## Poster Presentations

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Poster Presentations

Wednesday, Session P

P.1 Temperature dependent magnon-polariton spectroscopy in YIG sphere

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In information technology research, spin based approaches are promising candidate for new applications such as data storage or logic. The collective excitation of a spin ensemble results in a spin wave that is often in the microwave (GHz) regime and termed magnon. Experimentally, we interface magnons with microwave cavities to investigate dynamics within the magnetic system. To this end, magnonic elements are strongly coupled to a photonic resonator, resulting in hybridized magnon - resonator states, i.e. cavity magnon polaritons (CMP). We have set up an experimental apparatus for the resonant coupling of spin waves in a magnetic bulk or thin film to either inside a microwave cavity or a coplanar waveguide (CPW) in the strong coupling regime [1,2]. This enables both readout at a fixed frequency or broadband measurements employing ferromagnetic resonance (FMR) and input-output theory for temperatures from 5 K to 300 K. We present temperature dependent spectroscopic measurements of magnon - polariton states. The sample is a YIG sphere (diameter 0.5 mm), placed in the 6.5 GHz bright mode of a re - entrant cavity [3]. Features of the strongly coupled systems such as the coupling strength g, resonance frequency of Kittel mode and linewidth are analyzed. We discuss the proportionality of the coupling strength of the Kittel mode to the temperature dependent saturation magnetization of our sample. Furthermore, the influence of additional higher order magnetostatic modes is taken into account. Similarly, we study the temperature dependence of the magnon linewidth of the Kittel mode. Accordingly, we investigate the changes in the loss factors of cavity and magnon, when approaching resonance [5].

Direct measurements of a supercurrent spin transport in YIG films at room-temperature

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Recently, we reported on the indirect observation of magnon supercurrents in a room-temperature magnon Bose-Einstein condensate (BEC) [1]. The magnon BEC is created using parallel parametric microwave pumping in an in-plane magnetized yttrium-iron-garnet (YIG) film. It is studied by means of the time-resolved Brillouin light scattering (BLS) spectroscopy technique. An absorption of the focused probing laser beam in YIG layer leads to the temperature-induced spatial variation in the saturation magnetization and, thus, to the variation in the local magnon frequencies across the heated film area. Because the magnon BEC is coherent across the entire heated area, in a cause of time a spatially varying phase shift is imprinted into its wavefunction. This spatial phase gradient propels a magnon supercurrent flowing out of the probing point. The supercurrent occurrence was evidenced by the observation of the different relaxation behaviors of the magnon BEC at different heating times [1]. In the present work we report direct evidence of spin transport by a magnon supercurrent. In order to perform transport measurements we implemented into our experimental set-up an additional heat source, namely a second laser. As the probing and the heating laser spots now are decoupled, it is possible to study the transport properties of the magnon supercurrents. During the measurement, the heating laser spot remains stationary while the low-power probing beam performs a spatial scan of the condensate area along the pumping resonator. The obtained spatial maps of the condensate’s density as a function of time directly evidence magnon supercurrent occurrence with a group velocity of 350m/s.

The work is supported by the European Research Council within the ERC Advanced Grant “Supercurrents of Magnon Condensates for Advanced Magnonics”, EU-FET (Grant InSpin 612759) and Deutsche Forschungsgemeinschaft within the SFB/TR49 (project INST 161/544-3).

P.3 A ferromagnetic resonance and spin-wave spectroscopy study of the magnetic anisotropy at Fe/MgO interfaces

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Interfaces of MgO with iron-based alloys play a key role in modern MRAM technology, not only to promote high values of tunnel magnetoresistance, but also to stabilize an out-of-plane orientation of the magnetization by virtue of the large perpendicular magnetic anisotropy (PMA) at the MgO/Fe interface. In this work, we use a spectroscopic method allowing one to extract the values of the magnetic surface anisotropy constant of individual film surfaces (top or bottom) in MgO(001)/Fe(t=10-30nm)/MgO films grown by molecular beam epitaxy. Using a newly developed broadband / high-field microwave set-up (1-50 GHz, +/-2.7 T), we followed the frequencies of both the uniform ferromagnetic resonance (FMR) and first perpendicular standing spin-wave (PSSW1) modes as function of the magnetic field applied both in and out of the film-plane. fitting these measurements to Kittel-like expressions of the mode frequencies, and using a complementary measurement of the frequency non-reciprocity of propagating surface spin-waves,[1] we could unambiguously determine constants of perpendicular surface magnetic anisotropy amounting to 1.9 mJ/m² and 0.5 mJ/m² for the bottom and top interfaces, respectively. The large difference between these two values is attributed to the strong dependence of the surface anisotropy on the exact atomic structure of the Fe/MgO interface [2,3].

P.4 Frequency non-reciprocities in CoFeB/Py bilayers

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For the purpose of designing magnonic devices and logic elements \cite{1}, it is essential to be able to manipulate propagating spin waves in ferromagnetic tracks. One of the specific properties of magnetostatic surface waves in thin films is the frequency non-reciprocity, which occurs as soon as the magnetic film exhibits vertically asymmetric properties \cite{2}. This peculiar effect might be useful in order to build non-reciprocal microwave devices like isolators. In this context, we have investigated the frequency non-reciprocities in the case of a bilayer made of two ferromagnetic materials (CoFeB and NiFe) with different saturation magnetizations. first, a numerical approach has been used for determining the spin-wave normal modes \cite{3}. As expected, the simulations show a difference in the frequencies of counter propagating spin waves as soon as the wave vector is not zero. Moreover, for a suitable choice of the two films thicknesses, the dispersion relation for the fundamental mode shows a frequency plateau, which means a group velocity close to zero, only for the $k_\parallel 0$ branch. Thus for this frequency, the spin wave propagation is only possible for $k_\parallel 0$. In this poster, we will present ferromagnetic resonance and Brillouin light scattering measurements obtained for a CoFeB (20 nm)/Py (26 nm) bilayer sputter deposited on intrinsic silicon substrate. These results will be discussed and compared with the theoretical predictions.

\begin{itemize}
\item \cite{1} B. Lenk, H. Ulrichs, F. Garbs, M. Münzenberg, Phys. Rep. 507, 107 (2011).
\item \cite{2} O. Gladii, M. Haidar, Y. Henry, M. Kostylev and M. Bailleul, Phys. Rev. B. 93, 054430 (2016).
\item \cite{3} Y. Henry, O. Gladii and M. Bailleul, arXiv:1611.06153v1, Cond. Mat. (2016).
\end{itemize}
P.5 Spin wave channeling in Bloch wall arrays

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We present a theoretical study of spin wave channeling in Bloch domain walls in thin ferromagnetic films with perpendicular anisotropy. We carried out numerical simulations using a newly-developed approach based on the dynamic matrix method [1], along with micromagnetics simulations with MuMax3 [2], where spectacular nonreciprocal effects due to dynamic dipolar interactions are brought to light. First, we show that spin waves channeled along single Bloch walls are in fact nonreciprocal and exhibit a strongly asymmetric dispersion relation, i.e., magnons with identical wave numbers propagating in opposite directions have very different frequencies. Whether the frequency is the largest or the smallest is determined by the sign of the magnetization within the domains. Next, we show that for arrays of parallel Bloch walls (in stripe domain configurations) there exist as many domain-wall-channeled-spin-wave (DWCSW) modes as there are domain walls. A complex spin wave manifold develops, which can be understood from the single wall picture by considering that the wall array consists of a sequence of up/down and down/up walls with opposite nonrecipienties. At low wave vectors, the dynamic dipolar coupling between neighboring walls leads to the formation of anti-crossings and a hierarchy of regularly-spaced spin wave bands appears at k = 0. At large wave vectors, the domain walls become decoupled and the DWCSW bands form two distinct groups, with all the modes in a group corresponding to spin-wave propagating exclusively inside domain walls of a particular type (in one in every two walls). Finally, we discuss the response of an array of dipolar decoupled Bloch walls (large k regime) to various localized rf field excitations and we show that there exist conditions for which the propagation of domain-wall channeled spin-waves can be made purely unidirectional.

P.6 High-efficiency control of spin-wave propagation in ultra-thin Yttrium Iron Garnet by spin-orbit torque

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One of the most important advantages of the spin-orbit torque (SOT) is the possibility to implement spin-torque devices based on insulating magnetic materials, such as Yttrium Iron Garnet (YIG). In the past years, the applicability of this material was limited by the large micrometer-range thickness of high-quality YIG films. Only very recently, with the developments in preparation of high-quality nanometer-thick YIG films, the implementation of insulator-based spin-torque devices became practically feasible. Here we report the study of the propagation of spin waves in microscopic, 20nm thick YIG waveguides subjected to SOT generated due to the spin-Hall effect in the adjacent Pt film. We demonstrate that the propagation length of spin waves in such systems can be increased by nearly a factor of 10, which corresponds to the increase of the spin-wave intensity at the output of a 10 micrometer long transmission line by three orders of magnitude. We also show that, in the regime, where the magnetic damping is completely compensated by the SOT, the spin-wave amplification is suppressed by the nonlinear scattering of coherent spin waves from current-induced excitations. Our observations should stimulate both the development of advanced magnonic devices and theoretical work to deepen the understanding of the interaction of spin currents with spin waves. [1] V. E. Demidov, et al., Appl. Phys. Lett. 104, 152402 (2014).
P.7 Nonlinear spin-wave switching in the array of magnonic stripes

