SP 15 Spin waves and magnonics

SP15 - Parallel Session 1

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SP15.1.02

Imaging of large amplitude strain spin waves

B. Casals, N. Statuto, A. Hernández-Mínguez, M. Foerster, L. Aballe, J. M. Hernàndez, F. Macià

Text In this talk we will show stroboscopic images of large amplitude “strain spin waves” over areas of a few millimeters in nickel thin films. Surface Acoustic Waves (SAW) are propagating strain waves that can be generated through oscillating electric fields at the surface of a piezoelectric material and can couple to a magnetic system in specially designed hetrostructures comprising both a piezoelectric and a magnetic material. We have shown recently that magnetic states in nanostructures can be dynamically changed at the SAW frequencies (GHz) [1]. In this talk we report an experimental study on photo-emission electron microscopy (PEEM) where we image the magnetization dynamics in a ferromagnetic thin film of Ni deposited directly onto a piezoelectric material (LiNbO3) capable to produce directional SAW. We have synchronized the SAW with the synchrotron repetition rate and acquired instant images of the magnetization state simultaneously with the strain wave. By exciting different SAW frequencies (100 MHz-1 GHz) we have observed strain spin waves with different wavelengths propagating on a large area of a few millimeters. The results we present in this talk provide fundamental insight into magnetoelastic coupling in nanostructures having implications in the design of strain-controlled magnetostrictive and magnonic devices.

SP 15 Spin waves and magnonics

SP15 - Parallel Session 1

SP15.1.03

Magnonic band structure in thin FeN magnetic films with stripe domains

S. Tacchi, I. Camara, R. Silvani, L. C. Garnier, G. Carlotti, M. Madami, M. Eddrief, M. Marangolo

Text Stripe domains structure, characterized by a periodic modulation of the out-of-plane magnetization component alternately directed up and down with respect to the sample surface, represents an attractive magnetic configuration for magnonic applications and microwaves devices engineering. This structure results from the energy competition between the perpendicular magnetic anisotropy and the easy-plane dipole-dipole magnetostatic interaction. Interestingly, it has been observed that the direction of the stripes domains is always parallel to the last saturation direction, and it is independent on the crystallographic direction. In this work, magnetic excitations in stripe domains configuration in a 78-nm nitrogen-implanted iron FeN film have been studied by broadband ferromagnetic resonance (CPW-FMR) and Brillouin light scattering (BLS). The experimental results are successfully interpreted on the basis of dynamical micromagnetic simulations performed using by the open-source, GPU-accelerated software MuMax3. Several surface and volume modes have been observed and their behavior as a function of the external magnetic field applied along the stripes direction has been investigated. In addition, the dispersion relation of the spin waves modes has been measured by means of BLS for the in-plane transferred wave vector parallel and perpendicular to the stripes axis, and it has been compared with the simulated band structure.

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SP15 - Parallel Session 1

SP15.1.04

Programmable control of spin-wave transmission in a domain-wall spin valve

S. J. Hämäläinen, M. Madami, G. Gubbiotti, H. Qin, S. van Dijken

Text Wave-like computing based on spin waves has generated interest as a potential low-power and parallel computing alternative for conventional CMOS technologies. Here, we demonstrate the use of two parallel magnetic domain walls as magnetic spin-wave valve for logic operations. Periodic 90° rotations of uniaxial magnetic anisotropy firmly pin the domain walls in our system, preventing their motion under the action of spin waves. Because of pinning, a magnetic field can switch the internal structure of the Néel walls between two non-volatile states; narrow 90° head-to-tail and wide 90° head-to-head (or tail-to-tail) walls. Using phase-resolved micro-focused Brillouin light scattering and micromagnetic simulations, we show that broad domain walls are transparent for spin waves over a broad frequency range. In contrast, spin waves are resonantly reflected by narrow domain walls. Reprogramming of the domain-wall state by reversing the magnetization of the magnetic stripe domain between two parallel domain walls toggles the spin-wave transmission between nearly 0% and 100%.

