Poster Session C

Poster C

SP2, SP4, SP5 (1/3), SP14, SP15, SP16, SP18
Poster C

P-C.002

Bismuth and antimony chalcogenides: peculiarities of electron density distribution, unusual magnetic properties and superconductivity

V. Orlov, G. Sergeev, E. Kravchenko

Text Electron band structure calculations and analysis of critical points parameters in the electron density distribution in Bi_2Te_3, Bi_2Se_3, Bi_2S_3, α-Bi_2O_3, Sb_2Te_3, Sb_2Se_3 and Sb_2S_3 at ambient and high pressures were performed to determine interrelations between the crystal structure, unusual physical (including magnetic and superconducting) properties and peculiarities in the electron density distribution. The programming code WIEN2k was used for band structure calculations. The previously found correlation between the superconducting transition temperature T_c and the electron density Laplacian value in the bond critical point with the highest electron density [1] was confirmed by calculations made for crystal structures under high pressure. The revealed parameters of bond critical points indicate the significant role of charge density fluctuations in the compounds studied.
The $^{121, 123}$Sb NQR spin echo envelopes assigned to the ν_1 transition (Δm=1/2-3/2) were measured for the two crystallographic positions of antimony atoms in the Sb_2S_3 structure. Unexpectedly deep oscillations of NQR spin echo envelopes were observed in very small (1-3 Oe) external magnetic fields, evidencing for the existence of local magnetic fields in Sb_2S_3 similar to those earlier observed in bismuth oxide compounds [2].

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Poster Session C

Poster C

P-C.003

DC and AC magnetic characterization on Nd1.85Ce0.15CuO4 cuprate superconductor

A. Galluzzi, A. Nigro, R. Fittipaldi, A. Guarino, A. Leo, G. Grimaldi, S. Pace, M. Polichetti

Text We report the analysis of the magnetic response detected on the cuprate superconductor Nd1.85Ce0.15CuO4. In particular the magnetic behavior of the sample has been studied by means of DC magnetization (M) measurements as a function of the temperature (T) and DC magnetic field (H). The superconducting critical temperature Tc has been obtained by analyzing the M(T) curve performed in Zero Field Cooling-Field Cooling conditions. Moreover, the M(T) curve shows the presence of a magnetic background for temperatures above Tc. By considering the superconducting M(H) hysteresis loop at different temperatures, it can be noted that the width of the curves appears narrow corresponding to a weak superconductivity. This is confirmed by the field dependence of the critical current densities Jc extracted from the superconducting hysteresis loops M(H) at different temperatures within the Bean critical state model. In fact, at the lowest measurement temperature, Jc is near to zero already at low magnetic fields. In order to correlate this superconducting response of the material to the vortex lattice dynamics, the temperature dependence of the 1st and 3rd harmonics of the AC magnetic susceptibility (χ) has been measured for different frequencies and amplitudes of the AC magnetic field with and without a superimposed applied DC field. This alternative approach gave us the possibility to investigate the different dissipative magnetic flux regimes acting in the sample.

Poster Session C

Poster C

P-C.004

Edge currents as a probe of the strongly spin-polarized topological noncentrosymmetric superconductors

M. Biderang, M. Zare, H. Yavari, P. Thalmeier, A. Akbari

Text Recently the influence of antisymmetric spin-orbit coupling has been studied in novel topological superconductors such as half-Heuslers and artificial heterostructures. We investigate the effect of Rashba and/or Dresselhaus spin-orbit couplings on the band structure and topological properties of a two-dimensional noncentrosymmetric superconductor. For this goal, the topological helical edge modes are analyzed for different spin-orbit couplings as well as for several superconducting pairing symmetries. To explore the transport properties, we examine the response of the spin-polarized edge states to an exchange field in a superconductor-ferromagnet heterostructure. The broken chiral symmetry causes the uni-directional currents at opposite edges.

[1] arXiv:1803.02591

Poster Session C

Poster C

P-C.005

Electron polaron effect and inhomogeneous distributions of spin and charge in strongly-correlated electron systems.

M. Kagan

Text In the beginning of the talk I observe briefly the advances in the subject of electronic phase separation and formation of different types of nanoscale FM metallic droplets (FM polarons or ferrons) in antiferromagnetically ordered (AFM), charged ordered (CO) or paramagnetic (PM) insulating matrices. I consider also the formation of the heavy-particle state and electron polaron effect (EPE), as well as anomalous resistivity characteristics in strongly correlated two-band systems with one narrow band . I discuss the formation of spin polarons in the inhomogeneous Griffits phase in high magnetic fields as well as the manifestation of EPE in the tunneling density of states in the microcontact with deep two-level trap. Finally I analyze the formation of orbital polarons and entangled spin-orbital excitations in degenerate two-band Hubbard model and the anomalous magnetic and transport properties and phase diagrams in different rare-earth hexaborides.

References

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Poster Session C

Poster C

P-C.006

Interplay between superconductivity and magnetism in $YBa_2Cu_3O_{7-\delta}$ nanolayers

L. Omelchenko, A. Solovjov

Text Importantly, apart from the high T_c's, cuprates possess the so-called pseudogap (PG) which opens below PG temperature $T^* \gg T_c$ [1-3]. To clarify the issue, we studied the fluctuation conductivity (FLC) and PG in $YBa_2Cu_3O_{7-\delta}$-$PrBa_2Cu_3O_{7-\delta}$ (YBCO-PrBCO) superlattices (SL's) and YBCO-PrBCO double-layer films(so-called "sandwiches", SD's). Pr^{+3}atoms are known to have an intrinsic magnetic moment, $\mu_{eff} \approx 3.58\mu_B$ and $\mu_{eff} \approx 2\mu_B$ in the PrBCO compound. Thus, such compounds are considered to be very promising in studying the change of interplay between superconductivity and magnetism in HTSC's which is expected to increase with an increase of the number of PrBCO layers N_{Pr}. PG analysis obtained for all five samples using with corresponding set of parameters derived from experiment. As expected, SL1 shows $\Delta^*(T)$ being typical for unadulterated YBCO films with a wide maximum at $T_{max} \sim 130$ K and $\Delta^*_{max} \approx 250$ K. Thus one may conclude that the basic mechanism of the interplay between the superconductivity and magnetism is the same in all HTSC's where superconductivity can coexist with magnetism.

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Poster Session C

Poster C

P-C.007

Pf-hybridization and magnetic phase transitions in ferromagnetic superconductors

A. Povzner, A. Volkov, A. Punchenko

Text In uranium ferromagnets, such as UGe2, UCoGe, URhGe et al., superconductivity may occur at temperature of electron pairing (TSC) whose value is much below the Curie temperature (TC). The conditions of occurrence of superconductivity may depend on the pressure (e.g. UGe2 in the range of from 7 to 15 kbar). Studies of the electronic structure indicate the hybridization of localized 5f-electrons of uranium with p-electrons. We studied the magnetic phase transitions and the spin-fluctuation mechanism of the formation of superconductivity within the Anderson hybridization model taking into account of the pf-jumps with spin flips. It is shown that near the superconductivity temperature, a strongly ferromagnetism of f-like electrons loses thermodynamic stability. In this case, a triplet and a singlet pairing arise due to the spin-fluctuation mechanism. With increasing temperature, p-like states appear inside the hybridization gap. As a result, weak ferromagnetism occurs near the Curie temperature. This leads also to a weakening of the effects of double exchange. A feature of the dependence of Tc on pressure is the presence of a boundary point (pc) in which the mod-mode coefficient in the Ginzburg-Landau functional □= 0, which leads to a first-order transition. For p>pc ferromagnetic solutions available and superconductivity can occur due to singlet pairing. The results of the developed theoretical approach are compared with the p-T diagram of UGe2.

Poster Session C

Poster C

P-C.009

Structural and magnetic properties of the compounds of Fe-Se-Te superconducting family

K. Frolov, P. Naumov, V. Ksenofontov, I. Lyubutin, V. Belikov, S. Kazakov, S. Gavrilkin, V. Pudalov, N. Korotkov, I. Perunov

Text Among new iron-based superconductors, Fe-Se-Te family has the simplest crystal structure and considered as modeling objects for the study of the interplay between magnetism and superconductivity. In this work $Fe_{1+x}Te$ (x = 0.075 – 0.225) and $FeSe_{1-y}Te_y$ (y = 0.5, 0.8) compounds were studied by the X-ray diffraction, calorimetry, magnetometry and Fe-57 Mössbauer spectroscopy in the 5 – 295 K temperature range.
The Mössbauer spectra of the non-superconducting Fe-Te are the slightly asymmetric paramagnetic doublets at room temperature. We found that asymmetry is the texture effect. We used that for the correct determination of the structural and spin states of Fe ions. Below 70 K spectra demonstrate complex magnetic splitting which can be fitted by at least 6 sextets corresponding different states of Fe.
Mössbauer spectra of the superconducting Fe-Se-Te samples are mostly paramagnetic at all temperatures and below 70 K only non-intensive magnetic components appear. So we assume that the excess Fe ions are responsible for strong magnetic ordering in the $Fe_{1+x}Te$ compounds.
This study was supported by the Federal Agency of Scientific Organizations (Agr. 007-ГЗ/Ч3363/26), Russian Science Foundation (17-72-20200), Russian Foundation for Basic Research (17-02-00766) and Russian Academy of the Sciences Program #12 “Fundamental problems of high-temperature superconductivity”.

Poster Session C

Poster C

P-C.012

Temperature dependence of the magnetic penetration depth in the ensemble of spin polarons

K. K. Komarov, D. M. Dzebisashvili

Text The unusual properties of cuprate superconductors (SC) are due to the strong electron correlations[1] which lead in particular to the strong spin-charge coupling underling the formation of spin-polaron quasiparticles (SPQs)[2]. The spin-polaron approach (SPA) correctly accounting for the SPQs proved to be very efficient in describing both SC and normal properties of these materials.

This work is devoted to the calculation of the magnetic penetration depth λ within the SPA. We developed a method for calculating the response of an ensemble of SPQs to a homogeneous vector potential $A_{q=0}$. The method was used to calculate the temperature and concentration dependence of λ. Calculated temperature dependence of λ^{-2} was compared with available experimental data. It is argued that the inflation point revealed experimentally in the temperature behavior of λ^{-2} in $La_{1.83}Sr_{0.17}CuO_4$[4] may be considered as a manifestation of the spin-polaron nature of quasiparticles in cuprates.

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Poster C

P-C.013

Upper critical field in (Li-EDA)$_y$(FeSe$_{0.88}$S$_{0.1}$)$_x$ - superconducting selenide intercalated with organic molecules

A. Lynnyk, A. Krzton-Maziopa, E. Pesko, R. Puzniak

Text The magnetic and nonmagnetic mesoscopic phase separation in superconducting selenides, and particularly in selenides intercalated with organic molecules, opened discussion on the nature of the superconducting phase and, despite many efforts put on the explanation of this problem, there is still lack of proof showing if one of the phases or the phase boundary is responsible for superconductivity. Superconducting (Li-EDA)$_y$(FeSe$_{0.88}$S$_{0.1}$)$_x$, with transition temperature, T_c, equal to about 43 K, determined by ac susceptibility in zero magnetic field, was obtained by solvothermal intercalation of polycrystalline FeSe$_{0.88}$S$_{0.1}$ in a solution of metallic Li in anhydrous ethylenediamine (EDA) using Schlenk technique. Upper critical field, H_{c2}, was determined with ac magnetic susceptibility in external magnetic field. It was found that H_{c2}, recorded in the temperature range up to 30 K, decreases with increasing temperature, with dH_{c2}/dT typical for superconducting layered A_xFe$_{2-y}$Se$_2$ (A = K, Rb, Cs). However, the value of dH_{c2}/dT at the temperature range above 30 K is significantly smaller than that for lower temperatures. Importantly, the field range, where the superconductivity at the temperatures above 30 K is observed, corresponds to irreversibility field in the hysteresis loop. It maybe suggested that, appearance of superconductivity at the temperatures higher than T_c of A_xFe$_{2-y}$Se$_2$ is related to magnetic inhomogeneity in the studied system.

Poster Session C

Poster C

P-C.014

A new mechanism of memorization of previous magnetic states in RCrO3 compound

M. Tripathi, T. Chatterji, S. Majumder, D. Phase

Text The hysteresis in magnetic isotherms for any coercive magnetic material shows a presence of a regime in which the sign of magnetic moment becomes independent of present applied field and governed by previously applied field only, caused by domain phenomenology: impediments in domain wall motions; the process of domain wall motion: either coherent rotation or curling and domain wall pinning at disorder sites. All these effects are moderated by the coercivity of any material, which is used to quantify the memorization capacity; very large coercive materials are used as permanent magnets and moderate coercive for recording tapes.

Here, we present the evidences of memorization of previous magnetic history by non-coercive collinear anti-ferromagnetic state of RCrO3 material. The kind of history effect has some additional features than conventional ferromagnetic material; the memorization process happens only in a short temperature window of 5 K across Neel temperature. This phenomena of memorizing the direction of cooling field is very different than the aging effect observed in spin glass systems and molecular magnets. We also propose the idea of utilizing the unique memorization process in thermo-magnetic switches equipment with sharp temperature windows.

Poster Session C

Poster C

P-C.015

Alternative mechanism for establishing and tailoring the exchange bias in IrMn-based thin films

A. Migliorini, B. Kuerbanjiang, D. Kepaptsoglou, M. Muñoz, J. L. F. Cuñado, J. Camarero, C. Aroca, G. Vallejo-Fernandez, V. Lazarov, J. L. Prieto

Text We present an alternative mechanism for establishing the exchange bias (EB) in IrMn/FeCo bilayers, based on a structural phase transition in the IrMn[1]. We demonstrate that IrMn sputtered at high deposition rates can be quenched into a metastable amorphous phase, which does not induce EB in the adjacent FeCo layer. The activation temperature for the crystallization of the amorphous IrMn is about room temperature and can be tuned by varying the layer thickness. The crystallization occurs according to a two-dimensional nucleation and growth process, leading to a highly crystalline γ-phase with grains size of the order of hundreds of nanometers. As the crystalline phase of the IrMn propagates across the sample, the EB is progressively established in the FeCo adjacent to the crystalline areas, according to its magnetization direction. As a consequence, exchange-biased magnetic domains in the FeCo layer, detected by Kerr microscopy, nucleate and expand, reflecting the evolution of the structural phase transition in the IrMn. By repeatedly switching the external magnetic field during the crystallization of the IrMn, we achieve microscopic patterning of the EB direction, in both exchange-biased bilayers and spin valve devices. The study of this mechanism can contribute toward the clarification of fundamental aspects of the EB, as well as toward the development of innovative spintronic devices.

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Poster C

P-C.016

Anisotropic damping constants in Ni-Fe single crystal thin films

Y. Yoshida, S. Yamanaka, T. Suzuki, Y. Takahashi, N. Inaba, F. Kirino, M. Ohtake, M. Futamoto

Text Gilbert's damping constant α is an important factor to develop high speed magnetic recording system and MRAM. The α of Ni-Fe polycrystalline thin films was reported to be correlated to the magnetostriction. We investigated crystal direction dependence of α in Ni-Fe(110) single crystal thin films deposited on MgO(110) substrates in terms of magnetostriction.

Ferromagnetic resonance(FMR) spectra of the specimens were measured by a conventional Q-band FMR spectrometer. The α values were estimated by peak widths of the spectra. The α was two-fold symmetrically varied in the (110) plane of the specimens. The α of the Ni_xFe_{1-x} specimens(x>0.8) had the minimum, maximum, and metastable values at the [111], [100], [110] directions. For instance, the α_{111}, α_{100}, and α_{110} of the $Ni_{92}Fe_8$ sample were 0.0152, 0.0133, and 0.0142, respectively. While the α of the specimens with x<0.8 had the maximum and minimum values at the [111] and the [100] directions.

The magnetostriction $\delta L/L$ of the specimens was measured by using the new measurement system[1]. Variations of $\delta L/L$ in the (110) plane on crystal direction were similar to those of α. The $\delta L/L_{100}$, $\delta L/L_{111}$, and $\delta L/L_{110}$ of the $Ni_{92}Fe_8$ sample were 2.20×10^{-5}(max.), 1.67×10^{-5}(min.), and 1.80×10^{-5}(metastable), respectively. The linear relationship existed between α and $\delta L/L$. These results suggest that the magnetostriction is one factor to bring the anisotropic α in Ni-Fe single crystal thin films.

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Poster Session C

Poster C

P-C.017

Chemical and structural analysis on magnetic tunnel junctions using a decelerated scanning electron beam

E. Jackson, M. Sun, T. Kubota, K. Takanashi, A. Hirohata

Text A series of magnetic tunnel junctions (MTJs) were produced on a single wafer with a stack structure of MgO(Sub.)/Cr(80)/Pd(5)/$Co_2Fe_{0.4}Mn_{0.6}Si$(CFMS)(5)/MgO(2)/CoFe(5)/IrMn(10)/Ru(7)/Cr(5)/Au(80)(thickness in nm). These MTJs could be split into two distinctive groups, High (>80%) or low (~0%) tunnelling magnetoresistance (TMR), corresponding with the effective yield. To improve the yield the devices were investigated using a recently developed imaging technique. This utilises CASINO, an electron scattering in solids simulator, to find a controlled voltage which will penetrate the sample down to a selected interface. The impact voltages chosen were 10, 10.5 and 11 keV allowing the CoFe, MgO and CFMS interfaces to be analysed using the back scattered electrons produced. These images were taken using the JEOL JSM-7800F Prime. The technique found the main difference between the two groups was a build-up of material around the low TMR MTJs. Energy-dispersive X-ray spectroscopy was utilised to identify the material around the pillar. These two techniques led to the conclusion that the material was most likely to be an aluminium carbide, such as Al_4C_3, formed during the deposition of the insulator, AlO, and carbon from the resist used during the etching stage.
We thank JEOL UK for their support and acknowledge the funded provided through EPSRC EP/M02458X/1 and the JSPS Core-to-Core grant.

Poster Session C

Poster C

P-C.018

Control and influence of the current path in thin-film multilayer giant magnetoimpedance sensors

V. Serea, G. Buettel, U. Hartmann

Text The GMI ratio is known to significantly increase in microwires, when the magnetic outer is separated from the metallic core shell by an insulating shell [1]. In sputtered planar thin-film GMI sensors this mechanism was so far not investigated and measured, as a more complicated fabrication process is necessary to ensure this separation of the layers. We report on the change of the GMI ratio in case of sputtered microstructured GMI devices based on a Cu core layer and surrounded by NiFe layers. The current flow in the magnetic layers is strongly suppressed by deposition of semiconducting TiO2 between the Cu and NiFe layers. Additionally, by an optimization of the order of the sputtering deposition and alignment of the lithography masks in the multilevel e-beam lithography fabrication process, the contacts between the microstructured GMI multilayer and the Cu coplanar waveguide are controlled in a way that the overlap of Cu and NiFe is minimal in comparison to a conventional one-step lithography and deposition of the full GMI microstructure [2]. Devices fabricated by the multilevel and the ordinary one-step process without and with TiO2 layers are compared and the latter show a further increase of the GMI ratio, which can lead to even higher field and strain sensitivities for GMI sensors as for XMR-based effects reported recently [2,3].

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Poster Session C

Poster C

P-C.019

Curie temperature modulated structure to improve performance in heat-assisted magnetic recording

O. Muthsam, C. Vogler, D. Suess

Text In the almost 60 years since heat-assisted magnetic recording (HAMR) was proposed, quite a number of investigations have been performed to understand HAMR in all details. However, to the best of our knowledge, most of these theoretical works do not take into account the temperature reduction in z-direction within the material in the writing process. Since the temperature of the heat pulse acts differently on different layers in the material in reality, it is interesting to study how this affects the performance of HAMR. We investigated how a temperature gradient along the z-direction within the material influences the switching behavior of a grain with a diameter of 5nm and a height of 10nm. In the atomistic simulations, pure hard magnetic grains were considered and different temperature gradients of the heat pulse in z-direction were assumed.

The results show that a linear temperature reduction of about 10% on average leads to a switching temperature that is not only 10% but 20% higher than for no temperature gradient. Simultaneously, both the AC and the DC noise increase.

Additionally, we studied if an artificial Curie temperature gradient within the material, produced by a cleverly designed multilayer structure, can compensate the HAMR performance loss due to the temperature gradient. Our simulations show that this is indeed the case. Further, due to the graded Curie temperature, DC noise can be reduced compared to a structure where no temperature gradient is considered.

Poster Session C

Poster C

P-C.020

Development of Gold and Graphene Nano Hall Sensors for Scanning Magnetic Field Microscopy

M. Gerken, A. Müller, D. M. Pakdehi, T. Weimann, A. Solignac, A. Doll, F. Nording, F. Hohls, S. Sievers, M. Schilling, H. W. Schumacher

Text Within the overall miniaturization, also magnetic devices are being scaled down into the micro- and nanometer range. This leads to an increasing demand for high-resolution quantitative metrology for the resulting spatially varying device stray fields. One promising approach is scanning magnetic field microscopy using nanoscale Hall sensors. Here, we present our results on the development of gold and graphene Hall sensors with active areas down to 50 nm x 50 nm.

The sensors were fabricated using combinations of electron beam lithography, lift-off process and etching of epitaxially grown graphene. The resulting device structures were verified by scanning electron microscopy. To investigate sensor sensitivity as well as stability they were characterized in homogeneous magnetic fields up to 250 mT. Furthermore, we discuss noise figures and an estimation of the uncertainty budget for quantitative magnetic field measurements.

The gold sensors show a sensitivity of 3 mV/AT with very good reproducibility and a low calibration uncertainty of 2.4 %. In contrast, graphene sensors reveal a much higher sensitivity of about 700 V/AT, but a reduced stability over time. Finally, we present a concept for fabricating gold Hall sensors on cantilevers to integrate them into a metrological atomic force microscope for high precision scanning Hall magnetometry.

This work was supported by the EMPIR JRP 15SIB06 NanoMag through EU and EMPIR participating countries within EURAMET.

Poster Session C

Poster C

P-C.021

Development of an isotropically coercive free layer for MTJ-based artificial synapses

M. Mansueto, S. Auffret, I. Joumard, L. D. Buda-Prejbeanu, I. L. Prejbeanu, B. Dieny

Text Bio-inspired technologies are very appealing today for many potential applications. In particular, brain-like network is representing an example of efficient and low power consumption computational tool for big data analysis tasks. In this context, the development of a proper hardware is essential and memristive devices, with their synapse-like behaviour, represent a key element for this purpose.
Our objective is to conceive a spintronic memristor based on the angular variation of tunnel magneto-resistance in a nanopillar with the magnetic state controlled by spin transfer torque. One of the main challenge is represented by the realization of a special magnetic media able to stabilize the magnetization along various directions in the plane of the layer. Here we are developing such a media by exploiting the ferromagnet/antiferromagnet (F/AF) coupling. For small thicknesses of the antiferromagnetic layer, the coercivity of the ferromagnetic adjacent layer is enhanced while the exchange bias phenomenon is still negligible. In this condition, the strength of the coupling and the anisotropic energies (both ferromagnetic and antiferromagnetic) should ensure the stability of the magnetization independently from its direction. The magnetometry and anisotropic magnetoresistance measurements confirm that the (F/AF) coupling results in an equivalent solid friction on the F magnetization allowing its stabilization in any in-plane direction with same pinning energy.

Poster Session C

Poster C

P-C.023

Effect of additive elements on the morphology and magnetic properties for FePt thin films

K. Ishida, M. Doi, T. Shima

Text Since L10 ordered FePt alloy with high uniaxial magnetocrystalline anisotropy (7.0×10^{7}erg/ cm^{3}) has attracted much attention, it is good candidate for future magnetic devices such as next generation ultrahigh density magnetic storage media and biasing nanomagnets. It is also thought to overcome the problem of thermal fluctuation in nano-meters scale. A lot of studies have been studied for granular films and self-assembled nano particles, however, magnetic properties of FePt(Cu, Ag) thin films with a small addition of Cu and Ag has not yet fully understand. In order to see the effect of additive elements on the morphology and the magnetization process for the FePt thin films, FePt(Cu, Ag) thin films have been investigated. Samples were prepared using an ultrahigh vacuum sputtering system. FePt(Cu, Ag) thin films of 10 nm were deposited on a MgO(100) single crystalline substrate at 700 ºC. The crystal structure was determined X-ray diffraction with Cu Kα radiation. The film morphology was observed by AFM. The magnetic properties were measured by a SQUID magnetometer. From the XRD patterns, it was confirmed that the fundamental (002) peak, (001) and (003) superlattice peaks of the L10-FePt phase were clearly observed for all samples. With increasing Cu content, the peak position was shifted to a higher angle. It was also confirmed that the coercivities were decreased from 60.5 to 18.4 kOe by the addition of Cu. Further detail results will be presented at the conference.

Poster Session C

Poster C

P-C.024

Electric field control of spin-orbit torques in perpendicularly magnetized thin films for MRAM

M. Filianina, K. Lee, D.-S. Han, J.-P. Hanke, M. Kläui

Text Electric field control of magnetism has attracted significant interest with its great potential for spintronic memory devices with high performance and energy efficiency. Up to now, the magneto-electric effects have been intensively studied in various systems. While most of the work has focused on the manipulations of magnetic anisotropies [1,2], electric field effect on current-induced spin-orbit torques (SOTs), which is a key element for magnetization switching for MRAM has been little investigated [3].
Here, we report on strain-controlled SOTs in perpendicularly magnetized W/CoFeB/MgO multilayers for MRAM. The anisotropy and the SOTs are evaluated by the first- and second-harmonic method [4] under the different in-plane and out-of-plane strain. We find that the strain, modulated by the electric field applied across the piezoelectric substrate, leads to an anisotropy change and in particular a non-trivial change in damping-like and field-like torques, with the latter being affected by more than a factor 2. We also compared experimental results to density functional theory (DFT) calculations for better understanding of underlying mechanisms of the strain-induced change of SOTs and anisotropy showing that the switching can be optimized for MRAM applications by strain.

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Poster Session C

Poster C

P-C.025

Fabrication of planar microcoils around thin-film giant magnetoimpedance devices by multilevel e-beam lithography

G. Buettel, V. Serea, V. Petricevic, U. Hartmann

Text Microwire-based commercial GMI sensors with pT sensitivity are commonly operated by pulsing a current through the wire for the detection of magnetic fields. Subsequently, the characteristic magnetic response in the ferromagnetic wire within a distinct external magnetic field induces a characteristic voltage signal in a metallic coil, which is wound around the wire. As microwires cannot be fabricated, aligned and assembled by means of thin-film deposition and lithography techniques, the effort of fabrication for such sensors is high compared to XMR-based sensors. In this contribution we report a fabrication process that allows the fabrication of thin-film GMI microstructures covered by PMMA resist to isolate electrically the metallic microcoil from the GMI microstructure. The PMMA resist is planarized by optimization of the resist coating and isotropic reactive ion etching with oxygen. The microcoil and GMI microstructure are fabricated by magnetron sputtering and e-beam lithography with orthogonal copolymer resists and developers to prevent a structuring of the PMMA. Finite-element simulations were carried out to find an ideal geometry of the coil. The developed process will allow future investigations and further optimization of thin-film GMI prototype sensors for commercial applications by versatile e-beam lithography and a more economic fabrication of such sensors on a wafer scale in comparison to microwires.

Poster Session C

Poster C

P-C.026

Flexible Hall sensors manufactured by multiple transfer-printing graphene onto 75µm-thick PET film

U. Inkaya, K. Celik, A. Oral, S. Sürücü

Text Flexible Hall sensors were made from the copper/graphene/PET stack obtained via lamination with hot rollers. The graphene was synthesized by using atmospheric pressure chemical vapor deposition (APCVD) on 20µm-thick copper foil. The devices having 5x5mm^2 active area were manufactured by cutting Hall crosses out of the laminate followed by selective etching of the copper layer with aqueous ferric chloride [$FeCl_3$(aq)] solution in order to both transfer-print graphene and form electrical contact pads of the device in a single step. Furthermore, we performed multiple transfer-printing of graphene onto the PET film by recursively iterating this manufacture process up to ten times and characterized the resultant graphene-based multilayered conductive thin films with resistance and Hall-effect measurements, and AFM. The Hall sensors resulted from single transfer-printing of graphene showed sensitivities up to 1200 Ω/T with the resistance of 7 kΩ, and the sensitivity and resistance changed almost in inverse proportion to the number of transfer-printings.

Poster Session C

Poster C

P-C.027

Impact of buffer layers on the thermal behavior of MnIr and MnPt magnetoresistive stacks

H. Lv, D. C. Leitao, S. Cardoso, P. Freitas, K. Pruegl, W. Raberg

Text Ensuring a reliable reference in magnetoresistive devices requires robust exchange biased bilayers with strong resilience to high temperatures [1,2]. In this work, we address the impact of the buffers on Mn-based systems: bilayers [Buffer/AFM 15/CoFe 2.7(nm)], and tunnel junction (MTJ) stacks [Buffer/AFM 15/CoFe 2.7/Ru 0.8/CoFeB 2/MgO 1.2/Free-Layer/Cap(nm)]. For MnIr bilayers, larger H_{ex}, smaller T_b and H_c are achieved. All data suggests that: (i) below T_b a large AFM anisotropy (k_{AFM})[3] reduces spin drag and H_c; (ii) near T_b, k_{AFM} reduces substantially dragging AF spins, and leading to a sudden increase in $H_c(T)$, which critically depends on the buffer. In contrast, MnPt samples combine low H_{ex}, large H_c and $T_{b,center}$. For high temperature most AFM grains retain the initial spin orientation, not evidencing spin drag. The broad T_b distribution can arise from k_{AFM} distribution and/or AFM grain size [4] studied with XRD.
For MTJ stacks the pinned-SAF promotes an increase in the bias field (>1.4 kOe) and thermal robustness, strongly influenced by the buffer. Similar to the bilayers, MnIr samples show an accentuated $H_{bias}(T)$ decrease compared to all MnPt samples. The high T_b in MnPt samples point to improved thermal stability, advantageous for devices operating at high temperatures. Although MnIr samples show larger H_{ex} an inferior resilience is thus expected [5]. These detailed thermal studies support the optimization of the buffer layers for automotive and industrial sensors.

Poster Session C

Poster C

P-C.028

MERAM on the basis of the elastic interaction: problems and limitations

A. Morosov

Text The problems arising in the process of development of the magnetoresistive memory with the electric field recording (MERAM) based on elastic interaction between the electrosensitive layer and the ferromagnetic layer comprising the magnetic tunnel junction were considered. The limitations were discovered concerning the size of the cells connected with the existing superparamagnetic threshold. Studying of the elastic interaction between the ferromagnetic and electrosensitive layers shows that the use of the ferroelectric-ferroelastic material as the electrosensitive layer is most promising for development of MRAM with electric field recording.
For development of MRAM, in which an electric field is applied to the (110) cut of PMN-PT layer, it is necessary to determine experimentally the characteristic number of the consecutive cycles of the polarization vector for transition to a metastable state between two failed switchings accompanied by a disruption of the equilibrium state.
The study of the prototype of the memory based on the ferroelectric-ferroelastic layer should be based not on an active, but on a passive substrate, on which an electrosensitive PMN-PT layer with dimensions corresponding to a separate cell is to be developed.

Poster Session C

Poster C

P-C.029

Magnetization reversal of ferromagnetic nanoparticles induced by torsional oscillations in static magnetic fields

S. Philippi, H. Schlörb, D. Mukherjee, B. Büchner, T. Mühl

Text Magnetization reversal of small ferromagnetic particles requires to overcome an energy barrier which is mainly defined by the magnetic anisotropy. Usual reversal stimuli include the application of static or time-dependent external magnetic fields, thermal activation, spin transfer torque, or combinations thereof. Here, we report on repeated, quasi-periodic magnetization reversal in single-domain particles that are exposed to a constant magnetic field perpendicular to the magnet's easy axis. The continuous sequence of reversals is induced by torsional oscillations of the magnet's anisotropy landscape, which are caused by angular oscillations of the magnet's body. In our experiments, a nickel nanowire constitutes both a mechanical resonator and a nanomagnetic sample with uniaxial anisotropy. We measure the transient flexural vibration behavior by electron beam based methods and find strong signatures of periodic magnetization switching between two magnetic states of the nanowire.
Our approach may have significant impact for basic investigations of magnetization reversal and for applications which require mechanical vibration amplitudes that are precisely controlled at the nanoscale. Furthermore, it can be extended to a concept of mechanically-controlled single reversals of magnetization that are induced by pulsed mechanical excitation. The latter might be the foundation for a novel ansatz for energy-efficient magnetic data storage.