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In the past decades, the patterning of insulating magnetic materials emerges as a promising technology for magnonic integrated circuits. The insulating magnetic materials, such as yttrium iron garnet (YIG), possess significantly smaller dynamic magnetic damping compared to the metallic magnetic films. Using of YIG microstructures opens a promising alternative to signal processing by spin waves to provide the basis for beyond-CMOS computing technology with low-level energy consumption. Utilizing the nonlinear effects in YIG opens the possibility to develop nonlinear magnonic devices such as intensity dependent nonlinear phase shifters and filters, all-magnonic insulator-based switching devices. Here, we report on the experimental study of the intensity dependent spin wave switching in the lateral array of magnonic stripes. Using the high resolution Brillouin light scattering (BLS) spectroscopy we demonstrate the spin-wave power transfers from one stripe to the other in a periodic manner with the spatial period equal to the double coupling length. It is also worth to note, that the coupling length is increased with the increase of the input microwave signal level. Thus, we find that increase of the input microwave signal level leads to the variation of the power transmission coefficient between magnonic stripes. Next, we elucidate the mechanism of nonlinear spin-wave coupling between the adjacent magnonic stripes by the means of micromagnetic simulations and simple analytical model on the basis of the two coupled Landau-Ginzburg equations. We demonstrate that it is necessary to take into account the multimode coupling between the transverse width modes of each stripe. These features make the studied phenomenon very promising for applications of side-coupled magnetic stripes in spin-wave-based integrated circuits and magnonic networks.
P.8 Dipolar-exchange magnon and phonon spectra in arbitrarily magnetized yttrium-iron-garnet films

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We report on the experimental and theoretical investigation of thermal spectra of dipolar-exchange magnons and transversal acoustic phonons in obliquely magnetized yttrium-iron-garnet (YIG) thin films. The developed theoretical approach, which is based on the model presented in [1], fully describes the observed spectra. Magnon and transversal phonon dispersions were probed by wavevector-resolved Brillouin light scattering (BLS) spectroscopy. The scattering geometry allows for detection of wavevectors directed along the projection of the bias magnetic field (H=2500 Oe) on the film surface. The sample constitutes a YIG film of 5.6 µm thickness which was grown in the (111) crystallographic plane on a gadolinium-gallium-garnet substrate by liquid-phase epitaxy. It has been found that in the case of oblique magnetization the spectra of long-wavelength dipolar magnons split into spin-wave modes with forward and backward dispersions. It is remarkable, that in the experiment only the modes with quasi-uniform redistribution across the film thickness are detected due to the back-scattering geometry used in the experiments. The important consequence of this experimental limitation is that the visibility of the modes in the measured spectra strongly depends on the homogeneity of the spin-wave mode profiles. It is remarkable, that in the case of an obliquely magnetized films profiles of higher modes become more homogeneous than profile of lower mode and the highest mode profile becomes non-homogeneous during transition to exchange area of spectrum. We show, that by taking into account calculated spin-wave mode thickness profiles we can perfectly fit the experimentally observed dispersion relations.

Financial support by the European Research Council (ERC) within the ERC Advanced Grant “Supercurrents of Magnon Condensates for Advanced Magnonics” is gratefully acknowledged.

Localized magnetic textures have attracted interest both from a fundamental physics perspective and for potential applications in spintronics. Two such localized textures are topologically trivial droplets and non-trivial skyrmions. Typically, droplets are sustained in devices where damping is compensated for, [1] whereas skyrmions are ground states in materials with Dzyaloshinskii-Moriya interaction [2]. In uniaxial ferromagnets, both textures are unstable. We analytically explore their decay to provide insights into the behavior of droplets and skyrmions. We use a differential geometry method [3] to parameterize the perimeter dynamics of droplets and skyrmions. For large-diameter droplets, the perimeter is the curve in space where the magnetization is purely in-plane. In this regime, a skyrmion can be interpreted as a droplet with an integer number of in-plane magnetization phase rotations around the perimeter that ultimately confers topology. Exploiting this feature, we obtain a linear partial differential equation within the large diameter regime for the perimeter dynamics. Remarkably, the non-trivial topology of the skyrmion does not influence the dynamics, implying that droplets and skyrmions behave identically in this regime. We find that the textures’ diameter shrinks algebraically on a timescale proportional to $\alpha$. Furthermore, perimeter excitations exhibit a diffusive decay proportional to $n\alpha$, where $n > 2$ is the quantized mode number, in agreement with a recent report [4]. The differential geometry method allows us to analytically study the perimeter excitations of large-diameter droplets and skyrmions and their decay to damping. This method will permit to include other perturbations that may impact the decay and stability of these textures, such as external fields and non-local dipole fields.

P.10 Role of magnons in the formation of the thermal resistance of a ferrodielectric-dielectric interface.

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We discuss the size effect in the heat transfer from heated ferrodielectric (F) plates (films) for the case when the magnonic contribution to the thermal resistance of the ferrodielectric-dielectric (D) interface plays a decisive role. Really, although the magnons are principal carriers of the heat in the F [1] at low temperatures, they cannot penetrate into the D, so that heat transfer through the F-D interface is provided by phonons and depends on the acoustic transparency of the interface. On the F side there exists therefore near the interface a transition layer in which the thermal energy, transported by the magnons is transformed into a phonon flux. The thickness of this layer is of the order of the mean free path of the thermal phonon relative to scattering by magnons, \( l_{ps} \). If \( d \ll l_{ps} \) (is the thickness of the F plate), the detailed structure of this transition layer is of no importance in the calculation of the thermal resistance of the F-D interface; this leads to the usual acoustic-mismatch approach [2], in which the magnonic contribution is neglected. On the other hand, if \( d \leq l_{ps} \), then a kinetic calculation of the phonon dynamics in the transition layer is necessary. Below we describe the results of such calculation, with account taken of the finite transparency of the F-D interface to phonons. We have considered a F plate (film) of thickness \( s_z \), in contact on both sides with bulky dielectrics \( D_1 \) and \( D_2 \), whose temperatures \( T_1 \) and \( T_2 \) are known. We assume that magnon temperature of the F is \( T_s \). It is required to find the heat fluxes \( Q_1 \) and \( Q_2 \), at given the transparencies \( \alpha_1 \) and \( \alpha_2 \) of the interfaces to phonons. If \( d < l_{ps} \), then it may be shown [1] that the inhomogeneity of \( T_s \) along the F thickness can be neglected because the parameter \( K_p/K_s \ll 1 \), where \( K_p \) and \( K_s \) are the heat conduction coefficients of the phonons and magnons, respectively. At the same time, the phonon distribution function \( N_q(z) \) (where \( \mathbf{q} \) is the wave vector of phonon and \( z \) axis is perpendicular to the F) can be essentially inhomogeneous, and must be determined from the kinetic equation for \( N_q(z) \) with appropriate boundary conductions. We present the final result for the heat flux \( Q \) passing through the two F-D interfaces at \( T_1 = T_2 = T \)

\[
Q = \sum_{q_z>0} \hbar \omega_q s_z \bar{\alpha}(\mathbf{q}, d)[N_q(T_s) - N_q(T)]
\]

\[
\bar{\alpha} \equiv (1 - x)[\alpha_1(1 - \beta_2 x) + \alpha_2(1 - \beta_1 x)]/(1 - \beta_1 \beta_2 x^2)
\]

where \( x = \exp 1 - d/l \), \( l \equiv s_z/v_{ls} \), \( \hbar \omega_q \) is the phonon energy, \( s \) is the speed of sound and \( \beta \equiv 1 - \alpha \)

We propose and experimentally demonstrate a means of broadband phonon-magnon interconversion that relies on combining magnetoelastic coupling with translational symmetry breaking. This quasiparticle coupling mechanism has applications in the addressing of magnonic signal processors for use in future low-power wave computing architectures.
A magnonic crystal cavity (MCC) allow a build up of spin wave energies, similar to reflective mirror cavities in lasers. The MCC is designed using anti-dots (air holes or filled with a second material) with a reciprocal lattice constant that is an integral multiple of the longitudinal wave number $k$ of the spin waves. The periodic structure of the MCC creates band gaps that trap energy within the cavity. Spin waves excited at frequencies within the band gap accumulate energy within the cavity, while all other excitations are dissipated into the lattice [1]. To complete the device design for spin wave amplification by simulated emission of radiation (SWASER), we also introduce a gain in the cavity using a nano-contact that injects spin polarized electrons into the magnetic thin film. Alternatively, we can consider optical excitation using pulsed lasers [2]. Energy from the MCC is evanescently coupled to a magnonic crystal waveguide (MCW) and then guided towards external circuitry e.g. a coplanar waveguide. Our designs thus enable steady-state generation of spin wave devices, suitable as an RF source or for further information processing using magnonic logic gates. We use a combination of analytic reasoning, borrowed from our experiences with microwave waveguides and resonators, along with micromagnetic modeling of magnonic crystals to design the SWASER. The design rules are easily summarized as a requirement that the longitudinal wave vectors supported by the MCC be picked off the $\omega(k)$ dispersion diagram of the infinite thin film, while the transverse wave vectors of the MCC be matched to those of the MCW. Using a nano-contact to inject spin polarized electrons generates a spin torque, with the benefit of being able to tune the spin wave excitation frequency to achieve the matching of longitudinal and transverse wave vectors. Our simulations suggest that it is possible to design resonant cavities that offer 3 to 4 decades of improvement in quality factor with a corresponding decrease in ferromagnetic resonance linewidth. Further design improvements using a series of nano-contacts each within a resonator, and using graded magnonic crystals, are envisaged.