SP 15 Spin waves and magnonics

SP15 - Parallel Session 1

SP15.1.05

Micromagnetic simulations of non-reciprocal Hawking radiation from magnonic black hole

M. Dvornik, R. Khymyn, J. Åkerman, V. S. Tiberkevich, A. N. Slavin

Text It has been predicted that spin-current-induced Doppler shift of magnons might lead to the emergence of the magnonic black hole[1,2]. Similar to the Hawking radiation phenomenon, it emits magnons from its event horizon in the direction of the applied current. Here we employ finite-temperature micromagnetic simulations to demonstrate, for the very first time, a realization of magnonic black hole and nucleation of Hawking radiation of sub-100 nm magnons in Py intrinsic spin torque nano-oscillator proposed by Haidar et al.[3]. Then we show that by engineering the dispersion of backward volume magnetostatic spin waves and introducing an interfacial Dzyaloshinskii-Moriya interaction, e.g., by using a thin Pt adjoin layer, we can (a) substantially reduce the threshold current of radiation and (b) make it non-reciprocal with respect to the applied current direction. Our findings not only provide a toy model of the intriguing astronomical object but would enable creation of highly tunable unidirectional spin wave sources.

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SP 15 Spin waves and magnonics

SP15 - Parallel Session 1

SP15.1.06

Local spin-wave dispersion and damping in thin yttrium-iron-garnet films

R. Dreyer, N. Liebing, E. R. J. Edwards, G. Woltersdorf

Text We demonstrate a new detection scheme for scanning time-resolved magneto optical Kerr microscopy (TR-MOKE) with arbitrarily high frequency resolution. Using this ultrafast magneto-optic sampling technique, we investigate the spin-wave dispersion and spin-wave damping locally in yttrium-iron-garnet films in frequency steps much smaller than the laser repetition rate of 80 MHz. With the aid of the inhomogeneous magnetic field generated by coplanar waveguides spin-waves are excited at a fixed frequency while the wavelength is determined by the external magnetic field. By imaging the excited spin-waves and mapping the dispersion we identify a method to determine the damping of the uniform mode locally. The group velocity approaches zero in the vicinity of an avoided crossing of different spin-wave modes. A local Gilbert damping parameter is extracted for such spin-waves with finite wave vector and the result is in good agreement with the local measurement for the uniform mode. The resonance linewidths are much narrower compared to inductive ferromagnetic resonance measurements performed on the same sample indicating that in the linewidth is limited by inhomogeneous properties in the inductive measurement. The avoided crossing investigated with our method indicates a strong coupling of the different spin-wave modes.

SP 15 Spin waves and magnonics

SP15 - Parallel Session 1

SP15.1.07

Optimizing propagating spin wave spectroscopy as a technique to determine the Dzyalosinksii-Moriya interaction

J. Lucassen, C. F. Schippers, L. Rutten, D.-S. Han, R. A. Duine, H. J. M. Swagten, B. Koopmans, R. Lavrijsen

Text We carefully explore and optimize propagating spin wave spectroscopy (PSWS) as a technique to measure the interfacial Dzyaloshinksii-Moriya interaction (DMI). Its ability to separate clockwise (CW) and counterclockwise (CCW) spin waves, as well as its wave-vector selectivity, makes it a potentially extremely interesting technique to measure the DMI-induced frequency non-reciprocity. However, PSWS requires a very careful interpretation of the obtained spectra including the measured non-reciprocity which is so far not reported in literature. Depending on the strip width, we demonstrate the importance of de-embedding the measurements for the small waveguide required to connect the antennas to the probe tips. Waveguide-induced phase changes as small as 10o can lead to 90o phase changes in the inductive FMR response. However, even after de-embedding the measured inductive response of the transmitted spin waves unexpected behaviour is observed. It is well known that there is a significant difference in excitation efficiency for CW and CCW spin waves, which is not present in our measurements. Moreover, the measured non-reciprocity of the transmitted spin waves shows unexpected field and wavevector-dependent behaviour. Therefore, we speculate that de-embedding does not completely resolve the spin wave transmission measurements which suggests the importance of carefully picking the device dimensions to eliminate the need for de-embedding that can introduce artefacts in PSWS.

SP 15 Spin waves and magnonics

SP15 - Parallel Session 2

SP15 - Parallel Session 2

SP15.2.01

Exchange-torque-induced excitation of perpendicular standing spin waves in nanometer-thick yttrium iron garnet films

H. Qin, S. Hämäläinen, S. van Dijken

Text Spin waves in ferrimagnetic yttrium iron garnet (YIG) films with ultralow magnetic damping are relevant for magnon-based spintronics and low-power wave-like computing. The excitation frequency of spin waves in YIG is rather low in weak external magnetic fields because of its small saturation magnetization, which limits the potential of YIG films for high-frequency applications.