Poster Session C

Poster C

P-C.030

Magneto-impedance properties of thin-film sensors using CoNbZr/SiO_2 multilayer films

H. Yokoyama, Y. Hayashi, K. Kusunoki, S. Hashi, K. Ishiyama

Text Improvement of the sensitivity of magneto-impedance (MI) sensors is required for detecting weak biomagnetic signals. With an aim to obtain high sensitivity sensors, we have been investigating thin-film MI sensors composed of a conductive layer sandwiched between magnetic layers. In this study, we investigated the MI properties of sensors using amorphous CoNbZr single layer films and CoNbZr/SiO_2 multilayer films as the magnetic layers. Our sensors detect magnetic fields by utilizing mainly the inductance change associated with the permeability change of the magnetic films. Therefore, MI sensors using magnetic films divided by insulator layers are considered to obtain a larger MI ratio because the permeability is improved by the reduction of the eddy current loss in the magnetic films.
As a result, we confirmed that the MI ratio of the sensors increased from 150 % to 325 % with increasing the number of the divided magnetic layers from 1 layer to 4 layers. Because the measured permeability of the magnetic films was improved with increasing the number of the divided magnetic layers, this increase of the MI ratio is considered to be caused by improving the permeability. This result indicates that the use of the magnetic multilayer films can improve the sensitivity of MI sensors.

Poster Session C

Poster C

P-C.031

Micromagnetic simulations of the voltage-induced switching of Spin Transfer Torque Random Access Memory

P. Bouquin, J.-V. Kim, S. Rao, T. Devolder

Text We studied voltage-induced switching in perpendicularly magnetized STTMRAM using micromagnetic simulations. We focused on the influence of the device size and the applied voltage amplitude. The free layer is simulated and described with material parameters extracted from spin wave spectroscopy [1].

We find that the minimal voltage for switching at 0 K matches the value predicted from the macrospin model. For larger applied voltages the switching is found to be faster while undergoing a similar path for reversal.

For diameters of 20 nm or below, the free layer magnetization remains uniform during the switching at 0 K. Between 22 and 50 nm, however, a domain wall is nucleated near the device edges when the precession amplitude reaches a threshold and reversal takes place via wall propagation. For larger devices, the nucleation occurs at the device center, resulting in a bubble domain that expands towards the edges during reversal. We will discuss this size dependence and the impact of finite temperature fluctuations on these processes.

[1] T.Devolder, Phys. Rev. B 96, 104413 (2017)

Poster Session C

Poster C

P-C.032

Micromagnetic understanding of Spin-Torque Majority Gate devices

A. Vaysset, O. Zografos, M. Manfrini, E. Raymenants, I. P. Radu

Text As CMOS scaling is approaching fundamental limits, the search of next-generation logic devices is becoming more and more active. In this respect, spintronics offers unique properties such as intrinsic non-volatility and the possibility to write, propagate and detect information via current. New logic gates can also be designed. This is the case of the Spin Torque Majority Gate (STMG) which should lead to very compact and energy-efficient circuits. In this device, the magnetization orientation is manipulated with Spin-Transfer Torque at the inputs and detected by Tunnel Magneto-Resistance at the outputs.
In this work, we use micromagnetic simulations to understand experimental results of our STMG devices. More specifically, we study magnetization dynamics in an extended free layer shared by several MTJs. Moreover we simulate different free layer shapes and study the impact of different pinning sites to ensure device functionality. The goal is to ensure that the minority domain remains pinned while the majority domain goes to the output. Domain wall motion is thus investigated in various complex geometries with non-uniform current distribution. This fundamental understanding allows to design the optimal shape for STMG.

Poster Session C

Poster C

P-C.033

Modern applications of glass-coated magnetic microwires.

R. Varga, D. Kozejova, L. Frolova, T. Ryba, K. Richter, L. Galdun, R. Sabol, L. Hvizdos, R. Jurc

Text Modern technical solutions require novel SMART materials that exhibit multifunctional properties being together actuators and sensors. Such novel materials sometimes do not exist or their application is expensive or technically very difficult. In that case, wide range of small sensors that are possible to introduce into various materials without changing their mechanical or other functional properties are welcome.
Glass-coated magnetic microwires are such type of materials that can serves for production of miniaturized contactless sensor or actuator of various parameters like temperature, magnetic field, mechanical stress or any other property that can be transformed into them.
In the given contribution, we show the main features (magnetic bistability, induced anisotropy, fast domain wall propagation, temperature and stress dependence of the switching field) that allows to employ the unique magnetic properties of glass-coated amorphous microwires for sensing various parameters in biomedicine (for contactless sensing the temperature), engineering (for sensing the stress distribution), automotive industry, IoT etc. or for construction of SMART miniaturized actuators.

This work was supported by the projects, Slovak VEGA grant No. 1/0164/16, APVV-0027-11 and APVV-16-0079.

Poster Session C

Poster C

P-C.034

Multilayered current-induced domain wall motion for high density magnetic memory

Y. Kurokawa, S. Sumi, H. Awano, H. Yuasa

Text Manipulating a magnetic domain wall by using an electric current has been paid much attention from the viewpoint of device application such as new types of magnetic memories and logic circuits. In particular, the racetrack memory is a novel data storage using current induced domain wall motion (CIDWM), and it has potential as a future memory. For practical application, the magnetic memory based on CIDWM is required to have a high recording density. In this study, we propose novel technique for high recording density, which is multi-level magnetic wire memory based on multilayered CIDWM using stacked magnetic layers. The multilayered CIDWM means that the DWs in upper and lower ferromagnetic layers which have different domain arrays, respectively, are controlled by single current source. In this study, we fabricate the wire with the stacked asymmetric structure to observe multilayered CIDWM.
As a result, it was found that multilayered CIDWM can be observed using Pt/Tb-Co/Ta/Tb-Co/Pt multilayered wire. It indicates that multi-level magnetic wire memory can be fabricated using wires with the stacked asymmetric structure.
This work was financially supported by the MEXT-Supported Program for Strategic Research Foundation at Private University (2014-2020), MEXT KAKENHI Grant Number 26630137 (2014-2016), Iketani Science and Technology Foundation, Research Foundation for Electrotechnology of Chubu, and a research grant from The Mazda Foundation.

Poster Session C

Poster C

P-C.035

Temperature stable magnetic field sensors based on current annealed microwires

A. Dzhumazoda, L. Panina, A. Adam, A. Morchenko, N. Yudanov, S. El-Demrdash, F. Tabarov

Text The development of magnetic sensing materials with enhanced performance and low dimensions is significantly critical for various applications. Glass-coated magnetic microwires exhibiting GMI effect are attractive candidates for this purpose. Sensitive magnetic field sensors suitable for detection of very low magnetic fields for bio-medical applications have been developed with their use. However, GMI in glass-coated microwires may show huge temperature variations in industrial temperature range of 20-100 C. Various heat treatments were proposed to improve the temperature stability of the magnetization processes and GMI in these materials. Typically this is achieved for the expense of reduced sensitivity. In this work, current annealing was proposed to induce a well-defined circular anisotropy in $Co_{60.51}Fe_{3.99}Cr_{12.13}B_{13.53}Si_{9.84}$ amorphous wires, which is not sensitive to the internal stresses. As a result, both high sensitivity and high temperature stability of GMI were realized in the operational temperature range. We also investigated the effect of glass removal on GMI and temperature stability. As the internal stress is partially caused by glass-metal interface, the GMI performance improves. Annealing the microwires after glass removal strengthens the circular anisotropy and temperature variations of the impedance were less than 0.01% per 10 degrees. Therefore, the wires can be employed as field sensors working in ambient environment without loss in sensitivity.

Poster Session C

Poster C

P-C.036

The annealing effect on the perpendicular anisotropy and interlayer coupling in perpendicular magnetic tunnel junctions with ultrathin MgO barrier

H. Lv, D. Leitão, A. Silva, J. Fidalgo, P. Freitas, S. Cardoso, T. Kämpfe, S. Riedel, J. Langer, J. Wrona

Text Perpendicular magnetic tunnel junction (p-MTJ) arises great interest because of its excellent performance in spin-transfer-torque magnetic random access memory (STT-MRAM). The annealing process is critical to achieve the required structural and magnetic properties, therefore obtaining high perpendicular tunneling magnetoresistance (p-TMR) and lower switching current.
In this work, CoFeB/MgO/CoFeB-based p-MTJ stacks were fabricated with pillar size down to 50 nm. The samples were annealed at various temperature (T_A) of 300, 340, 360 and 400 °C. The resistance at parallel (R_P) and antiparallel (R_{AP}) state were obtained by applying a ±30 mT perpendicular magnetic field, obtaining p-TMR = (R_{AP}-R_P)/ R_P. In our study, a significant increase of p-TMR with the increasing T_A was found and the maximum p-TMR of 120% was obtained at T_A = 400 °C, maintaining the *RA* of 7.5 $\Omega\mu m^2$ independent of the T_A. The angle of magnetization between storage and reference layer at memory state, θ_P and θ_{AP}, are derived from the P and AP resistance ratios with and without magnetic field. The $\theta_P = \theta_{AP} = 60°$ was found in as-deposited samples, indicating a ferromagnetically interlayer coupling between storage and reference layer. The $\theta_P = 0°$ and $\theta_{AP} = 180°$ at T_A = 300 and 340 °C demonstrate a stable memory state. Our work assesses the effect of T_A on the θ_P and θ_{AP} and the consequent change of perpendicular anisotropy and interlayer coupling, so to better control the performance of pMTJ-based STT-MRAM.

Poster Session C

Poster C

P-C.037

Thermal Stress Evaluation of Tunneling Magnetoresistive (TMR) Structure in HDD Reading Sensor

S. Tungasmita, P. Rakpongsiri, S. Pintasiri, K. Ruthe, P. O. Å. Persson

Text The modern reading sensor technology used in hard disk drives is the tunneling magnetoresistive (TMR) device. The revolutions of technology have been developed to achieve high performance of reading signal resulting in very thin and complicated device layers which thermal induced degradation and defects would be concerned. In this work, the TMR device in HDD magnetic heads were fabricated by physical vapor deposition (PVD) processes on Al_2O_3-TiC (AlTiC) substrates. The main structure composes of a magnetically free layer, a tunneling barrier, a pinned layer, and pinning layer. A thermal stress has been applied to TMR devices between 150-250°C. The resistance, amplitude and asymmetry parameters were measured and calculated from quasi-static test (QST), both before and after applying the thermal stress. The results reveal a temperature dependence performance of the TMR devices. The microstructure of the annealed devices was further studied using STEM-EDX, revealing structural defects that are related to the observed QST parametric changes. Both atomic misalignment of the MgO layer and Ir depletion are proposed as origins for the instability of the magnetic response in the device after thermal stress.

Poster Session C

Poster C

P-C.038

Tunneling anisotropic magnetoresistance at high temperature in an Fe spin-dependent quantum well

M. Al-Mahdawi, Q. Xiang, M. Belmoubarik, H. Sukegawa, K. Masuda, Y. Miura, S. Mitani

Text Ultra-thin magnetic structures are important as magnetic memories, sensors in high-density magnetic recording, and other sensing applications. The dominant mechanism is the tunneling magnetoresistance effect, which requires a barrier with two ferromagnetic (FM) layers, in addition to other auxiliary layers. Spintronics based on a single-layer FM is fundamentally ultra-thin. Tunneling anisotropic magnetoresistance (TAMR) is the effect where the tunneling resistance depends on the relative orientation between tunneling current and local magnetization at one electrode. At low temperatures, TAMR has been demonstrated with magnetic semiconductors and metals [1,2]. For applications, TAMR above room-temperature has yet to be shown clearly.

In this report, we show the increase of TAMR by quantum-well (QW) formation in an ultra-thin FM metal. We fabricated single-crystal stacks of MgO sub./Cr/Fe (t_{Fe})/$MgAl_2O_4$/CoFeB, and they were micro-fabricated into tunnel junctions. Due to a mismatch of Δ_1 bands of Fe and Cr, spin- and symmetry-selected QW states in Fe were formed [3]. We found clear resonant tunneling even at 380 K. At t_{Fe} = 6 monolayers, TAMR was 1% (5%) at 380 K (5 K). This sizable TAMR ratio indicates an enhancement by the QW states.

This study was supported by the ImPACT Program, and JSPS KAKENHI Grant No. 16H06332.

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Poster Session C

Poster C

P-C.039

Very low noise spin electronics based magnetic sensors.

C. Chopin, J. Moulin, J. Torrejon-Diaz, A. Solignac, M. Pannetier-Lecoeur, C. Fermon

Text Spin electronics based magnetic sensors,namely GMR and TMR are acquiring now enough robustness and stability to be incorporated in products like automotive applications for speed, angle or current measurements [1]. However, their main limitation for very sensitive applications is still their low frequency noise. As GMR and TMR resistances are isotropic and the low frequency noise is due to resistance fluctuations, there is no easy way to suppress it. This low frequency noise has a magnetic and an electrical origin. We will present first the techniques used to suppress mainly the magnetic low frequency noise by inducing a very coherent rotation in the sensor layers. After, we will present new routes for suppressing the remaining electrical noise based on the rapid modulation of the sensitivity of the sensors. This routes open the possibility of reaching pT range sensitivity at room temperature et fT range temperature in superconducting-magnetoresistive sensors in the low frequency domain.
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Poster Session C

Poster C

P-C.040

On the increase of coupling strength in nanomagnetic logic devices

G. Ziemys, V. Ahrens, S. Mendisch, M. Becherer

Text Perpendicular nanomagnetic logic (pNML) is listed in the International Technology Roadmap for Semiconductor as a promising beyond CMOS technology. It is based on field-coupled nanomagnets structured in ultra-thin multilayer films. The feasibility of pNML on device and system level has been shown recently. Furthermore, the 3D nature of magnetic stray fields enables monolithic 3D integration. PNML promises low-power and highly parallel digital computation and, even with sub-GHz clocking rates, huge data throughput can be achieved. At the same time, pNML is competitive in integration density when compared to CMOS.
In this work, we optimized Pt/Co/Ir multilayers for pNML applications and proved the benefit of using DMI enhanced films for field-coupled logic devices by fabricating and measuring pNML inverters. The thickness of the Iridium layer was varied and the multilayer was characterized by measuring the magnetic hysteresis curves as well as the size of domains. Besides the significant increase of domain wall velocity, experiments show that the Iridium layer allows to increase the overall Cobalt thickness in the multilayer stack by the factor of two and at the same time showing sufficient perpendicular magnetic anisotropy. Characterization of the switching behavior of a fabricated nanomagnetic inverter, while varying spacing between the two magnets, reveals two times higher magnetic coupling in pNML devices compared to the standard Co/Pt films.

Poster Session C

Poster C

P-C.041

Ordered Phase Formation in Sm-$Co_{1-x}Cu_x$ and Er-$Co_{1-x}Cu_x$ Alloy Films Prepared on Cr(100) Single-Crystal Underlayer

M. Ohtake, K. Serizawa, M. Futamoto, F. Kirino, N. Inaba

Text RCo_5 (R: rare earth metal) ordered alloys have potential to achieve high K_u and high T_c values. T_c value increases with increasing the atomic number of R element (57 => 68). However in the bulk phase diagrams, RCo_5 phase is metastable below 1100 ºC with atomic number higher than 66 (R = Dy, Ho, or Er). In the present study, $R_{17}(Co_{1-x}Cu_x)_{83}$ (at. %) films of R = Sm or Er are prepared on Cr(100) single-crystal underlayer at 500 °C by varying the Cu content, x, from 0 to 1. The effect of Cu/Co composition on the phase formation is investigated. $Sm_{17}(Co_{1-x}Cu_x)_{83}$ films consisting of hexagonal R(Co,Cu)$_5$ phase grow epitaxially on the underlayers for all the compositional range of x = 0-1. On the contrary, when Sm is replaced by Er, the structure of $Er_{17}(Co_{1-x}Cu_x)_{83}$ film varies depending on Cu content. Amorphous phase is formed in the $Er_{17}Co_{83}$ (x = 0) film. $Er_{17}(Co_{1-x}Cu_x)_{83}$ epitaxial films with R(Co,Cu)$_5$ phase are obtained on the underlayers for a compositional range of x = 0.25-0.5. With further increasing x value, the film crystal structure varies to a phase other than R(Co,Cu)$_5$. Partial substitution of Co sites with Cu atoms in $ErCo_5$ structure and control of the amount of Cu atom are important to stabilize the Er(Co,Cu)$_5$ phase. The in-plane magnetic anisotropy is reflecting the magnetocrystalline anisotropy of R(Co,Cu)$_5$ crystal and the configuration of epitaxial variants. The magnetic anisotropy of R(Co,Cu)$_5$ film decreases with increasing the Cu amount.

Poster Session C

Poster C

P-C.042

POLREF: Time of flight Polarised Reflectometer

A. Caruana, C. Kinane

Text Polarised Neutron Reflectometry (PNR) measures surfaces, buried interfaces and layers, yielding information about layer thicknesses, densities, surface/interface roughness and interdiffusion. Uniquely it can provide the magnetic equivalents of these quantities, including the total in-plane magnetisation [1,2].
A large variety of thin film phenomena can be investigated using the POLREF beamline, including topological insulators, proximity-induced and fundamental magnetism, superconductivity and spintronic devices. Furthermore, POLREF has the capability to perform off-specular PNR and specular Polarisation Analysis (PA) measurements. If the problem can be made flat and is in the right length scales (~1 nm – 200 nm) then it can be probed by PNR.
The POLREF time of flight PNR beamline is located in the second target station at the ISIS neutron and Muon source [3,4]. With a polarised wavelength band of 2-15 Å (P~96%), low instrument backgrounds of I/I0 $< 10^{-7}$ and a resolution of dQ/Q better than 1%, Q_{MAX} = 0.25-0.3 $Å^{-1}$ is routinely accessible for small (10x10 mm) samples within reasonable count times.
Here, we will present the capabilities of the POLREF beamline, including science highlights and how to get access to the ISIS neutron facility and POLREF beamline.

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Poster Session C

Poster C

P-C.043

Pattern file generation for 3D magnetic nanostructure fabrication by focused electron beam induced deposition

L. Keller, M. Huth

Text Fabrication of three-dimensional (3D) nano-architectures by focused electron beam induced deposition (FEBID) has matured to a level that highly complex and functional deposits are becoming available for nanomagnetics and plasmonics. The main issue of generating a desired 3D nanostructure is the control of the electron beam in the xy patterning plane. However, the generation of suitable pattern files that define the electron beam deflection at any time during the deposition and reliably map the desired target 3D structure from a purely geometrical description to a shape-conforming 3D deposit is non trivial. For example, the pattern generator has to handle precursor dynamic related issues like proximity effects and has to correct for height-dependent precursor coverage. Here we present a selection of successfully deposited magnetic 3D nano- structures, generated with our implementation of a pattern file generator. We demonstrate that our approach does also allow for the fabrication of 3D mixed material structures by combining ferromagnetic with paramagnetic 3D elements.

Poster Session C

Poster C

P-C.044

Pinned and rotatable spins in core/shell ferrite nanoparticles

R. Carvalho Leite, V. Pilati, F. Gomes da Silva, R. Cabreira-Gomes, G. Gomide, P. Coppola, R. Aquino, G. Goya, R. Perzynski, J. Depeyrot

Text Core/Shell Ferrite Nanoparticles (CS-NPs) with a high contrast of anisotropy between shell and core have recently been proposed for high power loss efficiency in magnetic hyperthermia assays. However, recent measurements performed with magnetic nanocolloids based on $MnFe_2O_4@\gamma\text{-}Fe_2O_3$ and $CoFe_2O_4@\gamma\text{-}Fe_2O_3$ CS-NPs did not indicate any exchange coupling contribution to the heating efficiency [1]. Then we investigate here the exchange coupling fields in such NPs. After cooling under field, the hysteresis loops of the samples shift along H axis indicating the existence of a coupling between the ordered spins of the core and the pinned spins of the disordered surface layer. The bias field is larger for CS-NPs with larger core anisotropy. A comparison with powder shows the influence of intra- and inter-particle interactions on the exchange bias [2]. Ferromagnetic Resonance measurements indicate two kinds of spins in the surface layer: one following the FI core with rotatable anisotropy and another pinned. The training behavior is also well described by a model considering frozen (pinned) and rotatable components with different relaxation rates at the interface. The results point to interfaces between highly frustrated surface spins that rearrange up to one order of magnitude times more slowly than more inner reversible spins corresponding to better coordinated atoms.

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Poster Session C

Poster C

P-C.045

Possible spin-gapless semiconductor type behavior in CoFeMnSi epitaxial thin films

V. K. Kushwaha, J. Rani, A. Tulapurkar, C. V. Tomy

Text Recently, spin-gapless semiconductors (SGS), because of their unique band structure, have attracted much attention due to their interesting magnetic and transport properties that can be utilized for spintronics applications. SGS materials exhibit a band gap in one spin channel (↓) and a zero band gap in other spin channel (↑) at the Fermi level, which leads to 100% spin-polarization at the Fermi level. Among the known SGS candidates, Heusler alloys have attracted much attention due to their very high Curie temperature (T_C) and compatibility of their crystal structure for epitaxial growth on semiconductors. We have deposited the thin films of SGS CoFeMnSi (CFMS) Heusler alloy on MgO (001) substrates using pulsed laser deposition system. These films show epitaxial growth along (001) direction and display uniform and smooth crystalline surface. The magnetic properties reveal that the film is ferromagnetically soft along the in-plane direction and its T_C is well above 400 K. The electrical conductivity of the film is low (2.86×10^3 S/cm at 300 K) and exhibits a nearly temperature independent semiconducting behavior. The temperature coefficient of resistivity (TCR) for the film is around -7×10^{-10} Ω.m/K, which is comparable to that of reported for other SGS Heusler alloys. Therefore, the SGS behavior with a high T_C makes CFMS thin films as a potential candidate for fabricating the practical spintronics devices. (e.g., spin valves, magnetic tunnel junctions, spin injectors etc.).

Poster Session C

Poster C

P-C.046

Preparation and characterization of (001) oriented Co ferrite thin films on glass and Si substrates

T. Ishibashi, K. Yasuda, M. Nishikawa

Text Co ferrite having the spinel structure is attracting attentions because Co ferrite thin films epitaxially grown on MgO (001) substrates showed large perpendicular magnetic anisotropy. The large perpendicular magnetic anisotropy could be expected even in polycrystalline Co ferrite films, if 001 orientation was preferable. In this paper, we report on (001) oriented Co ferrite thin films for the first time.
Co-ferrite thin films were prepared by metal-organic decomposition (MOD) method. MOD solution with the ratio of Co : Fe = 1 : 2 and the total concentration of metal-organic materials of 4% was spin-coated on a glass or Si (001) substrates at 3000 rpm for 30 s, followed by drying at 100ºC for 10 min. To decompose organic materials and to obtain precursor films, samples were pre-annealed at 310-340ºC for 30 min in air, and then each samples were annealed at 730ºC for 10h in N_2.
X-ray diffraction measurement showed that polycrystalline Co ferrite thin films were obtained. However, it was found that intensity of 004 peak became higher for samples prepared with pre-annealing temperature of 310 and 320ºC. The largest coercivity, 6.7 kOe was obtained for the sample with pre-annealing temperature of 310 - 320ºC. We consider that CoO formed at the substrate surface segregated during the pre-annealing played an important role in the (001) orientation of Co ferrite thin films.
This work was partly supported by JST program, Collaborative Research Based on Industrial Demand.

Poster Session C

Poster C

P-C.047

Process control of tungsten β-phase window for spin-orbit torques MRAM applications

K. K. Vudya Sethu, S. Ghosh, S. Couet, J. Swerts, B. Soree, J. De Boeck, K. Garello, G. S. Kar

Text Current MRAM technology uses spin transfer torque (STT) to switch the magnetization direction of the storage layer in the MTJ. Alternatively, spin-orbit-torque (SOT) induced switching is vigorously explored as it increases the switching speed and reduces the power consumption. SOT allows the control of magnetization using in-plane current which enables 3-terminal MTJ geometry with isolated read/write paths. This significantly improves the device endurance, read stability and allows reliable sub-ns switching. Tungsten in its beta phase (W_{β}) has the largest reported charge-to-spin conversion ratio (θ_{DL}~-30%) for heavy metals. However, W_{β} has two limitations for reliable technology integration: poor adhesion to oxide substrate and the beta phase is limited to few nm when using industry relevant 300 mm PVD platform. In our results, above 4 nm W enters α-phase, which dramatically reduces θ_{DL} (-2%) and leads to a perpendicular-to-in-plane magnetic anisotropy transition. Here, we report a novel approach to extend W_{β} while maintaining large SOT and improving adhesion to substrate. Resistivity and XRD measurements confirm the extension of W_{β} from 3.8nm to more than 10nm, and transport characterization shows SOT efficiency as large as -35% maintained on the full thickness range. In addition, we demonstrate the possibility to control and enhance the perpendicular magnetic anisotropy of the storage layer (CoFeB). Our results open the path to use W for SOT-MRAM technology integration.

Poster Session C

Poster C

P-C.048

Properties of La1.85Sr0.15CuO4/La0.5Sr0.5MnO3 nanowire networks

M. Koblischka, X. Zeng, T. Karwoth, U. Hartmann

Text In some former work, we have successfully fabricated La1-xSrxMnO3 with various x level, and La1.85Sr0.15uO4 nanowires/nanoribbons via electrospinning [1-3]. The CMR of the La1-xSrxMnO3 nanowire networks have been investigated, and the TC of the La1.85Sr0.15uO4 nanowires and nanoribbons are around 19.2 K and 29.3 K respectively. Currently, we establish a La1.85Sr0.15CuO4/La0.5Sr0.5MnO3 nanowire hybrid system. From obervation by scanning electron microscopy, the average diameter of the nanowires is around 220 nm and the average length can reach over 50 µm. The randomly aligned La1.85Sr0.15CuO4 and La0.5Sr0.5MnO3 nanowires show numerous connections and form a complicated hybrid network system.
The nanowires are polycrystalline with a grain size at around 30 nm as confirmed by transmission electron microscopy. According to four-probe electrical transportation measurements, superconductivity of the sample is suppressed and an anti-magnetoresistance effect is observed. In further experiments, the field angular dependence of the sample magnetization was investigated by tilting the angle within the applied magnetic field. SQUID measurements of M(T) and M(H) were carried out as well, revealing the soft magnetic character of the nanowires.

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Poster Session C

Poster C

P-C.049

Reversal processes in perpendicular pseudo-spin-valves based on CoCrPt thin films

D. Navas, F. Beron, C. T. Sousa, M. Puydinger, K. R. Pirota, C. A. Ross

Text The magnetization reversal and spin transport properties of perpendicular pseudo-spin-valves (PSVs), based on CoCrPt thin films, have been analyzed as a function of thickness by using hysteresis and magnetoresistance loops, as well as first-order reversal curves (FORC) measurements. In particular, the PSV film structures are Ti (5 nm) / CoCrPt (5 nm) / Ti (5 nm) / CoCrPt (10 or 20 nm)/ Ti (3 nm). The Ti serves both as a seed, to promote a perpendicular c-axis orientation, and top layers, to avoid oxidation, as well as the spacer between the magnetic layers. PSVs hysteresis and magnetoresistance loops confirm characteristic two-steps switching with wide plateaus, as larger as 65 and 57 Oe for 10- and 20-nm-thick CoCrPt PSVs respectively, and corresponding to antiparallel alignments of the magnetic layers. Moreover, the reversal behavior is accompanied by complex FORC distributions showing several features related with irreversible processes.
It was previously confirmed that while the magnetic domains in single 10-nm-thick CoCrPt film nucleates and grows with the external field resembling a fractal structure, a labyrinth stripe domains configuration was observed for 20-nm-thick films [1]. In this work, we have studied the evolution of these domain configurations when 10- and 20-nm-thick CoCrPt films are coupled with 5-nm-thick CoCrPt films using both FORC distributions and micromagnetic simulations.

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Poster Session C

Poster C

P-C.050

Room Temperature Ferromagnetism in TOP Functionalized Ni doped ZnO Thin films for Spintronic Applications

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Text Dilute magnetic semiconductors (DMS) are one of the most prominent classes of materials in spintronics, due to the combined effect of magnetic and semiconducting behavior. There are many works have been investigated on the transition metal ions doped ZnO. However, among the transition ions, Ni doped ZnO samples giving the large driving force. In addition, the organic functionalization with Ni doped ZnO exhibit an enhanced ferromagnetic behavior. The ferromagnetism in Ni doped ZnO thin film can be enhanced by altering the electronic configuration of ZnO by surface functionalization with organic molecules. Here, we presented Ni doped (3, 5 and 7 mol %) ZnO thin films grown by RF magnetron sputtering and the same were functionalized with Trioctylphosphine (TOP) by spin coating. The XRD analysis confirms the heaxagonal wurtzite structure of grown films. The grain size was found to decrease from 44.35 to 27.21nm. The Hall Effect shows all the grown samples are exhibit n type conduction. The PL emission intensity at 2.8 eV reveals the presence of Oxygen vacancies, which in turn originates the ferromagnetism. The saturation magnetization values are 5.70emu/cm3 to 9.78 emu/cm3 and enhanced to 8.01emu/cm3 to 13.03 emu/cm3 for TOP functionalized Ni doped ZnO thin films. This clearly shows the enhancement of ferromagnetism is due to functionalization. The Zn-P bond observed in the XPS spectrum reveals the formation of surface layer between Zn and P atom.

Poster Session C

Poster C

P-C.051

Shell thickness dependent exchange bias blocking temperature and coercivity in Co-CoO core-shell nanoparticles

K. Reethu, T. Thanveer, S. H. Al-Harthi, S. Thomas

Text The exchange bias blocking temperature distribution of naturally oxidized Co-CoO core-shell nanoparticles were investigated. The distribution exhibits two distinct signatures. These are associated with the existence of two magnetic entities which are responsible for the temperature dependence of exchange bias field. One is from the CoO grains which undergo thermally activated magnetization reversal. The other is from the disordered spins at the Co-CoO interface which exhibits spin-glass-like behavior. The oxide shell thickness dependence of the exchange bias effect was also investigated. For particles with a 3 nm thick CoO shell, the predominant contribution to the temperature dependence of exchange bias is the interfacial spin-glass layer. On increasing the shell thickness to 4 nm, the contribution from the spin-glass layer decreases, while upholding the antiferromagnetic grain contribution. For samples with a 4 nm CoO shell, the exchange bias training was minimal. On the other hand, 3 nm samples exhibited both the training effect and a peak in coercivity at an intermediate set temperature T_a. This is explained using a magnetic core-shell model including disordered spins at the interface.

Poster Session C

Poster C

P-C.052

Simultaneous control of perpendicular magnetic anisotropy and Dzyaloshinskii–Moriya interaction in asymmetrically sandwiched ferromagnetic films through the MgO capping modification

A. Samardak, T. Kim, A. Stashkevich, Y. Roussigné, M. Belmeguenai, S. Chérif, A. Ognev, Y. K. Kim

Text In this work, we study the effect of the MgO capping thickness on magnetic properties and interfacial Dzyaloshinskii–Moriya interaction (iDMI) of a Ta/Pt/CoFeSiB/MgO system produced by magnetron sputtering. The as-deposited samples Ta(3)/Pt(5)/CoFeSiB(1.5)/MgO(0.25, 0.5 nm) have robust perpendicular magnetic anisotropy (PMA). At the thicker MgO capping PMA transforms to in-plane anisotropy. The 3-nm Ta coverage does not widen the MgO thickness range where PMA exists.
The magnitude and sign of iDMI were measured with Brillouin Light Scattering (BLS). The peak value of iDMI (D= -1.25 erg/cm^2) was observed at tMgO = 0.25 nm. The increased thickness of MgO promotes the sharp decrease of D down to -0.65 erg/cm^2 at tMgO=0.5 nm with the following small increase up to -0.8 erg/cm^2 at tMgO = 0.75 nm and saturation at the higher thicknesses. The found effect of the MgO capping on iDMI can be explain by the stronger degree of hybridization between magnetic atoms and oxygen in the case of a ultrathin MgO. The important finding is that the coverage of the MgO capping by Ta leads to a twice decrease of iDMI, which can be attributed to the prevention of the oxygen penetration into the CoFeSiB/MgO interface resulting in a weak contribution to the net iDMI.
This work was supported by RFBR (17-52-45135), by the Russian Ministry of Education and Science (3.5178.2017) and by Future Materials Discovery Program through the National Research Foundation of Korea (2015M3D1A1070465).

Poster Session C

Poster C

P-C.053

Spectroscopic Ellipsometry of Diffusion in Magnetic Multilayer Stacks

A. Sharma, M. Almeida, O. Selyshchev, V. Dzhagan, P. Matthes, S. E. Schulz, D. R. Zahn, G. Salvan

Text Spintronic devices are often based on pseudo-spin-valve configuration, which is an empirically spin-valve with an additional antiferromagnetic (AFM) material layer adjoining the ferromagnetic (FM) layer. To this, Iridium Manganese alloy is the vastly explored AFM material for spintronic applications. Recently Y.Wang et al. demonstrated using HR-TEM and line scan EDS, that at high-temperatures Mn diffuses into the CoFeB layer through grain boundaries. That study, however, was restricted due to the limited transmission length of electrons through matter and also by the sample area. In this work, we attempted to identify and study the annealing driven diffusion in layers using spectroscopic ellipsometry (SE). Unlike TEM SE is a non-invasive, robust, and swift technique which measures the changes in refractive indices of the layers. A proper modelling of the measured spectra can provide evidence of diffusion in layers as well as estimation of the diffusion length. The samples with the layer stack Si/SiO_2(100)/Ta(3nm)/Ru(5nm)/IrMn(8nm)/$Co_{60}Fe_{20}B_{20}$(5nm)/Ta(3nm) were prepared by DC-magnetron sputtering. After a thorough characterization of the pristine samples with SE, the samples were then annealed at 100, 200, 280, and 375 ºC for 20 minutes in ultra-high vacuum. Additionally, magnetometry and XRD measurements were done for conformity of the results. Finally, pieces of samples were characterized by XPS to obtain the diffusion profile and to correlate this to the SE data.