Artificial Spin Ices (ASI) are arrays of single-domain ferromagnetic islands arranged on geometrically frustrated lattices so that no micromagnetic configuration globally satisfies the dipolar interactions between nearest-neighbours. In ASI on a honeycomb lattice three islands meet at each vertex whose magnetization is constrained to point either into or out of the vertex. The system energy is minimized when all vertices obey “ice rules”, i.e. when they adopt two-in/one-out or one-in/two-out configuration. This leads to a vast ground-state degeneracy even in relatively small systems since the number of ice-rule obeying configurations scales exponentially with the system size. The vast number of microstates available to ASI systems suggests that it should be possible to smoothly tune the spin-wave response of such systems by moving between different microstates with the desired properties. It has been suggested for this reason that ASI systems may find applications as reprogrammable magnonic crystals. It has recently been demonstrated that ASI systems may be prepared in specific microstates by locally reversing the magnetization of individual islands using the stray field of a magnetic-force microscopy tip, bringing devices based on moving between selected microstates within reach. In this work, the spin-wave dynamics of honeycomb ASI systems were probed via micromagnetic simulations. It was found that altering the microstate of honeycomb ASI allows significant control over spin-wave eigenspectrum including the ability to shift resonant frequencies and tune the size of a magnonic bandgap. ASI systems thus offer good prospects as components of reprogrammable magnonic devices.
P.14  Route toward high-speed nano-magnonics

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The ability of a spin-wave source to generate short wave packets is particularly important for the practical implementations of high-speed integrated magnonic circuits. The performance of the traditional inductive excitation technique is very limited in this respect, since the externally generated microwave signal has to be pulse-modulated by semiconductor switches, which are generally characterized by a relatively low power efficiency, and on-off times of at least several nanoseconds. The fastest spin-wave excitation rate demonstrated so far was achieved by utilizing ultra-short laser pulses. However, this approach requires a high-power femtosecond optical source, and therefore has significant technological limitations. Here, we use the time- and space-resolved micro-focus Brillouin light scattering spectroscopy to study the temporal characteristics of the nonlocal spin injection (NLSI) mechanism for the excitation of propagating spin waves. We show that the NLSI mechanism is sufficiently fast to enable generation of short spin-wave packets with the duration down to 2 ns, close to the best results achieved by using optical-pulse excitation. Moreover, we find that the intense spin-wave packets generated by the pure spin current experience a nonlinear compression while propagating in the magnonic nano-waveguides, which further reduces their temporal width. A similar mechanism is responsible for the formation of nonlinear spin-wave solitons. It allows one to compensate for the dispersive broadening of spin-wave packets by engineering the nonlinear characteristics of magnonic transmission lines, resulting in improved information flow capacity. Our findings clearly demonstrate the unique benefits of NLSI oscillators as nanoscale sources of short spin-wave packets for the implementation of high-speed magnonic devices. We believe that our results should stimulate further developments in magnonics, and bring this area of research closer to the real-world applications.
P.15  Evidence of energy conservation in magnon-phonon coupling by ISHE in YIG/Pt heterostructure

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We have investigated spin-pumping effect from Y$_3$Fe$_5$O$_{12}$(YIG) thin film into Pt layer of power and frequency dependence. The magnetization precession in YIG excited by microwave cause spin injected into attached Pt layer. The diffusion of spin current transform to electrical charge by inverse spin Hall effect (ISHE). YIG was grown on GGG substrate with thickness of 260nm. Pt strip with 10nm thickness was deposited on YIG by DC sputtering method. The sample was flipped upside down on co-plane waveguide. By extract the H$_{ST-FMR}$ and its V$_{ISHE}$, we merely observe monotonic increasing curve of P$_{mw}$-V$_{ISHE}$, no definite relationship between different frequencies. Then we integrated the curve of H$_{bias}$ and V$_{ISHE}$ to get the area of the curve S$_{ST-FMR}$ at 6 GHz. A nearly linear correlation between P$_{mw}$ and S$_{ST-FMR}$ was discovered. To confirm this relation, more frequencies were measured and they all got the same result. We consider S$_{ST-FMR}$ as a parameter that has linear correlation with dynamic magnetic loss in Pt layer. The energy comes from spin pumping process. The linear relationship give direct evidence of pumping efficiency has little influence of exciting power and energy conservation between phonon, magnon and spin currents.
Inspired by the experiments performed by Cornelissen et al. [1], we calculate the microscopic theory to describe the transport between two electronic reservoirs mediated by magnons. The main idea is to describe the transport of magnons generated by a localized spin accumulation in a magnetic insulator (e.g. YIG). The spin accumulation is achieved by injecting a spin current in the magnetic material through one of the electronic reservoirs. The magnons travel along the material and they reach the second reservoir. The coupling between the reservoirs and the magnetic insulator is mediated by exchange interaction. We applied the path integral formalism and linear response theory to calculate the effective interaction between the reservoirs and to calculate the transport coefficients of the effective system.

P.17  Spin wave propagation in perpendicularly magnetized nm-thick yttrium iron garnet films

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Magnonics offers a new way for information transport that uses spin waves (SWs) and is free of charge currents. Unlike Damon-Eshbach SWs, the magnetostatic forward volume SWs offer the reciprocity configuration suitable for SW logic devices with low power consumption. Here, we study forward volume SW propagation in yttrium iron garnet (YIG) thin films with an ultra-low damping constant $\alpha = 8x10^{-5}$. We design different integrated microwave antenna with different k-vector excitation distributions on YIG thin films. Using a vector network analyzer, we measured SW transmission with the films magnetized in perpendicular orientation. Based on the experimental results, we extract the group velocity as well as the dispersion relation of SWs and directly compare the power efficiency of SW propagation in YIG using coplanar waveguide and micro stripline for SW excitation and detection.
P.18 Tuning spin wave resonance using lateral current spread in nano-contact spin torque nano-oscillators

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A spin wave (SW) is a collective disturbance of the magnetization [1]. The SW characteristics are governed by strong local exchange and relatively weak, but long-range, dipole-dipole interactions. SWs with short wavelengths, which are mostly controlled by the exchange interactions, are now receiving the most research attention, since they offer higher frequencies and group velocities, and greater propagation lengths. Nanocontact spin torque nano-oscillators (NC-STNOs) allow for SW propagation and interaction over large distances [2]. They give the advantage of the ability to generate a wide range of highly non-linear localized and propagating SW modes [3] for use in magnonics [4]. In previous work, we investigated how the current distribution and therefore the performance of the device depend on the copper thickness of the bottom electrode (tCu) in NC-STNOs based on Co/Cu/NiFe stacks [5]. Further, using homodyne-based measurement techniques we studied the magnetodynamics in the case of in-plane fields, which align the magnetization of both the free and reference layers [6]. In this study we apply the theory from the previous work to tune the SW resonance (SWR) mode by changing the current distribution, and as a result the distribution of Oersted field, by varying tCu. Our findings show that the lateral current spread can be used to tailor the spatial characteristics of the resulting SW beams. The effective diameter decreases and SWR linewidth increases by increasing tCu. We can therefore conclude that the current spread must be wider for lower Cu thicknesses, at least in the NiFe layer. This interpretation is also confirmed by micromagnetic simulations.

Spin-wave mode conversion via optically induced landscapes of the saturation magnetization

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Magnons - eigen excitations of the electrons’ spin system - are of great interest for future logic devices as data carriers [1]. Several prototypes of such devices have already been demonstrated [2, 3] but there are no experimental realizations of any two dimensional magnon circuits, yet. One of the main reasons for this is the strong spin-wave anisotropy in in-plane magnetized films. The backward volume magnetostatic spin waves (BVMSW) propagating parallel to the biasing field and the magnetostatic surface spin waves (MSSW), propagating perpendicularly, exist in different frequency ranges. first attempts to realize the BVMSW-MSSW-mode conversion have been demonstrated via T-junctions [4, 5]. Here, we use reconfigurable optically-induced thermal landscapes [6] to convert BVMSW to MSSW in a wide frequency range with a high efficiency. Computer generated holograms provide all degrees of freedom to realize arbitrary intensity distributions. The laser light impinges on the sample and is absorbed. Thus, the waveguide heats up locally and temperature gradients are formed. By increasing the temperature the saturation magnetization decreases. The dispersion relation of both modes therefore shifts to lower frequencies and, thus, allows for a conversion from BVMSW in the cold region to MSSW in the heated region. Furthermore, we show that the mode conversion is possible only in the presence of a properly-oriented magnetization gradient that is needed for the conservation of the spin-wave momentum.

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Recent work studying the characteristics of magnon systems at very low temperatures has created interest in the possibility of integrating magnonic components into hybrid quantum systems. One possible area of integration is quantum information technology, where standing excitations could be used for quantum memory applications, and propagating excitations may be used for delay lines or other transmission components. With a view to building new hybrid systems for quantum information applications, and for studying the quantum-mechanical behaviour of single magnons, we have conducted studies characterising the dispersion of spin waves at millikelvin temperatures. We present measurements of propagating spin wave pulses in films of yttrium-iron garnet in surface and backward wave configurations at millikelvin temperatures. In surface wave configuration, we are able to accurately simulate the dispersion of the pulses using frequency domain analysis. Surface waves are also seen to display a strong temperature dependence of their allowed frequencies in the range of 10mK to 5K. This is attributed mainly to the effects of the GGG substrate. Comparisons are made with the backward wave configuration.
**P.21 Magnetostatic spin waves in irregular narrow ferromagnetic waveguides**

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Recent results in magnonics demonstrate the possibility of developing magnonic logic circuits - promising counterpart to conventional electron-based logic circuits. The use of magnons instead of electrons provide several advantages (low losses, tunability). Current prototypes of magnonic logic gates are represented by joint of spin wave (SW) interferometers. The interferometers themselves and the connections between them are made of narrow magnetic waveguides. However at the moment there is no rigorous theory describing propagation of SW in such structures especially on nanoscale where the confinement effects reveals. The aim of the current work is to study magnetostatic surface spin wave propagation (MSSW) in a ferromagnetic films of varied width. We have investigated dynamics of MSSW propagation in such waveguides by theoretical and experimental technique. These waveguides were fabricated from YIG film by laser cutting. Frequency transmission coefficients and spatio-temporal dynamics were measured by Brillouin light scattering technique (BLS). The superposition of different spatial MSSW modes was detected. It was in particular found that magnetization distribution in an irregular waveguide was due to MSSW modes superposition with the specific beating. We have also developed a theoretical method for describing spin wave propagation in such structures based on approach of irregular waveguides. As a result the energy re-distribution between various modes were obtained. Furthermore with specific material and geometrical parameters, external field and excitation frequencies energy re-distribution between modes can lead to dominance of different spatial modes in output signal. It is also important to note that focusing in such the irregular waveguide can compensate losses and even overcome nonlinear threshold.

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P.22 Theory of linear spin wave emission from a Bloch domain wall

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The generation of small wavelength spin waves for future magnonic technologies will require nanometer-sized spin wave sources. Recent work has shown that pinned domain walls can generate spin waves when excited by an external microwave field [1-4] or spin-polarized current [5], even with wavelengths down to tens of nanometers. These results would benefit from a quantitative, theoretical explanation of the underpinning physics. Here, we use analytical theory to demonstrate and explain the emission of exchange spin waves from a Bloch domain wall driven by a uniform microwave magnetic field directed perpendicular to the plane of the wall. Crucially, we find that the spin wave emission is the result of a linear process, hence the spin wave frequency matches that of the excitation field. Furthermore, we explore the peculiar characteristics of the Pöschl-Teller potential well, which naturally represents the graded magnonic index due to the Bloch domain wall in the Schrödinger-like linearized Landau-Lifshitz equation. This potential is known to allow 100% transmission of incident waves at any frequency, for certain parameters of the potential. We find that the domain wall is naturally sized not only to exhibit this property, but also to maximize its spin wave emission.