Here, we demonstrate how exchange-coupling to a CoFeB film enables efficient excitation of high-frequency perpendicular standing spin waves (PSSWs) in nanometer-thick (80 nm and 295 nm) YIG films using uniform microwave magnetic fields. In the 295-nm-thick YIG film, we measure intense PSSW modes up to 10th order. Strong hybridization between the PSSW modes and the FMR mode of CoFeB leads to characteristic anti-crossing behavior in spin-wave spectra. We explain the excitation of PSSWs by exchange coupling between forced magnetization precessions in the YIG and CoFeB layers. If the amplitudes of these precessions are different, a dynamic exchange torque is generated, causing the emission of spin waves from the interface. PSSWs form when the wave vector of the spin waves matches a perpendicular confinement condition. PSSWs are not excited if exchange coupling between YIG and CoFeB is eliminated by a 10 nm Ta spacer layer. Micromagnetic simulations confirm the exchange-torque-driven mechanism [1].

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SP 15 Spin waves and magnonics

SP15 - Parallel Session 2

SP15.2.02

An integrated magnonic half-adder

T. Brächer, Q. Wang, P. Pirro, A. Chumak

Text Spin waves and their quanta, magnons, open up a promising branch of high-speed and lowpower information processing [1]. This has been substantiated by the realization of individual magnonic prototype devices such as majority gates[2], transistors [3], and units for non-Boolean computing [4]. Nevertheless, the realization of an integrated magnonic circuit consisting of at least two logic gates suitable for further integration is still a challenge.

Here we demonstrate such an integrated circuit at the example of a magnonic half-adder. Using nano-scale directional couplers [5], we build and combine an all-magnonic AND gate with an all-magnonic XOR gate to layout the half-adder. The functionality of this nano-sized magnonic circuit is investigated and tested by means of micromagnetic simulations.

This research was supported by the European Research Council Starting Grant 678309 MagnonCircuits and by the DFG (DU 1427/2-1).

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SP 15 Spin waves and magnonics

SP15 - Parallel Session 2

SP15.2.03

Local spin-wave modes in 2D array of dipolarly coupled magnetic nanodots with a “defect” dot

R. Verba, E. Galkina, B. Ivanov

Text Magnonic crystals based on arrays of dipolarly coupled magnetic nanodots are promising for applications in microwave and signal processing techniques. In real life a large nanodot array always contains defects of different kinds, which affect array’s properties. From the other hand, defects may possibly have their own applications analogous, e.g., to the defects in photonic crystals.

Here we present comprehensive analytical and numerical study of spin-wave modes, localized on defect dots in a two-dimensional array of magnetic nanodots. It is shown that the appearance of a localized mode depends on the peculiarities of bulk spin wave spectrum near its bottom or top. In the case of smooth parabolic spectrum, a localized mode appears for a vanishingly weak defect, while in the case of nonanalytic spectrum behavior a localized mode is created only by a defect of a finite strength exceeding a certain threshold value. Number of localized modes depends on whether a defect dot has modified dipolar interaction with other dots (dipolar defect), or just different eigenfrequency (point defect). In the former case higher-order localized modes may appear, while in the later only one local mode exists. In the case of complex array (e.g., an array in antiferromagnetic state) having several spin-wave branches, localized modes may appear near some or all the energy bands depending on the spin wave structure for these branches and defect properties.

SP 15 Spin waves and magnonics

SP15 - Parallel Session 2

SP15.2.04

Angular Dependent Magnetization Dynamics of Quasicrystalline Nanomagnet Lattices

V. Bhat, D. Grundler

Text Recent quasistatic studies on artificial quasicrystals—arrays of nanobars arranged on lattices with long-range order but without translational symmetry—have reported exotic properties in the switching regime [1, 2]. Spin wave resonances in an interconnected quasicrystal lattice have been proposed to be due to the collective nature of the lattice and may help to better understand the exotic properties in the reversal regime [1].

We fabricated large arrays of interconnected networks of Ni80Fe20 nanobars on periodic and quasicrystal lattices and performed angular dependent broadband spectroscopy in the GHz frequency regime as well as micromagnetic simulations. The interconnected nanobars (810 nm long, 130 nm wide, and 25 nm thick) were arranged on square, Penrose P2, Penrose P3, and Ammann lattices. Our spin wave spectra show systematic and reproducible spin wave resonances in the nearly saturated state and switching regime of the planar quasicrystal structures. We discuss our experimental results in view of self-biasing effects induced by local magnetic environments which result in characteristic eigenfrequencies of subgroups of nanobars. Our work contributes to the understanding of aperiodicity and its effect on spin dynamics via a material-by-design approach.

The work was supported by the SNF via grant number 163016 and DFG via TRR80.