Poster Session C

Poster C

P-C.054

Sputtered FeCr Alloy Thin Films: Effect of Different Rotation Speeds of Substrate on Their Magneto-structural Properties

A. Karpuz, B. Kaya, N. Kaplan, H. Kockar

Text FeCr films were deposited by a DC sputtering technique with thickness of 50 nm and rotation speed of their substrates was systematically increased from 0 to 45 rpm. The atomic Fe content in the films increased from 79.38 % to 82.14 % while atomic Cr content decreased from 20.62 % to 17.86 % with the increase of rotation speed of substrate from 0 to 45 rpm. The crystal structure of the films was observed to have a body centered cubic phase. The intensity of (110) peak increased with the increasing rotation speed. The surface observation done by a scanning electron microscope exposed that the number of surface grains decreased, whereas they became more observable as the rotation speed increased. According to surface roughness analysis done by an atomic force microscope, the roughness of the film surface increased as the rotation speed of the substrate increased. The magnetic measurements of the films were achieved between ± 10 kOe by a vibrating sample magnetometer at room temperature. With the increase of rotation speed of the substrate, the saturation magnetization increased from 820 emu/cm^3 to 1270 emu/cm^3 and the coercivity value also increased from 64 Oe to 137 Oe. It was concluded that rotation speed of the substrate plays a considerable role on the structural and magnetic properties of the sputtered FeCr thin films.

Poster Session C

Poster C

P-C.055

Sr2FeMoO6 films: effect of gas flow during deposition

I. Angervo, R. Siekkinen, H. Huhtinen, M. Saloaro, P. Paturi

Text Sr2FeMoO6 thin films are half metallic with high Curie temperature and thus interesting for spintronic applications. Unfortunately, they are very sensitive to the deposition conditions. Different kinds of defect structures are induced depending on the deposition temperature and gas choice and pressure. Defect strucure, on the other hand, largely defines the properties of the films. Oxygen vacancies, which are due to low deposition pressure, increase the Curie-temperature, but do not affect the half metallicity. Antisite disorder decreases the Curie-temperature and saturation magnetization as well as the half metallicity. Thus, oxygen vacancies are beneficial, where as antisite disorder is not. In this work, we have modified the argon flow during deposition and see that large flow increases the coercive field and lowers saturation magnetization. This can be understood to arise from the extra structural defects induced during growth, which is confirmed also by x-ray diffraction measurements.

Poster Session C

Poster C

P-C.056

Strain and magnetic anisotropy in YIG heterostructures

A. Korovin, V. Bursian, B. Krichevtsov, L. Lutsev, S. Suturin, M. Volkov, N. Sokolov

Text Yttrium iron garnet ($Y_3Fe_5O_{12}$ or YIG) is known as a suitable material for microwave applications. It has been shown recently [1,2] that in thin (<100 nm) films a substantial reduction of spin wave damping constant can be expected.
In this work, thin (10-50 nm) YIG films grown by Laser MBE on $Gd_3Ga_5O_{12}$ (111) (GGG) and $Nd_3Ga_5O_{12}$ (111) (NdGG) substrates were studied. By X-Ray diffraction it was shown that samples grown on both NdGG and GGG substrates show pseudomorphic growth. Also samples grown at different temperatures (500-1000^0 C) and samples with different thickness have different deformation along [111] direction. Deformation along [111] direction can be caused by non-stoichiometry YIG film and Ga diffusion from substrate to YIG film, which we observed by Secondary Ion Mass Spectroscopy.
In samples grown on GGG anisotropy field $H_a < 0$ was observed by combination of VSM and FMR measurements, on the other hand YIG film grown on NdGG substrate show $H_a > 0$. By controlling film stoichiometry and Ga diffusion into YIG film the samples with different in and out of plain deformation can be produced. As the result, YIG films with different H_a values can be fabricated. Such combined chemical and strain engineering gives a chance to produce YIG films with perpendicular magnetic anisotropy.
This work was supported by the Russian Science Foundation (project 17-12-01508).

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Poster Session C

Poster C

P-C.057

Strain effect on the magnetism of CaMnO3

A. Lopez Pedroso, S. Carreira, J. Briatico, L. Steren

Text Bulk $CaMnO_3$(CMO) has an orthorhombic crystalline structure and is weak ferromagnetic below $T_N \approx 120K$. This structure can be described, in the pseudocubic approximation, with a ac≈3.73Å lattice parameter. Ab-initio calculations have recently shown that the magnetic behavior of CMO depends on surface conditions. In fact, Keshavarz et al [1] demonstrated that the Mn atoms at the surface and the sub-surface of the compound are very sensitive to structural changes, giving rise to ferromagnetic couplings. With the aim of studying the effect of substrate-induced strains onto the magnetic behavior of CMO thin films we grew a series of samples by pulse laser deposition onto $SrTiO_3$(001) single-crystalline substrates. In order to examine the effect of strains onto the magnetism of CMO, the film's thickness was varied from 3nm to 30nm.
Structural and magnetic measurements were performed to characterize the sample's properties. The film's structure, analyzed by X-ray diffraction measurements, reveals a strongly textured growth along the (0k0) direction and remarkable substrate-induced strains effects on the lattice parameters of the compound. The mismatch between bulk CMO ac≈3.73Å and $SrTiO_3$ aSTO≈3.905Å lattice parameters is 4.48%. The magnetic characterization was performed with a SQUID magnetometer. Magnetization loops, measured at 10K show that the magnetization of the samples is strongly enhanced for the thinner films.

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Poster Session C

Poster C

P-C.058

Stripes rotation in $Fe_{78}Si_9B_{13}$ thin films with perpendicular anisotropy by field-dependent MFM

M. Coïsson, G. Barrera, F. Celegato, P. Tiberto

Text $Fe_{78}Si_9B_{13}$ thin films prepared by rf sputtering on Si_3N_4 substrates with a thickness of 230 nm are characterised by a weak perpendicular anisotropy and a dense stripe domain configuration, originating from internal stresses quenched during film growth that can be progressively released by means of relaxation thermal treatments. As the magnetisation of the films is organised into parallel stripes tilted upwards and downwards, magnetic force microscopy (MFM) is particularly apt at studying their evolution as a function of the applied field. By exploiting a recently developed field-dependent MFM technique, we have been able to investigate the orientation of the magnetisation in the stripes as a function of the applied field, and their rotation towards saturation when the field is applied along a direction orthogonal to the one used to bring the sample to magnetic remanence. After a threshold field H_{rot}, the MFM contrast changes abruptly indicating that the stripes rotate along the field direction. The rotation field turns out to decrease with decreasing perpendicular magnetic anisotropy, which is controlled by means of thermal treatments. The detailed field evolution of the magnetisation in the stripes is investigated by direct comparison of vector VSM measurements and field-dependent MFM, as a function of the magnetic anisotropy of the samples. The origin of the threshold field, whose amplitude is independent on the field direction in the sample plane, is discussed as well.

Poster Session C

Poster C

P-C.059

Strong correlation between electrodeposition technological regimes and microstructure of thin NiFe films

T. Zubar, S. Sharko, D. Tishkevich, N. Kovaleva, D. Vinnik, E. Trukhanova, S. Chizhik, K. Sudilovskaya, L. Panina, S. Trukhanov, A. Trukhanov

Text Thin Ni-Fe films are widely used for practical applications thanks to optimal magnetic and functional properties. Magnetic and electrical properties of the Ni-Fe films are critically depend on the microstructure and surface condition. The microstructure and the features of the crystal structure are determined by technological regimes of the film production and film growth mechanism. The analysis of the film growth for different technological regimes of the electrolyte deposition is perspective and actual problem. From the fundamental point of view, the understanding of the kinetics of the film growth and surface morphology evolution is critical moment for an explanation of the anomalous phenomena in magnetic and transport properties for unfilled Ni-Fe films near the percolation region.
The Ni-Fe nanogranular films have been grown onto silicon substrates via different electrodeposition regimes (direct and pulse current regimes with pulse duration from 1 s to 10 μs) to investigate the correlation between technological regimes, chemical composition and microstructure. The transition from the direct current regime to the pulse-regimes and with a shortening of the pulse duration provides a reduction in grain size. The results showed that using electrodeposition regimes, which ensure growth with the average crystal size less than the critical value (10 nm), provides less roughness, defectiveness and greater film uniformity in thickness, and, therefore, stable properties.

Poster Session C

Poster C

P-C.060

Structural and magnetic properties of $Gd_{0.6}Ca_{0.4}MnO_3$ thin films on different substrates

A. Beiranvand, E. Rivasto, J. Tikkanen, H. Huhtinen, P. Paturi

Text Epitaxial thin films of $Gd_{0.6}Ca_{0.4}MnO_3$, a low bandwidth manganite, have been prepared on different substrates ($SrTiO_3$, $SrLaAlO_3$, $(LaAlO_3)_{0.3}(Sr_2AlTaO_6)_{0.7}$ and MgO) by pulsed laser deposition. The x-ray diffraction data reveal that all the films are single crystalline and have an orthorhombic structure. The magnetic properties of the films, including magnetization, coercive force and orbital ordering temperature, depend strongly on the substrate. The optimized film shows maximum magnetization of 6 ×10 5 A/m at 10 K, with orbital ordering temperature close to 360 K. The films characteristics can be good candidates for potential device applications.

Poster Session C

Poster C

P-C.061

Structural and magnetic properties of $Mn_{3-x}Fe_xGa$ thin films

K. Sato, T. Shima, M. Doi

Text The MnGa thin films are one of the attractive materials for the devices, which require perpendicular magnetic anisotropy. Previous researches have suggested that Mn_3Ga thin film shows saturation magnetization M_s = ~ 300 emu/cm^3 and uniaxial magnetic anisotropy K_u = ~ 10 Merg/cm^3. These magnetic properties let this material interesting for physical investigations and spintronic applications. In this work, $Mn_{3-x}Fe_xGa$ thin films have been fabricated by using an ultra-high vacuum electron beam vapor deposition system and their magnetic properties were investigated. The samples were grown by base pressure less than 8.9×10^{-7} Pa. The stacking structure of the samples were follow: MgO (100) substrate/Cr buffer layer/$Mn_{3-x}Fe_xGa$ layer/Cr protection layer. The MnGa alloy targets were fabricated from row material of Mn (5N) and Ga (6N), through the arc melting method. All growths of the films were monitored by reflection high energy electron diffraction. The crystal and surface structure were investigated by X-ray diffraction and atomic force microscope, respectively. The composition of samples was analyzed by energy dispersive X-ray spectroscopy. Magnetic properties were measured by superconducting quantum interference device. From the results, relatively high Ku of 6.4 Merg/cm^3 was confirmed at $Mn_{2.3}Fe_{0.7}Ga$ thin films with Ms of 340 emu/cm^3. Detail relationship between crystal structure, composition of Mn3-xFexGa and magnetic properties will be discussed.

Poster Session C

Poster C

P-C.062

Structural and magnetic properties of nanowires based on metals of the iron group

K. Frolov, I. Perunov, S. Bedin, D. Zagorskii, M. Chuev, A. Lomov, I. Lyubutin, V. Artemov, S. Sulyanov, I. Doludenko, A. Ivanova, T. Khimich

Text Magnetic nanowires (NW) are promising materials for the sensors, spintronics, biomedical technologies, including antitumor therapy [1-3].
Arrays of the Fe, Co-Fe and Ni-Fe NW electrodeposited in the pores (30-200 nm) of polymer track membranes were investigated by the electron microscopy, X-ray diffraction, Fe-57 Mössbauer spectroscopy and vibrational magnetometry.
All samples of the NW arrays demonstrate magnetic ordering of iron ions. Samples of solid solutions of Co-Fe and Ni-Fe have the spontaneous (without external magnetic field) orientation of the magnetic moments of domains along the length of NW. The degree of magnetic anisotropy depends on the synthesis conditions and the pores diameters. Magnetic properties of the NW and continuous electrodeposited layers with the same compositions are different. For pure iron NW, the formation of the spontaneous orientation of the magnetic moments was observed only at certain electrodeposition conditions.
This study was supported by the Federal Agency of Scientific Organizations (Agr. 007-ГЗ/Ч3363/26), Russian Foundation for Basic Research (18-32-01066), Russian Science Foundation (14-12-00848) and performed using the equipment of the Shared Research Center of the Shubnikov Institute of Crystallography of FSRC "Crystallography and Photonics" RAS.

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Poster Session C

Poster C

P-C.063

Structural and magnetic properties of thin Tm3Fe5O12 layers: Effect of cooling conditions and thickness

O.-T. Ciubotariu, M. Albrecht

Text Tm3Fe5O12 (TmIG) thin films exhibit an out-of-plane (oop) magnetic easy axis when grown under tensile strain on substituted Gd3Ga5O12 (SGGG) (111) substrates due to the dominant strain anisotropy [1]. A slow cooling procedure after deposition has been reported to result in high quality layers [2]. Here, we report the effect of the cooling procedure and layer thickness (t) on the structural (by XRD) and magnetic (by SQUID-VSM) properties of TmIG layers. 70-nm thick films were grown by pulsed laser deposition on SGGG (111) substrates. After deposition, slow and fast cooling rates were implemented. By comparing the position of the (444) and (4-44) reflections, a higher tensile strain is observed for the fast cooled layer resulting in a stronger difference between easy and hard magnetic axes. Next, 20-400 nm thick layers have been prepared. XRD investigations showed strong differences between the (444) and (4-44) reflection positions for 20 nm thick layers corresponding to a distorted crystal structure. With increasing t, the two reflections approach each other. A complete overlap, corresponding to a cubic crystal structure, is observed for t>300 nm. The magnetic easy axis switches from oop to ip direction due to the overcome of the strain anisotropy by shape anisotropy.

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Poster Session C

Poster C

P-C.064

Structural and theoretical investigations of MnBi/MnGa-FeCo exchange spring bilayers

S. Sabet, A. Moradabadi, S. Gorji, M. Yi, Q. Gong, M. H. Fawey, E. Hildebrandt, D. Wang, H. Zhang, B.-X. Xu, C. Kübel, L. Alff

Text Exchange spring magnets are promising candidates towards production of high performance rare-earth free magnets. In this study, we investigate the magnetic exchange coupling behavior for two different bilayer systems of MnBi-FeCo and MnGa-FeCo. The bilayers with various soft magnetic layer (FeCo) thicknesses were deposited in a DC magnetron sputtering unit from alloy targets. Our HR-TEM measurements confirm growth of highly textured (001) MnBi layer and a polycrystalline FeCo film with coexisting amorphous and (110) phases on top. We note that the hard-soft interface in this case is rough. However, in case of MnGa-FeCo system, epitaxial growth of single crystalline (001) layers with sharp and smooth interface is evident resulted from a rather low lattice misfit. In MnBi-FeCo bilayer, using a Co-rich FeCo layer results in better exchange properties with optimum thickness of ~1 nm, however, a complete single-phase hysteresis cannot be obtained for higher FeCo thicknesses. By means of TEM analysis as well as DFT and micromagnetic simulations, it is found that the thickness of the FeCo layer as well as the interface roughness both control the degree of exchange coupling in MnBi-FeCo exchange spring system. This can also explain the reason behind more coherent hysteresis plots and higher critical thickness of ~2 nm observed in the case of MnGa-FeCo system. This study shows that structural factors play an important role in the physics of exchange spring coupling.

Poster Session C

Poster C

P-C.065

Structural, Magnetic and Magnetoresistance Properties of NiFe/Cu Superlattices Electrodeposited on Titanium Substrate Depending on NiFe Layer Thickness

H. Kuru, N. Aytekin, M. Haciismailoglu, M. Alper, H. Kockar

Text Electrodeposition of NiFe/Cu superlattices was performed on polycrystalline titanium substrates as a function of the NiFe layer thicknesses. The NiFe layer thickness of the superlattices was increased from 1.5 nm to 10 nm while the Cu layer thickness was constant at 1nm. The elemental analysis indicated that the Ni content in the superlattices increased; the Cu and Fe content decreased with increasing NiFe layer thickness. All superlattices have a face-centered cubic structure. The lattice parameters slightly decrease from 0.3601 to 0.3538 nm with increase in the NiFe layer thickness. The surface morphology dramatically altered with different thicknesses of NiFe layers. The saturation magnetisation increased from 12.9 to 291.3 emu/cm3 with the increase of the NiFe layer thickness confirming the increase of the Ni atoms and decrease of the Cu. The superlattices with NiFe layer thickness less than 3.5 nm was exhibited giant magnetoresistance (GMR), while the anisotropic magnetoresistance (AMR) component was begin to occur when the NiFe layer thickness was above 3.5 nm. The samples with NiFe layer thickness more than 4 nm exhibited fully AMR. GMR values of 2 % were obtained in NiFe/Cu superlattices. The results show that the NiFe layer thickness plays an important role on the amount of magnetic and nonmagnetic materials in the layers and thus on the properties of the superlattices.
This study was supported by Balikesir University under Grant no BAP 2015/192

Poster Session C

Poster C

P-C.066

Structure and magnetic properties of iron oxide nanopowders and the hybrid «core-shell» nanopowders

I. Grebennikov, A. Savchenko

Text The aim of this work were studying the regularities of phase-structure and magnetic properties formation of the iron oxides nanopowders of the core-shell type ($Fe_{3-x}O_4@SiO_2$). Dimensions and shape of nanopowders were determined using TEM studies. Phase composition was determined by XRD and Mossbauer spectroscopy analysis. Magnetic properties were investigated using measuring facility PPMS-9. There were determined phase-structural characteristics, morphology. It is shown that nanopowders are nonstoichiometric magnetite Fe3+$[Fe^{2+}_{1-3x}Fe^{3+}_{1+2x}V_x]O_4$, in which there are volume and surface areas differing by the electronic state of iron ions. The results revealed a correlation of dispersion and magnetic properties of nanopowders. The quantitative estimate is made of the thickness change and specific magnetization depending on the average nanoparticle size and the presence of the coating. The obtained dependences are constructed and analyzed.

Poster Session C

Poster C

P-C.068

Superferromagnetic LoC systems

V. Kondratyev

Text Superferromagnets (SFMs), e.g., magnetic nano-crystal self-assemblies and/or arrays, represent promising candidates for Lab on a Chip (LoC) systems including many laboratory tasks. Such soft magnetic systems provide an opportunity to develop new materials with characteristics far beyond traditional solids. The randomly jumping interacting moments (RJIM) model, see [1] and refs. therein, gives useful framework for studies of SFMs. In particular, it provides a basis for developing analytical tools employed in order to specify, quantify and analyze respective magnetic structures. Such tools explore correlations of magnetic noise amplitudes and allow for quantitative definition, description and study the SFM origin, as well as self-organized criticality in the response properties. In this contribution we briefly overview some results for a sensor mode of SFM reactivity associated with spatially local external fields, i.e., a detection of magnetic particles. Favorable designs of superferromagnetic systems for sensor implications are revealed.
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Poster Session C

Poster C

P-C.069

Surface spin disorder induced by wet milling in Fe/Fe_xO_y core-shell nanoparticles

M. Lostun, M. Porcescu, G. Stoian, M. Grigoras, G. Ababei, N. Lupu

Text Fe-oxide nanoparticles (NPs) are of considerable interest nowadays because of their unique characteristics, such as superparamagnetism, high saturation fields, and extra anisotropy contributions. We report here our recent results on the effect of wet milling on the induced surface anisotropies and magnetic properties of Fe/Fe_2O_3 and Fe/Fe_3O_4 core-shell NPs prepared by high-energy ball milling in H_2O and oleic acid, respectively. To understand the surface spin disorder and its influence on the magnetic properties of Fe/Fe-oxide core-shell NPs, we used different milling times from 12 to 88 h. Fe/Fe_3O_4 NPs of 22-25 nm are obtained by milling the precursor Fe microparticles for 48 h in H_2O. After more than 80 h of milling in H_2O the core-shell structure evolves into Fe_3O_4/Fe_2O_3. On the contrary, the milling in oleic acid does not change significantly the structure of precursor Fe microparticles, even after 80 h, as confirmed also by very small variations of the hysteresis curves. The magnetic properties of Fe/Fe_xO_y core-shell NPs prepared by milling in H_2O can be tailored from ferromagnetic to weak ferromagnetic depending on Fe/Fe_3O_4/Fe_2O_3 ratio. In addition, ZFC/FC curves indicate a strong influence of the milling time on magnetic properties, ascribed to the decrease of spin-orbital coupling and surface anisotropy of magnetic nanoparticles due to the surface coordination.

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Poster Session C

Poster C

P-C.070

Surfaces effects and cationic distribution in ultra-small CoFe2O4 nanoparticles

A. Omelyanchik, M. Salvador, C. Cannas, D. Fiorani, A. Musinu, M. Rivas, V. Rodionova, G. Varvaro, D. Peddis

Text Nanocomposites of cobalt ferrite nanoparticles (NPs) in silica matrix ($CoFe_2O_4/SiO_2$) with low concentration of magnetic phase were synthesized by a sol-gel auto-combustion method. The particles size control was achieved by varying the NPs concentration (from 5 to 15 %) in mesoporous silica matrix and annealing temperature. The growth of particle sizes (from ~2.5 to ~7 nm) with the increase of annealing temperature (from 700°C to 900°C) was observed by TEM. The magnetic properties were studied by SQUID magnetometer, Mössbauer spectroscopy and AC susceptibility measurements. The value of effective magnetic anisotropy constant (K_{eff}) increases with the decrease of particle size, being two times higher than the bulk value for ~3 nm particles. This is due to the increase of the anisotropy surface contribution. Moreover, for particles of same size, but annealed at different temperature, we observed a significant variation of K_{eff} due to the change in the cation distribution, strongly affecting the magnetocrystalline anisotropy.

Poster Session C

Poster C

P-C.072

Temperature Controlled Anisotropy in Cobalt Confined In AAO Matrix

K. Nath, J. Sinha, M. A. Ali, S. S. Banerjee

Text Magnetic configurations in nanoscales are primarily determined by a competition between different energy scales and anisotropies. We investigate the temperature dependent structural and magnetic properties of an assembly of cobalt nanopillars in nanoporous anodized alumina (AAO) matrix with pores of diameter 50 nm & 10 nm. A temperature dependent magnetization study of these nanopillars in AAO reveals that below 100 K there are unusual changes in the shape of the magnetization hysteresis loop for different orientations w.r.t the applied magnetic field. We observe flip in the easy axis of magnetization along with an abrupt increase in the saturation magnetization below a certain temperature, T_{cr} which depends on the nanopore diameter. Analysis of our M(H) data shows that the magnetized volume of the sample shows a rapid growth as T falls below T_{cr}. Low-T XRD studies reveal crystallographic distortions at low T in the nanocomposite, which trigger changes in anisotropy in the system due to a change in the balance between magneto-crystalline and shape anisotropy energies. Using micro-magnetic simulations we are able to generate hysteresis loops similar to our experiments by varying the magneto-crystalline anisotropy in the system. Based on our studies we propose that magneto-structural coupling in the Co-nanopillars can be tuned easily by temperature, through large temperature dependent strain acting on the Co-nanopillars embedded within the AAO matrix.

Poster Session C

Poster C

P-C.073

Temperature dependence of magnetic properties in annealed (340°C) MgO/CoFeB/CL/Pt where CL=capping Layer=Ta or W/Ta

J. Chatterjee, F. Fettar, J. M. Tonnerre, S. Auffret, I. L. Prejbeanu, B. Dieny

Text The control of magnetic anisotropy is crucial in spintronic devices since it directly influences the orientantion and thermal stability of the magnetization in the various magnetic layers. For instance, in magnetic tunnel junctions, the easy axis of both magnetic electrodes might be planar or perpendicular depending on their thicknesses. In this study, the influence of the capping layer (**CL**) on the magnetic properties of the storage layer and its temperature dependence were investigated on semi-tunnel junctions of the form MgO(≈1.4nm)/CoFeB(X)/**CL**/Pt(3nm) where **CL** is either Ta(3nm) or W(2nm)/Ta(1nm). All samples were annealed at 340°C. SQUID measurements were carried out between 4K and 400K for the 2 series of samples where X is varied in the (1.2-2.6)nm range. The linear variation of saturation magnetization with X at each temperature T allows deriving the dead layer thickness versus temperature, as well as the mean saturation magnetization. Anisotropy constants, extracted from magnetic loops measured with in-plane and out-of-plane fields, yield the interfacial and volume anisotropy constants for each T value. The dependence of the magnetic characteristics (anisotropy constants, dead layer, and saturation magnetization) versus T are discussed for the 2 series. By using a CoFeB/W interface rather than a CoFeB/Ta one, perpendicular magnetic anisotropy is significantly increased over the whole investigated range of termperature (4K-400K).

Poster Session C

Poster C

P-C.074

Temperature evolution study of free hole concentration in (Ga,Mn)As

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Text In the present study the temperature evolution of free hole concentration in (Ga,Mn)As have been investigated with Raman scattering spectroscopy through the analysis of hole-plasmon related mode in the spectra. A set of 100 nm thick (Ga,Mn)As layers has been prepared by the low-temperature molecular-beam epitaxy (LT-MBE), with the Mn contents x ranging from 0 (LT-GaAs reference layer) to 1.6%. Micro-Raman measurements were performed using 532nm, 514nm and 488nm laser lines in the backscattering configuration in a wide range of temperatures (4-300K).

In p-type GaAs, as well as in (Ga,Mn)As, longitudinal-optical (LO) phonon mode couples with the hole-gas-related plasmon forming so-called coupled plasmon–LO phonon mode (CPPM). Under the LT-MBE growth conditions an excess of arsenic builds into GaAs, mainly in the form of arsenic antisites, which act as deep double donors and lead to an n-type hopping conductivity in LT-GaAs and ultra-low Mn doped (Ga,Mn)As. In the case of the present set of samples about 0.3% of Mn is needed to form the CPPM band in the Raman spectra, indicating that (Ga,Mn)As turns to p-type at around this concentration of Mn. With further increase in x the CPPM mode starts to dominate the spectra, simultaneously with a shift of its energy towards the TO-phonon-line wavenumber. This is the direct indication of an increasing hole density with x, which depends on temperature and Mn concentration and can be quantified from the full line-shape fitting.

Poster Session C

Poster C

P-C.075

Temperature inversion of exchange bias in the FeMn/(Gd-Co) films

V. Vas'kovskiy, O. Adanakova, A. Svalov, V. Lepalovskij, E. Stepanova

Text Exchange bias effect in the FeMn/Gd(x)Co(100-x) films containing pinning FeMn antiferromagnetic layer and pinned Gd-Co amorphous ferrimagnetic layer was studied. The Gd amount in the pinned layer varied within a range of x = 15–25 at.% in order to realize different behavior of the temperature dependence of spontaneous magnetization Ms(T). The magnetic properties of the films were determined using the hysteresis loops measured with the MPMS XL7 at the temperature range of 5–350 K. A correlation between Ms(T) and the temperature dependences of the exchange bias field Hb(T) was found. In particular, it was shown that there were a sharp increase and an inversion of the sign of Hb near the magnetic compensation state of Gd-Co layer. The first one is a consequence of the minimization of the spontaneous magnetization of Gd-Co layer at the compensation temperature. The second one shows the predominance of the exchange interaction of the antiferromagnetic layer with the ferrimagnetic layer cobalt magnetic subsystem as a contribution to the interlayer exchange coupling. The temperature dependences of the interlayer coupling constant Kb(T) were determined. It was found that, depending on the composition of the pinned layer, Kb(T) monotonically decreased or showed a nonmonotonic behavior with a wide maximum in the middle of the temperature range. Possible reasons for different behavior of Kb(T) are discussed.
The work was supported by the RFBR (project No. 18-32-00220 mol_a).

Poster Session C

Poster C

P-C.076

The effect of magnetization on the capacitance of capacitor structures based on nanoporous alumina with electrodeposited Ni nanowires

G. Moraes Oliveira, D. Reinaldo Cornejo, E. Padrón Hernandéz, A. André Quivy

Text The search for devices that allow efficient energy storage in a microcircuit is a relevant topic of research in our days. Recently, capacitive nanostructures (CN) using nanoporous alumina membranes (NAM) as a dielectric material, has led to very promising results.

We have developed a CN consisting of two metal electrodes (Al and Ag) with NAM as the dielectric separator. The NAM was obtained from a high-purity Al sheet, using the two-step anodization process, which preserves a thin layer of Al on one side of the sheet. Before coating the opposite plane with Ag, Ni nanowires (NNW) were electrodeposited in the hexagonal pore array (pores of ~50 nm of diameter and 5 um of length). The CN was characterized by XRD and lateral SEM. Measurements of capacitance versus voltage for frequencies between 10e3 and 10e6 Hz were performed using a Cascade Microtech probe station whit a B1500A Analyzer. Capacitances per unit planar area of around 50 nF/cm2 were obtained for this nanostructure.

The presence of NNW in the CN allowed studying the behavior of the capacitance for three well-defined magnetic states of the NNW: a) demagnetized state, b) remanence state after the in-plane magnetic saturation, and c) remanence state after the magnetic saturation along the axis of the NNW. Our results clearly show the increase in capacitance when the magnetization of the NNW increases, which is an experimental evidence of the interface coupling between a dielectric and a spin-polarized metal.

Poster Session C

Poster C

P-C.078

The magnetic moment of polycrystalline Co thin films on Pt/MgO(100)

S. Pütter, A. Syed Mohd, S. Mattauch, T. Brückel

Text The variation of the magnetic moment of magnetic materials with its dimensionality is a longtime studied issue. In thin films, however, additional effects may come into play, like intermixing and surface roughness. In contrast, a constant magnetic moment of the thin film is often assumed in modelling.

With the help of polarised neutron reflectometry (PNR) we study this open question for polycrystalline Co thin films on 20 nm Pt/MgO(001). Sample growth by molecular beam epitaxy and PNR measurements were performed at the Heinz Maier-Leibnitz Zentrum (MLZ) in Garching, Germany.

Several Co thin films between 3 and 50 were investigated at room temperature and in saturation under UHV conditions by utilising a special UHV transfer chamber. Our results reveal a vertical depth profile of the magnetic moment of the Co thin film. In fact, the magnetisation is not a constant but smeared out at the edges, due to roughness. The variation of the film thickness reveals the evolution of the magnetic moment which is separated in a bulk and a surface contribution and discussed with respect to published results.

Access to PNR measurements and sample preparation with the MBE system is provided to interested people via the MLZ user office system (www.mlz-garching.de) and the nanoscience foundry and fine analysis project (www.nffa.eu) where you can also apply for funding.
This project has received funding from the EU’s H2020 research and innovation programme under grant agreement n. 654360.

Poster Session C

Poster C

P-C.079

The microstructure and magnetic properties of Cu/CuO/Ni core/ multi-shell nanowire arrays

F. Yang

Text Multifunctional metal/oxide/metal core/multi-shell nanowire arrays were prepared mostly by physical or chemical vapor deposition. In our study, the Cu/CuO/Ni core/multi-shell nanowire arrays were prepared by AAO template-electrodeposition and oxidation processes. The Cu/Ni core/shell nanowire arrays were prepared by AAO template-electrodeposition method. The microstructure and chemical compositions of the core/multi-shell nanowires and core/shell nanowires have been characterized using transmission electron microscopy with HADDF-STEM and X-ray diffraction. Magnetization measurements revealed that the Cu/CuO/Ni and Cu/Ni nanowire arrays have high coercivity and remanence ratio.

Poster Session C

Poster C

P-C.080

The role of supermalloy thickness on the enhancement of maximum energy products of PrFeB/supermalloy thin films

A. Ghasemi, A. Ashrafizadeh

Text Ta/PrFeB/ spermalloy thin films were deposited on CORNING 7059 by sputtering technique followed by rapid thermal annealing. The thickness of PrFeB was kept constant at 50nm. The role of thickness of soft magnet of supermalloy on the structural and magnetic consequences of thin films was studied by means of X-ray diffraction, Transmission electron microscopy, atomic force microscopy and vibrating sample magnetometer and SQUID. The (00l) texture was fully developed at annealing temperature of 650°C. It was found that with an increase in thickness of supermalloy from 0 to 20 nm in a step of 4 nm, the coercivity was enhanced from 0.67MA/m to 1.2MA/m. The maximum remanent-magnetization ratio and coercivity were obtained at thickness of 16 nm. The maximum energy products were enhanced from 28 MGOe for pure PrFeB thin films to 42 MGOe for multilayer with soft magnet thin films of 16nm and then decreased with a further increase in thickness of supermalloy. The magnetization reversal process is accompanied by the combination of domain wall motion (DWM) and Stoner-Wohlfarth (S-W) rotation. However, for PrFeB/ supermalloy films at thickness between 8 to 16 nm it is closer to the S–W model than DWM modes. Effective magnetic susceptibility versus temperature at different frequencies was also measured for the whole series of samples. The mechanism for enhancement of maximum energy products was deeply investigated based on correlation of microstructure and obtained magnetic properties.