Yttrium iron garnet thin films with very low damping obtained by recrystallization of amorphous material

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Yttrium Iron Garnet is a room temperature ferrimagnet, which has recently gained importance for magnonics and spintronics [1,2]. For the integration into magnonic devices, however, very thin films must be used which are mostly fabricated by pulsed laser deposition (PLD) and often suffer from increased damping. We achieve very high quality using YIG deposition by PLD at room temperature and subsequent annealing [3]. For a 56 nm thick layer a damping constant of $\alpha = 6.15 \cdot 10^{-5}$ and a linewidth as small as 1.30 Oe @ 9.6 GHz are obtained which are the lowest values for PLD grown thin films reported so far. Even for a 20 nm thick layer a damping constant of $\alpha = 7.39 \cdot 10^{-5}$ is found. In this case the FMR linewidth is 3.49 Oe @ 9.6 GHz. The layers show high crystalline quality and sub nanometer surface roughness in various structural characterizations. Even transmission electron microscopy reveals no visible defects neither in the bulk nor at the interface to the substrate. While the first annealing experiments were performed in oxygen atmosphere we also observe no degradation for annealing in argon. Changing the atmosphere during deposition from oxygen to argon, however, results in increased damping and reduced saturation magnetization. We are going to present the results of structural and magnetic characterization for different layer thicknesses and annealing parameters.

Magnonic devices require the control of spin waves (SWs) on the nanoscale. Magnonic crystals (MCs) seem promising as they allow for tailoring the dispersion relation of SWs. They are created by periodic modulation of magnetic properties. Local deviations from the periodic order are expected to add further functionality. It was already shown that a single magnetic defect in 1D MCs controlled SW amplitudes. It is now interesting to explore how the phase of propagating SWs is affected. We prepared a 1D MC consisting of an array of 25 nm thick permalloy nanostripes with a width of 320 nm spaced 80 nm apart. SWs with a wavelength of 12 $\mu \text{m}$ were locally excited with a coplanar waveguide (CPW). By adjusting the magnetic history, a single stripe with opposed magnetization was created between signal and ground line of the CPW as evidenced by magnetic force microscopy. The phase and intensity of SWs at and around an oppositely magnetized stripe in the MC was studied with phase-resolved focused Brillouin light scattering microscopy. At zero field, a local phase-shift of $\pi$ in out-of-plane direction is detected at this defect. Beyond the defect, phases coincide with the defect-less case and SW intensities are only weakly reduced. The stripe with opposed magnetization thus couples resonantly via the dynamic in-plane magnetization component and do not shift the phase of traversing SWs with long wavelengths. When a magnetic field is applied collinear to the stripes a strong deviation of the SW phases around the defect is observed. The field dependent scattering was further explored via broad band microwave spectroscopy. In a specific field regime, the SW amplitude varied almost linearly with the applied field. These observations are attributed to the biasing field dependent mismatch of resonance frequencies. The work contributes to the optimization of magnetic defects for SW control on the nanoscale. We thank V. E. Demidov and funding by SNF via grant 163016.
P.25 Spin wave excitations in ferromagnetic antidot lattices with Penrose tilings

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Interconnected nanomagnets periodically arranged in one (1D) and two dimensions (2D) provide tailored band structures for spin waves. These so-called magnonic crystals (MCs) are expected to provide control of spin waves in both the dipolar and exchange-dominated regime. For 2D MCs based on periodic antidot lattices with translational symmetry allowed minibands and a large spin-wave velocity of up to 6 km/s have been reported [1]. Spin wave band structures in artificial magnetic quasicrystals exhibiting rotational but no translation symmetry are much less explored. We fabricated lattices of nanoholes (antidots) in thin films of CoFeB that show a quasicrystalline arrangement (Penrose tiling). We performed broadband spin wave spectroscopy using a vector network analyzer for different orientations of magnetic field. Experiments were based on different aperiodic antidot lattices where we varied the sizes of nanoholes, the kind of Penrose tiling and the so-called generation (lateral size). The spectra showed a large number of spin wave modes which were not present in plain CoFeB films. We attribute the modes to the aperiodically arranged nanoholes and the inhomogeneous internal field due to the demagnetizing effect. We report on both absorption and propagating spin-wave spectroscopy data that are found to reflect different sets of eigenmodes of the quasicrystalline nanohole lattices. The work was supported by SNF via grant number 163016.

P.26  Spin waves in solid nanowire of circular cross subsection

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Nanoscale magnetic systems have been studied extensively in various geometries, such as wires of different cross subsections, arrays of wires, dots, rings, etc. Such systems have promising applications in advanced magnetic devices[1]. Uniform magnetic nanowires are the basic structures which were widely studied. In this work we focus on spin waves in solid Ni nanowire of circular cross subsection. We investigated spin wave dynamics in crossover dipolar-exchange regime. Solution for spectrum of the spin waves propagating along the wire axis was obtained in semi-analytical form and compared with numerical computation based on finite element method to find spin wave eigenmodes using the Landau-Lifshitz equation. We obtained spin wave spectrum as a set of branches with different character of dispersion. Crossing and anticrossing branches appeared for uniform nanowire for the case of absence of magnetization pinning on the external surface of the wire. We discussed possibility of branches identification and their crossings and anticrossings by calculating the contribution of exchange and dipolar energies and investigation of spatial profiles of spin wave amplitudes and magnetostatic potential. We showed that points of crossing and anticrossing of spectrum branches can be also obtained using overlap integral of the magnetization.

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P.27 Angular dependent magnetization dynamics of quasicrystalline nanomagnet lattices

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Studies on the effect of aperiodicity on fundamental physical phenomena have been pursued for more than three decades [1]. Recent quasistatic studies on artificial quasicrystals—an array of nanobars on a quasicrystal lattice—have reported exotic properties such as the presence of knee anomalies and non-stochastic switching during magnetization reversal [2, 3]. Spin wave resonances (SWR) in a quasicrystal lattice of interconnected nanobars have been proposed to be due to the collective nature of the lattice and may help to better understand the exotic properties reported for the reversal regime [2]. We have fabricated interconnected networks of Permalloy nanobars on quasicrystal lattices and performed angular dependent broadband spectroscopy in the GHz frequency regime supplemented by micromagnetic simulations, magnetic force microscopy, and X-ray photoemission electron microscopy. The interconnected nanobars (810 nm long, 130 nm wide, 25 nm thick) were arranged on Penrose P2, Penrose P3, and Ammann quasicrystal lattices. Our spectra show systematic and reproducible spin wave resonances in the switching regime of these planar quasicrystal structures. We discuss our experimental results in view of reprogrammable magnonic devices [4] based on artificial quasicrystals. The work was supported by the SNF via grant number 163016 and DFG via TRR80.

P.28  Propagation of spin waves through a film with spiral magnetic structure

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Magnetic materials with spiral magnetic structure are an exotic type of magnetic materials where the period of the magnetic structure is much greater than and, as a rule, incommensurate with the period of the crystalline structure [1]. Incommensurate magnetic ordering originates from the competition between the nearest and next-nearest-neighbor exchange interactions, or due to the Dzyaloshinsky-Morya antisymmetric exchange interaction. Since the discovery of the first incommensurate magnets in 1956, the static and dynamic properties of incommensurate magnets have been subjected to intense research aiming to disclose specific properties of the magnetic order. Currently, peculiarities of the magnetization dynamics in such structures have attracted interest of both theorists and experimentalists. The researchers are attracted, in particular, by the exotic and complex micromagnetic states and dynamic characteristics. A complex ground configuration of incommensurate magnets causes a number of interesting phenomena in spin waves propagation and offers new opportunities for magnonic devices. The presented work is devoted to understanding the peculiarities of spin wave propagation in layered structures created by a film with spiral magnetic order and a film with commensurate magnetic order. The expression for the transmission coefficient of spin waves in such structure has been obtained and analyzed in detail.

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P.29 Spin-wave propagation in sub-micron sized CoFeB waveguides

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Spintronic devices based on spin waves are promising alternatives to the CMOS technology and have high potential for power and area reduction per computing throughput [1,2]. To be CMOS-competitive the spin-wave devices [1,3,4] need to be reduced to the nanoscale. Here we report on Brillouin light scattering spectroscopy on spin-wave propagation in 10 nm thick CoFeB waveguides with scaled widths down to 500 nm. The saturation magnetization of 1200 kA/m and an exchange constant of 18.5 pJ/m were determined from the dependence of the frequency of perpendicular standing spin-wave modes on the applied bias field. A Gilbert damping of 0.005 was extracted from FMR experiments using a vector network analyzer. The spin wave are exited by a RF driven Au antenna of 250 nm width deposited on top of the CoFeB conduit. We find that for waveguides with widths up to 1 µm, the spin waves exhibit a continuous spectrum between the FMR frequency and the limit given by the excitation efficiency of the antenna. However, in scaled waveguides of 500 nm the spin-wave spectrum is not continuous anymore, but unveils frequency gaps. These gaps could be attributed to either strong finite-size effects and wave confinement or to the inhomogeneous ground state of the magnetization and of the internal field. To distinguish between the two hypothesis we performed micromagnetic simulations considering two different scenarios: i) an uniform magnetization state (created artificially) to address only the quantization effects, and ii) non-uniform distributions of the magnetization and the internal field due to the partial saturation of the waveguide. We find that the appearance of the frequency gaps originates in the inhomogeneous ground state of both internal field and magnetization. Understanding of this discovered phenomena is of crucial importance for the further miniaturization of magnonic devices. financial support by the DFG (SFB/TRR 173) is acknowledged.

P.30  Nanotubes, novel layouts for magnonic applications.