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SP 15 Spin waves and magnonics

SP15 - Parallel Session 2

SP15.2.05

How to generate whispering gallery magnons

K. Schultheiss, R. Verba, K. Wagner, F. Wehrmann, L. Körber, A. Kákay, T. Hache, A. Awad, V. Tiberkevich, A. Slavin, J. Fassbender, H. Schultheiss

Text One fascinating topic in quantum physics are hybridized systems, in which resonators of different quantum systems strongly couple. Prominent examples are circular resonators that couple optical whispering gallery modes to microwave cavities or magnon resonances. However, the coupling to magnons with finite wave vectors has not yet been achieved due to the lack of their efficient excitation.
We present the generation of whispering gallery magnons via nonlinear 3-magnon scattering in a magnetic vortex. These modes exhibit a strong localisation at the disc’s perimeter and zero amplitude in an extended area around the vortex core. They originate from the splitting of the fundamental radial magnon modes, which can be resonantly excited by an out-of-plane microwave field. We will shed light on the basics of this non-linear scattering mechanism from experimental and theoretical point of view. Using Brillouin light scattering (BLS) microscopy, we investigated the frequency and power dependence of this nonlinear mechanism. The mode profiles show localisation at the disk’s boundaries and unprecedented high azimuthal wave vectors. Furthermore, time resolved BLS revealed the temporal evolution of the 3-magnon splitting and its dependence on the applied microwave power.
Financial support from the DFG within programme SCHU 2922/1-1 is acknowledged. Samples were prepared at the Nanofabrication Facilities (NanoFaRo) at the HZDR. K.S. acknowledges funding by the Helmholtz PostDoc Programme.

SP 15 Spin waves and magnonics

SP15 - Parallel Session 2

SP15.2.06

Magnonic properties of dipolar coupled assemblies of few nanoparticles

B. Zingsem, T. Feggeler, A. Terwey, S. Ghaisari, D. Spoddig, D. Faivre, R. Meckenstock, M. Farle, M. Winklhofer

Text Using Ferromagnetic Resonance (FMR) spectroscopy, we demonstrate, that nanoscale magnonic devices can be realized in dipolar coupled chains of magnetite nanoparticles. FMR spectra where recorded on individual chains of nanoparticles consisting of 10-20 magnetite crystals each, with a crystal size of about 30 nm. As a direct result of altering the geometric arrangement of particles our measurements reveal intriguing properties regarding the formation of magnonic band gaps, as well as unusual curvatures of angular dependent resonance lines. We show that by manipulating geometric properties, i.e. by introducing kinks and defects, magnonic properties of these chains can be altered in a tailorable fashion. The measured spectra are supplemented with high performance GPU accelerated micromagnetic simulations, which provide further insight into the unusual magnon band structure, allowing us to identify the connection between spatial arrangements and spectral properties. A new prospect for nano-sized magnon-logic and spintronic devices is presented.

SP 15 Spin waves and magnonics

SP15 - Parallel Session 2

SP15.2.07

Spin-wave generation by radio-frequency spin-orbit torque antenna: torques and efficiencies

G. Talmelli, F. Ciubotaru, K. Garello, X. Sun, M. Heyns, I. Radu, C. Adelmann, T. Devolder

Text Spin orbit torques (SOTs) generated by direct electrical currents have shown their potential to switch the magnetization in nanomagnets or to generate and control propagating spin waves.
In this work, we investigate the generation of spin waves in a thin in-plane magnetized Ta/CoFeB waveguide using SOT effects created by local RF currents in a Ta layer. The fabricated devices were based on a stack consisting of Ta(2)/MgO(2)/FeCoB(5)/Ta(8)/SiO2(300)/Si(substrate), where the numbers represent the layer thicknesses in nm. SOTs at RF frequencies were generated in the 8 nm thick Ta layer by RF currents that flowed across a confined region of the CoFeB conduit of 5 µm width. Au contacts were patterned on top of the Ta layer to inject the RF current. An Au antenna on top of the CoFeB conduit allowed for the detection of spin waves generated by the SOT line. We demonstrate the broadband excitation of propagating spin waves and analyze their propagation properties. Micromagnetic modeling as well as electromagnetic simulations were used to understand in detail the excitation mechanism, the propagation behavior, and the mode formation. An analytic model was developed to distinguish between effects due to the anti-damping spin-Hall effective field and the Oersted field both generated by the current in the Ta layer. Scaling properties of SOT antennas with respect to conventional inductive antennas are also discussed.