Poster Session C

Poster C

P-C.081

Transport and magnetic properties in atomically controlled grown oxide-based magnetic tunnel junctions

F. Gelle, F. Schleicher, K. Katcko, R. Chirita, L. Teodorescu, G. Versini, S. Barre, C. Ulhaq-Bouillet, A. Dinia, L. Badie, D. Lacour, M. Hehn, M. Bowen, S. Colis

Text $La_{0.67}Sr_{0.33}MnO_3$ (LMSO) is an interesting material for spintronic devices due to its ferromagnetic properties at room temperature and its half-metallic character suggesting a strong spin polarization at the Fermi level. It is characterized by a small magnetic anisotropy, a low coercive field and a low resistivity. These properties recommend this system to be used as electrode in magnetic tunnel junctions (MTJ) that can be further integrated in spintronic devices. However, as already pointed out by previous studies, the transport and magnetic properties are strongly correlated to the quality of the magnetic/non-magnetic interfaces.

The present work is focused on the growth, structural, magnetic and transport properties of LSMO/$SrTiO_3$/LSMO heterostructures. The samples are deposited by pulsed laser deposition on atomically flat TiO_2-terminated $SrTiO_3$(100) substrates and the layer-by-layer growth is monitored by RHEED. X-ray diffraction and STEM observations indicate clearly that the samples are single crystalline and that the interfaces are flat and sharp at the atomic level. Magnetic measurements show a sharp two step magnetization reversal corresponding to the two LSMO layers. Spin dependent transport results show a TMR of 70% at 10 K and 350 mV bias voltage. Voltage and temperature dependent effects on the TMR, coercive field and dI/dV will be also discussed.

Poster Session C

Poster C

P-C.082

Tuning the magnetism of epitaxial cobalt oxide thin films by electron beam irradiation

Q. Lan, X. Zhang, X. Shen, H. Yang, W. Wang, H. Zhang, X. Guan, Y. Yao, Y. Wang, Y. Peng, B. Liu, J. Sun, R. Yu

Text The ability to tailor the magnetism of perovskite cobalt oxide thin films is important for exploring and developing applications that include data processing, storage and energy conversion. We recently found that a stripe-like superstructure shows a close correlation with saturation magnetization in epitaxial $La_{1-x}Sr_xCoO_3$ ($0 \leq x \leq 0.1$) thin films. Here, we demonstrate the effect on the magnetism of $La_{0.9}Ca_{0.1}CoO_3$ (LCCO) thin films by introducing a stripe-like superstructure in a controllable manner using electron beam irradiation (EBI), both in a transmission electron microscope and in an electron accelerator. The microstructure, electronic structure, strain and origin of magnetism in the LCCO thin films are studied in detail using aberration-corrected scanning transmission electron microscopy, electron energy-loss spectroscopy and ab initio calculations based on density functional theory. The results indicate that an EBI-induced unit cell volume expansion is accompanied by the formation of oxygen vacancies and leads to a spin state transition of the Co ions. A low spin state of the Co^{4+} ions is found to inhibit the formation of the stripe-like superstructure, while higher spin states with lower valences are conducive to its formation. Our work clarifies the origin of magnetism in epitaxial LCCO thin films, and contributes to a comprehensive understanding of correlated physics in cobalt oxide thin films.

Poster Session C

Poster C

P-C.083

Tuning the perpendicular magnetic anisotropy in sputter deposited thin films

B. Tudu, K. Tian, A. Tiwari, J. Luning

Text The ever-increasing demand for faster, higher capacity, energy efficient memory devices have driven extensive research and development of materials with perpendicular magnetic anisotropy (PMA) such as the ferromagnetic and non-magnetic metal heterostructure multilayers. Thus, understanding the magnetic anisotropy in such materials is very important for exploiting them for potential memory device applications such as in spin-transfer torque Magnetoresistive Random Access Memories (STT-MRAM). Here, we have investigated the control of magnetic anisotropy in sputter deposited (Co/Pd)n multilayers by tailoring different growth parameters. A systematic study on the effect of Co/Pd composition, growth pressure and deposition rate on the magnetic anisotropy of (Co/Pd)n multilayers have been studied. Magnetic and structural characterizations have been done by MOKE, VSM, AFM/MFM and XRD. We found that proper Co/Pd composition ratio is very important for attaining maximum PMA. In addition, the PMA can be further tuned by changing the growth pressure and deposition rate. Our results demonstrate a facile method to tune the anisotropy of (Co/Pd)n multilayer thin films.

Poster Session C

Poster C

P-C.084

Twisted magnetization states and inhomogeneous resonance modes in a Fe/Gd ferrimagnetic multilayer

A. Drovosekov, A. Savitsky, D. Kholin, N. Kreines, V. Proglyado, M. Ryabukhina, E. Kravtsov

Text Rare-earth/transition-metal multilayers are model ferrimagnets demonstrating a rich magnetic phase diagram. A new rise of interest to the magnetization dynamics in such materials is caused by recent idea to use them for realization of ultrafast magnetic switching, promising for potential applications in magnetic storage devices.
In this work, static and dynamic magnetic properties of a Glass/[Fe(35Å)/Gd(50Å)]x12 superlattice were investigated in a wide 4-300 K temperature range.
Static magnetization studies showed the presence of a compensation point in the system at Tc ≈ 90 K. In weak fields applied in the film plane, a collinear magnetic phase was realized with Fe magnetization vector directed either parallel (at T > Tc) or antiparallel to the field direction (at T < Tc). An increase of the magnetic field initiated a non-uniform distribution of magnetization inside Gd layers (“twisted state”). Magneto-optical Kerr effect measurements performed on both Fe and Gd terminated sides of the film allowed us to distinguish between the “bulk” and “surface” twisted states of the superlattice. As a result, the experimental H-T magnetic phase diagram of the system was obtained.
Ferromagnetic resonance studies at frequencies 7-37 GHz demonstrated the presence of two spectral branches in the superlattice. Theoretical simulations of the experimental spectra showed that the observed spectral branches corresponded to a uniform and essentially non-uniform resonance modes in the multilayer.

Poster Session C

Poster C

P-C.086

magnetic and thermodynamic properties of a simple-wall hexagonal spin nanotube

Z. El Maddahi, M.Y. El Hafidi, M. El Hafidi

Text A hexagonal spin nanotube is studied using the Effective Field Theory with correlations (EFT) and the differential operator technique (DOT)[1, 2]. Each spin is connected to the nearest-neighbors through exchange couplings both along the chains (J//) and adjacent chains (J⊥). The effects of the exchange, the single-ion anisotropy and the magnetic field on the phase diagram and the magnetic properties have been examined. It is shown that the longitudinal and transverse exchange parameters have strong effect on the shape of the phase diagram. Some original behaviors have been emerged. In particular, when the two exchange parameters are opposite, strong frustrations occur, atypical magnetization plateaus and jumps appear.

Poster C

P-C.087

α-Fe2O3: Dependence of Morin temperature on the size and shape of the nanoparticles

J. Kohout, D. Kubániová, T. Kmječ, L. Kubíčková, D. Nižňanský, P. Brázda, M. Klementová, K. Závěta

Text A spin-reorientation transition from a weakly ferromagnetic to an antiferromagnetic spin ordering in hematite(α-Fe2O3) during cooling occurs at Morin temperature (Tm ~264 K for bulk). The transition is strongly size dependent and Tm generally decreases with the decreasing volume. For particles smaller than approximately ~20 nm, the Morin transition may be even suppressed. The upper size limit for superparamagnetic behaviour is observed to vary with the method used for preparation.
We report an investigation on nanoparticles prepared by hydrothermal method and sol-gel technique (in silica)of pure α-Fe2O3 phase as confirmed by XRD (space group R3c, lattice parameters a = 5.038(2) Å, c = 13.772(12) Å) differing in the mean size derived by TEM in the range of about 5-125 nm.
By means of Mössbauer spectra acquired between 4.2 and 300 K and DC magnetic measurements, we determined the relative concentrations of magnetic phases within the 57Fe enriched sample and searched for the best finite-scaling theoretical model (mean-field, 3D Heisenberg, Ising) describing the derived size dependence of Morin temperature of the nanoparticles with a log-normal size distribution. Comparison of the numerical values of relevant parameters of the theoretical relations indicates the appropriateness of the mean-field model.
Acknowledgments
The financial support under the grant GAČR 16-04340S is gratefully acknowledged.

Poster Session C

Poster C

P-C.088

Asymmetric Skyrmion Hall Effect in Systems with Hybrid Dzyaloshinskii-Moriya Interaction

K.-W. Kim, K.-W. Moon, K. Everschor-Sitte, J. Nothelfer

Text We examine the current-induced dynamics of a skyrmion that is subject to both interfacial and bulk Dzyaloshinskii-Moriya interactions (DMIs), arising either in magnetic systems with certain symmetries or in magnetic multilayers composed of chiral magnets with non-centrosymmetric crystal and non-magnets with strong spin-orbit coupling. As a striking result, we find that, in systems with a hybrid DMI, the spin-orbit-torque-induced skyrmion Hall angle is asymmetric for the two different skyrmion polarities, even allowing one of them to be tuned to zero.[1] We propose several experimental ways to achieve the necessary straight skyrmion motion (with zero Hall angle) for racetrack memories, even without any interaction with another magnet or an antiferromagnetic interaction. Our results can be understood within a simple picture by using a global spin rotation which maps the hybrid DMI model to an effective model containing purely interfacial DMI. In this sense, the formalism directly reveals the effective spin torque and effective current acting on systems with a hybrid DMI.

[1] K.-W. Kim, K.-W Moon, K. Everschor-Sitte arXiv:1802.07327

Poster Session C

Poster C

P-C.089

Computer simulation of control of a Skyrmion motion by a gourd nanowire

K. Migita, K. Yamada, Y. Nakatani

Text Recently, a magnetic Skyrmion has been intensively studied because it is expected that a high density and low power racetrack memory can be realized with it [1,2]. That is a shift register type memory, Skyrmions should be moved in the device by spin current or other methods. In that type memory, it is important to create a position where a Skyrmion is likely to exist and to stop a Skyrmion accurately at that position. In this research, we propose a gourd type nanowire and investigates the possibility to control a Skyrmion motion. The gourd type nanowire was made by four circles with a diameter of 100 nm and a center-to-center distance of 85 nm. A Skyrmion was placed on the leftmost circle, and a pulse current was applied to right to move it. From the simulation results, it was found that a Skyrmion can be catched at the circle center of the wire, and a Skyrmion moves automatic to the center with no current. Therefore a strict pulse width control of the current is unnecessary by using the gourd type nanowire,. Further simulation was carried out by changing the current density and the pulse width. It was found that when the current density was 3 MA/cm2 or less, the skyrmion was pinned at the joining portion of the circle, and it did not move to the next circle.

[1]T. H. R. Skyrme, Proc. Roy. Soc. Lond. A 31, 556(1962)
[2]J. Sampaio, et. al., Nat. Nano. 8, 839 (2013)

Poster Session C

Poster C

P-C.090

Current driven domain wall creation in chiral magnetic nanowires

N. Sommer, D. R. Rodrigues, K. Everschor-Sitte

Text The controlled creation of magnetic domain walls in nanowires is an essential part of domain wall-based racetrack memory devices. It has been predicted that magnetic domain walls can be generated and injected into ferromagnetic nanowires by all electrical means exploiting an interplay of a magnetic inhomogeneity and an electric current. [1] This process requires a certain critical current density above which domain walls are shedded.

Here, we consider the domain wall creation in chiral magnets which are subject to the Dzyaloshinskii-Moriya interaction. We also generalize the previous work by considering the influence of other fixed magnetization orientations. We find that both effects are relevant for the strength of the critical current density. We find that the presence of Dzyaloshinskii-Moriya interaction can significantly decrease the threshold current whereas a smaller inhomogeneities increase the critical current strength.

[1] Sitte et al., PRB 94, 064422 (2016)

Poster Session C

Poster C

P-C.091

Current-Induced Skyrmion Generation Through Morphological Phase Transitions in Chiral Ferromagnetic Heterostructures

I. Lemesh, K. Litzius, P. Bassirian, N. Kerber, D. Heinze, J. Zázvorka, F. Büttner, L. Caretta, M. Mann, M. Weigand, S. Finizio, J. Raabe, M.-Y. Im, H. Stoll, G. Schütz, M. Kläui, G. S. D. Beach

Text Magnetic skyrmions are topologically stabilized nanoscale spin structures that are promising candidates for future spintronic devices [1]. Their creation [2] and current driven motion [3,4] have been recently observed, but the key mechanisms of their formation are poorly understood. Here we show that in heavy metal/ferromagnet heterostructures, pulsed currents can drive morphological phase transitions between labyrinth-like, stripe-like, and skyrmionic states. Using high-resolution transmission x-ray microscopy, we image the evolution of the spin texture with temperature and magnetic field, and demonstrate that transient Joule heating [5] can drive the system hysteretically across the stripe phase - skyrmion phase boundary. The observations are explained by micromagnetic simulations that reveal a crossover to a global skyrmionic ground state above a threshold magnetic field, which we find experimentally to decrease with increasing temperature. We demonstrate how by tuning the phase stability, we can reliably generate skyrmions by short current pulses and stabilize room-temperature skyrmions at zero field, providing new means to manipulate spin textures in engineered chiral ferromagnets.

References:
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[2] Romming, N. et al., Science 341, 636–639 (2013).
[3] W. Jiang et al., Nat. Phys. 13, 162-169 (2017).
[4] Litzius, K. et al., Nat. Phys. 13, 170-175 (2017).
[5] Legrand, W. et al., Nano Lett. 17, 2703–2712 (2017).

Poster Session C

Poster C

P-C.092

Current-driven Domain Wall Dynamics in Cylindrical Nanowires with modulated diameter

A. De Riz, J.-C. Toussaint, C. Thirion, O. Fruchart, D. Gusakova

Text Ordered arrays of cylindrical nanowires fabricated by template-assisted electroplating techniques are promising for the development of a three-dimensional memory. In such memory, the information would be carried by magnetic domains separated by domain walls (DWs) which are driven by spin-polarized current pulses via a spin-transfer effect. The control of the DWs position could be obtained by creating localized diameter modulations which act as pinning sites. In order to optimize the DWs propagation through the modulations, it is essential to understand the influence of the geometry on the magnetization vector field behavior. Numerical modeling is a powerful tool for this task. Here we consider a transverse DW inside a cylindrical nanowire presenting a smooth modulation in diameter [1]. We performed micromagnetic simulations using our finite elements based software FeeLLGood which solves the Landau-Lifshitz-Gilbert equation augmented with current-driven effects [2]. We develop a simple analytical model which allows us to calculate the domain wall position and thus to extract a scaling law for the domain wall pinning conditions as a function of geometrical parameters.

[1] J. A. Fernandez-Roldan, A. De Riz, B. Trapp, et al. (2018), submitted.
[2] M. Sturma, J.-C. Toussaint, D. Gusakova, J. Appl. Phys. 117, 243901 (2015).

Poster Session C

Poster C

P-C.093

Dipolar domain wall tuning in Fe/Py core-shell cylinders

R. Souza, S. Martins Jr., A. Dantas, A. Carriço

Text We report a theoretical study of the impact of the Fe core dipolar field on the Py shell domain walls in rectangular core-shell nanocylinders (CSNC). We show that the core-shell geometrical parameters may be chosen to allow large changes in the location and width of the Py walls. The intrinsic isolated shell magnetic pattern may be severely modified by the core dipolar field. The Py shell walls are pinned by the Fe core stray field and may be moved using moderate external field strengths. We show that, at remanence, flat core-shell cylinders display in-plane shell domain walls, and above a critical CSNC height the shell walls are narrower and located at the CSNC lateral surface.

Poster Session C

Poster C

P-C.094

Domain wall phase diagram of in-plane systems with interfacial anisotropy

R. Kohno, J. Sampaio, R. Ferreira, A. Thiaville

Text The Phase diagram for magnetic domain walls in in-plane systems, that is transverse wall (TW) or vortex wall (VW), has been studied both theoretically (R.D. McMichael et. al. IEEE Trans Mag 1997) and experimentally (e.g. M. Kläui et. al. APL 2004). Basically, VWs are stable in thick layers and wide wires, and TWs prefer thin layers and narrow wires.

However VWs were observed in thin (~3 nm) ferromagnetic samples (M. Laufenberg et. al. APL 2006), for which TWs were the predicted structure. The authors attributed this to imperfections of the film.

Recently the interfacial anisotropy has caught much attention because it can induce perpendicular anisotropy in very thin films. The effect of this interfacial energy on the phase diagram of in-plane systems is still unknown. Here we studied the phase diagram with interfacial anisotropy by micromagnetic simulations. We considered CoFeB/MgO system, which is well known for its high interfacial anisotropy, and calculated the domain wall energy as a function of the width and thickness of the wire for both TWs and VWs.

We have found that VWs are more stable with higher interfacial anisotropy, and the boundary between VWs and TWs in the phase diagram shifts enlarging the VWs stability region. We have also found that in narrow wires near the critical thickness, the TWs rotates out-of-plane. We have not found however a second separate vortex stability region in the thin limit that has been experimentally reported.

Poster Session C

Poster C

P-C.095

Domain-wall-assisted magnetoimpedance of nanotube- and nanostripe-containing structures

A. Janutka, K. Brzuszek

Text We study the magnetoimpedance (MI) of transversely- (circumferentially-)magnetized empty nanotubes and nanotubes filled with a non-magnetic conductor as well as structures of a conducting nanolayer covered with a magnetic nanostripe, with micromagnetic simulations. Contrary to widely-investigated micro-sized counterpart systems, the low-field mechanism of MI of the nanostructures is unique. It follows from the oscillations of the positions of domain walls (DWs) driven by ac Oersted field while influenced by ac spin-transfer torque as well. We show the low-field MI to can be regarded as a giant effect, which is of potential importance for sensing with nanometer spatial resolution [1]. We discuss in detail consequences of DW interactions with nanotube ends and mutal interactions of DWs on MI. Unlike for the nanotubes, in nanostripes, states of many DWs are stable in the presence of the ac Oersted field and they result in largely-asymmetric low-field MI (a property that is desired for sensor applications). In addition to the nanostripes with the uniaxial transverse anisotropy, we discuss using crystalline nanostripes of materials with the cubic anisotropy. We address the effect of Joule heating on MI.

[1] A. Janutka, K. Brzuszek, arXiv 1803.09512

Poster Session C

Poster C

P-C.096

Drift speed direction reversal in iron garnet single crystals in an alternating magnetic field

L. Pamyatnykh, M. Lysov

Text A dislocation mechanism of the drift of domain walls (DWs), connected with the nucleation and motion of magnetic dislocations (MDs) in a system of stripe domains, was proposed in [1]. Possible scenarios of the motion and interaction of MDs were considered in [2]. This report is devoted to investigation of connection between the processes of nucleation and motion of MDs and the direction of DWs drift. The investigations were carried out on single crystalline (110) plates of $(TbErGd)_3(FeAl)_5O_{12}$ iron garnet with a thickness of 70 μm in an alternating magnetic field oriented perpendicular to the plane of the sample with frequencies 50-1000 Hz and amplitudes up to 200 Oe. Dynamic domain structure was revealed using the Faraday effect and recorded by a high-speed camera with a recording rate up to 2000 fps. The DWs drift velocities, the MDs motion velocities, and the activities of MD nucleation centers were measured. The activity of MD nucleation center is the number of MDs nucleated in a certain nucleation center during one second. Reversals of DWs drift direction with change of external field amplitude and frequency were detected. It is shown that change of the activity of MD nucleation centers is the determining factor in the reversal of the DWs drift direction.

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[2] Pamyatnykh, L. A., Filippov, B. N., Agafonov, L. Y., & Lysov, M. S. (2017). Sci. rep., 7(1), 18084.

Poster Session C

Poster C

P-C.097

Dynamic SEMPA imaging with enhanced phase-sensitive detection

D. Schönke, A. Oelsner, P. Krautscheid, R. M. Reeve, M. Kläui

Text Scanning electron microscopy with polarization analysis (SEMPA) is a magnetic imaging technique with a competitive high-spatial resolution of around 20 nm. However, the low efficiency of the spin detection and lack of dynamic imaging schemes in conventional approaches limit its applicability. Here we show that with a novel setup where we employ a time-to-digital converter to detect the individual arrival time of each single electron pulse [Frömter et al., Appl. Phys. Lett. 108, 142401 (2016)], new measurement schemes are possible including phase-sensitive detection of periodically changing magnetic states and full dynamic imaging on the ns timescale. We test the upgraded system by imaging the manipulation of a variety of mesoscopic Py elements including quasi-uniform, vortex and multi-domain states and are able to demonstrate a temporal resolution of around 2 ns and an improvement in signal-to-noise ratio (SNR) of up to 5 times for certain measurements. The upgraded SEMPA system can be used for a broad range of measurement applications and fulfills the desire for high spatial and temporal resolution in a laboratory setting [Schönke et al., arXiv:1803.09775]. The improved SNR is expected to be particularly helpful for the imaging of novel materials with low intrinsic contrast, while the nanosecond temporal resolution is of interest, for instance, to study automotive domain wall dynamics [Mawass et al., Phys. Rev. Applied 7, 044009 (2017)].

Poster Session C

Poster C

P-C.099

Dynamics of coupled breathing modes in one- and two-dimensional periodic skyrmion lattices

J. Kim, J. Yang, Y.-J. Cho, J.-H. Lee, B. Kim, S.-K. Kim

Text Magnetic skyrmions have been intensively studied owing to their fundamentally interesting features and technological applications. Here, we report on a delicate micromagnetic study on dynamics of coupled breathing modes in one- and two-dimensional (1D and 2D) skyrmion lattices periodically arranged in thin-film media. The observed coupled breathing modes exhibit characteristic concave-down dispersions that represent in-phase high-energy mode at zero wavenumber and anti-phase low-energy mode at the Brillouin zone boundary in 1D skyrmion lattices. The bandwidth of the allowed modes increases with decreasing inter-distance between nearest-neighboring skyrmions. Furthermore, the collective breathing modes propagate well through the thin-film nanostrips, as fast as 200 ~ 700 m/s, which propagation is controllable by the strength of magnetic fields applied perpendicularly to the film plane. Also, we present coupled breathing modes in 2D skyrmion lattices. The breathing modes in 1D and 2D skyrmion lattices formed in thin-film media may be used as information carrier in future potential signal processing devices.

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Reference

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Poster Session C

Poster C

P-C.100

Effect of transverse field on domain wall dynamics in thin magnetic wires with gradient of perpendicular magnetic anisotropy

L. Fecova, K. Richter, R. Varga

Text Recently developed spintronics logic devices are based on magnetic transport properties of uniaxial magnetic materials [1-2]. In these materials, logic value is encoded by the direction of magnetization, whereas its change of logic value is performed by the domain wall movement. Speed at which domain wall can travel through the wire is then a key factor, which determines the speed rate of these devices. Accordingly, the search for finding methods that allow increasing the domain wall velocity of given magnetic wires in a controlled manner is of big relevance in advanced spintronics research.
In the present work, we introduce a detailed experimental study on the longitudinal propagation and dynamics of a domain wall motion under the presence of magnetic field, Ht, transversally oriented to the wall propagation trajectory in amorphous glass coated microwires. It is shown that a proper orientation of a magnetic field can speed up domain wall more than two times. Our experimental results can be explained by presence of a gradient of perpendicular magnetic anisotropy that stems from progressive water quenching of microwires from one side during its preparation by Taylor-Ulitovski method. Our experimental findings on domain wall motion in wires with gradient of perpendicular anisotropy are confirmed by micromagnetic simulations in thin stripes.

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[2]C. Y. You, Appl. Phys. Lett. 92, 152507 (2008).

Poster Session C

Poster C

P-C.101

Effective Hamiltonian descriptions for skyrmion and antiskyrmion dynamics

B. F. McKeever, D. R. Rodrigues, M. Sitte, J. Sinova, A. Abanov, K. Everschor-Sitte

Text The dynamics of magnetic textures described by the Landau-Lifshitz-Gilbert equation is complex; however, the description of the low energy physics often requires only a reduced set of effective variables. One route to such a description follows a generalization of the method by Thiele, originally introduced for the steady translational motion of rigid domains. Here we exploit an alternative, equivalent method that is independent of microscopic details and derives an effective Hamiltonian description from an action principle. The practical advantage of this approach is that it can be extended to magnetic textures with soft internal modes and does not rely on the usual rigid texture approximation. By way of illustration, we develop an effective model for the breathing modes of rotationally symmetric skyrmions and antiskyrmions in magnetic thin films, and we compare this to extensive micromagnetic simulations. This investigation reveals the extent to which the breathing modes behave like an underdamped simple harmonic oscillator. We calculate the breathing mode frequencies for different skyrmion/antiskyrmion equilibrium radiuses and Gilbert damping strengths.

Poster Session C

Poster C

P-C.103

Electrical detection of magnetic domain wall by inverse and direct spin Hall effects

V. T. Pham, A. Marty, G. Zahnd, W. Savero-Torres, C. Bouard, P. Noel, P. Warin, L. Vila, J.-P. Attané

Text Manipulation of magnetic domain walls (DWs) in spintronic nanostructures has become a very active field of research during the two last decades because of the discovery of spin transfer torques acting on DW. This can be done in lateral nanostructures, using non-local measurements, but the most exciting way to produce pure spin currents is obviously the use of spin orbit effects such as the spin Hall effect (SHE) and the Rashba effects, which can generate in a ferromagnetic layer Spin Orbit Torques (SOT). This topic has been driven by possible spintronic applications such as magnetic memories and logic devices. Here, we show that if the SHE is known to generate SOTs, it is also possible to use the SHE or the ISHE to detect the presence of a DW. A DW pinned on a constriction in a ferromagnetic wire can indeed be used to inject or detect a pure spin current in an adjacent SHE wire. Then sharp spin signal variations will correspond to the pinning and depinning of the DW. Reciprocally, the spin accumulation produced by direct SHE effect in a wire can also be used to probe the presence of a DW. Also, this method allows to distinguish between the head-to-head and the tail-to-tail configurations. Simulations allowed to estimate the spin Hall angle from experimental results (7.5 ± 0.2 % for Pt). This technique provides an electrical way to study the DW motion, in a device akin to the Ferromagnetic/spin Hall effect bilayers typically used for spin-orbit torques experiments.

Poster Session C

Poster C

P-C.104

Fabrication and characterisation of a three-dimensional magnetic nanowire lattice

M. Hunt, A. May, A. van den Berg, S. Ladak

Text A key challenge today is the nanostructuring of magnetic materials into arbitrary 3D geometries. Such work would allow the realisation of next generation information technologies such as racetrack memory, the probing of novel curvature-induced energy terms, and 3D magnetic metamaterials with tuned properties. Here we show that $Ni_{81}Fe_{19}$ nanowires of novel curved cross-section can be placed into complex 3D lattices by using a combination of two-photon lithography and line-of-sight deposition. In this study, the focus is upon samples where the nanowires map onto the bonds of a diamond lattice. The nanowires have width of approximately 200nm, length of 1000nm and thickness 50nm. Micro-magnetic modelling shows that the nanowires are single domain. Optical magnetometry has successfully been utilised in order to measure the switching within the array, in both longitudinal and polar geometries. Longitudinal loops exhibit an abrupt transition with an enhanced coercive field (8mT) when compared to the sheet film, indicative of domain wall motion. Polar loops also exhibit an enhanced coercive field (10mT) with respect to the sheet film, but with a more gradual approach to saturation. The loops will be discussed by comparison to magnetic force microscopy images, which have been obtained after saturation along principle directions.

Poster Session C

Poster C

P-C.105

Hysteresis free switching between collinear and vortex states in closely packed Fe-Pd nanocap arrays

P. B. Aravind, M. Heigl, M. Fix, J. Gräfe, S. Thomas, M. Krupiński, M. Marszałek, M. R. Anantharaman, M. Albrecht

Text For soft magnetic micro disks, in an applied magnetic field, the magnetization reversal from a uniform state to a vortex state or vice versa involves an energy barrier giving rise to distinct nucleation and annihilation field resulting in hysteretic side lobes in the M-H loop [1]. If the energy barrier is small and the thermal energy is sufficient, a magnetic bistability occurs between single domain and vortex state. This will result in a hysteresis-free switching from the single domain state to a vortex state and vice versa at elevated temperatures [2].
Here, we present our recent results on the tuning of the energy barrier associated with the switching between collinear and vortex state or vice versa. A bottom-up self-assembly method was adopted to realise magnetic vortices [1] in which thin films of composition Ta(5 nm)/Fe_xPd_{1-x}(20 nm)/Ta(5nm) [x=0.13, 0.15, 0.17 and 0.20] were DC magnetron sputter deposited onto dense arrays of self-assembled silica particles of 480 nm diameter. Depositing soft magnetic Fe_xPd_{1-x} thin films onto a spherically curved surface will result in the formation of magnetic cap structures, where the equilibrium magnetic configuration will be vortex like. Temperature dependent magnetization measurements showed that the critical temperature for hysteresis-free transition can be tuned by varying the composition of the films.

References:
[1] D. Nissen *et al.*, Phys. Rev. B **94**, 134422 (2016).
[2] E. Östman *et al.*, New J. Phys. **16**, 053002 (2014).

Poster Session C

Poster C

P-C.106

Imaging of the gyration dynamics of nπ states in materials with weak perpendicular magnetic anisotropy

S. Finizio, S. Wintz, D. Bracher, E. Kirk, K. Zeissler, T. Wessels, M. Weigand, J. Raabe

Text A rich magneto-dynamical behavior is predicted for magnetic skyrmions and, in general, for more complex nπ spin configurations. Such magneto-dynamical processes can be excited e.g. through the application of a magnetic field gradient [1]. However, most predictions consider perfect materials, with low Gilbert damping and low density of pinning sites, both of which are difficult to achieve for the typical materials exhibiting perpendicular magnetic anisotropy (PMA) [2,3]. This led to the consequence that only limited experimental reports on the dynamical processes of nπ spin configurations exist.

Here, we present an alternative approach to the use of “standard” PMA materials for the investigation of the magneto-dynamical processes in nπ spin configurations, where a NiFe-based system exhibiting weak PMA is employed for the stabilization of such magnetic states.

Thanks to a combination of low Gilbert damping and low density of pinning sites, the gyration dynamics of nπ spin configurations could be resolved by time-resolved scanning transmission x-ray microscopy. The experiments presented here prove that the weak PMA system employed here can be employed as an ideal test system for the investigation of the fundamental properties of complex magnetic and topological structures.

[1] C. Moutafis et al., PRB 79, 224429 (2009)
[2] A. Barman et al., JAP 101, 09D102 (2007)
[3] K. Zeissler et al., Sci. Rep. 7, 15125 (2017)

Poster Session C

Poster C

P-C.107

Influence of inhomogeneous current distributions on current induced dynamics of magnetic textures

V. K. Bharadwaj, K.-W. Kim, K. Everschor-Sitte

Text Magnetic domain walls and skyrmions are promising candidates for spintronics applications such as racetrack memory devices. Recently, it was demonstrated that skyrmions can be generated by blowing magnetic domain walls through a constriction. In the experiment, the inhomogeneity of current distribution plays a crucial role in the unexpected magnetization dynamics. Motivated by the experiment, we study the interactions between domain walls and skyrmions and their interplay in the presence of inhomogeneous current distributions. In the first step, we performed numerical simulations with Micromagnum with some software extensions to calculate current distribution in different geometries. Based on the current distribution, we studied the magnetization dynamics through the constriction, and analyze the production of different magnetic textures and the possibility to form skyrmions upon the collision of domain walls.

Poster Session C

Poster C

P-C.108

Large STT-driven domain wall velocities in perpendicularly magnetized Mn4N ferrimagnetic thin films

T. Gushi, M. Klug, L. Vila, J.-P. Attané, F. Takata, A. Anzai, T. Suemasu, S. Pizzini

Text In the last years, research on current induced domain wall (DW) motion concentrated on stacks with perpendicular magnetic anisotropy (PMA) and Dzyaloshinski-Moriya interaction (DMI), where the drive is the spin-orbit torque associated to Spin-Hall effect (SOT-SHE). In this work we present exceedingly fast DW motion in Mn4N ferrimagnetic films, driven by the “classical” spin-transfer torque (STT). Mn4N has a strong PMA with Ku of 1 Merg/cm^3 and small MS of 110 emu/cm^3, leading to narrow domain walls. With these properties and consisting of only abundant and light elements, this system is a promising candidate for spintronic devices such as racetrack memories. These films, grown by molecular beam epitaxy on SrTiO3(001) substrate, have excellent crystallinity with low density of defects, confirmed by the formation of millimeter size magnetic domains observed with Kerr effect microscopy. We have studied DW dynamics in 10 nm thick films patterned into 1-2 µm wide strips. Due to the reduced magnetization of this ferrimagnet, the STT is very efficient. Domain walls can be driven up to 600 m/s with current densities as low as 1.3 x 10^12 A/m^2. These velocities largely surpass those found in FeNi by STT (100m/s) and are of the same order of magnitude or even larger than those found in stacks with large DMI with larger current densities. We attribute the large STT efficiency to the small magnetization of this system together with the large spin polarization of our material.