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The knowledge of mechanisms and architectures for controlling spin waves in ferromagnetic systems can be exploited to design novel electronic devices. In the field of signal processing, data computation as well as information transfer, magnonic devices are already investigated as alternatives. In this work we propose a system possessing surface curvature, namely magnetic nanotubes, as promising layouts for magnonic devices. Here, we highlight their tunable and non-reciprocal spin-wave properties. Their curvature-induced non-reciprocity is maximum at the nanotube ground state. Furthermore, it is significant and is present not only in the SW dispersion, but also manifests itself via a wave vector-dependent absorption leading to the difference in the extinction length of counter-propagating magnons along the tube and the azimuthal direction [1,2]. The magnons in nanotubes are quasi-monochromatic (plane waves) and the non-reciprocity can be controlled with application of weak DC external magnetic fields applied along the tube’s long axis. Our findings suggest that magnetic nanotubes can be exploited as a novel layout for conducting magnons along curved path, for one-dimensional non-reciprocal magnonic crystals, therefore for flexible and reconfigurable magnonic circuits.

P.31  Tailoring spin wave band structure of one-dimensional magnonic crystals consisting of L-shaped iron/permalloy nanowires


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We have investigated both experimentally and numerically the magnonic band structure of arrays of closely spaced Fe/Permalloy nanowires (NWs) with an L-shape cross-subsection using the Brillouin light scattering technique and GPU-based micromagnetic simulations. NWs consist of a 340 nm wide and 10 nm thick Permalloy layer covered by a 170 nm wide Fe overlayer. The thickness of the latter was varied in the range from 0 to 10 nm in order to analyze its influence on the magnonic band structure. The edge-to-edge separation is d = 100 nm and the array periodicity a = (w/2 + d) = 440nm, resulting in the edge of the first Brillouin zone (BZ) at π/a = 0.71x10⁷ radm⁻¹. The spin wave dispersion has been measured by Brillouin light scattering technique up to the third BZ and compared to band structure simulations performed by the MUMAX3, open-source, GPU-accelerated software. All the detected modes exhibit an oscillating dispersion related to the periodicity of the NWs array. The magnonic band structure consists of frequency bands where SWs are either allowed or forbidden to propagate through the crystals. We found that both the frequency and the spatial profile of the most intense and dispersive mode, can be efficiently tuned by the presence of the thin Fe NW overlayer. In particular, by increasing the Fe thickness, one observes a substantial frequency increase, while the spatial profile of the mode narrows and moves to the Permalloy NW portion not covered by Fe. This blue shift is due to an increase in the dipole energy contribution to the mode frequency with a decrease in the effective standing-wave wavelength. In addition, the presence of the Fe overlayer causes a significant increase of the number of detected modes and a change of their intensity in the Brillouin spectra as a function of the Bloch wave number. These results show that it is possible to engineer the band structure of magnonic crystals consisting of bi-layered, L-shaped, NWs by a careful control of the overlayer thickness.
P.32 The role of the demagnetizing fields in the transition from thin films to magnonic crystals

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The transition from a film to a full magnonic crystal is studied by sequentially ion-milling a periodic stripe pattern into a 40 nm thick Ni_{80}Fe_{20} film. The spin-wave resonances of each milling stage are detected by ferromagnetic resonance for both in-plane main field axes, i.e. parallel and perpendicular to the stripe pattern. Theoretical calculations and micromagnetic simulations yield the individual mode profiles, which are analyzed in order to track changes of the mode character. The latter is strongly linked to the evolution of the internal demagnetizing field. Its role is further studied and imaged by electron holography measurements on a hybrid magnonic crystal, which is made with a 10 nm deep surface modulation. The complex effects of mode coupling, mode localization, and anisotropy-like contributions by the internal field are unraveled. Simple transition rules from the \( n \)th film mode to the \( m \)th mode of the full magnonic crystal are formulated. This work has been supported by DFG grant KL2443/5-1.
P.33 Spin wave refraction and reflection (Snell’s law) at the interface between two NiFe thin films of different thickness. A new perspective for spin wave steering and wavelength manipulation.


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Efficient manipulation and steering of spin waves is one of the fundamental problems that needs to be solved before spin waves can be effectively used in magnonic devices. [1-4]. Furthermore the need to scale down the dimensions of magnonic devices is currently hindered by the difficulty to efficiently excite short (sub 1.0 micron) wavelength spin waves by means of lithographically defined transducers. Here we report an experimental study of spin wave refraction and reflection (Snell’s law) at the interface between two NiFe thin films. The interface is realized by a thickness step between a thicker film (60 nm, fixed) and a thinner film (30, 20, 15, 10 nm) which present different dispersion relations. The spin waves have been excited by a lithographically defined coplanar waveguide transducer and they have been detected by both phase sensitive micro-focused Brillouin light scattering and time resolved magneto optic Kerr effect. Since the dispersion relation for spin waves in thin ferromagnetic films is inherently anisotropic, deviations from the isotropic Snell’s law, known in optics, are expected and experimentally observed for incidence angles larger than 25° with respect to the interface normal between the two magnetic media. Furthermore, we show that the thickness step modifies both the wavelength and the amplitude of the incident waves. In particular the wavelength is reduced when the spin wave is transmitted from a thicker to a thinner film by a factor equal to the ratio of the two thicknesses. Finally we observed an enhancement of spin wave amplitudes in the vicinity of the transition region. Our findings open up a new way of spin wave steering for magnonic applications.

Magnetism has been studied intensively since the dawn of physics. Even though we have known for a century that magnetism eludes explanation in classical physics, most experimental work on magnetism is done at high temperatures, where the underlying microscopic quantum mechanisms cannot be probed. As magnons have similar energies as superconducting qubits, and as these qubits are sensitive to electromagnetic fields, it should be possible to couple superconducting qubits to magnons. The high level of precision in qubit control and readout could then be leveraged for the manipulation, creation and measurement of single magnons. This could lead to new experimental methods for the study of magnon physics on the single-excitation level, and to new devices for quantum information processing utilizing the rich physics of magnons.

Recently, work on magnonic resonators and superconducting qubits has revealed it is possible to create single excitations and magnetization Fock states inside a magnonic resonator [1]. Here, we discuss the design of superconducting quantum circuits specifically intended to couple to propagating magnons in a thin-film Yttrium Iron Garnet waveguide.

Parallel parametric pumping of magnons is a powerful technique, which allows for the efficient excitation and amplification of spin waves and consequently for the observation of such prominent effects as the formation of Bose-Einstein magnon condensates and supercurrents [1, 2]. In order to understand the physical nature of the mechanisms leading to the creation of Bose-Einstein magnon condensates, magnon-magnon and magnon-phonon scattering processes, which are responsible for the thermalization of parametrically pumped magnons, should be revealed for a wide temperature range. Furthermore, a decrease in temperature also holds the potential of increasing the lifetime of a magnon condensate allowing thus for the observation of such quasi-equilibrium macroscopic quantum phenomena as Josephson oscillations and persistent magnon supercurrents. Here, we present the study of parametrically excited magnons in a single crystal yttrium-iron-garnet film performed in a wide range of wave numbers for the temperature range from 40 to 340 Kelvin. In our measurements, we obtained an almost linear decrease of $4\pi M_S$ with increasing temperature. Simultaneously a strong non-monotonic increase of the magnon relaxation parameter with decreasing temperature was found. The observed temperature influence on the magnon damping and the saturation magnetization in yttrium iron garnet / gadolinium gallium garnet epitaxial structures is being discussed.

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Characterization of single YIG microstructures using Brillouin light scattering microscopy

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Spin-waves are a promising candidate for a new-wave based information and data processing technology \cite{1,2}. Yttrium iron garnet (YIG) exhibits the lowest known spin-wave damping and is therefore of interest for such a technology. The downscaling of YIG structures to the nano-scale is a primary necessity. The characterization of the magnetic properties of such structures tends to be challenging. Common stripline FMR only allows for the investigation of large arrays of structures while optical methods such as Brillouin Light Scattering (BLS) yield an insufficient frequency resolution. We therefore use a technique that combines a common stripline for microwave excitation and microfocussed BLS for magnetization dynamics detection to be able to characterize single YIG nanostructures. The investigated structures are patterned from a sub-100nm thick YIG LPE film \cite{3} by using ion beam etching and focussed ion beam etching to fabricate lateral patterns down to the nanometer scale. By exciting the magnetization dynamics and performing BLS microscopy measurements, different lateral standing modes are observed. Comparing the measurements to micromagnetic simulations, the spin-wave modes are identified. A magnetic field dependent determination of the resonance frequency and the linewidth of the fundamental mode is performed. For the subsequent determination of the saturation magnetization and the Gilbert damping parameter of individual microstructures, quantization effects need to be taken into account. The results indicate a decrease of a few percent of the saturation magnetization and an increase of the overall damping by a factor of three.

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\cite{2} A. V. Chumak et. al., Nat. Phys. 11, 1505 (2015).
\cite{3} C. Dubs et. al., arXiv :1608.08043v1 (2016).
P.37  Realization of a macroscopic spin-wave majority gate and its miniaturization

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By promising a significant reduction of Joule heating due to Ohmic losses, spin-wave logic devices offer large advantages compared to modern CMOS-based elements. An example for such a logic element is the majority gate \[1\]. It features three inputs and one output with the output logic state representing the majority of the input logic states. In contrast to current logic gates based on transistors, a majority-based logic allows for a reduction of the number of gates for implementing a given operation \[1\]. The functionality and capabilities of such a device have been investigated by numerical methods \[2\]. We used microwave techniques to investigate the spin-wave propagation in a macroscopic spin-wave majority gate made from a 5.4 µm-thick yttrium iron garnet (YIG) film \[3\]. YIG is of particular interest due to its intrinsically low Gilbert damping parameter and large spin-wave propagation lengths. The investigation of the logic operation of the device was realized by adjusting the phase of the input signals. By defining phase shifts of 0 and \(\pi\) (that correspond to logic “0” and logic “1”) for each input channel, the operation of the device as a majority gate was proven - the output phase of the signal was defined by the majority of the input phases. Additional time-resolved measurements have shown that the device can switch logic output within 11.3 ns, which corresponds to a clock frequency of 88.5 MHz \[3\]. In order to scale down spin-wave majority gate devices, we fabricated different combiner structures made from a 100 nm-thick YIG film and examined the spin-wave transmissions and reflections by using Brillouin light scattering (BLS) microscopy. This research has been supported by DFG SFB/TRR 173 “Spin+X”, EU-FET Grant InSpin 612759, ERC Starting Grant 678309 MagnonCircuit, and DFG DU 1427/2-1.

