "pinning", that gradually increases with the increase of the magnon in-plane wavenumber. In contrast, in the case of an oblique (out-of-plane) magnetization the thickness profiles of the magnon modes turn out to be *quasi-traveling* waves that do not transfer energy, but create a unidirectional flow of spin angular momentum (or spin current) along the film thickness. The work is supported by the DFG within the SFB/TR 49.

MA 27.7 Wed 11:00 EB 407

From kinetic instability to Bose-Einstein condensation and magnon supercurrent — •Halyna Yu. Musiienko-Shmarova[1], Alexander J.E. Kreil[1], Dmytro A. Bozhko[1], Victor S. L'vov[2], Anna Pomyalov[2], Burkard Hillebrands[1], and Alexander A. Serga[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Germany — [2]Department of Chemical Physics, Weizmann Institute of Science, Rehovot 76100, Israel

By means of electromagnetic parametric pumping an ensemble of magnons, quanta of spin waves, can be prepared as an overpopulated Bose gas of weakly interacting quasiparticles. The evolution of this gas via magnon-magnon scattering processes can lead to the formation of a Bose-Einstein condensate (BEC) at the bottom of spin-wave spectrum. We studied this phenomena experimentally (by Brillouin light scattering spectroscopy) and theoretically in an yttrium-iron-garnet film in a wide region of the external magnetic field. This allows us to compare features of the condensation process in the cases when one of two physical mechanisms of the magnon transfer from a pumped high-frequency area to the BEC state prevails: a step-by-step Kolmogorov-Zakharov cascade of weak wave turbulence process or a kinetic-instability channel, which directly transfers magnons from the pumping area to the BEC point. As a result, we demonstrate the formation of a coherent condensed magnon state even in the presence of the kinetic instability processes leading to a strongly unbalanced non-equilibrium population of the low-energy part of the magnon spectrum. Financial support from the ERC Advanced Grant "SuperMagnonics" is acknowledged.

15 minutes break

MA 27.8 Wed 11:30 EB 407

Unified relativistic theory of magnetization dynamics with spin-current tensors — •Ritwik Mondal, Marco Berritta, and Peter M. Oppeneer — Department of Physics and Astronomy, Uppsala University, SE-75120 Uppsala, Sweden

Spin currents play a crucial role in operative properties of spintronic devices. To study current-driven magnetization dynamics, spin-torque terms providing the action of spin-polarized currents have previously been added in a phenomenological way to the Landau-Lifshitz-Gilbert (LLG) equation describing the local spin dynamics, yet without derivation from fundamental principles[1,2]. Starting from the Dirac-Kohn-Sham theory[3] and incorporating nonlocal spin transport we rigorously derive various spin-torque terms that appear in current-driven magnetization dynamics. In particular we obtain an extended magnetization dynamics equation that precisely contains the nonrelativistic adiabatic and relativistic nonadiabatic spin-transfer torques of the form proposed by Berger as well as relativistic spin-orbit torques[4]. We derive in addition a previously unnoticed relativistic spin-torque term and show that the various obtained spin-torque terms do not appear in the same mathematical form in the Landau-Lifshitz and LLG equations of spin dynamics.

[1]D. C. Ralph and M. D. Stiles, J. Magn. Magn. Mater. **320**, 1190 (2008). [2]P. Gambardella and I. M. Miron, Phil. Trans. Roy. Soc. London A **369**, 3175 (2011). [3]R. Mondal, M. Berritta and P. M. Oppeneer, Phys. Rev. B **94**, 144419 (2016). [4] S. Zhang and Z. Li, Phys. Rev. Lett. **93**, 127204 (2004).

MA 27.9 Wed 11:45 EB 407

Persistent precessions in spin-torque systems far from equilibrium — •Tim Ludwig[1], Igor Burmistrov[1,2,3], Yuval Gefen[4], and Alexander Shnirman[1] — [1]Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [2]L. D. Landau Institute for Theoretical Physics RAS, 119334 Moscow, Russia — [3]Institut für Nanotechnologie, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany — [4]Department of Condensed Matter Physics, Weizmann Institute of Science, 76100 Rehovot, Israel

We consider persistent precessions of an itinerant single domain nanomagnet driven by a thermally induced spin-transfer torque current. In [1] it was found that, far from equilibrium, stationary adjustments of the electronic distribution functions can render electrically driven persistent precessions unstable. In contrast, as we now show, stable persistent precessions can be maintained by thermal driving even far from equilibrium. Interestingly, to obtain consistent results for the stability, we have to include dynamic adjustments of the distribution function to the trajectory of the magnetization. On the technical level, we follow the approach of [1], i.e., we derive an effective action of the Ambegaokar-Eckern-Schön type for the magnetization. For the determination of the stability, we have to extend the calculations of [1] and include higher orders terms.