Poster Session C

Poster C

P-C.109

Large topological Hall effect in single crystalline Heusler compound $Mn_{1.4}PtSn$

P. Vir, N. Kumar, C. Shekhar, C. Felser

Text Skyrmions are topologically stable vortex-like spin structure which are considered as potential candidate for future high density memory devices. They have been detected in many chiral and polar compounds such as MnSi, FeGe, Co-Mn-Zn, GaV_4S_8, $VOSe_2O_5$ etc. Three types of vortex spin structure have been predicted and observed so far namely, Bloch, Néel and antiskyrmions. Existence of these exotic spin structures depend upon the crystal symmetry. Recently, with the help of Lorentz transmission electron microscopy, antiskyrmions have been discovered in Mn-based tetragonal Heusler compound $Mn_{1.4}PtSn$ and $Mn_{1.4}Pt_{0.9}Pd_{0.1}Sn$ [1]. Antiskyrmion is considered to be anti-particle of Néel or Bloch type skyrmion because it consist opposite topological charge [2]. Due to this topologically stable spin nature, it can give rise to non-vanishing Berry phase in real space. In other word, there could be nonzero topological Hall Effect. Here, we report large topological Hall effect and its origin in single crystal of antiskyrmion hosting compounds $Mn_{1.4}PtSn$.

[1] Ajaya K. Nayak et al., Nature **548**, (2017) 561-566.
[2] Wataru Koshibae et al., Nat. Com. **7**, (2016) 10542.

Poster Session C

Poster C

P-C.110

Lifetime of magnetic skyrmionons in a quasicontinuous model

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Text The stability of magnetic skyrmions is often associated with topological protection and the existence of a topological charge that differs for ferromagnetic (FM) and skyrmion states and cannot be changed by continuous transformation of the magnetization. In real systems, magnetic moments are localized on a discrete lattice and, strictly speaking, topological protection does not exist. Instead, we can expect finite but possibly large energy barriers between states with different topological charges making the chances of transitions due to thermal fluctuations small. We perform calculations of the energy of a skyrmion state as well as the minimum energy path and activation energy for annihilation to a FM state as a function of lattice constant. All the parameters of the system such as exchange and anisotropy constants as well as Dzyaloshinsky-Moriya interaction are chosen in such a way as to keep the size of the skyrmion and its energy constant. The activation energy and pre-exponential factor in the Arrhenius rate law for annihilation within the harmonic approximation to transition state theory are evaluated for several lattice constants and the scaling relations are predicted. In this way estimates are obtained corresponding to the limit of a quasicontinuous model. The pre-exponential factor is found to decrease by several orders of magnitude as the lattice constant is decreased, thereby increasing the stability of the skyrmion as its size grows.

Poster Session C

Poster C

P-C.111

Lifetime of skyrmions in Ta/Co20Fe60B20/Ta/MgO/Ta at room temperature

M. Potkina, I. Lobanov, V. Uzdin, J. Zázvorka, M. Kläui

Text Chiral magnetic skyrmions are localized non-collinear magnetic structures considered as a promising candidates of information carriers in ultrafast and superdense magnetic memory.
Stability of skyrmions respect to thermal fluctuations is substantial question for its application in such devices. Along with experimental findings, theoretical predictions for skyrmion stability have a great importance. Magnetic skyrmions in Ta/Co20Fe60B20/Ta/MgO/Ta, observed by means of Kerr microscopy, were found to be stable at room temperature. Series of experiments let us define lifetime as a function of magnetic field in the range of 0.2-0.3 mT. The lifetime of skyrmion states was estimated by Arrhenius rate law within harmonic transition state theory for magnetic degrees of freedom. We found dependence of the activation energy and pre-exponential factor in the Arrhenius rate law on size of skyrmion. Parameters of Heisenberg model were changed keeping micromagnetic parameters constant. Extrapolation up to the size of micrometer allowed us to estimate lifetime of skyrmions, which corresponds to experimentally observed ones. While energy barrier for decay went to constant value, pre-exponential factor was found to decrease by several orders of magnitude as the size grows, so increasing skyrmion stability. Our theoretical estimations gave skyrmion lifetime of several minutes, which is in good agreement with experimental results.

Poster Session C

Poster C

P-C.112

Magnetic Skyrmion Avalanches

S. A. Diaz, C. Reichhardt, D. P. Arovas, A. Saxena, C. J. O. Reichhardt

Text We simulate flux-driven magnetic skyrmion avalanches in the presence of random quenched disorder and study their dependence on the nondissipative Magnus force. The avalanches exhibit power-law distributions in their duration and size, and the average avalanche shape for different avalanche durations can be scaled to a universal function, in agreement with theoretical predictions for systems in a nonequilibrium critical state. Increasing the ratio of the Magnus term to the damping term, a change in the universality class of the behavior occurs, the average avalanche shape becomes increasingly asymmetric, and individual avalanches exhibit motion in the direction perpendicular to their own density gradient.

Poster Session C

Poster C

P-C.114

Magnetic anisotropy control of skyrmion motion

Y. Zhou, R. Mansell, S. van Dijken

Text Magnetic skyrmions are particle-like spin textures with a non-trivial topological number [1]. Technologically, control of skyrmions through applied electric fields could lead to low power memory and logic devices, which could be achieved through voltage-controlled magnetic anisotropy (VCMA) [2]. By micromagnetic simulations, we show that skyrmion motion can be induced by manipulating the perpendicular magnetic anisotropy. Firstly, we explain theoretically skyrmion motion due to an anisotropy gradient using the Thiele equation [3]. Secondly, we simulate a nanotrack with an anisotropy gradient, showing that the skyrmion moves almost perpendicular to anisotropy gradient with a drift angle of up to 89°. We investigate the skyrmion dynamics in detail, revealing the acceleration and the expansion of the skyrmion during motion. Moreover, we demonstrate that the speed and drift angle are modified by material parameters such as the exchange energy, the DMI energy, the anisotropy energy, the anisotropy gradient and the damping constant. Lastly, we further show that a step in anisotropy can provide the same action as a gradient and introduce a device that could form the basis of an electric-field controlled skyrmion racetrack memory.

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[2] U. Bauer at al., Nature Mater 14 174 (2015)
[3] A. A.Thiele, J. App. Phys 45, 377 (1974)

Poster Session C

Poster C

P-C.115

Magnetic domain nucleation and magnetization reversal in $SrRuO_3$-$SrIrO_3$ heterostructures on $SrTiO_3$(100)

D. Ivaneyko, P. Milde, L. Wysocki, I. Lindfors-Vrejoiu, L. M. Eng

Text Structural and magnetic textures of bare $SrRuO_3$ ultra-thin films and $SrRuO_3$-$SrIrO_3$ (SRO-SIO) heterostructures capped with 2 unit cells $SrZrO_3$ are investigated here with both atomic-force (AFM) and magnetic-force microscopy (MFM). The clue goal is to test the hypothesis of Matsuno et al. [1], whether or not SRO-SIO bilayers might host Néel-type magnetic skyrmions of a ~10-nm size. Hence, we analyze here the mutual correlation of sample topography and magnetic texture using LT-AFM and MFM [2].
Bare SRO films and SRO-SIO heterostructures were epitaxially grown by pulsed-laser deposition using vicinal $SrTiO_3$ (100) (STO) substrates, with SRO and SIO layers measuring 5 and 2 pseudo-cubic unit-cells in thickness, respectively. The SRO/SIO interface breaks inversion symmetry and provokes interfacial Dzyaloshinskii-Moriya interaction through large spin-orbit coupling. Repetitively sweeping the magnetic field, we observe ferromagnetic domains to always nucleate from the same sample surface spot. Such domains grow to a few 100 nm in diameter and correlate well with the terrace width of the vicinal STO substrate. Comparing bare SRO and SRO-SIO thin films at 80 K and 55 K, we observe an increase of both coercive fields and magnetization for individual domains in heterostructures. Hints for magnetic skyrmions in bare SRO films are found at 10 K only, where nanometer-sized domains nucleate.

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[2] P. Milde et al., *Nano Lett.* **16**, 5612 (2016).

Poster Session C

Poster C

P-C.116

Magnetic investigation of the skyrmion generation in Fe/Gd and Co/Tb amorphous multilayers

F. Fettar, M. Mergo, J. M. Tonnerre, L. Ortega, D. Mannix, D. Carbone, M. Rubio Roy, S. Auffret, I. L. Prejbeanu, B. Dieny

Text Skyrmions are chiral topological magnetic domains, which are currently of scientific interest due to their potential in novel memory device applications. Skyrmions have been shown to exist in an array of materials from bulk magnet to thin films and are known to become stable under a variety of physical conditions. Thin films with perpendicular magnetic anisotropy (PMA) have been the focus of extensive research over the last decade. However, the skyrmion generation reported in PMA magnetic films still requires are complete understanding and the discovery of this effect in other material systems is of crucial importance in providing a general physical understanding of this effect. Very recently, skyrmions in Fe(~0.3nm)/Gd(~0.4nm) thin films was recently reported [Phys. Rev. B 95, 024415 (2017)], with a very large number of repeats (80). In this study, $[Fe/Gd]_M$ and $[Co/Tb]_N$ multilayers sputtered on Si_3N_4 for different thicknesses of each layer, and for different number of repeats, are analyzed by SQUID and extraordinary hall effects measurements. The temperature T is comprised between 5K and 300K, and the magnetic loops were measured with in-plane and out-of-plane fields. For instance, for N=20 and M=40, and appropriate thicknesses of each thicknesses (as developed in the presentation), particulars magnetic loops for specific T seem to indicate a possible existence of skyrmions. The dependence of the anisotropy constant with the rare earth content will be discussed.

Poster Session C

Poster C

P-C.117

Magnetic reversal and domain wall velocity induced by electical current in twisted glass-coated microwires

S. Corodeanu, H. Chiriac, N. Lupu, T.-A. Óvári

Text Recent studies showed that the electrical current can induce magnetic switching in the glass coated microwires showing large Barkhausen effect [1]. In this paper we report on torsion influence on current induced domain wall motion in glass coated microwires. The domain wall velocity was measured using a setup similar with the one described in reference [2] which in addition allow to make electrical contacts with the sample ends and to pass a current through it. For annealed Co68.18Fe4.32Si12.5B15 glass coated microwire with 20 µm in diameter and 11 µm glass coating the current at which the longitudinal magnetic reversal occurs, decrease from 16.5 mA to 9 mA when the torsion angle is increased from 42 rad/m to 168 rad/m. The domain wall velocity increase from 1110 m/s to 1940 m/s when the twisting angle increase in the same interval, for an applied a.c. current having 150 mA in amplitude. At a twisting angle of 168 rad/m the domain wall velocity increase from 680 m/s to 2290 m/s when the amplitude of the a.c. current applied trough the magnetic sample increase from 9 mA to 240mA.
The current driven magnetization reversal in microwires can found application for new magnetic logic/storage systems or sensors development.

Acknowledgment – Work supported by the Nucleu Programme (Project PN 16 37 01 02 and PN 18 06 01 01).

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Poster Session C

Poster C

P-C.118

Magnetic skyrmion low-frequency dynamics in thin circular nanodots

K. Gusliyenko, Z. Gareeva

Text Magnetic skyrmions, robust particle-like nanosize objects, attracted considerable attention due to promising applications in spintronics and information technologies. Being a kind of topological solitons in 2D spin systems, skyrmions exhibit a wide variety of unusual properties related to their topology.
In this talk we focus on the low frequency skyrmion dynamics in the systems of restricted geometry: isolated cylindrical nanodots. We consider Bloch- and Neel skyrmions as the ground states of thin circular nanodots stabilized due to an interplay of the isotropic and Dzyaloshinskii-Moriya exchange interactions, out-of-plane magnetic anisotropy and magnetostatic interaction.
We calculate low-frequency spin excitations over the skyrmion background. We show that only one gyrotropic mode (rotation of the skyrmion center position with the frequency about of 1 GHz) exists for the skyrmion of definite polarity and other low frequency modes in the skyrmion spectra correspond to spin waves. The gyrotropic frequencies in isolated nanodot do not depend on the type of skyrmion configuration, they appear to be identical for the Bloch and Neel skyrmions. The internal skyrmion structure manifests itself in the collective mode frequencies of the magnetostatically coupled skyrmion dot arrays. The dynamic responses of the Bloch and Neel skyrmions arranged in 1D array are different that allows to recognize the type of a skyrmion, particularly, on the base of ferromagnetic resonance measurements.

Poster Session C

Poster C

P-C.119

Magnetic skyrmions in the Heusler compound Mn1.4PtSn studied by small-angle neutron scattering

A. Sukhanov, P. Vir, A. Cameron, A. Heinemann, K. Manna, D. Inosov, C. Felser

Text Mn1.4PtSn belongs to the family of tetragonally-distorted Heulser compounds where non-collinear magnetic order is expected to appear as a result of competition between Heisenberg exchange interaction, the Dzyaloshinskii-Moriya interaction and uniaxial magnetocrystalline anisotropy. Recent examples include the canted antiferromagnetic order in the compound Mn2RhSn and the lattice of antiskyrmions in Mn1.4Pt0.9Pd0.1Sn, which is a structural analogue of the discussed compound [1,2].
We conducted small-angle neutron scattering experiments on an oriented single crystal of Mn1.4PtSn and revealed that the magnetic ground state gives rise to 6 different Bragg peaks in the (HK0), (H0L) and (0KL) reciprocal planes with the modulus of the propagation vector that corresponds to approximately 100-nm periodic structure in the real space. We analyzed the scattering patterns recorded for different magnitudes and direction of the applied magnetic field and concluded that the magnetic structure is described by a multi-k structure and not as domains of differently oriented single-k modulations. The observed multi-k structure might be interpreted as a 3D lattice of skyrmions or antiskyrmions.

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[2] A. K. Nayak et al., Nature 548, 561 (2017)

Poster Session C

Poster C

P-C.120

Magnetic textures due to non collinear magnetic quasi particles in ultrathin LSMO films on strained interfaces

A. A. Burema, A. Das, P. Zhang, T. Banerjee

Text Non-collinear magnetism based new phenomena have found recent interest due to the discovery of quasi-particles like skyrmions. Non-collinear magnetic effects can be induced in ultrathin films due to symmetry breaking at the interface. Exploiting the coupling between electronic transport and magnetism, we have studied broken inversion symmetry driven non-collinear magnetic textures at interfaces between ultrathin LSMO films on different oxide substrates. We will discuss the contributions to the different components of the Hall effect when the compressive strain is tailored at such interfaces. We will show how the enhancement in the out-of-plane magnetization in combination with spin-orbit coupling driven interaction gives rise to non-collinear magnetic structures at such interfaces. Our results indicate that the films we have are suitable to host non-colinear magnetic quasi-particles from magnetic bubbles to skyrmions.

Poster Session C

Poster C

P-C.121

Magnetization reversal and helical domain wall formation in Ni/Cu/Ni cylindrical nanowires

K. Yamada, M. Kikuchi, Y. Nakatani, M. Shima

Text Magnetic/nonmagnetic multilayered cylindrical nanowires are expected to serve as future three-dimensional recording media [1, 2]. To realize it, it is required to clarify the mechanism of their magnetization reversal and interlayer coupling. This paper reports our latest experimental and computational findings on the magnetization reversal and domain wall dynamics in Ni/Cu/Ni cylindrical nanowires investigated as a function of Cu layer thickness dCu.
Pulse electrodeposition and polycarbonate pore templates were used to grow Ni/Cu/Ni wires of ~100 nm in diameter, 3 μm in each Ni length, and 0-1000 nm in Cu length dCu. Magnetization reversal was measured by vibrating sample magnetometry under magnetic fields applied in a direction parallel to the wires. Our magnetic hysteresis curve measurements show that with increasing dCu, the squareness decreases from 0.71 to 0.38 while the coercivity is almost constant around 310 Oe. Our micromagnetic simulations prove that when dCu = 20 nm and 300 nm, the Ni cylinders have both vortex and single-domain structures [2] and that helical domain walls (HDWs) nucleate upon reversal where the location of their formation depends on dCu. The fields required to initiate the reversal do not greatly differ for dCu = 20 nm and 300 nm though the locations of their reversal to occur are apparently different.

[1] P. Sergelius, et al., Nanotechnology 28, 065709 (2017).
[2] M. Chandra Sekhar, et al., Appl. Phys. Lett. 101, 152406 (2012).

Poster Session C

Poster C

P-C.123

Magneto-optical study of domain wall inclination in FeSiB amorphous glass-coated microwires

O. Váhovský, K. Richter, R. Varga

Text Amorphous glass-coated microwires with positive magnetostriction have been thoroughly studied recently, due to their very high values of domain wall velocity [1]. It was shown, that domain wall propagation can be tuned by mechanical stress, temperature or perpendicular field [2]. Despite the capability of tuning the domain wall dynamics, the origin of fast propagation is unclear.
It is evident that for understanding the domain wall dynamics, detailed knowledge of the shape and spin-structure of the wall is necessary. The magneto-optical Kerr effect (MOKE) represents a non-invasive technique to study the surface magnetization of microwires. Most of the studies devoted to this subject have been based on the assumption that the cylindrical shape of the microwire can be neglected, or they used optical microscopy that has disadvantage of a finite numerical aperture.
Here, we perform time-resolved magnetometric measurements of domain wall motion carried out by laser-based loop tracer. The model allowing for cylindrical shape of the wire is used to optimize our experiment. It is shown that magnetization change does not occur exactly at the same time at different positions on a perimeter of wire, hence implying a tilted structure of domain wall. Moreover, such tilting is not constant along the entire length of wire, but it varies in both orientation and tilting angle.

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[2] A. Zhukov et al., Nanoscale Res. Lett. 7, 223 (2012).

Poster Session C

Poster C

P-C.124

Micromagnetic simulations of skyrmions along defect

N. Del-Valle, J. Castell-Queralt, L. González-Gómez, A. Sanchez, C. Navau

Text The movement of current-driven skyrmions guided along one-dimensional defects is studied using micromagnetic simulations. We show how, under adequate circumstances, the defect guides the skymion in the desired path, regardless of the direction of the current-driving electrons or the shape of the borders of the track. The study is done considering ultrathin films and interfacial Dzyaloshinskii-Moriya, as well as exchange and anisotropy interactions. The results show how and under which conditions the skyrmion gets trapped on the line of the defect and, when trapped, which are the dynamical properties of the movement along the defect. We consider several geometries for the defect: parallel, perpendicular and stair-like line with respect to the direction of current-driven electrons. The skyrmionic Hall effect is overcome for the presence of the defect and a significant acceleration can be produced along the defect. Threshold velocities for the trapping and guiding velocities along defects are found as a function of the parameters of the system (velocity of current-driving electrons, interaction constants, ...). When possible, these magnitudes are estimated analytically using Thiele’s approach.

Poster C

P-C.125

Optimizing stability of nanoscale magnetic skyrmions

A. Varentsova, S. von Malottki, S. Heinze, P. Bessarab

Text Available experimental data on magnetic skyrmions in various materials demonstrate inverse correlation between the skyrmion size and skyrmion stability: small skyrmions tend to be less stable compared to large ones [1,2]. The question arises how fundamental this trend is and whether it is possible to obtain long-lived magnetic skyrmions at ambient conditions while keeping their size at the nanoscale.
Here, we demonstrate by means of transition state theory [3] and minimum energy path (MEP) calculations [4] that the skyrmion lifetime at a given temperature is not a unique function of the skyrmion size. Skyrmions of the same size could have different stability depending on the strength of Dzyaloshinskii-Moriya (DM) interaction and magnetocrystalline anisotropy. We also show that it is possible to systematically tune material parameters so as to minimize the size of skyrmions while keeping their stability at a desired level.

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[2] Romming N., et al. (2013). Writing and deleting single magnetic skyrmions. Science **341**, 636.
[3] Bessarab P.F., Uzdin V.M., Jónsson H. (2012). Harmonic transition state theory of thermal spin transitions. Phys. Rev. B **85**, 184409.
[4] Bessarab P.F., Uzdin V.M., Jónsson H. (2015). Method for finding mechanism and activation energy of magnetic transitions, applied to skyrmion and antivortex annihilation. Comput. Phys. Commun. **196**, 335.

Poster Session C

Poster C

P-C.127

Resonance beyond frequency-matching: multidimensional resonance

R. Wang, Z. Wang, M. Li

Text Resonance, conventionally defined as the oscillation of a system when the temporal frequency of an external stimulus matches a natural frequency of the system, is important in both fundamental physics and applied disciplines. However, the spatial character of oscillation is not considered in this definition. We reveal the creation of spatial resonance when the stimulus matches the space pattern of a normal mode in an oscillating system. The complete resonance, which we call multidimensional resonance, should be a combination of both the temporal and the spatial resonance. We further elucidate that the spin wave produced by multidimensional resonance drives considerably faster reversal of the vortex core in a magnetic nanodisc. Multidimensional resonance provides insight into the nature of wave dynamics and opens the door to novel applications.

Reference:Zhenyu Wang et al 2017 New J. Phys. 19 033012

Poster Session C

Poster C

P-C.128

Route to form skyrmions in soft magnetic films without Dzyaloshinskii-Moriya interaction

D. Navas, R. Verba, A. Hierro-Rodriguez, S. Bunyaev, X. Zhou, A. Adeyeye, B. Ivanov, K. Guslienko, G. Kakazei

Text Magnetic skyrmions, topologically nontrivial magnetization configurations, attracted much attention recently as promising for applications in information recording, signal processing and microwave devices. Commonly, magnetic skyrmions are stabilized in non-centrosymmetric B20 bulk crystals and ultrathin magnetic films with out-of -plane magnetic anisotropy by chiral bulk or interfacial Dzyaloshinskii-Moriya interaction (DMI), respectively. Here we demonstrate that artificial magnetic skyrmions can exist in a soft ferromagnetic film without any DMI, coupled to a hard magnetic antidot matrix by exchange and dipolar interactions. Neel skyrmions, either isolated or arranged in 2D array having a high packing density can be stabilized using an antidot as small as 40 nm in diameter (for soft magnetic film made of Permalloy). Depending on the material and geometry parameters, one can achieve at remanence either the formation of the stable Neel solitons (skyrmions or their non-topological counterpart), or curled solitons with a complex magnetization distribution, being an intermediate between the Neel and Bloch skyrmions. The formation of the curled solitons is a result of competing demagnetization energy and Zeeman energy in the stray field created by antidot matrix. The curled skyrmions are realized in the case of relatively thin hard layer and large antidot diameter, while smaller antidots and thicker hard layers support the formation of the Neel skyrmions.

Poster Session C

Poster C

P-C.129

Scanning electron microscopy with polarization analysis on ex-situ sputter-deposited ultrathin Ir\ Co\ Pt films

S. Kuhrau, F. Kloodt-Twesten, J. Wagner, R. Frömter, H. P. Oepen

Text Scanning electron microscopy with polarization analysis (SEMPA) is a magnetic imaging technique with the capability to measure two components of the magnetization simultaneously. This makes is very attractive for studying non-collinear states like skyrmions or DMI walls.

However, due to its high surface sensitivity the applicability with typical DMI trilayers comprising a non-magnetic top layer was unclear. Samples for SEMPA investigation are often prepared in situ. Ex-situ prepared samples have to be capped to prevent oxidation during transfer. It is commonly assumed that capping with non-magnetic material in the range of nm will destroy the magnetic contrast, in particular using strong spin scatterers like Pt. Therefore, prior to a SEMPA measurement the capping layer is either removed by ion sputtering or dusted by Co or Fe to re-establish magnetic contrast [1]. However, both methods influence the properties of the sample, either by intermixing of the topmost layers or by adding additional magnetic material.

Using wedge shaped Pt top layers we have investigated the magnetic contrast of as-prepared $\{Ir\backslash Co\backslash Pt\}_n$ (n = 1, 2) samples. Magnetic domains can be imaged up to the maximum Pt thickness of 2 nm. The contrast reduction due to oxidation as well as capping has been analyzed as a function of Pt thickness. A maximum of the magnetic contrast is found around 1 nm Pt thickness, yielding sufficient 30% of the pure Co contrast.

[1] J. Lucassen, et al., APL **111**, 132403, (2017).

Poster Session C

Poster C

P-C.130

Selective circulation switching by single nanosecond current pulse.

M. Dhankhar, M. Vanatka, V. Uhlir, M. Urbanek, T. Sikola

Text Magnetic vortices are characterized by the sense of in-plane magnetization circulation and by the polarity of the vortex core, which leads to four possible stable configurations (vortex states). The four distinct combinations of circulation and polarity in a single element promise possible applications related e.g. to multibit memory cells.

We present a method for selective writing of arbitrary vortex state by appropriate selection of the polarity and shape of the writing current pulse. The electric current pulses are passed through [Pt/Co]n/Ni80Fe20 asymmetric (flat edge or thickness tapering) disks. The circulation control is achieved via shape asymmetry [1] and polarity control is possible by using the [Pt/Co]n perpendicular magnetic anisotropy under-layer. We study the pulse parameters in dependence of the disk shape and size. The vortex states are read out via all electrical detection using current-induced rectifying effect [2].

[1] V. Uhlíř et al., Nat. Nanotechnol. 8, 341–346 (2013)
[2] Shimon et al., Appl. Phys. Lett. 105, 152408 (2014)
[3] M. Goto et al., Appl. Phys. Lett. 109, 07D306 (2011)

Poster Session C

Poster C

P-C.131

Skyrmion Dynamics in Bulk Antiferromagnets and Synthetic Antiferromagnets

A. Salimath, F. Zhuo, A. Manchon, R. Tomasello, G. Finocchio

Text Absence of gyroscopic forces for skyrmionic textures and zero stray field make antiferromagnets attractive materials for next generation integrated circuits. Synthetic antiferromagnets (SAF) constitute another class of systems that are easier to achieve experimentally and that share attractive properties of antiferromagnets such as low stray magnetic fields and absence of skyrmion Hall effect. In this work, we compare skyrmion motion driven by spin-orbit torque in these two systems in the high velocity regime through both micromagnetic simulations and analytical approach based on the Lagrangian formalism. We investigate the anisotropic distortion of the skyrmion, and the emission of spin waves under spin Hall torque. The skyrmion in a SAF can reach high velocities for reasonable driving current density before undergoing velocity saturation through the emission of spin waves. In contrast, at high velocities we do not observe any saturation in bulk antiferromagnets at such current densities. The key factor that differentiates skyrmion dynamics in bulk and SAF is the strength of the antiferromagnetic exchange that affects the spin wave emission and the distortion of the skyrmion shape. In bulk antiferromagnets, due to strong exchange the coupled skyrmions in two sublattices travel as one entity in high velocity regime. This strong coupling prevents any mistracking between the two sublattices resulting in suppression of spin waves.

Poster Session C

Poster C

P-C.132

Skyrmions for two-dimensional device applications

V. Rung, D. Pinna, K.-W. Kim, K. Everschor-Sitte

Text An example of a spintronic based non-volatile memory device is the racetrack memory, in which information is encoded in magnetic domains separated by domain walls moving along a nanowire. A limitation of a standard racetrack is that it is basically a one-dimensional device and motion occurs along one direction only. The average access time to obtain the desired information scales linearly with the amount of information characterized by the number of bits or equivalently length of the wire, which is a disadvantage. Recently, it has been proposed to put skyrmions on the track. The topological whirls are magnetic configurations with a particle-like character and can in principle move in two independent directions. Inspired by the Manhattan street network, we look into ways of exploiting the skyrmion nature for two-dimensional devices and analyze their stability and performance. A major advantage of such a two-dimensional network is the strongly decreased access time, scaling only with the square root of the information amount.

Poster Session C

Poster C

P-C.133

Spin-Orbit Torques in Platinum based Systems

J. Nath, A. V. Trifu, S. Auffret, I. Joumard, G. Gaudin, I. M. Miron

Text Since the demonstration of Spin-Orbit Torque (SOT) induced switching in Ferro-Magnet (FM)/Heavy Metal (HM) hetero-structures [1-2], there has been significant activity on trying to determine the physical mechanisms underpinning this effect. Presently, the two prominent models are based on either the Inverse Spin Galvanic Effect (ISGE) or the Spin Hall Effect (SHE). The ISGE, also known as the Rashba - Edelstein effect, leads to spin-accumulation at the FM/HM interface, which exerts a torque on the magnetization via exchange coupling [3]. The SHE, on the other hand, is a bulk effect in which the Spin-Orbit Coupling (SOC) in the HM layer leads to a spin current that transfers angular momentum to the FM via the Spin-Transfer Torque (STT) mechanism [4]. It is vital to understand these effects in order to be able to engineer such systems for use in SOT based Magnetic Random Access Memories (MRAM) and skyrmionic systems. In this work, we utilize second harmonic transport measurements to study platinum based systems with varying HM thickness, different interfacial and FM configurations. With an emphasis on accurate extraction of torques from the measurements, we aim to provide an insight into the mechanisms behind SOT.

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[3] Manchon, A. et al., Physical Review B 78, 212405, 2008
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Poster Session C

Poster C

P-C.135

Spirit: a modern Framework for Spin Dynamics

G. P. Müller, N. S. Kiselev, H. Jónsson, S. Blügel

Text Spin simulations using atomistic models have great importance in theoretical work on solid state magnetism, as they can provide valuable predictions and help interpret experimental data. We present an open source framework [1] of modern cross-platform computational tools for atomistic spin dynamics providing direct user interaction and powerful real-time visualisations.
The software, called SPIRIT, is designed to increase scientific productivity, simplify workflows and to minimize time spent on problem-specific programming. Through live visual feedback and parameter control, the time needed to study and understand properties and dynamics of a system is significantly reduced. Through simplified programming interfaces (C/C++ or Python), time-consuming and repetitive tasks can easily be automated, as all steps taken in the graphical user interface can be reproduced. The software can even be run in a web-browser [2].
SPIRIT is an ideal tool for the simulation of complex 3D spin textures and localized magnetic objects, such as magnetic skyrmions, chiral bobbers [3] or complex domain walls. Its core capabilities include Landau-Lifshitz-Gilbert dynamics simulations and the calculation of minimum energy paths and energy barriers for transitions between states, using the geodesic nudged elastic band method [4].

[1] https://spirit-code.github.io
[2] https://juspin.de
[3] F. Rybakov, et al. Phys. Rev. Lett. 115, 117201 (2015)
[4] P. Bessarab, et al. Comp. Phys. Commun. 196, 335–347 (2015)

Poster Session C

Poster C

P-C.136

Stable vortex-antivortex pairs in soft layer/hard layer nanostructures.

A. Hierro-Rodriguez, D. Navas, S. A. Bunyaev, X. Zhou, A. O. Adeyeye, R. Verba, B. Ivanov, K. Guslienko, G. Kakazei

Text We demonstrate micromagnetically the possibility to form vortex type configurations in a continuous film with in-plane magnetization that is dipolarly coupled with perpendicularly magnetized antidot array. The structure under study is $Ni_{80}Fe_{20}$ (3 nm)/ CoPd (t_{CoPd} nm), where *tCoPd* was varied from 5 to 60 nm. NiFe layer (saturation magnetization M_s = 8.1×10^5 A/m, no anisotropy) is continuous, when CoPd layer (M_s = 4×10^5 A/m, $K_\perp$ = 4×10^5 J/m^3) contains the periodic square array (period of 400 nm) of round holes with diameter of 100 nm. To suppress the exchange coupling between the layers, they were physically separated by 1 nm. External magnetic field was applied perpendicularly to the sample plane. Initially, the sample was saturated at 12 kOe and then the field was swept down to zero. In case of small CoPd thicknesses ($t_{CoPd} \leq$ 20 nm), the only influence of antidot array on NiFe film was the formation of small magnetization nonuniformity under the hole. With further increase of t_{CoPd} the pair radial vortex (i.e. vortex with radial chirality) – antivortex was formed in NiFe layer. The vortex appeared under the hole when antivortex appeared at some distance from the hole along the direction of in-plane magnetization. Cores of vortex and antivortex were directed along the initial orientation of the external magnetic field. Applying the negative perpendicular field, we were able to switch the direction of vortex core, obtaining the pair of cores with opposite orientations.