P.38  Auto-oscillations in YIG/Pt nanostructures driven by the spin Seebeck effect

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Spin-transfer torque (STT) [1] has attracted recent attention since it promises the potential realization of efficient microwave sources [2] and magnonic components with compensated spin-wave losses [3] by the use of spin currents. The spin Seebeck effect (SSE) is an alternative method to generate spin-currents. Here, spin currents originate from a thermal gradient rather than from a charge current, which is used in other approaches relying on, for instance, the spin Hall effect (SHE). The SSE is of tremendous practical interest since it promises the use of parasitic heat sources that already exist in the system for the spin-wave generation and manipulation. Recently, magnetization auto-oscillations due to the SSE [4,5] were demonstrated in YIG/Pt nanostructures. We present the time-resolved experimental observation of magnetization auto-oscillations driven by pulsed STT in YIG(66nm)/Pt(7nm) nanowires. We find that the SSE is the dominant excitation mechanism in our experiment. The application of 50 ns long current pulses results in Joule heating of the Pt layer, and, consequently, leads to the formation of a thermal gradient across the YIG/Pt interface. This gives rise to a SSE-induced spin current injected into the YIG layer, which exerts an anti-damping torque on the magnetization, and, eventually, excites magnetization precession. Time-resolved Brillouin light scattering microscopy is used to display the temporal evolution and spatial distribution of the excited magnetization dynamics in the nanostructures. This research has been supported by: ERC Starting Grant 678309 MagnonCircuit, EU-FET Grant InSpin 612759, and DFG (DU 1427/2-1, and SE 1771/4-2 within SPP 1538).

Frequency-division multiplexing in magnonic networks by spin-wave caustics

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Frequency-division multiplexing is the basis for parallel data processing in a single device and for efficient information transport through logic circuits. In such networks, signals at different frequencies are used to simultaneously transfer information through the same conduits in different frequency channels [1]. In this work, we present an approach for the realization of frequency-division multiplexing in magnonic networks, where spin waves (SW) are used to transport information and to perform logic operations by exploiting, e.g., interference effects. In particular, we utilize nondiffractive spin-wave beams in in-plane magnetized 2D magnetic media, so called SW caustics [2-4], which originate from the anisotropic SW dispersion. By using micromagnetic simulations, we demonstrate how the frequency dependency of the propagation direction of SW caustics can be used to split SW signals of different frequencies into different SW waveguides. Finally, we present the design of a passive device at the micrometer scale which performs frequency-division multiplexing in a magnonic network.

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Spin torque nano-oscillators (STNO) are based on spin transfer torque effect where a dc current flowing through a magnetic tunnel junction (MTJ) produces auto-oscillations when the current density is sufficiently high so that the spin torque can compensate the intrinsic damping. STNOs are attractive for applications in wireless communications due to their nanometric size, their frequency tunability and their multifunctionality: one can generate and modulate the signal simultaneously [1-4] without the need of external mixer. For communication, information is encoded by digital modulation of the amplitude or the frequency between two discrete values. Here, we demonstrate a frequency modulation by current in STNOs. In-plane MTJ nanopillars of 120 nm diameter with uniform magnetization were fabricated from a stack of PtMn/CoFe/Ru/CoFeB/MgO/CoFeB/Ta/NiFe. The MTJ shown here, is characterized by a tunnel magnetoresistance of 49%, frequencies of 6-9 GHz (for fields of 400-1000 Oe) and minimum line widths of 13-30 MHz. At the operating point of a field of 860 Oe applied at an angle of $7^\circ$ with respect to the polarizer, the threshold current is 0.5 mA and the frequency slope $df/dI = -260 \text{ MHz/mA}$. To demonstrate frequency shift keying, a square shaped train of voltage pulses is applied such that the current seen by our STNO varies between 0.7 mA and 1.6 mA. This leads to a frequency shift keying between the two values of $f_1=8.26 \text{ GHz}$ and $f_2=8.39 \text{ GHz}$. Upon varying the bit rate between 2-100 Mb/sec, it is found that the STNO can follow the digital modulation signal up to 20 Mb/sec. At higher rates, it is difficult to distinguish between the two levels of frequency due to the relatively low output power (4-15 nW) emitted by the STNO, i.e. to a low signal to noise ratio. Improvements are underway in materials and nanofabrication to enhance the output power and improve the spectral characteristics of the oscillations to push the bit rates to higher values.

Excitation and detection of short-waved spin waves in ultrathin Ta/CoFeB/MgO-layer system suitable for spin-orbit-torque magnonics


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The application of spin orbit torques promises exciting new ways to excite and manipulate spin waves [1-3]. Due to their interfacial nature, these effects are particularly pronounced in ultrathin films. Here, we present a study of the spin-wave properties in ultrathin CoFeB layers incorporated into a Ta/CoFeB/MgO stack. This layer system is known to host large spin orbit torques [4] and is commonly used in magnetoresistive random access memory cells. We demonstrate that spin pumping together with the inverse Spin Hall effect is well-suited to detect short-wavelength spin-wave dynamics in these ultrathin films [5], which are difficult to access with other experimental techniques. In addition, we discuss the impact of the large perpendicular magnetic anisotropy in these layers on the spin-wave spectrum, which, among others, results in a comparably large spin-wave lifetime. The intriguing combination of a large spin-wave lifetime and large spin-orbit torques in this material system and the wave-vector independent detection by the iSHE opens up the way for scalable magnonic devices.

P.42 Control of coupling between two spin-torque vortex oscillators with an external source

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Self-sustained auto-oscillators display rich collective dynamics and describe a large variety of systems in nature. A particularly interesting feature is the fact that they can synchronise, which allows improving their output amplitude and spectral purity, and can be used to study and mimic neural networks [1]. Spin torque nano-oscillators (STNOs) serve as outstanding candidates for understanding synchronisation phenomena as they are nonlinear and highly tunable. In this study we show that the coupled behaviours of two STNOs can be controlled using an external rf signal. Our sample consists of two identical vortex STNOs. They are close enough so that they can mutually synchronise thanks to the magneto-dipolar interaction. Their oscillation frequencies can be individually tuned, so that they can be operated into or out of synchronisation [2]. Here, an external rf field is applied through a stripline antenna fabricated on top of the STNO pair. In a case where the two STNOs are mutually coupled but not synchronised, we show that the rf field can pull their frequencies closer when phase-locking either STNO, as this enhances their effective coupling [3]. In a case where the two STNOs are mutually synchronised, we show that the rf field can destroy the mutual synchronisation state when it is applied at a frequency lower than the one of the synchronization peak. We also provide theoretical explanations of these two behaviours. An analytical model has been developed from the Kuramoto formalism, as the synchronisation dynamics of such oscillators are mainly driven by phase coupling. For the first case, the experiment can be fitted analytically to the model with the assumption of weak rf field. For the second case we show that the non-linear adjustment of the vortex oscillators’ amplitude is a key mechanism to explain the observed features.

Spin-transfer and spin-pumping in disordered normal metal-antiferromagnetic insulator systems

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We consider an antiferromagnetic insulator in contact with a normal metal. In the metal, a spin accumulation can induce spin-transfer torques on the staggered field and the magnetization in the antiferromagnet. Via Onsager reciprocity relations, these torques are connected to spin-pumping; the emission of spin-currents by a precessing antiferromagnet. We consider how the various components of the spin-transfer torque are affected by spin-independent disorder and spin-flip scattering in the metal. In a similar manner to Ohm’s law, spin-conserving disorder reduces the coupling between the spins in the antiferromagnet and the itinerant spins in the metal. Spin-flip scattering leads to spin-memory loss with a reduced spin-transfer torque. We discuss the concept of a staggered spin current and show that an associated staggered spin accumulation is very small in realistic situations.
Spin wave dispersion relation depends on a magnetic field. The resonance frequency is higher for higher magnetic fields. While it was previously reported how spin waves adapt to spatially inhomogeneous magnetic fields [1], we investigated spin-wave propagation under the influence of nanosecond magnetic field pulses. We fabricated a 2 µm-wide spin-wave waveguide from NiFe with an antenna for spin wave excitation and a dc line below the spin-wave conduit. An external magnetic field was applied perpendicular to the stripe. In order to modulate the internal magnetic field in the stripe, a dc pulse was injected into the dc line, because the dc pulse generates Oersted field. We measured a magnon density on the stripe using time-resolved Brillouin light scattering microscopy, and investigated spin-wave dynamics when the dc pulse came in. We succeeded to observe the temporal magnon density when the dc pulse came in and went out. For a fixed excitation frequency observed a decrease (increase) of the spin-wave frequency at the rising (falling) edge of the dc pulse. Since Oersted field is in the opposite direction to the external magnetic field, the internal magnetic field is lower than the external field while the dc pulse is on. The dispersion relation shifts to lower frequency, and it matches to the resonance magnetic field temporarily. At that time spin wave pulse is excited under the antenna. We also observed the position dependency of the excited spin wave pulse. The spin wave pulse propagated, and the frequency shifted lower at the rising edge of the dc pulse, or shifted higher at the falling edge of the dc pulse. We succeeded to observe the excited spin wave pulse following the change of the dispersion relation, and demonstrated the modulation of spin wave by the change of the magnetic field.