SP 15 Spin waves and magnonics

SP15 - Parallel Session 2

SP15.2.08

Nonlinear spin conductance of yttrium iron garnet thin films driven by large spin-orbit torque

N. Thiery, V. Naletov, L. Vila, J. Ben Youssef, O. Klein

Text Generation and detection of pure spin currents circulating in magnetic materials through spin-orbit torque (SOT) has attracted recently a lot of attention, especially for future applications exploiting magnonic concepts. Among them, Yttrium Iron garnet (YIG), a magnetic insulator with very low damping, appears to be a promising material since it can propagate very efficiently magnons (the spin carrier). It has been established that a pure spin current can be induced and detected between two Pt electrodes deposited few microns apart on top of YIG. Here we present a study of spin waves propagation in ultra-thin film of YIG (18nm) excited by large spin orbit torque. By injecting a high current density in Pt injector strip we are able to put our system strongly out of equilibrium. We show that at such high current density, an exponential decrease of the resistivity of the YIG must be taken into account and give rise to a parasitic non-magnetic offset voltage in the detector strip which is not related to magnon propagation. The main contribution of this work is an experimental evidence of a gradual spectral shift from thermal to subthermal magnon transport when a current density is injected in the Pt. This value corresponds to the expected threshold current for damping compensation of the Kittel mode. Our results suggest that a new spin conduction channel appear in the GHz frequency range when subcritical regime is reached.

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SP15 - Parallel Session 3

SP15 - Parallel Session 3

SP15.3.02

Bose-Einstein Condensation of Magnons by an Instantaneous Cooling

M. Schneider, T. Brächer, V. Lauer, P. Pirro, D. Bozhko, A. Serga, H. Musiienko-Shmarova, B. Heinz, Q. Wang, T. Meyer, F. Heussner, S. Keller, E. Papaioannou, B. Lägel, T. Löber, V. Tiberkevich, A. Slavin, C. Dubs, B. Hillebrands, A. Chumak

Text The fundamental physical phenomena of Bose-Einstein Condensation (BEC) is observed in different systems of quasi-particles. An external injection of bosons is required for the increase in chemical potential and is typically realized using laser or microwave irradiation.

Here, we propose and demonstrate experimentally a completely different and universal way to increase the chemical potential of quasi particles and to reach BEC. Fast electric current pulses applied to yttrium-iron-garnet (YIG)/Pt microstructures result in a strong heating. Consequently, this leads to an increased number of magnons, distributed over the whole spectrum. Once the current is switched off, the micro-sized system cools down rapidly. Due to the longer magnon lifetime, the magnon and the phonon system are driven out of equilibrium, which results in a redistribution of high frequency magnons over the spin-wave spectrum and in an increase in the chemical potential up to the bottom energy of the spin-wave band. Using time-resolved Brillouin light scattering spectroscopy, a strong increase of the magnon density at the bottom of the spectrum is observed after the current pulse is switched off. The discovered phenomena gives access to the usage of the macroscopic quantum magnon states in spintronics.

This research has been supported by ERC Starting Grant 678309 MagnonCircuits, ERC Advanced Grant 694709 Super-Magnonics, by the DFG TRR 173 “Spin+X” (Projects B01 and B07), and DFG DU 1427/2-1.

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SP15 - Parallel Session 3

SP15.3.03

Spin-Wave Optics in Magnetization Landscapes

M. Vogel, R. Aßmann, A. V. Chumak, B. Hillebrands, G. von Freymann

Text The refraction of electromagnetic waves in conventional optics as well as dipolar magnetic waves – namely spin waves – in ferrimagnetic films (several micrometers thick yttrium iron garnet) follows the well-known Snell's law [Phys. Rev. Lett. 117, 037204 (2016)]. Furthermore, to do optics with light, low divergent beams are needed in the experimental setup. In spin-wave optics, the excitation of spin-wave beams is necessary, too. Therefore, we use specially designed coplanar waveguides or microstrip antennas [Sci. Rep. 6, 22367 (2016)]. The spin-wave propagation can be observed in the experiment with micro-structured induction probes, which are scanned over the sample.
We propose to use optically-induced magnetization landscapes [Nature Physics 11, 487 (2015)] to create the building blocks of spin-wave optics, e. g., spin-wave (graded-index) lenses, fibers, beam-splitter or diffraction gratings. Moreover, spin-wave Fourier optics can be realized by exploiting the properties of spin-wave lenses. We compare our experimental results with micromagnetic simulations.