Poster Session C

Poster C

P-C.137

Switching of Skyrmion chirality by local heating

Y. Nakatani, K. Yamada, A. Hirohata

Text A magnetic Skyrmion is a chiral structure appearing in a magnetic thin film with Dzyaloshinskii-Moriya interaction (DMI) [1-4]. Because of its small size and the small threshold current for motion, it is expected to be used as an information carrier for a magnetic storage system [5-7]. The methods to manipulate the Skyrmion, nucleation, annihilation, switching of the core direction, motion, by external field, spin-polarized current and the others have been proposed. In this paper, we propose a method to switch the chirality of the Skyrmion by a pulse heat spot, and study it by micromagnetic simulation.
Two types of Skyrmions with clock wise (CW) and counter clock wise (CCW) chirality were used as the initial states. In the simulation, a pulse heat spot with Gaussian shape was applied. The σ of the head spot (σh) was varied from 25 to 50 nm. The room temperature and the maximum temperature of the heat spot were set to be 300 and 550 K. The material parameters Ms, Ku, A, and D of each prisms were decreased as temperature was increased.
The CCW Skyrmion expands by the heat spot keeping the magnetization direction. The Skyrmion shrinks after to cut the pulse, the magnetization rotates to the crock wise direction, and the CW Skyrmion appears. The CW Skyrmion expands slightly by the heat spot, however the magnetization rotates to the counter clock wise direction. The magnetization keeps to rotate to the same direction after to cut the pulse, and the CCW Skyrmion appears.

Poster Session C

Poster C

P-C.138

Synthesis and magnetic studies of nanocrystalline Cu_2OSeO_3, a chiral topological magnet

J. F. Malta, M. S. C. Henriques, J. A. Paixão, A. P. Gonçalves

Text Topological spin textures, such as magnetic skyrmions observed in certain chiral magnets, are one of the most interesting ordered phases in condensed matter. A skyrmion is a swirling spin structure carrying a topological quantum number.Skyrmions were first observed in MnSi in 2009[1] and later observed in Cu_2OSeO_3, a chiral antiferromagnet with T_N ~ 60 K that can be synthesized as single crystals by reacting CuO and SeO_2 in a chemical vapour transport reaction[2]. As skyrmion lattices may find use in nanotechnological devices, such as data storage systems and in other applications, the magnetic properties of nano-sized crystals obtained by different methods deserve to be investigated. We have obtained the nanocrystalline form of Cu_2OSeO_3 by heating $CuSeO_3$ in air, at ~400 ºC.
XRD, SEM and DSC/TG studies were performed to characterize our samples, and a detailed study of the magnetic phase diagram close to the Néel temperature under a small applied magnetic field where the skyrmion phase exists was undertaken. The results obtained compared to those of Cu_2OSeO_3 in single crystal form.

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2 *Panella, J. R., Trump, B. A., Marcus, G. G. & McQueen, T. M., Cryst. Growth Des. 17, 4944 (2017)*

Poster Session C

Poster C

P-C.139

The role of vortex-antivortex pairs in the magnetization reversal of Permalloy thin films

S. Singh, H. Gao, U. Hartmann

Text Substructures of magnetic domain walls such as vortex-antivortex pairs have a strong influence on the wall's static and dynamic properties within applied magnetic fields or under the influence of current pulses [1, 2]. By applying an in-plane magnetic field during Magnetic Force Microscope measurements, we analyzed the details of magnetization reversals along the long and short axes of micro-patterned Permalloy thin film samples, respectively. The evolution of domain wall clusters and the transfer of the magnetic flux across the domain walls were investigated by observing the nucleation and annihilation of substructures inside the walls. The transfer of magnetic flux across the domain walls was observed to be governed by cumulative transport of a resulting single vortex along the axis of the wall. Furthermore, the experimental findings were evaluated by micromagnetic calculations. Based on the resulting magnetic energies within the whole sweep range of the applied field, it can be concluded that the demagnetization and exchange energies dominate the Zeeman energy at small applied fields. This restricts the nucleation and annihilation of substructures inside the walls near the remanent state of the sample.

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Poster Session C

Poster C

P-C.140

Threshold current density for skyrmion expulsion from magnetic nanostructures

M.-W. Yoo, V. Cros, J.-V. Kim

Text Skyrmions have attracted much attention for their potential for efficient information storage applications [1, 2]. Most of the applications rely on their current-driven motion in confined structures. However, it is known that there is a threshold current density above which the skyrmion is expelled at the boundary edges [3, 4]. This threshold can be a severe constraint on the limit for skyrmion propagation speeds.
In this presentation, we present a theoretical investigation of the threshold current density of the skyrmion expulsion in nanostrips. From micromagnetic simulations, we explore the threshold current density, and show that this threshold is determined by the critical boundary. We also find the dependence of the critical boundary force on the magnetic parameters. Using an analytic model, we reveal the underlying physics of the dependence of the critical boundary force on the magnetic parameters based on the scaled Dzyaloshinskii-Moriya interaction parameter. This work provides a quantitative description of the skyrmion expulsion and the interaction between the skyrmion and device boundaries.
EU grant MAGicSky No. FET-Open-665095 and ANR grant TOPSky are acknowledged.

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Poster Session C

Poster C

P-C.141

Topological defects and critical phenomena in two-dimensional frustrated helimagnets

A. Sorokin

Text Using a simple model of a frustrated helimagnet, the critical behavior is numerically investigated for planar or isotropic spins, and for cases of one or two chiral order parameters. The helical structure in this model arises from the competition between exchange interactions of spins of the first two range orders in one direction (in both directions) of a square lattice. The main result is that the critical and temperature behavior is primarily determined by topological defects that are present in all cases.

In the case of planar spins, vortices, fractional vortices and domain walls are present in the system. Their interaction leads to the appearance of the phase of a chiral spin liquid, or induces a single first order transition, and in the vicinity of the Lifshitz point vortices lead to a reentrant phase transition to the phase with a collinear quasi-long order.

In the case of isotropic spins, so-called Z2-vortices are present. They do not lead to the appearance of a phase with long-range or quasi-long order in the case of one chiral order parameter. However, their interaction leads to a sharp change in the temperature dependence of the correlation length (crossover).

In the case of two chiral parameters, there are long-range chiral order of the Ising type (chiral spin liquid) and domain walls. However, as a result of the interaction of vortices and walls, the crossover and chiral transition occur at the same temperature as a first-order transition.

Poster Session C

Poster C

P-C.142

Topological states and even-odd effects in short chiral antiferromagnetic chains.

J. Chovan, D. Legut

Text We present a numerical study of a short classical Heisenberg antiferromagnetic (AF) chain with strong easy-plane (EP) anisotropy and Dzyaloshinskii-Moriya (DM) interaction in a magnetic field H. The chiral axis is perpendicular to the EP and we assume free boundary conditions. In the bulk limit, the ground state (GS) is a perfect spin spiral in the EP. With H in the EP, the spiral is distorted and its period grows. Above a critical field H_c the GS becomes spatially uniform.

In short chains, the number of spiral twists (solitons) *n* depends on H and chain size N. Recent experiments on thin films DM ferromagnets (FM) demonstrated field-induced discrete magnetization jumps. Such jumps are absent in bulk systems, and originate in transitions between the topological sectors (TS) with different number of 2π-solitons. For given N, *n* decreases with H in steps of 1; the transition to the uniform state occurs at the critical field that approaches H_c with N.

Here we study short AF chains. We numerically determine the GS, its magnetization M and TS. We find pronounced even-odd effects. For even N, the evolution of TS is virtually identical with that of FM. Odd-N chains are different. The true TS with $n \geq 1$ carry $(2n-1)$ π-solitons. The transition to the uniform AF state is modified, and occurs at the critical field H_2, significantly above H_c. At H_c, instead, the systems enters the TS $n=1$ with one π -soliton, which mediates the commensurate-to-incommensurate phase transition.

Poster Session C

Poster C

P-C.143

Tuning the noncollinear magnetic structure of the tetragonal Heusler system Mn-Pt-Sn

V. Kumar, A. Nayak, P. Adler, C. Shekhar, C. Felser

Text Noncollinear magnetic structures especially skyrmions substantiate their use for the next generation memory devices. Our recent work on the stabilization of antiskyrmions in the tetragonal Heusler compound $Mn_{1.4}Pt_{0.9}Pd_{0.1}Sn$ enriches the skyrmion family with the Bloch and Néel type skyrmions [1]. This compound has a high saturation moment of 4.5 μ_B and the size of the skyrmions is larger than 100 nm. Ideally, zero moment and relatively smaller size of the skyrmions are preferable for applications. The tunability of Heusler compounds allows to design such a desired material. Here, we investigated the change in the noncollinear spin structure by fixing and varying the number of valence electrons in $Mn_{1.4}PtSn$ by partial substitution of Pt with Pd and Rh, respectively using magnetization, transport and powder neutron diffraction experiments. Neutron and magnetization measurements show that the samples undergo a spin reorientation transition around 125 K below which a topological contribution to the Hall resistivity of the order of sub-μΩ cm has been detected. The magnetic as well as the transport properties significantly vary by Rh substitution whereas only a small change has been observed in the case of Pd substitution. Changes in exchange couplings and spin-orbit interactions due to substitution modify the noncollinear spin configuration and consequently the helical and skyrmionic phase existing in these materials.

[1] Nayak *et al.*, Nature **548**, 561 (2017).

Poster Session C

Poster C

P-C.144

Unconventional features of the antiphase domain walls in the model S=1 (pseudo)spin 2D system

A. Moskvin, Y. Panov, V. Konev, V. Ulitko, D. Yasinskaya

Text At variance with the s=1/2 quantum magnets the S=1 spin systems are characterized by a more complicated Hamiltonian with emergence of a single-ion anisotropy and biquadratic inter-site couplings that give rise to novel phases, in particular, quantum paramagnet (QP) and spin-nematic phase. Within classical approach the quantum paramagnetic state corresponds to an easy-plane phase. We start with a model 2D S=1 spin system whose ground state corresponds to a Neel antiferromagnetic (AFM) order along Z-axis, however, near the quantum phase transition to the QP phase. Computer modeling on large (256x256) square lattices shows that relatively small varying of single-ion anisotropy can dramatically change the antiphase domain wall structure from the uniform QP-phase to topologically nontrivial < < easy-plane >> spin-nematic XY-phase. The S=1 spin algebra can be used to describe strongly correlated systems such as a system of the charge triplets Cu1+,2+,3+ in cuprates or semi-hard-core bosons with the on-site occupation constraint: n=0, 1, 2. Interestingly, for such S=1 pseudospin systems we arrive at a possibility to observe a dramatic transformation of the antiphase domain walls of the charge-ordered AFM-type phase from uniform insulating phase ((< < parent >> Cu2+-phase in cuprates, n=1-phase for semi-hard-core bosons) to the filamentary superconducting (superfluid) phase with nontrivial topological arrangement of the superfluid order parameter phase.

Poster Session C

Poster C

P-C.145

Unconventional vortices in soft magnetic circular nanodots stabilized by dipolar coupling

R. Verba, D. Navas, A. Hierro-Rodriguez, S. Bunyaev, B. Ivanov, K. Guslienko, G. Kakazei

Text Magnetic vortices are the simplest topologically nontrivial magnetization configurations having promising applications in spin-torque oscillators, magnetic memory, etc. In the most of previous works common Bloch magnetic vortices in sub-micron soft ferromagnetic dots with thickness above 10-20 nm were studied.
Here we propose a way to stabilize the vortex states with unconventional structure in soft ferromagnetic circular dots. Our approach is based on the application of a hybrid nanostructure, in which a soft ferromagnetic dot is dipolarly coupled to a perpendicularly magnetized hard magnetic layer with an antidot. The same results can be achieved in multilayer soft/hard ferromagnetic dots in the absence of exchange coupling between the layers. By micromagnetic simulations and analytical calculations we show that depending on the strength of dipolar coupling, the ground state of the soft dot can be either radial (Neel) vortex or a magnetic vortex with a complicated configuration, being an intermediate between the Neel and Bloch vortices.
Moreover, the dipolar coupling to a hard layer reduces the characteristic sizes of a vortex core. Therefore, the vortex ground state in the studied nanostructures can be achieved in much smaller dots comparing to an isolated dot. For example, we observed formation of the Neel vortices in NiFe dots with diameter of 50 nm and thickness of 1-2 nm, which are essentially smaller than the critical sizes of the vortex formation in an isolated dot.

Poster C

P-C.147

Universality class of current induced magnetic domain wall creep

R. Díaz Pardo, N. Moisan, A. Lemaître, V. Jeudy

Text The aim of this work is to study the criticality of current induced domain wall (DW) motion in the thermally activated sub-threshold creep regime. We present a comparative study between current and magnetic field induced DW motion in a (Ga,Mn)(As,P) thin film.
In order to compare the universality class of both types of motion, we explore the self-affinity of DWs and measure the roughness exponent ζ. The average values of ζ determined for current *j* and field *H* induced domain wall motion ($\zeta_j = 0.60 \pm 0.05$ and $\zeta_H = 0.61 \pm 0.04$) are compatible with theoretical predictions (ζ=2/3) for the quenched Edward-Wilkinson model.
We have also compared the dynamics of DW driven by an applied magnetic field and an electric current. In both cases, the determined value of the creep exponent is close to predicted value (μ=1/4) for the quenched Edward-Wilkinson model ($\mu_j = 0.259 \pm 0.004$ and $\mu_H = 0.247 \pm 0.011$).
Moreover, similar measured effective pinning barrier heights strongly suggests current and magnetic field induced motion to be essentially controlled by the same pinning disorder.
In conclusion, we show that similar critical exponents describe the motion of domain wall in ultrathin films driven by magnetic field and electric current.

Poster Session C

Poster C

P-C.148

Variation and stability of magnetic anti-skyrmions in tetragonal Heusler material

A. K. Srivastava, R. Saha, T. Ma, J. Jena, P. Werner, C. Felser, S. S. Parkin

Text Magnetic skyrmions are topologically protected nanoscopic vortices of magnetization that can be stabilized in magnets with broken inversion symmetry. Recently, our Lorentz transmission electron microscopy (LTEM) studies have identified anti-skyrmion in the non-centrosymmetric inverse tetragonal Heusler compound, $Mn_{1.4}Pt_{0.9}Pd_{0.1}Sn$ with D_{2d} crystal symmetry[1]. One of the most promising features of anti-skyrmion in $Mn_{1.4}Pt_{0.9}Pd_{0.1}Sn$, unlike the skyrmion in B20-type FeGe system[2], is that they are stable at room temperature as well as at quite larger thickness. In order to understand that, we have employed LTEM to explore the variation and stability of magnetic anti-skyrmion in a wedge-shaped lamella of $Mn_{1.4}Pt_{0.9}Pd_{0.1}Sn$ and thereby, constructed the thickness-dependent magnetic phase diagram. The phase diagram shows the different thickness dependent stability of anti-skyrmion as compared to skyrmion in the B20-type FeGe[2], where the temperature-magnetic field stability of spin textures is limited to the thinner part and well below room temperature. We propose a model that this difference is corroborated to the difference in Dzyaloshinskii-Moriya exchange Interactions (DMI) vectors involved in the symmetry broken condition of the two crystal structures of D_{2d} and B20-type. These findings might pave the way to tune the stability of anti-skyrmion for future advances in spintronics.

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Poster Session C

Poster C

P-C.149

Acoustic excitation and electrical detection of spin waves and spin currents in hypersonic bulk waves resonator with YIG/Pt system

N. Polzikova, S. Alekseev, V. Luzanov, A. Raevskiy

Text In this report, theoretical and experimental studies on acoustic excitation and electrical detection of spin waves (SW) and spin currents (SC) in bulk acoustic waves (BAW) resonator with ZnO-GGG-YIG/Pt structure are presented. It has been established that BAW driven SW produces SC from YIG to Pt and dc inverse spin Hall effect voltage (U_{ISHE}) in Pt. In such system, the important features of acoustic spin pumping are determined by double resonance: the magnetoelastic (MER) in YIG film and BAW overtone f_n of the entire resonator structure. Electrical detection of BAW driven SWs occurs while simultaneously measuring the electrical response of ZnO transducer and the dc voltage signal on Pt stripe. The dependences of the resonance frequencies f_n and U_{ISHE} on the field H and the frequency f are correlated with each other. At the same time a significant asymmetry of the $U_{ISHE}(f_n(H))$ value in reference to the MER line $f_{MER}(H)$ position is revealed, which is confirmed by theoretical calculations. Comparison of the theoretical and experimental dependences allows us to determine a number of magnetic and magnetoelastic parameters of YIG. Thus we assume that the combination of the sensitive acoustic resonator spectroscopy technique with the electrical detection of the magnetic dynamics by ISHE is of interest for the study of SW dispersion and damping due to both back action from the acoustically driven SW on the resonant properties of the resonator and the detection of SC in Pt.

Poster Session C

Poster C

P-C.150

All-electrical spin wave interference towards logic operations

G. Talmelli, T. Devolder, M. Heyns, I. Radu, C. Adelmann, F. Ciubotaru

Text Spintronic devices based on spin waves are promising alternatives to CMOS technology and have high potential for power and area reduction per computing throughput. The information can be encoded in either the amplitude or the phase of the wave, while the logic operation is based on the interference of spin waves, which is a keystone for the realization of logic gates.
Here, we report on the spin wave interference in micron-sized ferromagnetic waveguides using a sequential "in-line" layout of input and output antennas. The waveguide consists of a 4 µm wide CoFeB stripe of 30 nm thickness, electrically isolated from the antennas by 40 nm of SiN_x. The spin waves are excited by the Oersted field produced by RF currents flowing through U-shaped Au antennas (500 nm wide, 100 nm thick) and detected by a single wire antenna. Microwave currents with the same frequency were applied to two or three inputs simultaneously and the output signal was studied as a function of the input frequency, magnetic bias field, and relative phase difference between the input signals. For a given set of field-frequency parameters, an oscillatory signal was detected by varying the phase of the input signals corresponding to the constructive or destructive interference of the generated spin waves. Controlling independently the phase (0 or π) and amplitude of the spin wave generated by each input we demonstrate the tuning of the interference pattern at the output allowing for the realization of logic gates.

Poster Session C

Poster C

P-C.151

Application of spin-wave caustics in magnonic logic networks

F. Heussner, M. Nabinger, T. Brächer, T. Fischer, M. Ender, A. A. Serga, B. Hillebrands, P. Pirro

Text Currently, the application of magnons, the quanta of spin-waves (SW), in wave-based logic networks is widely discussed due to its potential as CMOS complementary technology with extended functionality and improved performance. By utilizing interference effects, footprints of logic devices can be reduced, which allows for the realization of innovative and energy efficient ways of information processing.

An instructive example of the unique possibilities to realize novel concepts for data processing is the transport of SW encoded information in unstructured 2D media via focused SW beams and caustics. These beams occur due to the anisotropic nature of the SW dispersion relation, which can lead to (nearly) parallel directions of the group velocity of spin waves excited with a broad angular wave-vector spectrum. This provides outstanding peculiarities like beams with sub-wavelength narrow apertures.

In the presentation, we will discuss and demonstrate the generation mechanisms of focused SW beams and caustics. Subsequently, micromagnetic simulations are used to show the concept of a frequency-division (de-)multiplexer for spin waves, promising a multiplication of the throughput in magnonic networks. In addition, the design of a switchable SW signal splitter will be presented, which is exploiting the strong dependence of the direction of energy flow on the local magnetic field direction.

Financial support by DFG within project SFB/TRR 173 Spin+X is gratefully acknowledged.

Poster Session C

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P-C.152

Artificial crystals based on opal matrices with 3d metal and palladium particles subjected to high-temperature heat treatment

O. Nemytova, A. Rinkevich, D. Perov

Text The investigation of effect of high-temperature heat treatment on the structure and physical properties of artificial crystals with 3d metal and palladium particles is carried out. The artificial crystals are based on opal matrices with 3d metallic and palladium particles introduced into the inter-spherical voids. The temperature of heat treatment of samples is chosen from 450 to 960 0C. Under the high-temperature treatment the submicron opal spheres are melted over the sample surface; the “peel” is formed; the sample surface is cracked and subsequent annealing leads to the pronounced relief of surface. The internal structure of a nanocomposite sample, however, is preserved even at the high temperature of heat treatment of 960 0C. The magnetic properties are studied at the temperature range from 2 to 300 K and in the fields up to 350 kOe. The magnetic properties of samples before and after annealing in hydrogen significantly differ because the particles contain antiferromagnetic oxides of cobalt and/or nickel before annealing and the oxides are transformed into the metals after annealing. In particular, after high-temperature heat treatment the coercivity of samples increases whereas before annealing magnetic saturation is not observed.

Poster Session C

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P-C.153

Brillouin light scattering investigation of the spin wave beam focusing effect under excitation by curved transducer

M. Madami, Y. Khivintsev, G. Gubbiotti, G. Dudko, A. Kozhevnikov, V. Sakharov, A. Stal'makhov, Y. Filimonov

Text Anisotropy of the spin waves (SW) dispersion in tangentially magnetized ferromagnetic films can be used for SW beam focusing and propagation control [1,2]. We employed micro-focused Brillouin light scattering (μ-BLS) technique [3-4] and micromagnetic simulation [5] to study the focusing effect of SW, excited by a curved coplanar transducer in an yttrium iron garnet (YIG) film, in the backward volume spin waves (BVSW) geometry. Experimentally we observed a clear nonreciprocity in the excitation and propagation of SW on both sides of the coplanar transducer with very well defined SW beams propagating, and intersecting, on the concave side of the transducer. Measurements have been performed on a 5 μm thick YIG film, within an applied magnetic field of H=100 mT and over an area of 400×600 μm2. Micromagnetic simulations have been performed, using the OOMMF code, over an area of 3×3 mm and with the cell size of 3×3×1 μm. The results of micromagnetic simulations show a good agreement with the experimental results and successfully reproduced the nonreciprocity of the SW propagation.

This work was supported by the RFBR (grant No. 16-07-01092).

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Poster Session C

Poster C

P-C.154

Brillouin light scattering study of layered YIG-Gallium Arsenide

A. Sadovnikov, E. Beginin, A. Stognij, S. Sheshukova, Y. Sharaevsky, S. Nikitov

Text Recently, it was shown that the extreme low-damping yttrium iron garnet (YIG) materials is appropriate for emerging technologies, such as spintronics and magnonics due to excitation of magnetization dynamics by pure spin currents and spin-transfer torque [1]. The integration of magnonic functional structures in the semiconductor-based electronics faces a problem of incompactible substrates, which are typically used in YIG magnonics and conventional CMOS-based electronics. The former concept uses the gadolinium gallium garnet (GGG) substrate for magnetic films. The straightforward advantages of YIG on GaAs substrate over YIG on GGG substrate are integration capability of magnonic and spintronic elements in the semiconductor architecture. We report on experimental study of spin-wave spectra in the YIG/GaAs structure. The BLS spectra demonstrates the well-pronounced peaks, which are corresponded to the Damon-Eshbach modes and bulk spin-wave modes. Moreover we show the possibility to spin wave frequecy control using the IR laser radiation (positive frequency shift up to 150 MHz, at the spin-wave frequecy 5 GHz).

This work was partially supported by the Grant from Russian Science Foundation (#14-19-00760) and Scholarship (SP-2819.2018.5) and Grant (MK-3650.2018.9) of the President of RF.

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Poster Session C

Poster C

P-C.155

Broadband spin-wave spectroscopy on artificial ferromagnetic quasicrystals revealing characteristic mode motifs

S. Watanabe, V. S. Bhat, K. Baumgaertl, D. Grundler

Text Quasicrystals exhibit long range order but an absence of translational invariance. We investigate artificial ferromagnetic quasicrystals (AFQ) prepared from ferromagnetic thin films and explore how collective spin excitations reflect the aperiodicity of hole arrays arranged on quasicrystalline lattices.

In the experiments we performed broadband spin wave spectroscopy on AFQs in the few GHz frequency regime using a vector network analyzer and different orientations of an in-plane magnetic field. The AFQs consisted of 19 nm thick CoFeB thin films with nanoholes arranged on different Penrose tilings, i.e., 2D analogues of quasicrystals. We investigated nanoholes with different diameters between 135 nm and 220 nm. Relevant center-to-center separations between nanoholes amounted to 810 nm. We detected different sets of spin wave eigenmodes, which displayed a ten-fold rotational symmetry in angle dependent studies. Using micromagnetic simulations, we identified characteristic spin-wave mode motifs in the AFQs. To explain the eigenfrequencies of the different modes we considered both inhomogeneous internal fields and confinement effects. The work was supported by SNSF via grant number 163016.

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Poster C

P-C.156

Caustic-like spin transport by hybrid magneto-elastic bosons in a ferrimagnetic film

D. Bozhko, P. Frey, A. Serga, B. Hillebrands

Text Our recent observations of an overpopulated magnon gas in a single-crystal film of yttrium iron garnet by means of wavevector-resolved Brillouin light scattering (BLS) spectroscopy resulted in the discovery of a spontaneous accumulation of hybrid magnon-phonon bosonic quasiparticles [1]. These quasiparticles posses a nonzero group velocity, making them promising data carriers in magnonic devices.
In order to study a two-dimensional transport characteristics of the magnon-phonon hybrids, we parametrically injected magnons in a point-like 100µm-wide area by 200ns-long microwave pump pulses. By performing two-dimensional space-resolved BLS probing, we show that the emission of the accumulated quasiparticles from the injection area is highly anisotropic. We observed six propagation directions. Two hybrid wave packets contra-propagate along the magnetic field with a group velocity of 3500m/s, independent on the applied pumping power. In contrast, the other four packets propagate obliquely to the direction of the bias field. Although their group velocity is changed from 200 to 500m/s with fourfold increase in the pump power, the propagation directions remain constant.
The revealed behavior can be understood as a caustic-like phenomenon, which can be utilized for a long-distance spin transport in future two-dimensional magnonic circuits.
The support by the ERC AdG "SuperMagnonics" and DFG within the SFB/TR49 is acknowledged.
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Poster Session C

Poster C

P-C.157

Cavity-FMR studies of LPE epitaxial YIG films

H. Hurdequint, G. de Loubens, J. Ben Youssef, N. Beaulieu, N. Vukadinovic

Text The recent progress in the elaboration of **very thin** epitaxial **YIG** films has brought a renewed interest for exploiting the resonance properties of such films as well as of **bilayer** films (YIG layer coated by a heavy metal).We report basic results we have obtained in our **cavity-FMR** studies at X-band on 4 films (F1,F2,F3,F4).They correspond to (111)oriented **YIG** layers deposited by LPE[1]on GGG substrates.F1 and F3 are the virgin YIG films,F2 and F4 correspond to the same films with a **Pt** layer(3nm)deposited on top.We have F1[YIG58],F2[YIG58/Pt3],F3[YIG15],F4[YIG15/Pt3],thicknesses in nm.The experimental investigation consists in a detailed study of the angular variation of the resonance spectrum (angle of the dc field with the film normal). For F1 the principal resonance displays a fine structure [regularly spaced narrow lines which can be ascribed to standing **elastic waves** across the sample plate].For F2 and F4,two **standing** spin waves are observed.The linewidth is the sum of two contributions. The first one correspond to an **intrinsic** relaxation and the second to an inhomogeneous width.For(F1,F3)The width displays a sharp minimum at a specific field angle [well accounted for in terms of the theoretical description[2] for the inhomogeneous width], Δ is 1Oe (α is 2.5×10^{-4}).For (F2,F4) the increment Δs, associated to the interface (YIG/Pt),varies as the inverse YIG thickness.[1]C.Hahn et al, Phys.Rev.B87,174417 (2013).[2]H.Hurdequint,J.Magn.Magn.Mater.242-245,521 (2002).

Poster Session C

Poster C

P-C.158

Confined spin waves in ferromagnetic nanotubes detected by Brillouin light-scattering spectroscopy

M. C. Giordano, K. Baumgärtl, G. Tütüncüoğlu, A. Fontcuberta i Morral, D. Grundler

Text Ferromagnetic nanotubes are promising candidates for high density magnetic storage technology, due to the possibility to define their remnant states and control their magnetization reversal processes. The three geometrical parameters (length, inner, and outer radii), make them an interesting nanoelement also in the field of magnonics, allowing for tailoring the shape-related spin wave confinement.
We report an experimental study of spin-wave excitation in individual Ni80Fe20 nanotubes with lengths in the range of 5 to 12 µm and diameters on the order of 200 nm by means of Brillouin light-scattering (BLS) spectroscopy. Individual nanotubes were irradiated by microwaves via an integrated antenna being collinear to both their long axis and an applied in-plane magnetic field. In BLS spectra obtained in the central part of a nanotube we resolved a set of discrete resonances at a few GHz, which we attributed to azimuthally confined spin waves. Using a phase-resolved detection scheme, phase shifts close to 180° were detected for the fundamental mode at opposite edges in transversal direction. Further spin wave excitations were recorded spatially resolved in several spots along the nanotube. A low-frequency resonance (1-2 GHz) was detected at the ends of a nanotube, suggesting the excitation of a vortex-like magnetic configuration. Our findings provide microscopic insight into tubular nanocavities for magnons.

This work was funded by DFG GR1640/5-2 in SPP 1538.

Poster Session C

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P-C.159

Current-driven mode expansion and rotation in nano-constriction spin Hall nano-oscillators in out-of-plane fields.

A. Awad, M. Dvornik, A. Houshang, P. Dürrenfeld, M. Zahedinejad, Y. Yin, J. Åkerman

Text Spin Hall nano-oscillator (SHNO)[1] devices hold great promise as extremely compact, broadband, and versatile microwave oscillators and have unique opportunities for magnonic devices. The synchronization of nano-constriction based SHNOs[2] has been demonstrated recently[3]. The mutual synchronization of nano-constriction SHNOs is mediated through mode overlap, which occurs at high out of plan fields. Meanwhile its decisively vital to characterize the microwave auto-oscillation spatial distribution to develop further synchronized oscillatory networks of such SHNOs, qualitative description of the auto-oscillation spatial profile and its current tunability still lacking for the oblique field where synchronization is efficiently robust.
We demonstrate, by a combination of electrical, optical measurements and micromagnetic simulations, that the auto-oscillation localization weakens in oblique fields, giving way to an extended auto-oscillation mode with a spatial profile that, with increasing current, undergoes both expansion along, and rotation about, the constriction axis. The characterization of mode evolution and rotation with current is crucial for the future development of longer synchronized chains and potentially two-dimensional arrays, where the directional expansion will likely play a key role.

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Poster Session C

Poster C

P-C.160

Direct observation of sub-100 nm spin-wave propagation in magnonic waveguides

N. Träger, P. Gruszecki, F. Lisiecki, J. Förster, F. Groß, M. Weigand, P. Kuświk, J. Dubowik, G. Schütz, M. Krawczyk, J. Gräfe

Text In the research field of magnonics, capabilities of data communication via spin-wave propagation are currently of strong scientific interest. Magnonic computing with guided sub-100 nm wavelengths promises beyond-CMOS data processing technologies like non-Boolean computing algorithms or majority gates substituting several tens of CMOS transistors and making this an exciting candidate for next level computing.

Here, we investigate 350, 700 and 1400 nm wide and 50 nm thin and up to 40 µm long Py stripes as magnonic waveguides, using scanning x-ray microscopy (MAXYMUS@BESSY) with 18 nm spatial and 35 ps temporal resolution. Spin waves were from antennas that generated a uniform RF field in the GHz regime around the Py stripes.

We directly observe highly oriented emission of sub-100 nm spin-wave modes with tens of periods, which is beyond the measuring capabilities of conventional techniques. Furthermore, the waveguides are capable of simultaneously carrying multiple modes. Thereby, we observed non-dispersive propagation indicating high transmission velocity with uniform characteristics. Additionally, we observe the decay behaviour revealing information about different coexisting modes and their corresponding damping properties for $k \neq 0$, indicating an increased damping at $k >> 0$. These findings will be a crucial basis for magnonic logic relying on ultrashort spin-waves.

Poster Session C

Poster C

P-C.161

Direct writing of magnonic crystals with spatial modulation of magnetic anisotropy

L. Flajšman, O. Wojewoda, J. Gloss, V. Křižáková, P. Varga, M. Urbánek

Text Artificially patterned periodic magnetic structures - magnonic crystals - are prospective materials for controlling and manipulating spin waves. Common types of magnonic crystals are based on periodic modulation of saturation magnetization. We experimentally investigate the possibility of inducing a frequency band-gap by periodic modulation of the uniaxial magnetic anisotropy direction.
The experimental approach allowing fabrication of structures with periodic modulation of the direction of the uniaxial magnetic anisotropy relies on metastable paramagnetic fcc $Fe_{78}Ni_{22}$ films grown on Cu(100) substrate. This system can be locally transformed by focused ion beam (FIB) into ferromagnetic bcc phase [1]. The transformed areas have ordered crystalline structure, which can be controlled by the FIB irradiation procedure [2]. Using a directional scanning of the FIB allows us to grow different crystallographic orientations of the bcc structure with different direction of uniaxial anisotropy. This allows us to spatially change the direction of the uniaxial magnetic anisotropy while keeping the saturation magnetization constant. We exploit this feature to prepare magnonic crystals, where the periodicity arises from the modulation of the uniaxial anisotropy direction. We further investigate the band-structure of the crystals by micromagnetic simulations and Brillouin light scattering.