Biominalization, is a process of mineral formation by organisms which involves the uptake of ions from the environment, in order to produce minerals that generally controlled by proteins. Most proteins involved in mineral interactions are predicted to contain disordered regions that are important for their proper function. Magnetotactic bacteria, an iron biominalization model system, are Gram-negative bacteria that can navigate through geomagnetic fields using a specific organelle, the magnetosome. Each organelle comprises a membrane-enveloped magnetic nanoparticle, magnetite, whose formation is controlled by a specific set of proteins. One of the most abundant between these proteins is MamC, a small membrane protein (14 kDa) with two transmembrane helices with a connecting peptide between them directed to the magnetosome lumen. According to previous results, MamC loop adopts an \(-\)helical structure and affect magnetite size and shape during in vitro iron precipitation. Moreover, MamC loop was shown to interact with nanomagnetite particles using ITC method. According to MamC structure we identified to negatively charge amino acids (Glu 66 and Asp 70) which contribute to the negatively charge surface area and highly conserved among MamC homologs. Point and double mutations to alanine on those amino acids abolish the charges on the protein surface which interrupt MamC to interact with the magnetite particle and affect magnetite size and shape during in vitro iron co-precipitation. Moreover, we reported on the importance of MamC peptide structure to its function.
Spin waves can be used as data carriers in next-generation information processing systems. In this respect, artificial magnetic materials with properties periodically varied in space, known as magnonic crystals, are especially promising. The usage of electric currents is of interest for the manipulation of spin waves in magnonic crystals [1] as well as in other magnonic devices [2]. However, the associated Joule heating is a serious obstacle. One of the solutions is the usage of hybrid structures consisting of magnonic and superconducting elements. Here we use such a structure to realize a reconfigurable magnonic crystal. Specifically, we investigate the transmission of microwave spin waves through a reconfigurable magnonic crystal by broadband spectroscopy. The magnonic crystal is realized in a 80 nm-thick and 2.2 µm-wide permalloy waveguide located underneath of a 50 nm-thick superconducting Nb film. The experiment was performed in the temperature range from 5 to 9 K. In the mixed state, the magnetic field penetrates the Nb film in the form of flux-lines (fluxons) arranged in an Abrikosov lattice [3]. The lattice of fluxons induces a periodic spatial modulation of the magnetic field in Py, thus leading to the formation of a Bloch-like band structure (band gaps) in the magnon frequency spectrum. The rejection and transmission frequency bands are clearly observed and they can be tuned by both, the magnetic field value and the transport current applied to the Nb film. The reported results is the first step towards combining the advantages from the research domains of fluxonics [4] and magnonics [5] and they are relevant for the development of future microwave applications and data processing.

P.47 Magnon activation by hot electrons in magnetic semiconductors and half-metallic ferromagnets: the role of non-quasiparticle states


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We consider the situation when a femtosecond laser pulse creates a hot electron state in half-metallic ferromagnet (e.g., ferromagnetic semiconductor) on a picosecond timescale but does not act directly on localized spin system. We investigate the energy and magnetic moment transfer from hot itinerant electrons to localized spins. In a half-metal such a transfer is facilitated by the so-called non-quasiparticle states, which are the scattering states of a magnon and spin-majority electron. We predict that in a typical ferromagnetic semiconductor such as EuO magnons remain essentially in non-equilibrium on a scale of the order of microsecond after the laser pulse. In the framework of the s-d exchange model the evolution of the magnon distribution is described by a quantum kinetic equation that we derive using the non-equilibrium Keldysh diagram technique. At short time scales we obtain approximately linear-in-time growth of the number of magnons with a distribution that is, however, essentially different from the Bose-Einstein one. We argue that such a non-equilibrium magnon state must be typical for experiments on ultra-fast magnetization dynamics in many half-metallic materials and magnetic semiconductors.
Spin torques induced by spin waves, or magnons, under a temperature gradient is one of the important subjects in magnonics. In the absence of spin-orbit interaction, the spin torque consists of the spin transfer torque and its dissipative correction, called a $\beta$ term. The latter is quantified by a dimensionless parameter $\beta$, whose value relative to the Gilbert damping parameter $\alpha$ is important in the dynamics of magnetic texture such as domain wall motions. There are some experimental indications that suggest the existence of magnonic torque induced by temperature gradient [1]. On the theoretical side, magnonic torques have been studied based on a phenomenological stochastic Landau-Lifshitz-Gilbert equation [2,3]. In the case of electrically-induced spin torque due to conduction electrons, however, it is known that a phenomenological analysis [4] and a microscopic one [5] give different results. Therefore, it is desired to study the present problem (magnonic torque) from a microscopic viewpoint. In this work, we conduct a microscopic analysis of magnonic torques induced by a temperature gradient. As a microscopic origin of the Gilbert damping, we consider conduction electrons. The temperature gradient is treated a la Luttinger [6]. The obtained results indicate that there is a correction $\beta' = \alpha/2$ to the $\beta$ value obtained in the previous studies [2,3], where $\alpha$ is the Gilbert damping constant calculated microscopically. Several interesting aspects of the microscopic theory, such as the renormalization effects due to electron-magnon interaction, are also discussed.

P.49 Efficient dynamical thermal spin injection in the metallic bilayer system

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Dynamical spin injection based on the ferromagnetic resonance is attractive and powerful method for generating and manipulating the spin current. So far, in a ferromagnet(FM)/non-magnetic transition metal (TM) bilayer system, the spin pumping effect from the FM into the TM is only considered as the mechanism of the dynamical spin injection. However, recent studies pointed out the importance of the influence of the ferromagnetic proximity effect and the Dzyaloshinskii-Moriya interaction on the magnetization dynamics in the bilayer system. Moreover, the influence of the ac spin current with the precession frequency also induces the additional effects, which make it difficult to analyze systematically. Thus, the dynamical spin injection based on the spin pumping still has various problematic issues. On the other hand, we have found that the temperature increase occurs during the ferromagnetic resonance. Moreover, we have demonstrated that the CoFe-based alloy shows the excellent performance of the thermal spin injection. Here, we demonstrated that the heating effect due to the ferromagnetic resonance produces the dynamical spin injection in a CoFeB/TM bilayer system. We have systematically performed the following experiments for the dynamical spin injection by using the spin-charge conversion via inverse spin Hall effect in TM. First, we investigated the micro-wave frequency dependence of the output signal in CoFeB/Pt system. Second, we investigated the stacking-order dependence of the output voltage. Third one is the heat-conductivity dependence of the output voltage. All results suggest that the thermal spin injection is the dominant contribution for the spin current injected into the TM.
Over the last few decades, research onto both the fundamental physics and applications of spin waves/magnons has shown a multitude of magnetic phenomena that can be explored. They are also a candidate for next-generation information processing, presenting a promising alternative to the conventional charge-based systems. One magnonic system of interest for information processing is the magnonic crystal. A magnonic crystal is a magnonic waveguide with a periodic variation in its magnetic properties arranged, for example, by etching grooves in the waveguide material. Recently, there has been growing interest in combining spin waves system with superconducting circuit architecture to produce hybrid quantum devices. By cooling down magnon systems to milliKelvin temperatures, thermally excited magnons are essentially entirely suppressed allowing experiments to be carried out at the level of single externally excited magnons. Recent progress in this emerging field of quantum magnonics includes coupling a single magnon to a superconducting quantum bit in a 3D cavity [1] and coupling spin wave excitations in a Yttrium Iron Garnet (YIG) sphere to the photonic modes of various 3D cavities [2] and a 2D coplanar waveguide resonator [3]. In this work, we present our progress in investigating magnonic crystal based on a YIG waveguide at milliKelvin temperatures. This work is the first step into integrating magnonic crystals with two-dimensional superconducting coplanar circuits, with the goal of eventually coupling such structures to a superconducting qubit, thus paving the way for novel quantum devices.

P.51 The fabrication and characterization of Ag/Fe nano-dot arrays

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Nano-structured metal-magnet composite materials have been widely studied in order to enhance magneto-optical effects, a research activity known as magneto-plasmonics [1]. In this study, the influence of optical excitations on the ferromagnetic resonance and the converse effect of magnetic excitations on the plasmonic resonance were investigated. Bilayer Ag(~30 nm)/Fe(~50 nm) thin films were prepared on amorphous SiO2 substrates by using a dual ion-beam sputtering deposition technique [2]. The Ag/Fe nano-dot arrays were fabricated by using electron beam lithography and followed by Ar-ion etching techniques [3]. The continuous Ag/Fe thin films exhibit smooth surfaces with average roughness Ra ~0.9 nm, as measured by AFM. The Ag/Fe bilayer consisted of polycrystalline f.c.c. Ag and b.c.c. Fe (grain sizes ranged from ~10 to ~15 nm), as characterized by TEM. This reference Ag/Fe thin film exhibited soft magnetic properties with a coercivity Hc ~20 Oe, as measured by VSM. Nano-dot arrays of Ag/Fe thin films exhibit smooth surfaces with average roughness Ra ~0.9 nm, as measured by AFM. The Ag/Fe bilayer consisted of polycrystalline f.c.c. Ag and b.c.c. Fe (grain sizes ranged from ~10 to ~15 nm), as characterized by TEM. This reference Ag/Fe thin film exhibited soft magnetic properties with a coercivity Hc ~20 Oe, as measured by VSM. Nano-dot arrays of Ag/Fe (diameter ~180 nm, center-to-center distance ~400 nm) have been successfully fabricated. The ferromagnetic resonance (FMR) [4] data corresponding to a reference Ag/Fe thin film, which shows typical symmetric behavior for a magnetic thin film. However, the FMR spectra obtained in nano-dot arrays of Ag/Fe show significant modification with respect to those of the reference continuous bilayer. The high frequency mode appears to be similar to that of the continuous film indicating the resonance mode to be interface mode. In addition, at least two low frequency resonances imply the presence of dot array mode.