[1] T. Ludwig, I.S. Burmistrov, Y. Gefen, A. Shnirman Phys. Rev. B 95, 075425 (2017)

MA 27.10 Wed 12:00 EB 407

Ab-initio study on $L1_0$ FePt-based magnetic tunnel junctions for memory applications — •Mario Galante, Matthew O. A. Ellis, and Stefano Sanvito — School of Physics, Trinity College Dublin, Ireland

Magnetic random access memory (MRAM) is believed to be one of the most promising candidates for the future of scalable non-volatile memories. At the heart of these devices are magnetic tunnel junctions (MTJs), which store data on the relative orientation of two magnetic layers separated by an insulating barrier and can be operated via electric currents exploiting the tunnelling magneto-resistance (TMR) and the spin-transfer torque (STT) effects. Junctions with out-of-plane magnetisation minimise the demagnetising field contribution to the switching current but a large magneto-crystalline anisotropy is required to keep such geometries. Common CoFeB/MgO devices have been shown to have a suitable anisotropy due to interface effects [1] but materials with large bulk anisotropy, such as $L1_0$-FePt, are also possible candidates. In this work, we have applied the SMEAGOL method [2] for *ab-initio* quantum transport to Fe/MgO/Fe MTJs with a $L1_0$-FePt layer inserted at the MgO-free layer interface. We investigate the suitability of FePt-based MTJs for memory applications by calculating the atom-resolved spin torque and the TMR in comparison with a Fe/MgO/Fe junction. We also consider the presence of a thin Fe seed layer and discuss how this influences the decay of the STT in the free layer. [1] A. Hallal, et al, PRB 88, 184423 (2013) [2] A. R. Rocha et al, PRB 73, 085414 (2006)

MA 27.11 Wed 12:15 EB 407

The effect of atomically varying anisotropy and damping on spin-transfer torque switching — •Matthew Ellis, Maria Stamenova, Mario Galante, and Stefano Sanvito — School of Physics and CRANN, Trinity College, Dublin 2, Ireland

Magnetic tunnel junctions (MTJs) form the principle unit for an array of emerging spintronic devices. Of particular interest are magnetic random access memory (MRAM) devices, where binary data is stored on the relative orientation of the two ferromagnetic layers in the MTJ. Of paramount importance to the future of MRAM is developing MTJs with material properties that provide a high readability with a low write threshold. The write threshold is determined by the effective magnetic anisotropy and damping of the free ferromagnetic layer and the strength of the spin-transfer torque (STT).

In this work, a multi-scale methodology, combining ab-initio calculations of spin-transfer torque with magnetisation dynamics computed at the atomic level, is used to model the current-induced switching in an ultra-thin Fe layer. Atomic resolved properties of the magnetic anisotropy, damping and STT are employed to explore how variations of these on the atomic scale alter the switching threshold. Little non-collinearity is observed due to the high exchange coupling while the total effective anisotropy and average damping determines the switching threshold.

MA 27.12 Wed 12:30 EB 407

Facet-dependent Spin-Orbit Torques in Mn3X (X=Ir, Ge) Chiral Antiferromagnets — James M. Taylor[1], •Edouard Lesne[1], Anastasios Markou[2], Pranava K. Sivakumar[1], Fasil K. Dejene[1], Claudia Felser[2], and Stuart S. P. Parkin[1] — [1]Max Planck Institute of Microstructure Physics, Halle (Germany) — [2]Max

Planck Institute for Chemical Physics of Solids, Dresden (Germany)

An active field of research aims at controlling materials magnetic properties at the nano-scale without resorting to external magnetic fields, through magneto-electric coupling or spin currents. Antiferromagnets displaying sizeable spin Hall effect (SHE) will enable new generation of spintronic devices operating without net magnetization.

The present work is motivated by the recent theoretical predictions [1,2], and experimental confirmations [3,4] of Berry curvature driven (giant) anomalous Hall effect (AHE) in chiral antiferromagnets of the Mn3X (X=Ge,Sn,Ir) family.

Here we report on temperature-dependent spin-transfer torque ferromagnetic resonance experiments in epitaxial [001]- and [111]-oriented films of Mn3Ir, and Mn3Ge(0001), grown by magnetron sputtering. Building upon their respective temperature and thickness-dependent anomalous Hall conductivity, we tentatively assess the contribution of bulk- and interface-driven spin-orbit torques, and discuss their origin in terms of intrinsic and extrinsic contributions.

[1] H. Chen et al., Phys.Rev.Lett. 112, 017205 (2014). [2] J. Kübler & C. Felser, Europhys.Lett. 108, 67001 (2014). [3] S. Nakatsuji et al., Nature 527, 212 (2015). [4] A. Nayak et al., Sci.Adv. 2:e1501870 (2016).