SP 15 Spin waves and magnonics

SP15 - Parallel Session 3

SP15.3.04

Spin waves in nanometer epitaxial Galfenol films driven by ultrafast changes of magnetic anisotropy

N. Khokhlov, L. Shelukhin, A. Kalashnikova, A. Rushforth, A. Scherbakov

Text In contemporary magnetism femtosecond laser pulses became a powerful tool for driving magnetization dynamics with a number of significant advantages over conventional techniques [1]. Thus, in strong contrast to microwave-based excitation, generating spin waves and probing them by tightly focused laser pulses provides unprecedented flexibility enabling 2D mapping of spin waves [2], controlling their wavevectors and other parameters [3].

Here using a femtosecond pump-probe technique with 1 um spatial resolution we examine the laser-driven excitation and propagation of spin waves in thin films of ferromagnetic metallic alloy Fe0.81Ga0.19. In contrast to previous studies a pronounced in-plane magnetic anisotropy of the 20-nm thick (Fe,Ga) film offers an additional degree of freedom for manipulating spin waves parameters. We demonstrate that 100 fs laser pulses focused to a 1.5 µm spot excite the magnetostatic surface and backward volume waves with decay length up to 10 µm. The spin waves are excited due to ultrafast laser-induced magneto-crystalline anisotropy changes. By changing orientations of magnetic field with respect to the anisotropy axis we can tune the amplitude, phase and group velocities of the waves.

This work was partly supported by Russian Science Foundation under grant no. 16-12-10485.

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SP 15 Spin waves and magnonics

SP15 - Parallel Session 3

SP15.3.05

Significantly enhanced magnon-photon coupling in an inverted split-ring resonator/thin film YIG hybrid system

B. Bhoi, B. Kim, J. Kim, Y.-J. Cho, S.-K. Kim

Text The study of light-matter interaction is a central subject in photonics and quantum-information technology. In particular, the coupling of microwave photons to magnons [1] has received much attention due to its potential applications in coherent information storage. In the present study, we achieved magnon-photon coupling at room temperature in a compact planar hybrid system consisting of an inverted split-ring resonator (ISRR) and a YIG film. We experimentally demonstrated strong anti-crossing effects of the ISRR's photon mode and YIG's magnon modes with an effective photon-magnon coupling strength of 90 MHz at a microwave frequency of 3.79 GHz. Additionally, we observed, in the anti-crossing region, fine features originating from the excitation of spin-wave modes of magnetostatic surface waves and backward-volume magnetostatic waves. Using the coupled oscillator model, the coupling strength corresponding to each specific spin-wave mode was estimated quantitatively and found to decrease with the mode index. Our experimental results pave the way for the design of new types of high-gain magnon-photon coupling systems in planar geometry and also establish a new approach to the exploration of both the fundamental and practical aspects of signal processing, magnon conversion, and quantum memory.

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SP 15 Spin waves and magnonics

SP15 - Parallel Session 3

SP15.3.06

Nanoscale spin-wave circuits based on engineered reconfigurable spin-textures

E. Albisetti, D. Petti, G. Sala, R. Silvani, S. Tacchi, S. Finizio, S. Wintz, A. Caló, X. Zheng, J. Raabe, E. Riedo, R. Bertacco

Text The control of spin-waves holds the promise to enable energy-efficient computing. However, controlling spin-waves at the nanoscale, which is crucial for the realization of magnonic nanodevices, is extremely challenging due to the difficulty in controlling the nanoscopic magnetic properties via conventional nanofabrication techniques.
We recently demonstrated a new concept for creating reconfigurable magnonic structures by performing a highly localized field cooling with the hot tip of a scanning probe microscope, in an exchange bias bilayer. In such structures, the spin-wave excitation and propagation can be spatially controlled at remanence, and can be tuned by external magnetic fields. [1,2]
Here, we provide direct evidence for the channeling and steering of propagating spin-waves in arbitrarily shaped nanomagnonic waveguides based on patterned domain walls, with no need for external magnetic fields or currents, and demonstrate a prototypic nanomagnonic circuit based on two converging waveguides, allowing for the tunable spatial superposition and interaction of confined spin-waves modes. [3]
The ability to control magnons via nanoscale-designed spin-textures opens up a plethora of exciting possibilities for the realization of energy-efficient reconfigurable computing platforms.