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Poster Session C

Poster C

P-C.162

Discretized Spin Waves in Single Crystals of the Chiral Magnet Cu2OSeO3

P. Che, I. Stasinopoulos, A. Bauer, J. Waizner, H. Berger, M. Garst, C. Pfleiderer, D. Grundler

Text The chiral ferrimagnet Cu2OSeO3 hosts topologically protected spin textures known as magnetic skyrmions. It has been argued to exhibit very low spin-wave damping [1] and provide novel functionality in magnonics because the skyrmion lattices form magnon band structures with forbidden frequency gaps and minibands [2]. We conducted broadband spin-wave spectroscopy on single crystals of Cu2OSeO3 with magnetic fields applied in different orientations. In the field-polarized phase at 5K we observe numerous sharp resonances that we attribute to discretized spin waves in the mm-long crystals. The dispersion relation of both backward volume magnetostatic spin waves (BVMSW) and forward volume magnetostatic spin waves (FVMSW) were extracted experimentally. A group velocity of -1365 km/s of BVMSW was estimated in the long wavelength limit. The observation of the standing spin waves substantiates a very low damping parameter which is the key for magnonic and microwave applications. We acknowledge SNSF Sinergia Network NanoSkyrmionics CRSII5 171003, DFG TRR80, DFG FOR960 and ERC Advanced Grant 291079 (TOPFIT) for supporting this work.

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Poster Session C

Poster C

P-C.164

Elementary excitations in quantum S=1 paramagnet

E. Vasinovich, Y. Panov, A. Moskvin

Text At variance with s=½ quantum magnets the S=1 spin systems are characterized by a more complicated Hamiltonian with emergence of a single-ion anisotropy and biquadratic inter-site couplings that give rise to novel phase states, in particular, quantum paramagnet. Effective technique to describe elementary excitations for quantum magnets is provided by the method of so-called Schwinger bosons. The method was applied to S=1 spin system[1], however, for a rather simple Hamiltonian. Here, in the paper, we apply the method to an axial S=1 spin system described by a more complicated Hamiltonian including biquadratic terms:

$H = \sum_i (DS^2_{iz} - hS_{iz}) + J_\parallel \sum_{ij} S_{iz}S_{jz} + J_\perp \sum_{ij} (S_{i+}S_{j-} + S_{i-}S_{j+})$

$+ t_T \sum_{ij} (T_{i+}T_{j-} + T_{i-}T_{j+}) + t_b \sum_{ij} (S^2_{i+}S^2_{j-} + S^2_{i-}S^2_{j+})$,

where $T_\pm=\{S_\pm,S_z\}$. Three boson operators are introduced to denote the three S=1 eigenstates: $|+1\rangle = u^+|v\rangle$, $|0\rangle = g^+|v\rangle$, $|-1\rangle = d^+|v\rangle$ with a constraint $u^+u+g^+g+d^+d=1$ (where $|v\rangle$ is the vacuum state). Assuming the quantum paramagnet being the ground state, we make the mean-field decoupling to the four operator terms and after Fourier-Bogoliubov transformation we get the diagonalized Hamiltonian for the two modes of noninteracting magnons. We calculated the dispersion relations for the two modes and the T_c–h phase diagrams for different parameters t_b and t_T, where T_c is the temperature when the magnon energy gap goes to 0, indicating a transition from the large-D quantum paramagnetic phase to the Néel phase.

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Poster Session C

Poster C

P-C.165

First Time-resolved X-ray Microscopy Imaging of Spin Waves in Yttrium Iron Garnet

J. Förster, S. Wintz, J. Bailey, H. Stoll, J. Gräfe, C. Dubs, D. Meertens, E. Josten, M. Weigand, G. Schütz

Text Magnonics, the research of spin waves, has become a prominent topic in magnetism research. The prospect of possible technological applications in future computer technology has played a major part in this development. Yttrium iron garnet (YIG), a ferrimagnetic insulator, has received a lot of attention in this field because of its remarkably low intrinsic damping.

Common measurement techniques for spin waves are Kerr microscopy (MOKE) and Brillouin light scattering (BLS), which are limited in spatial resolution to at best 200 nm. However, for applications the devices and spin waves need to be a lot smaller. Time-resolved scanning transmission x-ray microscopy (TR-STXM) can directly image spin waves with a resolution in space and time of down to 18 nm and 10 ps.

YIG has been a challenge for STXM because of its need for a bulk single crystal substrate. Our group successfully mastered this challenge and we can now present the world's first TR-STXM measurements of spin waves in YIG. We studied a lamella of YIG placed on a silicon nitride membrane. Spin waves were excited by RF-currents via a copper stripline crossing the lamella. Our experiments recorded multiple spin wave modes coexisting in the sample. Most prominent are the Damon-Eshbach and backward volume mode, as well as diagonal modes likely caused by the confinement. We are convinced that the ability to directly image spin waves in YIG at the nanoscale can provide valuable insights for future magnonics research.

Poster Session C

Poster C

P-C.166

Forward volume spin wave interference using YIG films for integrated devices

T. Goto, T. Yoshimoto, K. Sekiguchi, C. Ross, A. Granovsky, Y. Nakamura, H. Uchida, M. Inoue

Text Spin wave integrated circuits (SW ICs) made of thin films of magnetic materials are interesting because of their low power dissipation. In particular, the forward volume (FV) SW is suitable for SW ICs because of its uniform propagation along an in-plane direction. Yttrium iron garnet (YIG) is an excellent waveguide material because of its low damping factor, but there are few reports of SW waveguides made of thin YIG. In this study, we demonstrated the interference of FV SWs in a device made from a 54 nm thick YIG film.
The thin YIG was prepared by pulsed laser deposition and characterized using high resolution XRD, VSM, and, AFM. The crystallinity and magnetization were close to bulk. In addition, high frequency response was analyzed by ferromagnetic resonance using a microstrip line and SW spectroscopy using coplanar waveguides (CPWs). The measured damping factor was about 1.1×10^{-3}. The YIG film was lithographically patterned into a 400 μm by 100 μm region. Three CPWs composed of Au were placed onto the center and the edge of the YIG waveguide. When the difference of phase between two injected SWs were changed, the output SW was successfully changed as expected from theory. An isolation ratio of 19dB was obtained. The effect of the position and tilt angle of CPW with respect to the YIG waveguide was calculated using a 3 dimensional radio frequency simulation, explaining the interference results between out-of-phase SWs.

Poster Session C

Poster C

P-C.167

Frequency linewidth, group velocity and decay length of spin waves in nanotubular magnetic membranes

J. A. Otálora, A. Kákay, J. Lindner, H. Schultheiss, A. Thomas, J. Fassbender, K. Nielsch

Text The curvature of a magnetic membrane was presented as a mean for inducing non-reciprocities in the spin-wave (SWs) dispersion relation (see [Otálora et al. Phys. Rev. Lett., 2016 117, 227203] and [Otálora et al. Phys. Rev. B., 2017 95, 184415]) and with it, the toolbox for controlling SWs was expanded. This toolbox can be further complemented and this talk is oriented in this direction. We show analytically that the membrane curvature is also manifested in the SWs absorption leading to the difference in the frequency linewidth (or lifetime) of counter-propagating magnons. We studied the nanotubular case, predicting changes roughly above 10% and up to 20% difference in the frequency linewidth for nanotube radius between 30 nm to 260 nm and thickness of 10 nm. These percentages are comparable with those that can be extracted from experiments on heavy metal/magnetic metal sandwiches wherein linewidth asymmetry results from interfacial Dzyaloshinskii-Moriya interaction (DMI). Further, we also show that linewidth and group velocity seem to compensate each other, leading to small differences in the SW decay length. The predicted effects are identified to be the classical dipole-dipole interaction and the analytical expression of the frequency linewidth has the same mathematical form as in thin films with the DMI. Our findings consist in a step forward towards the realisation of three dimensional curvilinear magnonic devices.

Poster Session C

Poster C

P-C.168

Injection locking of constriction-based spin Hall nano-oscillators

T. Hache, T. Weinhold, S. S. P. K. Arekapudi, O. Hellwig, H. Schultheiss

Text Spin-Hall nano-oscillators (SHNOs) are modern auto-oscillation devices. Their simple geometry allows for an optical characterization by Brillouin-Light-Scattering microscopy at room temperature.
Here we report on the observation of auto-oscillations in constriction-based SHNOs under the forcing influence of an added microwave current. We show the possibility of injection locking between the applied external signal and the auto-oscillations driven by a direct current. Within the locking range the frequency of the auto-oscillations is forced to the external stimulus. In addition the intensity of the oscillations is increased strongly and the linewidth decreases. Due to the controllability of the auto-oscillations of the magnetization, injection locking could be used to influence the properties of future communication technologies, e.g. based on synchronized constriction-based spin Hall nano-oscillators arrays.
Financial support from the Deutsche Forschungsgemeinschaft within programme SCHU 2922/1-1 is gratefully acknowledged. Samples were prepared at the Nanofabrication Facilities (NanoFaRo) at the Institute for Ion Beam Physics and Materials Research at the Helmholtz-Center Dresden-Rossendorf (HZDR).

Poster Session C

Poster C

P-C.169

Investigation of Spin Wave Propagation in Magnetic Bilayer Systems

M. Geilen, M. Mohseni, M. Grassi, D. Louis, T. Brächer, B. Hillebrands, Y. Henry, M. Bailleul, P. Pirro

Text Surface spin waves have an imaginary wave-vector component across the film thickness, which leads to a localization of this mode to one surface of the film and to non-reciprocal propagation behaviour. But as long as both surfaces of the film are equal and the film itself has homogenous material parameters across its thickness, the frequencies of counterpropagating spin waves are degenerate. This symmetry is broken in a magnetic bilayer system leading to frequency shift between counter-propagating spin waves with the same wavelength.
We present the investigation of spin wave propagation in different bilayer systems. Therefore, the dispersion relations of bilayer films have been modelled using micromagnetic simulations and analytical calculations. The predictions were verified employing wave-vector resolved Brillouin light scattering spectroscopy (BLS). We find that the dispersion relation can be efficiently modified, e.g. to realise magnonic devices with large non-reciprocal propagation, which is an important property for future magnonic computing devices. Using BLS microscopy the propagation of spin waves in microstructured bilayer systems waveguides has been studied.

Poster Session C

Poster C

P-C.170

Magnetic dynamics and spin-phonon interaction in an antiferromagnet with competing exchange interactions Ni_2NbBO_6

M. Prosnikov, A. Smirnov, V. Davydov, N. Lyubochko, S. Barilo, R. Pisarev

Text Orthorhombic crystals of Ni_2NbBO_6 belong to the *Pnma* space group with a 3D long-range antiferromagnetic (AFM) transition at T_N=23.5 K, however its exact magnetic structure still remains unknown. We report on successful growth of Ni_2NbBO_6 single crystals and present experimental results on the both lattice and magnetic dynamics, and interaction between them with the use of polarized Raman spectroscopy in a wide temperature range 10-300 K. Nontrivial manifestations of the spin-phonon interaction with opposite signs of coupling constants, depending on particular phonon modes, were observed below T_N. In the AFM phase, several magnetic modes of different origin were registered at 4, 10.5, and 13.5 meV. While increasing the temperature, the low frequency mode, tentatively assigned to spin-dimer excitation, does not soften, but is strongly dampen and survives up to ~10 T_N with integral intensity at least an order of magnitude higher in comparison to phonon modes. Two weaker high-energy modes were observed only in the AFM phase assigned to two-magnon scattering process. Clear signs of magnon-phonon interactions were observed in the regions of mutual spectral overlapping of these modes.
These excitations were used to construct the model of magnetic structure with appropriate Hamiltonian including three exchange constants and one uniaxial single-ion anisotropy constant. Experimental results are supported by magnetic symmetry analysis and calculations within the linear spin wave theory.

Poster Session C

Poster C

P-C.171

Modulation of spin-wave propagation with time-varying magnetic fields

N. Nishida, P. Matthies, K. Wagner, K. Schultheiss, J. Faßbender, H. Schultheiss

Text We investigated spin-wave propagation under the influence of nanosecond magnetic field pulses in a 2 µm wide spin-wave waveguide made from NiFe. The spin-wave conduit is magnetized perpendicularly to its long axis by an external magnetic field. A coplanar waveguide serves as an antenna for spin waves. In order to modulate the amplitude of the internal field, we apply 20ns long current pulses to a gold conductor that was fabricated below the spin-wave waveguide.
The spin-wave intensity was measured using time-resolved Brillouin light scattering microscopy while applying current pulses with amplitudes that both increase and decrease the effective magnetic field. Depending on the applied microwave frequency, the initial magnetic field and the direction of the pulsed magnetic field, different phenomena are observed: First, short spin-wave packets can be created when starting the field sequence off resonance. Second, a pulse induced shift of spin-wave frequencies is detected when starting at resonance, i.e., when propagating spin waves feel a time dependent magnetic field.
Financial support from the DFG within the programme SCHU 2922/1-1 is acknowledged. N.N. acknowledges funding by the Alexander von Humboldt Foundation. K.S. acknowledges funding by the Helmholtz PostDoc Programme.

Poster Session C

Poster C

P-C.172

Nonreciprocal flexural dynamics of Dzyaloshinskii domain walls

R. Soucaille, F. Garcia-Sanchez, J.-V. Kim, T. Devolder, J.-P. Adam

Text A magnetic domain wall (DW) is a topological spin structure which exhibits a rich variety of dynamics. A particular example involves flexural motion, which is relevant for magnonics as a DW can host spin waves and act as a reconfigurable nanochannel [1]. The 1D model, parametrized by two uniform variables - the internal spin orientation and the mean DW position - fails to capture dynamics that involve DW deformations. We extend the 1D model to account for such a bending of the DW [2]: we account for spatial variations in the DW position and internal spin orientation. We apply this approach to the case of ultrathin ferromagnets with the Dzyaloshinskii-Moriya interaction (DMI), which favors Néel DW with a fixed chirality and induces non-reciprocal propagation of spin wave in a Damon-Eshbach configuration. This non-reciprocal propagation induced by the DMI is also present in spin wave channeling in DW. We show that the non-reciprocal propagation and the resonant frequency can be tuned with an external magnetic field. This non-reciprocity does not only depend on the DMI but also on the dipolar field. We also show that an in-plane magnetic field can destabilize a straight DW configuration when it is close to compensating the DMI.

[1] F. Garcia-Sanchez, et al. Phy. Rev. Letters 114, 247206 (2015).
[2] R.Soucaille et al. arXiv:1802.03068 (2018).

Poster Session C

Poster C

P-C.173

Numerical and analytical treatment of magnonic crystals with modulated direction of uniaxial magnetic anisotropy

O. Wojewoda, L. Flajšman, I. Turčan, J. Petráček, T. Šikola, M. Urbánek

Text In the field of magnonics many approaches have been presented in obtaining crystal like behavior showing e.g. formation of complex band structure with frequency band gaps. Conventionally, the periodic modulation is achieved by changing magnetic properties as saturation magnetization or material thickness [1,2]. We have recently presented a system where the uniaxial magnetic anisotropy can be spatially controlled [3]. This method allows very straightforward mean of fabrication of magnonic crystal, where the direction of the uniaxial magnetic anisotropy is periodically modulated.
In the presented study we explore the behavior of magnonic crystals with modulated uniaxial magnetic anisotropy direction. We developed a numerical model showing complex band structure with apparent band gaps and multiple backfoldings of dispersion at Brillouin zone boundaries. To further investigate and understand the origin of the band structure we also developed analytical model based on the transfer matrix method. From the knowledge of the dispersion of individual regions, the complete dispersion is obtained by solving the eigenvalue problem of the transfer matrix. Both models, with a very good agreement, show that the modulation of the uniaxial magnetic anisotropy direction is sufficient for formation of band structure.

[1] Chumak et al., J. Phys. D: Appl. Phys. 42, 205005 (2009)
[2] Obry et al., Appl. Phys. Lett. 102, 202403 (2013)
[3] Urbánek et al., arXiv:1803.04348, (2018)

Poster Session C

Poster C

P-C.174

Oblique propagation of spin waves in 1D magonic crystal

S. Mieszczak, J. W. Kłos

Text We investigated the propagation of spin waves in one-dimensional planar magnonic crystal which has a form of magnetic layer with periodic modulation in one direction only[1, 2]. The magnetic field is applied in-plane, perpendicularly to the direction of periodicity. We considered the general case of oblique propagation where each spin wave eigenmode can be decomposed into plane waves and Bloch waves for two orthogonal directions (perpendicular and parallel to the direction of periodicity). The Plane Wave Method was used to find the dispersion relation which gives us the information about the magnonic band gaps and allowed directions of propagation. The numerical calculations for dispersion relations were carried out using semi-analytical approach. We solved eigenvalue problem for linearized Landau-Lifshitz equation, where sought solutions of dynamic component of magnetization and material parameters i.e. exchange length and magnetization saturation are expanded analytically into Fourier series.
We showed how to tune the intrinsic anisotropy of dipolar spin waves by introducing the one-dimensional periodic modulation of material or structural parameters.

[1] J. Rychły et al., Phys. Rev. B (2015)
[2] R. A. Gallardo et al., arXiv:1610.04176 (2016)

The research has received funding from Polish National Science Centre project 2016/21/B/ST3/00452, and from the EU's Horizon2020 research and innovation programme under the Marie Sklodowska-Curie GA No644348 (MagIC).

Poster Session C

Poster C

P-C.175

Optimization of magnetic damping in yttrium iron garnet thin films

J. D. Costa, F. Amar, D. Tierno, G. Talmelli, M. Dekkers, T. Devolder, F. Ciubotaru, C. Adelmann

Text Yttrium iron garnet (YIG) is the reference material for magnonic applications due to its very low magnetic Gilbert damping (α). This allows for spin wave lifetimes of hundreds of ns and propagation lengths of the order of mm. Furthermore, its insulating nature prevents eddy current losses and parasitic effects and effectively decouples electrical and magnetic effects. The downscaling of magnonic devices requires high quality thin films (thicknesses < 100 nm) that preserve their spin wave propagation properties.
Pulsed laser deposition (PLD) is an outstanding technique for the deposition of YIG thin films as it allows for nm thickness control as well as epitaxial and stoichiometric deposition leading to very low magnetic damping below $1 \times 10{-4}$. It has been observed that the highest quality films require deposition in an O atmosphere. Moreover, most reports indicate that post deposition annealing is necessary to achieve well crystallized films. Yet, the effects of laser energy, deposition pressure, deposition temperature, annealing temperature, and the interplay between them are not well understood.
To obtain the full picture of YIG PLD growth, we discuss a design of experiments approach based on the four parameters mentioned above. From the resulting set of YIG samples, correlations between those factors and their effect on α were extracted using FMR. The PLD conditions required to achieve state-of-the-art YIG films with minimum damping are then described in detail.

Poster Session C

Poster C

P-C.176

Phase shift of spin waves traveling through the interface with broken spatial inversion symmetry

Y. Gusieva, O. Gorobets, Y. Gorobets

Text One of the biggest challenge in magnonics is spin waves (SWs) amplitude and phase manipulation at subwavelength distances [1]. Nowadays, the SW phase shifters attract much attention of researchers for development the logic devices encoding information in the phase of travelling SW packets and utilizing them for data processing.
We study analytically transmission of normally incident SWs through an ultra-narrow interface with asymmetrical properties. The system consisting of two semi-infinite ferromagnetic medias separated by an interface is considered. Between those medias we assume boundary conditions with broken spatial inversion symmetry (BSIS) [2]. The dependence of phase shift between the transmitted and incident SW on the interlayer exchange coupling is obtained and analysed for different value of parameter BSIS. Also the dependence of phase shift between the transmitted and reflected SW on the interlayer exchange coupling is considered. The new possibility to introduce a controlled phase shift of the propagating SWs is in transmission through interface with BSIS.
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 644348 (MagIC).
[1] Gruszecki P., Mailyan M., Gorobets O., and Krawczyk M. Phys. Rev. B 95, 014421 (2017).
[2] Kruglyak V.V., Gorobets O.Yu., Gorobets Yu.I., Kuchko A.N. J. Phys.: Condens. Matter, V. 26, pp. 406001(2014).

Poster Session C

Poster C

P-C.177

Properties of discrete diffraction in magnonic network

A. Sharaevskaya, E. Beginin

Text Magnonic crystals, which are artificial magnetic media with properties characterized by periodic lateral variation, are of great interest in both pure wave physics and application for future magnonics [1]. Special considerations for such applications are using coupled structures. Moreover, the idea of discrete optical components emerged led to study such components in area of magnonic materials. The main idea is theoretical investigation features of discrete diffraction of magnonic crystals networks .
In this model we assume identical single mode waveguides and weak coupling between them [2]. This allows the decomposition of the field into a sum of localized modes. Thus, we may resort to the discrete model, and use a system of coupled mode equations. Futher, features in Bragg bandgaps of the formation and propagation MSW beam in such planar lattice were showed . Our results for 2D lattice may be useful for component base of new magnonic devices.
The support from RFBR (18-37-00373) acknowledged.
[1] A. V. Chumak, A. A. Serga and B. Hillebrands, J. Phys. D: Appl. Phys. 50,24400,2017.
[2] Falk Lederer , George I. Stegeman, et al., Physics Reports 463,2008.

Poster Session C

Poster C

P-C.178

Protected Chiral Spin-Wave Modes for Backscattering-Immune Magnonic Transport

M. Mohseni, Q. Wang, T. Brächer, D. Bozhko, B. Hillebrands, P. Pirro

Text Spin waves are considered as a promising counterpart of electrons, photons and phonons to serve as information carriers in future wave-based data processing devices. This stimulated a lot of theoretical works on the potential topological protection of spin waves and different systems like, e.g., magnonic crystals have been proposed to host topological spin wave bands. Nevertheless, protected transport is still a great challenge since most of the proposed systems obtain their protection from Dzyaloshinskii-Moriya interaction or strongly inhomogeneous magnetic ground states which are properties that are hard to realize experimentally.
Here, we demonstrate that backscattering-immune spin-wave modes exist even in simple thin film systems which have homogeneous magnetic parameters and feature no DMI. By micromagnetic simulations, we investigate the transmission of different spin-wave modes in YIG films of varying thickness after scattering of the waves by different kinds of defects and inhomogeneities. In particular, we show that chiral waves known as Magneto Static Surface Waves (MSSW), whose reciprocity with respect to the inversion of the propagation direction is broken because of the dynamic dipole-dipole interaction, can be robust against even large inhomogeneities and defects. The protection of MSSW against scattering is particularly strong if the MSSW frequency is located in the band gap of the volume modes which is opened due to the quantized exchange energy.

Poster Session C

Poster C

P-C.179

Reconfigurable spin-wave transport along irregular magnonic waveguide

A. Sadovnikov, A. Grachev, S. Sheshukova, V. Gubanov, Y. Sharaevsky, S. Nikitov

Text Recent progress in the magnon-based electronics shows that spin wave (SW) can be used as a signal carrier in the magnonic waveguiding structures operating in the GHz and THz frequency range. The thin ferrimagnetic films of yttrium iron garnet (YIG) demonstrate significantly smaller spin-wave damping compared to the metallic magnetic films. SW in YIG-based magnonic waveguides and magnonic crystals (MC) can coherently propagate up to millimeter distances at room temperature. The possibility of the electric field tunability of a YIG-piezoelectric microwave devices opens a possibility to develop the strain coupled magnonic waveguides, which combine a relatively low SW damping with good strain coupling strength due to shift due to the the effect of the electric field-to-magnetic field conversion[1,2].

We report on the experimental and numerical study of the SW propagation in the reconfigurable MC waveguide. By the means of microwave vector network analyzer (VNA) and Brillouin light scattering (BLS) technique (by scanning the probing light spot over the MC surface) we demonstrate the electric field induced forbidden gap formation in the SW transmission.

This work was partially supported by the Grant from Russian Science Foundation (#14-19-00760) and Scholarship (SP-2819.2018.5) and Grant (MK-3650.2018.9) of the President of RF.

[1] A. V. Sadovnikov,et al, JETP Letters, 2017, Vol. 106, No. 7, pp. 465–469
[2] A.V. Sadovnikov, et al IEEE Trans. on Magn.2017. Vol. 53 Issue 11. Pp. 1-4.

Poster Session C

Poster C

P-C.180

Spin wave propagation in three-dimensional magnonic crystals

D. Kalyabin, E. Beginin, A. Sadovnikov, A. Sharaevskaya, A. Stognij, P. Popov, S. Nikitov

Text Recent achievements of spin wave investigations in magnonic logic circuits demonstrate the possibility of developing them as promising counterpart to conventional electron-based logic circuits. The use of magnons instead of electrons provide several advantages, namely, low losses, tunability. Current prototypes of magnonic logic gates are represented by the junction of SW interferometers. Control of spin-wave interference opens new perspectives for spin wave logic architecture. We suggest the idea how magnonics can be essentially three-dimensional. We present the novel concept of three-dimensional magnonic structures. We demonstrate results of investigations of the meander magnonic waveguide fabricated on the structured substrate.

We calculated numerically using micromagnetic simulation (mumax3) the dispersion characteristics of propagating forward and backward volume spin waves (out of plane magnetization for horizontal structure regions and in plane magnetisation for vertical joints) and showed how the wave band structure can be formed due to geometrical dimensions of the structures. Tuning geometrical parameters and external magnetic field we can control transmittance characteristics. 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.

The support from RFBR (18-57-76001, 18-07-00509) and RSF (14-19-00760) is acknowledged.

Poster Session C

Poster C

P-C.181

Spin-wave interference in magnetic vortex stacks

C. Behncke, C. F. Adolff, N. Lenzing, M. Hänze, B. Schulte, M. Weigand, G. Schütz, G. Meier

Text Spin waves with wavelengths in the nanometer-range could serve as data carriers in future magnonic logic or signal processing devices. We investigate the interference of spin waves emitted from magnetic vortices in two exchange-coupled vortex stacks. Each layer of the stack contains two vortices leading to an overall number of four vortices in the structure. The spin-wave dynamics are studied using scanning transmission x-ray microscopy at the MAXYMUS microscope of the BESSY II synchrotron in Berlin, Germany and micromagnetic simulations. Different ground state magnetization configurations and their spin-wave excitations are investigated. The two stacks of vortex cores each emit spin waves with tunable wavelength in the 100 nm regime. The spin waves interfere with each other, resulting in different interference patterns dependent on their ground state. Stacks of vortices provide an excellent controllability of spin-wave properties including a tunable wavelength and manipulation of their propagation direction via the magnetization configuration. Furthermore, interference gives rise to amplified or reduced spin-wave amplitudes in distinct areas of the structure providing controlled confinement crucial for possible future applications of spin waves. A cascade of the investigated structure might be used as an efficient way to carry and process information in such devices.

Poster Session C

Poster C

P-C.182

Spin-wave transport in hexagonal nanotubes

M. Zimmermann, J. A. Otálora, S. Wintz, E. Josten, T. Schneider, H. Schultheiss, J. Lindner, C. Back, J. Fassbender, A. Kákay

Text Spin-wave propagation in ferromagnetic nanotubes is fundamentally different than in flat thin films as shown recently[1]. In particular, the dispersion relation is asymmetric regarding the sign of the wave vector. As a consequence, spin waves traveling in opposite directions have different wavelengths. This purely curvature induced effect originates from the dipole-dipole interaction. Such non-reciprocal spin-wave propagation[2] is known for flat thin films with interfacial Dzyaloshinskii-Moriya interaction. In this work we investigate spin-wave transport in nanotubes with hexagonal cross section using micromagnetic simulations and time-resolved Scanning Transmission X-ray Microscopy. The flat thin-film elements combined into a tubular geometry, merges the spin-wave dynamics known from flat thin-films and that of predicted by simulations for nanotubes. When the nanotube is in the vortex magnetic state the spin-wave modes characteristic of nanotubes and the edge modes as well as the modes quantised along the width of the flat edges known from flat films will be present in the dispersion of the hexagonal tubes. Thus the hexagonal tubes provide multiple channels - reciprocal and non-reciprocal ones - for the 3D transport of spin-waves.

[1] J.A. Otálora, et. al., Phys. Rev. Lett. 117, 227203 (2016).
[2] K. Zakeri, et. al., Phys. Rev. Lett. 104, 137203 (2010).

Poster Session C

Poster C

P-C.183

Surface acoustic wave mediated magneto elastic investigation of magnetic thin flm systems

M. Küß, M. Heigl, M. Albrecht, A. Wixforth

Text Magnetostriction describes the geometrical deformation of a magnet, caused by an applied magnetic field. The effect vice versa is named inverse magnetostriction. This mechanism in combination with surface acoustic strain waves (SAW) enables the manipulation of the magnetization on short time scales (~ ns) and on micrometer distances. Since the SAW and magnonic modes are typically excited in the same radio frequency regime, both degrees of freedom have the potential to become strongly or even resonantly coupled [1]. Therefore, not only the magnetization, but also the properties of the SAW itself are characteristically changed. This can be easily measured in a delay line setup, made up of two interdigital transducers (IDT).

Besides highly magnetostrictive ferrimagnetic TbFe thin films, exchanged-biased CoFeB/CoO, consisting of a soft ferromagnet CoFeB and an antiferromagnetic CoO layer, are studied. Because the Néel temperature of the antiferromagnet is at about 160 K, it is possible to probe the impact of the exchange bias effect on the magnetoacoustic interaction below and above the blocking temperature. First results obtained on magnetization reversal at room temperature as a function of sample orientation show good accordance with the theory of elastically driven ferromagnetic resonance.

[1] M. Weiler et al., *'Elastically driven ferromagnetic resonance in nickel thin films'*, Phys. Rev. Lett. 106, 117601 (2011).

Poster Session C

Poster C

P-C.184

Temperature dependence of spin stiffness in ferri-magnet

M. Mori

Text A spin current can be injected into a metal from a ferromagnetic insulator (FI) by applying a temperature gradient. In the spin Seebeck effect, the injected spin current is converted into a voltage by the inverse spin Hall effect. The induced voltage should be proportional to the injected spin current and then also to a magnon density in the FI. However, the experimental data using yttrium iron garnet (YIG) about temperature dependence of the voltage could not be reproduced by theoretical estimations. Motivated by the discrepancy between theory and experiment, many authors have started to study the magnon in the YIG, which is one of typical ferrimagnets frequently used in spintronics. In this study, we will discuss a temperature dependence of spin stiffness, i.e., magnon velocity, in a ferrimagnet by using a simple model of ferrimagnet with two sub-lattice and the random phase approximation.

Poster Session C

Poster C

P-C.185

Towards a Field Theory of Magnetism

U. Köbler

Text From RG theory we know that on approaching the magnetic ordering temperature from the paramagnetic side the magnetic solid assumes the properties of a continuous medium. Microscopic structures such as spins and interactions between spins are unimportant for the critical (spin) dynamics. Unimportance of spins and exchange interactions has two important consequences: first, Hamiltonians are inadequate concepts, and, second, thermal energy is no longer in the system of the interacting spins but has changed via a crossover event to the boson field of the magnetic continuum. As experiments show, thermal decrease of the spontaneous magnetization is given by the heat capacity of the boson field. As we could show, the bosons of the magnetic continuum are magnetic dipole radiation emitted by the precessing spins. Emission is by stimulated emission. As a consequence, the boson fields of ordered magnets have a well defined dimensionality. The dimensionality of the relevant boson field can be recognized from the domain structure. For a three-dimensional boson field there are three types of domains oriented along x-, y- and z-direction. The order parameter is a property on the mesoscopic length scale of the magnetic domains. Domains are, however, not considered in atomistic theories such as the spin wave theory. In this contribution we will show, how the dispersion relations of the bosons and the heat capacities of the associated fields can be evaluated for all dimensions of the field.

Poster Session C

Poster C

P-C.186

Towards direct imaging of GHz magnetic dynamics with sub-100-nm resolution in a transmission electron microscope

Y. Murooka, T. Weßels, R. Speen, V. Migunov, U. Poppe, H. Soltner, A. Kovács, R. E. Dunin-Borkowski

Text Modern spin-based technology has been rapidly advanced by making use of microscopic magnetic processes, such as the generation of spin waves in nanoscale geometries. Subtle differences in nanostructure can result in significant changes in magnetic properties due to the competing energies. Conventionally, direct magnetic imaging is achieved in real space by using quantitative transmission electron microscopy (TEM) methods such as off-axis electron holography and Lorentz microscopy. However, the dynamics of spin waves that are far from equilibrium are often of interest, with excitation frequencies taking values that can exceed 10 GHz. At present, there is no standard technique that can be used to investigate such a time domain with nm spatial resolution. Here, we report a GHz TEM technique that allows the application of in-plane radio frequency (RF) magnetic fields to a sample between the MHz range and 15 GHz, in order to excite spin waves such as magnons. The RF signal is guided to the specimen by a coplanar waveguide, which is patterned on an exchangeable Si chip. The geometry of the guide is optimised using magnetic field simulation. Results obtained from magnetic specimens that are patterned into nanodisks, nanoparticles and nanowires will be presented.