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Magnonic devices are promising information processing elements having ultra-low power consumption. To miniaturize magnonic devices, a wavelength of spin waves (SW) needs to be decreased, determining an interference length for realizing functionalities. According to the dispersion curve of forward volume (FV) SWs, thin film SW waveguide can propagate short wavelength SW. Hence, in this work, yttrium iron garnet (YIG) thin films were fabricated by pulsed laser deposition and coplanar waveguide (CPW) was integrated onto the YIG film to form the three-port SW waveguide. ~50 nm thick YIG films were grown on (111) rare-earth substituted gadolinium gallium garnet (SGGG) or GGG substrates. A KrF excimer laser (λ = 248 nm, pulse rate 15 Hz, laser energy 360 mJ) was used. During the deposition, a substrate temperature was held at 850°C under 2.6 Pa oxygen partial pressure. After the deposition, 2θ − ω rocking curves in the vicinity of the YIG (444) and SGGG (444) or GGG (444) peaks and a reciprocal space mapping (RSM) around the asymmetric (880) peak was obtained. These results indicated that the YIG films were single crystalline and under in-plane stress. Fabricated YIG film was etched into a 50 μm x 1 μm mesa shape. Three CPWs for excitation and detection of SW were placed on YIG waveguide. 90 nm thick rectangular shaped golds were also deposited on the both ends of the YIG waveguide as SW absorbers. FV SWs were excited in the fabricated three-port waveguide using the two CPWs and detected by the CPW placed at the center of the two CPWs. A magnetic field of 2.8 kOe was applied perpendicular to the film surface. The frequency used was 4.0 GHz. The excited SW spectral positions were almost same and the amplitudes were also similar. These results suggested a possibility of FV SW logic gates based on a YIG thin film.
P.53  Integration of topological insulators with spin torque nano oscillators

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The topological insulator is an example for a topological phase of matter, just recently awarded with the Nobel prize in physics. The main characteristics of a topological insulator is that the bulk is insulating while conducting surfaces harbour electronic states with remarkable properties: the spins of the charge carriers are locked to their momentum, and transport is topologically protected, i.e. backscattering is suppressed [1]. Such properties are highly sought after for storing and processing information, explaining the excitement topological insulators have generated. A spintronic device which could particularly take profit from the incorporation of topological insulators is the spin-torque nano oscillator (STNO). This device generates excitations in the Gigahertz regime upon the application of a dc current. Using an x-ray based imaging technique, it could be shown that these excitations are localized spin waves, not much larger than the size of the nano contact of around 150nm [2]. Because of the extremely small contact area, the current densities are very large, leading to excessive ohmic heating and strongly limiting the lifetime of the present generation of STNO devices. Using ‘pure’ spin currents, where no net-charge transport takes place, could solve that problem, and topological insulators could be an efficient means of generating them. The challenge is to integrate topological insulators with magnetic thin film layer stacks, while maintaining the integrity of both topological states and magnetic materials. In this contribution, an account of my research activities in topological insulator device physics [3,4] and spin-torque nano oscillators [2,5] is given. An outline of a research program, with the goal to build integrated topological insulator spintronic devices, is presented.

Coupled spin-light dynamics in cavity optomagnonics

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Abstract text: Experiments during the past 2 years have shown strong resonant photon-magnon coupling in microwave cavities, while coupling in the optical regime was demonstrated very recently for the first time. Unlike with microwaves, the coupling in optical cavities is parametric, akin to optomechanical systems. This line of research promises to evolve into a new field of optomagnonics, aimed at the coherent manipulation of elementary magnetic excitations in solid-state systems by optical means. In this work we derive the microscopic optomagnonic Hamiltonian. In the linear regime the system reduces to the well-known optomechanical case, with remarkably large coupling. Going beyond that, we study the optically induced nonlinear classical dynamics of a macrospin. In the fast-cavity regime we obtain an effective equation of motion for the spin and show that the light field induces a dissipative term reminiscent of Gilbert damping. The induced dissipation coefficient, however, can change sign on the Bloch sphere, giving rise to self-sustained oscillations. When the full dynamics of the system is considered, the system can enter a chaotic regime by successive period doubling of the oscillations.
Electric field effect on exchange interaction in Co/Pt thin film

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Electric-field modulations of magnetic properties have been extensively investigated not only for practical applications but also for fundamental interests. We previously investigated the electric-field modulation of the exchange stiffness $A$ in a Co ultra-thin film by characterizing the domain size [1]. However, the measurement opportunity of the domain size was limited only in the vicinity of the Curie temperature and it prevents from further determining the exchange constant $J$. In the present work, we conduct another measurement in which we characterize the temperature dependence of the saturation magnetization for estimating the exchange constant $J$. We used an electric-double-layer capacitor structure consisting of a perpendicularly-magnetized MgO(2.0 nm)/Co(0.25 nm)/Pt(2.0 nm)/Ta(3.3 nm) electrode, Au/Ti side gate electrodes and ionic liquids. We measured the temperature dependence of the saturation magnetization using superconducting quantum interference device magnetometer while applying gate voltage. We obtained $J$ from the slope of the $T^{3/2}$ dependence of the saturation magnetization, and observed the change in $J$ applying the gate voltage.

Non-local measurement of asymmetric anisotropic magnetoresistance in ferromagnet/non-magnet hetero structures

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When a charge current flows in a bilayer of a heavy metal (HM) and a ferromagnetic metal (FM), a spin current is injected from HM to FM due to spin Hall effect (SHE). When the direction of injected spin is opposite to that of the FM magnetization, magnons are generated by a quantum spin-flip process. In this case, asymmetric anisotropic magnetoresistance (AMR) can be observed due to the electron-magnon scattering [1]. It has also been reported that the non-local harmonic measurement allows understanding the magnon propagation mechanism [2].

In this presentation, we investigate the magnon propagation in a Pt/Py bilayer by the non-local harmonic measurement. From the current density and distance dependences of non-local asymmetric AMR, we discuss the mechanism of the magnon propagation in the Pt/Py bilayer.


P.57 Theory for spin dynamics in disordered ferrimagnetic cobalt-gadolinium alloys.

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We present a dynamic variant of the non local coherent potential approximation theory (DNLCPA) developed to study the spin dynamics in disordered ultrathin cobalt-gadolinium ferrimagnetic alloys. The DNLCPA theory introduces the idea for the scattering potential of a defect, in an otherwise virtual crystal, as an operator (matrix) built up from the phase matching of the spin dynamics on the defect site with the spin dynamics in the virtual crystal approximation (VCA). The non-commuting scattering potential matrices calculated in this manner for the different species constituting the magnetic alloy are then used to determine the Dyson T-matrix equation. A mathematical approach is then developed to solve the Dyson T-matrix equation and determine analytic forms for the complex self-energy and the configurationally averaged Green’s function of the disordered system. The numerical calculations based on the derived Green’s function yield the spin excitations and the corresponding life-times in the cobalt-gadolinium ferrimagnetic alloys for any eutectic concentration. The developed theoretical approach aims to contribute to the understanding of novel magnetic phenomena in ferrimagnetic disordered alloys, such as the femtosecond laser excitation of spin resonances in such alloys. In addition, the developed theory was used to investigate the quality of cobalt-gadolinium alloy nanojunctions as spin waves filters. In particular, the DNLCPA was successfully integrated with the phase field matching theory and used to analyze the spin waves scattering across cobalt-gadolinium disordered alloy nanojunctions between cobalt leads.
P.58  Dynamics of current induced nano-skyrmions

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The dynamics of magnetic Skyrmions is investigated in a composite free layer spin valve nano pillar for different coupling mechanisms in the absence of Dzyaloshinski-Moriya Interaction (DMI). Nano meter sized Skyrmions and anti Skyrmions are trapped with different helices in the free layer. The spin polarized current under specific choice of system parameters changes the droplet solitons into Skyrmions and anti Skyrmions. The current driven dynamics is studied and the condition at which an isolated Skyrmions exists, is reported. We have optimized the current density (J) and spin wave vector (k) for which Skyrmions Hall Effect (SHE) completely vanishes and as a result the velocity, size and shape of Skyrmions are preserved. When the coupling between the composite free layers is changed, Skyrmions-anti Skyrmions pair and radial Skyrmion-chiral Skyrmions pair emerge. For the specific values of ’J’ and ’k’ these pairs show coupled motion along the layer and hence these pairs could also be used as a bit in the data processing and storage devices. Our investigation ascertains that a single material can host all the magnetic localized structures if the current density, spin wave vector and coupling constant are suitably chosen and tuned. This study would really be of fundamental importance owing to the possible applications in information processing and data storage in Skyrmions based logic circuits and magnetic sensors.
Spin wave logic gates based on yttrium iron garnets (YIGs) were studied widely because of its low Joule loss and interesting functionalities. In addition, YIG can propagate the high in-plane uniform mode, i.e. forward volume spin waves, because of its low saturation magnetization compared with other ferromagnetic materials. However, this mode has been suffering from spin wave noises due to edge reflections and scatterings. To solve issue, we previously reported the robustness enhancement of forward volume spin wave using absorbers comprising YIG covered with thin gold. In this paper, this absorbing technique was applied to the four-port spin wave logic showing AND and OR functions. A 10 micron thick YIG epitaxially grown on a gadolinium gallium garnet substrate was etched into four-port shape followed by mounting on four microstrip lines using flip-chip bonding technique. 10 nm thick gold films were deposited at the all edge of YIG waveguide to absorb extra spin waves. Amplitudes and phases of the spin waves introduced from the three-input ports were controlled individually. The temperature of the devices was stabilized at the room temperature. A magnetic field of 3095 Oe was applied perpendicular to the waveguide. At the frequency of 4 GHz, the spin wave interference was observed with changing the phase of excited spin waves. Due to high robustness to the noises, the phase AND and phase OR gate functions based on phase interferences of the spin wave was demonstrated using forward the volume mode. Details of the design rules of the device and the fundamental properties of the materials used in this experiments will be discussed in the conference.

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P.60 Nonuniformity of the dynamic demagnetizing field as a broad-band magnonic source

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Magnonics is attracting remarkable research attention due to the prospects of using magnonic devices for high-speed data and analogue signal processing. The operational principles of many magnonic logic devices are based on the interference of multiple spin waves. The ability to excite multiple coherent spin waves is therefore crucial for the perceived magnonic technology. Here, we use time resolved scanning Kerr microscopy (TRSKM) and micromagnetic simulations to demonstrate that the magnetisation aligned along the edges of patterned magnetic structures can serve as a source of propagating magnetostatic spin waves. Specifically, we consider a transversely-magnetised Permalloy stripe excited by a spatially-uniform microwave magnetic field at frequencies above that of the uniform ferromagnetic resonance (FMR). Spin waves at the frequency of excitation are observed in both experiments and simulations to propagate from the edges of the stripe. The excitation mechanism arises from the spatial variation of the dynamic demagnetising field intrinsic to the magnetic structure, rather than from the spatial inhomogeneity of the excitation field. The dynamic demagnetising field increases locally the FMR frequency, thereby enabling the global microwave magnetic field to efficiently couple to specific regions of the magnetisation. Our findings enable an approach for construction of magnonic architectures devoid of restrictions associated with the use of nanoscale electrical circuitry.

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