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SP 15 Spin waves and magnonics

SP15 - Parallel Session 3

SP15.3.07

Direct observation of broadband coherent magnetization wave emissions from magnetic domain walls

R. B. Holländer, C. Müller, J. McCord

Text The dynamic magnetization response of varying micromagnetic structures in soft-magnetic CoFeB stripe elements excited by homogeneous Oersted-fields is investigated in the regime of linear response using stroboscopic magneto-optical imaging [1]. Our wide-field Kerr microscopy technique allows for the separation of individual magnetization components [2] and by using continuous wave excitation for the direct observation of coherent magnetization waves in dynamic equilibrium [3].
By varying the excitation frequency, distinct modes of magnetization wave emission can be found and tuned by their dispersion relation. Directional and coherent magneto-static spin waves and elastic waves are distinguished by their dependence on the varied magnetic domain structure. The experimental evidence on the emission of magneto-static surface spin waves is supported by two dimensional micromagnetic modeling. The elastic wave emission follows the dispersion of an elastic shear wave.
The emission of magnetization waves from excited micromagnetic objects is a general physical phenomenon relevant for magnetization dynamics in patterned magnetic thin films. Furthermore, our results enable new and reconfigurable schemes for the excitation of spin waves and elastic waves.
We acknowledge funding from the DFG (Mc9/9-2, Mc9/10-2).
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SP15 - Parallel Session 4

SP15 - Parallel Session 4

SP15.4.01

Coherent excitation of heterosymmetric spin waves with ultrashort wavelengths

G. Dieterle, J. Förster, H. Stoll, A. Semisalova, S. Finizio, A. Gangwar, M. Weigand, M. Noske, M. Fähnlein, I. Bykova, D. Bozhko, H. Musiienko-Shmarova, V. Tiberkevich, A. Slavin, C. Back, J. Raabe, G. Schütz, S. Wintz

Text The investigation of spin-wave phenomena plays an important role in magnetism research [1]. In particular, spin waves are seen as signal carriers for future spintronic information and communication technology devices, with a high potential for further device miniaturization and reduced power consumption. Yet a successful implementation of magnonic technology requires the usage of spin waves with nanoscale wavelengths. Recently, it was discovered that multilayered spin vortex cores can be used for the excitation of short wavelength spin waves [2]. Here we will show that this excitation mechanism can be generalized to a plain film, in our case a $Ni_{81}Fe_{19}$ layer of 80 nm thickness [3]. The resulting spin waves were directly imaged by means of time- resolved x-ray microscopy. The emitted wavelength was found to be tunable by the driving frequency between 5 and 10 GHz, leading to ultrashort waves of λ~80 nm at 10 GHz. These waves belong to the first higher order mode of the Damon-Eshbach geometry, which is known to be antisymmetric over the film thickness in ferromagnetic resonance. For the short wavelengths observed, however, mode hybridisation leads to a heterosymmetric thickness profile. This peculiar profile coincides with a cross-sectional line of pure linear magnetic oscillation and regions with anti-Larmor precession sense.

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SP 15 Spin waves and magnonics

SP15 - Parallel Session 4

SP15.4.02

Pure spin current driven excitation of propagating spin waves in a spin Hall nano-oscillator

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Text In recent years, intensive research has been carried out in facilitating the use of spin waves for information transmission and computation with the aim of establishing a spin-wave-based technology that is believed to be significantly more energy efficient than the CMOS technology.[1-3] Spin Hall nano-oscillators (SHNOs) have particularly triggered significant interest owing to lower heat generation, higher oscillation coherence, and more flexible layout than spin torque nano-oscillators.[3] While SHNOs have been demonstrated with different device geometries, the leading nonlinear self-localization behaviour of auto-oscillations in the generating region limits their utilization as a nanoscale signal carrier in magnonic circuits.[2-3] Here, we report the first experimental demonstration of Spin-Hall driven controllable excitation of propagating spin waves in very low operational current nano-constriction based W (5 nm)/CoFeB (1.4 nm)/MgO (2 nm) SHNOs. Using electrical and optical characterization techniques, we establish that the strong perpendicular magnetic anisotropy (PMA field = 0.64 T) originating from the CoFeB/MgO interface significantly influences the nonlinearity of the system thereby inhibiting spin-wave localization and allows the auto-oscillating mode to radiate energy away from the constriction region.