Poster Session C

Poster C

P-C.187

Trimming of Permalloy Stripes to Enhance the Localized Edge Mode Spectrum Probed by Ferromagnetic Resonance

K. Lenz, T. Schneider, G. Hlawacek, R. Narkowicz, S. Stienen, M. Lenz, J. Fassbender, J. Lindner

Text Finite-size effects in ultrathin magnetic films are a well-known feature, i.e., when the surface or interfaces dominate the volume of the sample due to different roughness, texture, hybridization, modified magnetic moment, or dipolar fields. For nanostructures these effects could arise at the side walls as well. This leads to localized spin wave modes (edge modes). It has been shown that the quality of the side walls (angled side walls or roughness) influence these modes [1]. During preparation a certain edge roughness and side wall slope are sometimes inevitable. Nevertheless, in micromagnetic simulations these contributions are usually excluded from the model. We show, how successive trimming the sides of a 5 µm x 1 µm Permalloy stripe by a focused Ne ion beam improves the spin wave spectrum and enhances the edge mode spectrum as probed by planar microresonator ferromagnetic resonance (FMR) [2,3]. Including an rms edge roughness of ~2 nm (within the order of the permalloy grain size) in the simulations is enough to match the FMR data. Hence, we attribute the residual roughness to the ion induced damage by the lateral penetration during trimming of the side walls, and a small remaining edge roughness due to changes in the sputter yield for differently oriented Permalloy grains.

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[2] A. Banholzer et al., Nanotechnology 22, 295713 (2011).
[3] R. Narkowicz et al., Rev. Sci. Instrum. 79, 084702 (2008).

Poster Session C

Poster C

P-C.188

Tunable Spin Wave and Phonon Excitation in Magneto-Electric Fringing Capacitors

H. Ahmad, T. Jost, D. Tierno, M. Geilen, G. Talmelli, I. P. Radu, A. Chumak, B. Hillebrands, P. Pirro, F. Ciubotaru, C. Adelmann

Text A promising direction for future beyond-CMOS based computing technology is based on collective oscillations of quasi-particle-like magnons, also known as spin waves (SWs). Traditionally, SW excitation and detection has been achieved by microwave antennae. Here, we demonstrate the generation of SWs by the magnetoelectric effect using a fringing field capacitor design. The devices are based on thin $(Ba_{0.1}Pb_{0.9})(Zr_{0.52}Ti_{0.48})O_3$ (BPZT) films deposited on Si/SiO_2 substrates as the piezoacoustic layer and lithographically patterned Nickel/Permalloy bilayers as the magnetic waveguides (MWG) of different widths on top of BPZT. Two Au electrodes are patterned and positioned on opposite sides of the MWG with varying gaps. These electrodes produce electric fringing fields inside the piezoelectric layer, which in turn generate oscillating strain. The alternating strain induces a varying magnetic anisotropy in the MWG which changes the internal field and thus excites SWs. Furthermore, the alternating strain generates propagating phonon as well. Using microfocus Brillouin light scattering, we have experimentally investigated both phonon and SW generation inside the MWG. Furthermore, we show that the intensity of excited phonons can be tuned by applying DC bias voltages while the SW intensity can be changed by magnetic bias fields and DC voltages.

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Poster C

P-C.189

Yttrium iron garnet microwaveguide structures for magnonic networks

Y. Khivintsev, V. Sakharov, S. Vysotskii, A. Kozhevnikov, G. Dudko, Y. Filimonov, A. Khitun

Text Magnetostatic surface (MSSW) and backward volume (MSBVW) waves' propagation both in single waveguide (WG) and WGs combined in 8-port network (NW) was studied. Three types of the structures based on the 1µm-thick YIG film were explored: A) the WG of the constant width $w_A \approx$ 100 µm having length L≈ 800 µm; B) the WG with narrowed central part up to width $w_B \approx$ 20 µm; C) the NW consisting of four crossing WG having $w_C \approx$10 µm and $L_C \approx$ 100 µm.

In the structure “A”, the transmission band for both MSSW and BVMSW was extended in comparison with the plain YIG film due to spectra quantization effect through the waveguide width w. For “B”, the narrowed part works as a below-cutoff WG for the width modes with numbers n<5. Because of this filtration effect only quasiuniform (n=0) modes are capable to propagate through the narrowed part. In the case of the longitudinally magnetized WG “B”, the transmitted MSBVW signal increases by 10 dB. The last effect is due to higher group velocity of the quasiuniform MSBVW mode with respect to any width one. In addition, for the structure “B”, we observed the wavelength transformation effect due to different contribution of the shape anisotropy for the wide and narrow parts of the WG “B”. For “C”, the transmission efficiency from port 1 to ports 2-8 was enhanced and was almost of the same value for all ports at the frequency corresponding to the spin wave resonance across the YIG film thickness.

This work supported by the RSF project 17-19-01673.

Poster Session C

Poster C

P-C.190

Anomalous Hall conductivity of Fe, Co and FeCo under pressure

R. Gonzalez-Hernandez, B. Dupe, J. Sinova

Text The Anomalous Hall Effect (AHE) is a phenomenon which consists of an extra 'anomalous' transverse voltage developing when current is passed through a ferromagnetic material in a magnetic field [1]. In this work, we studied the dependence of pressure effect on the intrinsic anomalous Hall conductivity (AHC) in 3d transitions metals as Fe-bcc, Co-fcc, Co-hcp and in the FeCo alloy. In the case of Fe and FeCo, the AHC shows a slightly decreasing with the increase of pressure, being this associate to the magnetization dependence with the lattice constant. However, the AHC for lattices constants above of equilibrium (P=0) shows a downturn around of 70%, even when the magnetization has increased. This decreasing seems to be related to the change of electronic occupations of the d-states close to the Fermi level. In addition, the pressure independence of the AHC was observed for Co. The computation of the anomalous Hall conductivity was carried out using ab-initio calculations (included the effect of spin-orbit interaction for the ferromagnetic state) and the Wannier interpolation technique for the application of the Kubo-Greenwood formula [2].

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Poster Session C

Poster C

P-C.191

Application of Spin-Correlated Radical Pair System to Liposomal DDS under Exposure to Magnetic Fields

H. Nakagawa, M. Ohuchi

Text Spin-correlated radical pair mechanisms are known as the one and only phenomenon by which magnetic fields can switch over chemical reaction paths in spite of their low energies. In the present situation, some reports have shown the magnetic field effects with enzymatic reactions as the central figure, although exposures of biological systems to magnetic fields don’t have a perfect command of every radical reaction *in vivo*. Judging from the best of our knowledge, there are almost no reported studies of the application of radical pair mechanisms to drug-release controlling under exposure to magnetic fields. A radical pair is an extremely short-lived reactive intermediate, a liposomal membrane includes an extremely high viscos nonpolar zone in its bilayer structure to prolong the lifespan of the pair for the most efficient magnetic field effects. In this study, we carried out research into a new drug-release technology using liposomal nanoparticles equipped with magnetic controls. The tests observing the magnetic field effects might provide useful information on drug targeting. Hence, the use of radical pair mechanisms in liposomal drug-release technology is a promising new area of research.

Poster Session C

Poster C

P-C.192

Chemical design of single-ion magnets: a statistical study for quantum technologies

J. T. Coutinho, Y. Duan, J. J. Baldoví, L. E. Rosaleny, S. Cardona-Serra, A. Gaita-Ariño, E. Coronado

Text During the past 25 years, a new class of molecular magnets has gained its particular area in the field of Molecular Magnetism. Single-molecule magnets (SMMs) have become an important topic of research mainly due to their remarkable potential applications in spintronic devices, but also as they straddle the classical and quantum mechanical world, displaying fascinating phenomena from both sides.
An important breakthrough occurred with the report of mononuclear double-decker phthalocyanine complexes in 2003, by Ishikawa *et al.*, with the magnetic behavior ascribed to the mononuclear lanthanide. This study created a revolution in this field by showing slow relaxation of magnetization as a single-molecular property and since then hundreds of compounds have been published.

The measure of quality for SMMs in the context of molecular magnetism is translated directly, in the context of spin-based quantum technologies, into the spin-lattice relaxation time (T1). Thus, any insights obtained for the chemical design of molecules that perform well as SMM will be applicable in the design of resilient molecular spin qubits.

Driven by these interesting chemical and physical phenomena, the main purpose of this study was to perform a statistical analysis, and the correspondent database, of these mononuclear SMM compounds. Herein, I will present the methodologies and main guidelines to achieve these results that hopefully will led to the application of these compounds on quantum technologies.

Poster Session C

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P-C.193

Determination of crystal field parameters for Nd ions in Y_2SiO_5 and Sc_2SiO_5.

R. Eremina, V. Tarasov, A. Sukhanov, R. Likerov, I. Yatsyk, Y. Zavartsev, S. Kutovoi

Text The cells of the quantum simulation based on Josephson junctions are actively developing in the last decades offering high frequency data processing in the microwave range. The ability to convert quantum states from microwave photons to optical photons is important for hybrid system approaches to quantum information processing. The problem of conversion quantum states of microwave photons into optical photons and vice versa can be resolved by using impurity rare-earth ions in dielectric crystals. Y_2SiO_5 (YSO) and Sc_2SiO_5 (SSO) single crystals doped by 143Nd ions are examples of such systems. We investigated impurity ^{143}Nd ions in YSO and SSO. Crystal field parameters of $^{143}Nd^{3+}$ impurity centers in isotopically pure (^{28}Si) YSO and SSO single crystals were determined using data of EPR spectroscopy and the known schemes of electron levels. The ESEEM spectroscopy was used to determine crystal position of the $^{143}Nd^{3+}$ impurity ions in Y_2SiO_5 single crystal. It is established that neodymium ions substitute yttrium ions in the Y2 positions with seven nearest yttrium ions. We assume that it is due to the strong difference in Nd and Y ionic radii neodymium impurity ion strongly disturbs the structure the nearest environment. The values of the crystal field parameters for impurity Nd^{3+} ion in Y_2SiO_5 and Sc_2SiO_5 crystals are calculated on the basis of optic spectra and principal values of the g-tensor. This work was supported by the Russian Science Foundation (project no. 16-12-00041).

Poster Session C

Poster C

P-C.194

Experimental evidence of pinned solitons in anion-radical salt (Et-2,6diMe-Pz)(TCNQ)$_2$

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Text The crystal structure and magnetic properties of the new organic anion-radical salt (Et-2,6diMe-Pz)(TCNQ)$_2$ were investigated. The temperature dependence of magnetic susceptibility was measured in the temperature range from 1.8 K to 300 K and a spin-Peierls transition was observed at a temperature 165 K. Investigation of the crystal structure above and below the transition temperature confirms a crystal structure change related to the spin-Peierls transition. The observed transition is further accompanied by the appearance of a λ-anomaly in the temperature dependence of specific heat at the transition temperature. Electron paramagnetic resonance (EPR) experiments at 2 K, well below spin-Peierls transition, show evidence of S=1/2 species previously identified as pinned solitons. Our dynamic susceptibility measurements reveal a long spin-lattice relaxation time, which is a prerequisite for the observation of long quantum coherence time as observed in similar systems [1].

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Poster Session C

Poster C

P-C.196

Integration of molecular quantum bits with semiconductor spintronics

M. Kern, S. Bechler, H. S. Funk, M. Winkler, D. Weißhaupt, I. A. Fischer, S. Ludwigs, J. Schulze, J. van Slageren

Text Molecular nanomagnets hold great promise for quantum computing, as they have been shown to exhibit coherence times from tens of microseconds up to almost a millisecond. The molecular nature of these systems offers the possibility for extended chemical tailoring for higher coherence times or surface self-assembly.

To address the molecules, we plan to use spin polarized charge carriers in a spin valve geometry with various spin transport possibilities to programme/readout the quantum state of the qubits. We will try to interface these molecules with spin polarized carriers in Ge channels, in organic layers and in organic single crystal magnetic conductors. For the first option, we have already started to study spin injection into Ge channels from Mn_5Ge_3 ferromagnetic electrodes via the Hanle effect. We have developed a novel, CMOS compatible manufacturing possibility of the ferromagnetic electrodes and prepared 4-terminal structures. We have used these structures to study spin transport in highly doped Ge channels and observed spin injection up to 36 K. Next step will be combining this technology with molecular quantum bits.

To investigate the possibility of interfacing magnetic molecules with organic semiconductor technology, we are manufacturing hybrid materials made of conducting polymers and molecular qubits. We have successfully observed quantum coherence in the microsecond regime in thin films of these hybrid materials using a custom Fabry-Pérot resonator at 35 GHz.

Poster Session C

Poster C

P-C.198

Multitechnique investigation for rational design of molecular qubits

L. Tesi, M. Atzori, S. Benci, A. Lunghi, E. Morra, M. Chiesa, R. Righini, A. Taschin, R. Torre, L. Sorace, R. Sessoli

Text Molecular spins are quantum objects and, as such, they open the way to several applications: hybrid quantum architectures, quantum sensors, spintronics and quantum computation.(1) The great advantages in the use of molecules lie in their extraordinary tunability, of relevance for the realization of quantum-gates,(2) for their scalability, and for their processing.(3) The manipulation of their quantum properties has been already proved by performing Rabi Oscillations experiments with pulsed electron spin resonance (EPR), showing that coherence times limited by spin-lattice relaxation time, T1, can be achieved with a judicious design of the nuclear environment.(4) In this framework, effects of molecular vibrations, or phonons, on the relaxation mechanisms have been the focus of increasing attention. Thanks to a multitechnique approach based on alternate current susceptibility, cw and pulsed EPR, and time-domain THz spectroscopy, we have evidenced correlations between the low energy vibrations and T1 in molecular qubits.(5,6) These results are here presented for a series of vanadyl-based compounds, where a rational choice of ligands structure and coordination environment allow modulations of the spin dynamics.

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Poster Session C

Poster C

P-C.200

Skyrmion morphology in ultrathin ferromagnets revealed by scanning-NV magnetometry

I. Gross, W. Akhtar, L. Martinez, S. Chouaieb, A. Hrabec, J. Sampaio, B. Shields, P. Maletinsky, A. Thiaville, S. Rohart, V. Jacques

Text Magnetic skyrmions in ultrathin ferromagnetic films are appealing for potential applications in spintronics mainly because they are expected to display limited interaction with disorder, leading to highly efficient motion at low current densities. Surprisingly, several recent experiments have instead shown that skyrmion dynamics are in fact strongly affected by disorder [1], suggesting that pinning effects have been oversimplified in seminal simulations of skyrmion dynamics [2]. These observations motivate a more precise description of disorder in magnetic materials hosting skyrmions. Here, nitrogen-vacancy magnetic microscopy is employed in quenching mode as a non-invasive, high resolution tool to investigate the morphology of isolated skyrmions in ultrathin magnetic films [3]. The skyrmion size and shape are found to be strongly affected by local pinning effects and magnetic field history. Micromagnetic simulations including static disorder, based on a physical model of grain-to-grain thickness variations, reproduce all experimental observations and reveal the key role of disorder and magnetic history in the stabilization of skyrmions in ultrathin magnetic films. This work opens the way to an in-depth understanding of skyrmion dynamics in real, disordered media.

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Poster Session C

Poster C

P-C.201

Spin lifetime of optically pumped rubidium atoms in solid parahydrogen

A. Kanagin, S. Upadhyay, J. Weinstein

Text At the turn of the 21st century, it has become obvious that the field of quantum information and quantum technologies will vastly expand into our everyday lives. Whether at the forefront or quietly working in the background, the transition from the classical methods of storing or collecting data to its quantum counterpart is upon us. A promising candidate to lead us into the new and exciting technological era is the field of spin manipulation.

Currently at UNR, we have grown crystals of solid parahydrogen using a single closed-cycle cryostat. We have doped the crystals with rubidium atoms at densities on the order of 10^{17} cm^{-3} and used optical pumping to polarize the spin state of the implanted atoms. The optical spectrum of the rubidium atoms shows larger broadening than previous work in which the rubidium was implanted in solid argon or neon. However, the optical pumping behavior is significantly improved, with both a larger optical pumping signal and a longer longitudinal relaxation time. The spin relaxation time shows a strong dependence on orthohydrogen impurity levels in the crystal, as well as the applied magnetic field. Current performance is comparable to state-of-the-art solid state systems at comparable spin densities, with potential for improvement at higher parahydrogen purities.

Poster C

P-C.202

Thermalization of nuclear spins in a diluted $TbPc_2$ crystal

G. Taran, E. Bonet Orozco, W. Wernsdorfer

Text In the field of molecular magnetism, mononuclear lanthanide complexes occupy a special place because of their simple structure and strong uniaxial anisotropy. Amongst multiple examples of such systems, the $TbPc_2$ single molecular magnet (SMM) was often found at the center of attention, starting with the first studies that showed bistability and quantum tunneling of magnetization, and more recent ones, were it was successfully incorporated in spintronics devices. A special feature of $TbPc_2$ SMM, besides it's large zero field splitting, is the strong hyperfine interaction between the electronic shell and the nucleus of the Tb^{3+} ion. This interaction leads to hyperfine states that are well resolved and are clearly observed in magnetization curves that show quantum tunneling transitions. Through this presentation we report on the experimental observation of the thermalization process of nuclear spins in a $TbPc_2$ diluted crystal at subkelvin temperatures. From the analysis of the time dependence of the population of the hyperfine states we extract the lifetimes of individual levels and we identify the relaxation mechanism that connects the phonon bath with the nuclear spins. The possibility to readout the nuclear spin states using the dynamics of the electronic spin and the observation of the thermalization process, are unique features that make $TbPc_2$ a very attractive system for subsequent studies of coherence at the mesoscopic scale.

Poster Session C

Poster C

P-C.203

Universal quantum magnetometry with spin states at equilibrium

F. Troiani, M. Paris

Text Quantum sensing and metrology are the arts of using quantum system to design precise estimation protocols. A magnetic field is a typical quantity whose estimate can be obtained through a quantum probe. The most widely pursued approach ultimately relies on the measurement of the quantum phase accumulated by the spin, due to its interaction with the field. These protocols typically require the coherent control and dynamics of the spin state. Systems at thermal equilibrium represent a possible alternative, whereby the state preparation, though less general, is greatly simplified, and decoherence no longer represents a limiting factor.

In this paper, we address metrological protocols for the estimation of the intensity and the orientation of a magnetic field, and show that quantum-enhanced precision may be achieved by probing the field with an arbitrary spin at thermal equilibrium. We derive a general expression for the ultimate achievable precision, as given by the quantum Fisher information, and express this quantity in terms of common thermodynamic quantities. We also seek for the optimal observable, and show that it corresponds to the spin projection along a suitable direction, defined by a universal function of the spin temperature. Finally, we prove the robustness of our scheme against deviations of the measured spin projection from optimality.

Reference:
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Poster Session C

Poster C

P-C.204

Vibrations and spin relaxation in molecular spin qubits

L. Escalera-Moreno, A. Gaita-Ariño, N. Suaud, E. Coronado, J. J. Baldoví

Text The closely related fields of molecular spin qubits, single ion magnets and single atom magnets have been shaken in recent years, with a jump in the phase memory times of spin qubits from a few microseconds to almost a millisecond in a vanadium complex, magnetic hysteresis up to 60 K in a dysprosium-based magnetic molecule and magnetic memory up to 30 K in a holmium atom deposited on a surface. This rapid improvement in the physical properties deserves urgent attention. The old assumption of focusing on the energy barrier for the reversal of the spin orientation is clearly insufficient. Indeed, to design molecular spin qubits that are able to operate at high temperatures, there is an urgent need to understand the relationship between vibrations and spin relaxation processes. We will present a very simple first-principles methodology to determine the modulation that vibrations exert on spin energy levels. By theoretically identifying the most relevant vibrational modes, this methodology can help us offer general strategies to chemically design more resilient magnetic molecules, where the energy of the spin states is not coupled to vibrations.

Poster Session C

Poster C

P-C.205

Colloidal topological insulators

J. Loehr, D. de Las Heras, A. Jarosz, M. Urbaniak, F. Stobiecki, A. Tomita, R. Huhnstock, I. Koch, A. Ehresmann, D. Holzinger, T. Fischer

Text Topological insulators insulate in the bulk but exhibit robust conducting edge states protected by the topology of the bulk material. Here, we design a colloidal topological insulator and demonstrate experimentally the occurrence of edge states in a classical particle system. Magnetic colloidal particles travel along the edge of two distinct magnetic lattices. We drive the colloids with a uniform external magnetic field that performs a topologically non-trivial modulation loop. The loop induces closed orbits in the bulk of the magnetic lattices. At the edge, where both lattices merge, the colloids perform skipping orbits trajectories and hence edge-transport. We also observe paramagnetic and diamagnetic colloids moving in opposite directions along the edge between two inverted patterns; the analogue of a quantum spin Hall effect in topological insulators. We present a new, robust, and versatile way of transporting colloidal particles, enabling new pathways towards lab on a chip applications.

Poster Session C

Poster C

P-C.206

Edelstein effect in Weyl semimetals

A. Johansson, J. Henk, I. Mertig

Text In systems with broken inversion symmetry, such as Rashba and Dresselhaus systems as well as threedimensional topological insulators, an external electric field can generate a macroscopic spin polarization. This phenomenon is known as inverse spin galvanic effect or Edelstein effect [1-3].
Using semiclassical Boltzmann transport theory, we predict a current-induced spin polarization in Weyl semimetals, similar to the Edelstein effect of surface states in Rashba systems or in topological insulators. The theory is applied to the Weyl semimetal TaAs simulated by an effective two-band model [4,5], for which we estimate the magnitude of the Edelstein effect. The main contribution comes from the topological surface states, i.e. the Fermi arcs, which provide an enormous current-induced spin polarization enhanced by at least one order of magnitude in comparison to Rashba systems and the surface states of topological insulators [6].

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Poster Session C

Poster C

P-C.207

Geometrically induced reversion of Hall current and magnetic monopole in a topological insulator cavity

W. Campos, W. Moura-Melo, J. Fonseca

Text Topological insulators (TI's) are known to support gapped bulk band structure, and metallic surface states protected by time reversal symmetry (TRS). Breaking the TRS yields the so-called topological magneto-electric effect (TMEE). Whenever TMEE is in order, an external electric (magnetic) field induces both polarization and magnetization in the material. It has been shown that an electric charge near the plane surface of a TI induces an image magnetic monopole inside its bulk [1]. Here, we consider a configuration in which the TI surface has a negative curvature. More specifically, we calculate the induced Hall current and magnetic field generated whenever the electric charge is placed near a semispherical cavity in the surface of a TI. Our results show that a reversion in the rotation of the induced Hall current is achieved whenever the electric charge crosses the semisphere focus. Such a reversion is shown to be equivalent of inverting the charge of the image magnetic monopole [2]. We also discuss upon the case of a semicylindrical cavity, where the Hall current is separated into two branches of opposite reversible directions. These reversions are characteristic of negatively curved surfaces, and in general cannot happen in null (plane) nor positive (sphere-like) Gaussian curvature surfaces [1]. The authors thank CAPES, CNPq and FAPEMIG for financial support.

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Poster Session C

Poster C

P-C.208

Hybrid Weyl semimetal under electromagnetic field: field tuning of spectrum type

Z. Alisultanov, G. Abdullaev, N. Demirov

Text Due to the unique properties, Weyl semimetals (WSMs) are promising materials for future electronics. Currently, the two types (type-I and type-II) of WSMs are discovered experimentally. These types of WSMs differ from each other in their topological properties. In this paper we showed that a coexistence of type-I and type-II Weyls fermions is possible in some WSMs under crossed magnetic and electric fields. This situation is possible in systems with non-equivalent Weyl points (WPs). In particular, it is possible in strained WSMs. Such phase controlled by electromagnetic field is absolutely new for physics of topological systems. It is obvious that in this regime, the new features of electron transport will appear. We showed that this effect also can be considered as a mechanism of strain induced type-II-type-I transition. We applied our results to the hybrid WSM. The electromagnetic field induces transition between different types of spectrum in Weyl point. Thus, phase of hybrid WSM can be tunable using electromagnetic field. Finally, we proposed a new field-induced type of hybrid WSM in which a one of WPs is electric type (no Landau levels) and the other WP with opposite chirality is magnetic type (there are type-I Landau levels). Such situation arises if magnetic field is along the (010).

Poster Session C

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P-C.209

Interlayer Exchange Coupling between Ferromagnetic Films through Topological Insulators

S. Mehboodi, A. G.Moghaddam

Text Spintronics is the branch of physics for the study of the intrinsic feature of the electron (spin), and its associated magnetic moment, in addition to its fundamental electronic charge in solid state devices. Spintronics emerged in the 1980s concerning spin dependent electron transport phenomena in solid state devices. This includes the discovery of giant magnetoresistance (GMR) independently by Albert Fert and Peter Grunberg (1988). The simplest giant magnetoresistive device contains a paramagnetic layer which is sandwiched by ferromagnetic films. The study of these structures has been done for both metallic and insulator spacer. The topological insulators are new phase of matter that has noticeable features like spin-momentum locking. These substances are conductance in the surface and insulator-like in bulk. We investigated the interlayer exchange coupling (IEC) between ferromagnetic films through topological insulators. This study has been done in terms of quantum interferences due to confinement of electron wave function. This approach provides a remarkable physical view of the interlayer exchange coupling mechanism. In this thesis, we found that the interlayer exchange coupling between ferromagnetic films is independent of magnetism in the x direction. Moreover, it is different for various ferromagnetism configurations.

Poster Session C

Poster C

P-C.210

Laser induced DC photocurrents in 3D topological insulators/ferromagnet heterostructures and Nanowires

N. Meyer, T. Schumann, E. Schmoranzerová, K. Geishendorf, G. Mussler, P. Nemec, A. Thomas, D. Grützmacher, M. Münzenberg

Text Topological Insulators (TI) open up a new route to influence the transport of charge and spin in a surface film via spin-momentum locking [1,2]. It has been demonstrated experimentally [2] that illuminating a TI by circularly polarized light can result in excitation of a helicity-dependent photocurrents.

In this poster, we will sum up our results on (Bi, Sb)$_2$Te$_3$ thin films covered with a ferromagnetic layer and Bi_2Se_3 core-shell nanowires. We illuminate the TI's with visible laser light and analyze the photocurrent measured between two gold contacts, and determine the periodicity in the polarization dependence of the laser light. The position of the laser light can be changed in two directions parallel to the sample surface. Thus, we measure a 2D map of polarization dependent photocurrents.

We detect a polarization dependent photoinduced current depending on the position of the laser light, consistent with results at room temperature reported by McIver et al. [1]. The signal can be switched by the lights polarization properties but is very weak. Furthermore, we see lateral accumulation of spin polarization at the TI's edges and close to the ferromagnet.

We acknowledge funding through DFG priority program SPP "Topological Insulators" and DAAD PPP Czech Republic "FemtomagTopo".

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Poster Session C

Poster C

P-C.211

Magneto-transport properties of Bismuth Thin Films Grown on Kapton

N. Koutsokostas, A. Pilidi, C. Collia, C. Christides, T. Speliotis

Text Bismuth (Bi) thin films with thickness of 50 nm were grown by magnetron sputtering on kapton flexible substrates, at temperatures of 20, 80, 120, 200 and 270 ^{0}C. Atomic Force Microscopy (AFM) and Scanning Electron Microscopy (SEM) measurements reveal a nano-granular structure, with a progressive change of grain morphology and texture for samples grown at different temperatures. Resistivity and magnetoresistance (MR) measurements were performed with a PPMS, between 2K and 300K. Systematic variations in angular dependence of MR and of weak- antilocalization (WAL) effect were observed as a function of Bi growth temperature. Analysis of grain size distributions are related to systematic changes observed on magneto-transport properties [1] of Bi films as a function of in-situ temperature of growth. A comparison of film morphology and MR effect observed on Bi films grown at the same conditions on [2] Si and kapton substrates, shows that growth on kapton allows a direct connection of MR effects to Bi nano-granular structure.

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Poster Session C

Poster C

P-C.212

Magnetotransport Properties of Bi-Sb Thin Films

A. Pilidi, G. Kopnov, A. Gerber, T. Speliotis

Text The study of topological insulators (TIs) - new state of quantum matter - is now one of the fastest increasing research areas. Topological insulators are materials that are insulating in their bulk but can support the flow of electrons on their surface[1]. High-quality bulk single crystals of $Bi_{1-x}Sb_x$ alloy in the "insulating" regime, is the first material to be known as a 3D topological insulator, a novel state of quantum matter distinct from graphene, with a strongly spin–orbit coupled insulator, an odd number of Dirac points and a negative Z_2 topological Hall phase[2].
A series of $Bi_{1-x}Sb_x$ (x=0, 0.1, 0.2, 0.3, 0.5, 1, atomic percent) films were prepared with magnetron sputtering on $Si_{(111)}$ substrates. After the deposition films were annealed for 30 min at 80 ^oC in order to reduce the surface roughness due to bismuth coarsening during deposition. Results from x-rays show the (00*l*) preferential texture of bismuth at high bismuth concentrations and this texture disappears when antimony concentration increases. A detailed study of the magnetotransport - by a standard four-probe method on a square 4x4mm^2 sample - was performed, both the resistance $R_{xx}(B)$ and the Hall resistance $R_{yx}(B)$ were measured by sweeping B between +12 and -12 T from low temperatures up to RT.

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Poster Session C

Poster C

P-C.213

Majorana Modes in A Non-Superconducting Wire

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Text Searching for Majorana Fermions (MFs) in condensed matter systems has emerged as a very exciting field of research, especially after the recent experimental verification of edge modes in the topological materials. And these edge modes in 1D can manifest into Majorana Zero Energy Modes (MZMs). In this work we discuss the possibility of creating a topological phase, and MZMs, in a 1D wire that obeys attractive Hubbard interactions, in the presence of spin-orbit coupling and a Zeeman field. We show by calculation of the lowest energy gaps, and expectation values of the single spin creation operator, that the existence of MZMs is more likely in systems with low electron fillings and weak Zeeman field strengths, and can be created upon introduction of a parabolic potential in the system.

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P-C.215

Structural and magnetotransport characterization of Bi_2Te_3 - Co bilayer magnetron sputtered thin films

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Text Bi_2Te_3, besides being a thermoelectric material, is also a three-dimensional topological insulator, with surface states consisting of a single Dirac cone at the Γ point of the Brillouin zone. Topological insulator properties of Bi_2Te_3 have been examined so far in films prepared by molecular beam epitaxy or chemical methods, but not in magnetron sputtered ones, whereas this process is industrially relevant. Thin film samples of Co - Bi_2Te_3 bilayers, with either material as top layer and nominal thicknesses 12-50 nm were prepared via magnetron sputtering on Si(111) substrates, by using Co and Bi_2Te_3 targets. During the deposition of Bi_2Te_3, at 3 mTorr pressure, the substrate was heated at 300 ^oC. Crystallinity was investigated by x-ray diffraction (XRD), while surface morphology studies were performed using atomic force microscopy (AFM) and field emission scanning electron microscopy (FESEM). A preferred 00l texture was obtained with Bi_2Te_3 as the bottom layer. Magnetoresistance (MR) and Hall measurements were performed over a temperature range 2.5-300 K on bar-shaped specimens in a QD-PPMS 9T system. Samples with Bi_2Te_3 on top present hysteresis up to 1 T field and linear MR at higher fields. In samples with Co on top, MR does not become linear at high fields, while a sharp cusp close to zero field at low temperatures, below 10 K, is analysed as weak antilocalization effect (WAL).

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P-C.216

Structure, magnetism and magnetotransport of Bi_2Se_3 thin films with flat Eu-containing inclusions

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Text In most studies of magnetic topological insulators (TI) the distribution of magnetic atoms was assumed to be homogenous. We have studied the case of highly inhomogeneous distribution. Introducing Eu atoms into the film have led to the formation of flat inclusions (FI) observed by means of the transmission electron microscopy. At higher Eu content we've also observed the stacks of FI separated by single quint-layers of Bi_2Se_3.

With the increase of Eu content studied films start to demonstrate non-linear magnetic response that saturates below 1T. Unexpectedly, the magnetic moment per Eu atom start to decrease at higher doping levels. Theoretical estimations shows that the exchange interaction between FI is governed by magnetic dipole-dipole interaction. Thus, FI stacking leads to their antiferromagnetic ordering, resulting in lower values of magnetic moment per Eu atom.

We've observed weak antilocalization effect without consecutive weak localization for all studied films. But in doped films the dephasing length saturates below 2K, and it's value seems to correlate with the FI concentration. At higher magnetic fields a region of linear magnetoresistance appears which cannot be described in terms of common theories or simple superposition model. Thus, we assume that the main transport features of TI in our case are conserved due to the locality of magnetic FI interaction with carriers on the interfaces of the film.

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P-C.217

Topological Magnon Materials and Transverse Magnon Transport

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Text Insulating magnetic materials with a trivial electronic topology can still be topologically nontrivial with respect to the magnetic excitations. Using linear spin-wave theory, I theoretically demonstrate how to realize different topological phases in insulating magnets with magnons: the magnon pendants to topological insulators [1] as well as Weyl [2] and nodal-line semimetals are presented [3].
Similar to the electronic case, nonzero Berry curvature of one-magnon Bloch states causes transverse spin and heat transport, that is, magnon Hall, Nernst, and Righi-Leduc effects [1]. These effects can be quantified by spin dynamics simulations and the classical Green-Kubo relations which are used to study the topological magnon insulator Cu(1,3-benzenedicarboxylate) [4].

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