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SP 15 Spin waves and magnonics

SP15 - Parallel Session 4

Effects of Intermagnet Coupling on the Dynamic Properties of Nanodisc Arrays

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Text We studied the influence of intermagnet dipolar coupling on the dynamic properties of close spaced arrays of circular nanomagnets, also known as magnonic crystals. To this end, we performed broadband ferromagnetic resonance (FMR) experiments and made use of micromagnetic simulations to interpret distinct features in the measured resonance spectra such as center- and edge-modes. The magnets have a diameter of 300 nm and are ordered in either a square or a hexagonal lattice. The FMR bias field was applied in two different principle directions per lattice. For comparison, a reference sample was measured with decoupled, single discs. It was found that the presence of the lattice has a large impact on the measured FMR spectra. At low applied bias fields, distinctly different magnetic oscillation modes were observed, dependent on the symmetries of the lattice and the direction of the applied bias-field. In addition, we find that splitting of the Kittel curve into edge and center modes is dependent on the symmetry and field direction. These findings suggest a large influence of the dipole-dipole coupling between the individual nanomagnets on the excited spin-wave spectrum, which might be of interest to the development of novel spintronic devices.

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SP15.4.05

3D Magnonic crystals and networks

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Text Magnetic micro- and nanostructures are extensively investigated due to their potentials as candidates for future spintronic and magnonic devices. Main carriers of signals used for information processing in such structures are magnons. We suggest the idea how magnonics can be essentially three-dimensional. We present the novel concept of three-dimensional (3D) magnonic structures and networks. We demonstrate results of investigations of the meander type magnonic waveguides fabricated on the structured substrates. We study spin-wave propagation regimes in isolate and coupled meander magnonic waveguides.The fabricated samples are the promising candidates to the building blocks of 3D magnonic networks. We calculated numerically using finite elements method and micromagnetic calculations method the dispersion characteristics of propagating surface magnetostatic waves and showed how the wave band structure can be formed due to geometrical dimensions of these structures. Using transfer matrix method we showed further how the wave will be reflected and transmitted at corners where the waveguide turns at 90◦. Distributions of spin wave potentials in dependence of the wave frequency are also calculated using micromagnetic calculations method. Our results can be used for fabrication of the component base of logic and signal processing devices performing the enlargement of magnon spintronics in three dimensions.
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SP15.4.06

Magnon detection in an insulator-spintronics spin valve

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Text Magnon spin current driven spintronic applications yield a promising alternative to charge-based devices with respect to information transport and processing [1].We report on ferromagnetic resonance spin pumping measurements in a magnonic spin valve device comprising the insulating ferrimagnet yttrium iron garnet (YIG), the insulating antiferromagnet CoO as well as the metallic ferromagnet Co: YIG/CoO/Co. By microwave irradiation in external magnetic fields the YIG is brought into resonance, thus emitting a pure spin current through the sample stack. The spin current propagates through the antiferromagnetic CoO and is detected in the Co layer via the inverse spin Hall effect [2]. The CoO furthermore enhances the Co coercive field due to exchange bias such that switching between a parallel or antiparallel alignment of the YIG and Co magnetization at the YIG resonance field is enabled. For parallel and antiparallel alignment we observe a notable difference of the detected magnonic spin current signal, resulting in a spin valve effect amplitude of 120% [3]. In addition, a secondary signal whose sign depends on the Co magnetization orientation is detected, which is attributed to an anomalous Hall effect induced spin rectification effect.

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SP15 - Parallel Session 4

SP15.4.07

Enhanced Spin Wave Group Velocity due to Exchange Coupling in a Ferrimagnetic Insulator/ Ferromagnetic Metal Bilayer

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Text In the field of spintronics, building blocks for low-power consuming logic and data processing devices might exploit spin waves. Long propagation distance and high group velocity of spin waves are desired for such building blocks. In magnetic thin films, perpendicular standing spin waves (PSSWs) reflect exchange-dominated modes quantized between the top and bottom surface. When the PSSWs acquire in-plane wave vector components, the modes are known to have small group velocities. Here, we demonstrate that PSSWs can gain a large group velocity by depositing a metallic magnetic layer (permalloy) on a ferrimagnetic yttrium iron garnet (YIG), making them attractive candidates for magnonic devices. Electrical broadband spin wave spectroscopy was performed to explore propagating spin waves. In the bilayer structure the PSSW group velocity was found to be significantly higher than that of the bare YIG film. Using the finite element method, we confirmed these findings by simulating the mode profiles and dispersion relations. The calculated mode profiles illustrate the hybridization between two spin wave branches due to exchange coupling at the interface. The high speed propagating PSSWs found in the bilayer system can be utilized to configure multiple spin wave channels for spin wave based logic devices. The research was funded by the EPFL COFUND project No. 665667 (EU Framework Programme for Research & Innovation (2014-2020)) and DU 1427/2-1 (Deutsche Forschungsgemeinschaft)