SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 1

SP8 - Parallel Session 1

SP8.1.02

Real-space imaging of non-collinear antiferromagnetic order with a single spin magnetometer

I. Gross, W. Akhtar, L. Martinez, S. Chouaieb, V. Garcia, K. Garcia, C. Carretero, A. Barthelemy, P. Appel, P. Maletinsky, J. Kim, J.-Y. Chauleau, N. Jaouen, M. Viret, M. Bibes, S. Fusil, V. Jacques

Text Recently, Antiferromagnets have attracted considerable attention for next generation spintronic devices owing to their unique properties such as ultrafast magnetization dynamics and insensitivity to external magnetic field. To harness these unique traits for next-generation spintronics, the nanoscale control and imaging capabilities that are now routine for ferromagnets must be developed for antiferromagnetic systems. Here, using a non-invasive scanning nanomagnetometer based on a single nitrogen-vacancy (NV) defect in diamond [1,2], we demonstrate real-space visualization of non-collinear antiferromagnetic order in a magnetic thin film, at room temperature. We image the spin cycloid of a multiferroic BiFeO3 thin film and extract a period of ~70 nm, consistent with values determined by macroscopic diffraction. In addition, we take advantage of the magnetoelectric coupling present in BiFeO3 to manipulate the cycloid propagation direction by an electric field [3]. Besides highlighting the unique potential of NV magnetometry for imaging complex antiferromagnetic orders at the nanoscale, these results demonstrate how BiFeO3 can be used as a versatile platform for the design of reconfigurable nanoscale spin textures.

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SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 1

SP8.1.03

Nanoscale imaging of antiferromagnetic order using single-spin magnetometry

B. Shields, P. Appel, T. Kosub, N. Hedrich, J. Faßbender, R. Hübner, D. Makarov, P. Maletinsky

Text The nitrogen-vacancy (NV) color center in diamond is an exceptional atomic-scale system with a coherent electronic spin degree of freedom that can be initialized and measured optically. These properties make the NV attractive for applications ranging from quantum information to nanoscale metrology. Here, we use the NV electronic spin as a quantum scanning magnetic field probe to quantitatively image antiferromagnetic order in a granular thin film of Cr2O3. By incorporating a single NV into the tip of a monolithic diamond atomic force microscopy probe and monitoring the Zeeman shift of the NV ground state spin[1], we image the stray magnetic field of a 200-nm thick film of Cr2O3 at nanoscale resolution, observing the formation of antiferromagnetic domains as the film transitions from paramagnetic to antiferromagnetic order. In combination with Zero-Offset Hall Magnetometry[3], we characterize key material properties of the Cr2O3 sample, including local critical temperature and inter-granular exchange.

SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 1

SP8.1.04

Magnonic Transport In Single Crystal Antiferromagnetic Insulators over 40 µm

R. Lebrun, A. Ross, S. Bender, J. Cramer, L. Baldrati, A. Qaiumzadeh, R. A. Duine, A. Brataas, M. Kläui

Text Antiferromagnets are the most ubiquitous class of magnetic materials. They are stable, impervious to external fields and operate at THz frequencies. There are predictions that current-induced spin-orbit torques can manipulate the magnetic order with unparalleled efficiency. However, antiferromagnetic spin transport has so far been demonstrated only over distances of a few nm. Here, we report the injection and propagation of magnonic spin currents in a single crystalline easy axis antiferromagnetic insulator (AFI) over long distances.

In antiferromagnets, the degenerate magnon modes independently transport angular momentum so that at equilibrium, there is no net spin transport. We us the Spin-Hall effect to generate an interfacial spin-accumulation so that this “spin-bias” breaks the degeneracy of the magnon modes. This yields a finite spin conductance of the antiferromagnetic magnons. The conductance is further enhanced by reducing the magnon gap at the spin-flop field, where Néel vector rotates perpendicularly to the applied field. We demonstrate that the compensated moment (Néel order) of a 3d transition-metal AFI can convey spin information as efficiently as the net magnetic moments in the best ferromagnets, with persisting signals at 40 µm. This is a factor 1000 larger than previously observed propagation distances. These novel spin transport mechanisms open the way to low-power and ultra-fast AFM insulator based spin-logic devices and interconnects at room temperature.

SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 1

SP8.1.05

Néel Spin Orbit Torque driven antiferromagnetic resonance in Mn2Au probed by time-domain THz spectroscopy

N. Bhattacharjee, A. Sapozhnik, S. Bodnar, V. Grigorev, S. Y. Agustsson, D. Dominko, O. V. Gomonay, J. Sinova, M. Kläui, H.-J. Elmers, M. Jourdan, J. Demsar

Text Antiferromagnetic (AFM) materials are attracting significant interest in the field of spintronics. One of the key advances in this field is the recent proposal of an all-electrical switching of the staggered magnetization in metallic AFMs with a lack of local inversion symmetry. Here, charge currents produce a staggered Néel spin-orbit torque (NSOT), which presents a novel route of manipulating metallic AFMs. Indeed, current switching has been experimentally realised recently in CuMnAs and Mn2Au.

Aiming at determining the possible switching rates in the metallic antiferromagnet Mn2Au, which are determined by the collective mode frequencies, we performe temperature dependent THz spectroscopy on thin Mn2Au films. We observe a strong absorption centered near 1 THz. Upon heating from 4 K to 450 K the mode shows softening and displays a pronounced loss of intensity. A comparison with the estimated eigenmode frequencies implies that the observed mode is an in-plane antiferromagnetic resonance (AFMR) mode. Based on its absorption strength, which exceeds those found in antiferromagnetic insulators by three orders of magnitude, and recent observations of the current induced switching in Mn2Au, we suggest this AFMR mode to be driven by the Néel spin-orbit torque generated by the THz driven in-plane current, and not by the magnetic field of the THz radiation.

SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 1

SP8.1.06

Role of thermal activation in the electrical switching of antiferromagnetic Mn_2Au and CuMnAs

M. Meinert, D. Graulich, T. Matalla-Wagner

Text We report on the electrical switching of magnetron-sputtered films of Mn_2Au and CuMnAs. In both materials, a exponential dependences of the switching amplitude on the current density are observed. We analyze the switching with a macroscopic stochastic switching model and propose an analytical expression for the critical curent density required to switch the Néel vector in the presence of thermal activation. A kinetic Monte Carlo technique is applied to simulate the switching and quantitative agreement between experiments and model calculations is obtained. The switching is thermally assisted by the Joule heating of the current pulses, which facilitates the switching of Mn_2Au. The electrically set magnetization state of Mn_2Au is long-term stable at room temperature ($\Delta = E_B / k_BT = 60$) [1]. We estimate the spin-orbit torque efficiency as 0.25 ... 0.15 mT / (10^{11} A/m^2), in reasonable agreement with the prediction by Zelezny et al. [2]. In the case of CuMnAs, we find a notable dependence of the switching amplitude per pulse on the temperature, with a pronounced peak around 260K. Similar switching behaviour as compared to Mn_2Au is observed, however at much smaller current densities and in agreement with the previously reported switching in epitaxial CuMnAs [3].

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SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 1

SP8.1.07

Spin-dependent transport and dynamics of antiferromagnetic skyrmions

C. Akosa, O. Tretiakov, G. Tatara, A. Manchon

Text The control of the magnetic state of nanoscale magnetic textures by spin-polarized current is attracting enormous interest as a promising mechanism for ultra-fast, ultra-dense and innovative memory applications [1,2]. In spite of the remarkable properties such as weak sensitivity to defects [3, 4] and ultra-low critical current density [4-6], ferromagnetic skyrmions suffer from the parasitic effect of skyrmion Hall effect which hinder its robust electrical manipulation. Recently, antiferromagnetic skyrmions which shows no skyrmion Hall effect [7,8] has been proposed as alternative candidate for memory applications.

We demonstrate that the non-trivial magnetic texture in antiferromagnetic skyrmions promotes a non-vanishing topological spin Hall effect on the flowing electrons which results in a substantial enhancement of the non-adiabatic torque and hence improves the skyrmion mobility. This non-adiabatic torque increases when decreasing the skyrmion size, and therefore scaling down results in a much higher torque efficiency.

References

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SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 2

SP8 - Parallel Session 2

SP8.2.01

Current induced Néel vector manipulation and large AMR of Mn2Au

M. Jourdan, S. Bodnar, L. Smejkal, A. Sapozhnik, H.-J. Elmers, J. Sinova, M. Kläui

Text Using antiferromagnets as active elements in spintronics requires the ability to manipulate and read-out the Néel vector orientation. We demonstrate for Mn2Au, a good conductor with a high ordering temperature suitable for applications, reproducible switching using current pulse generated bulk spin-orbit torques and read-out by magnetoresistance measurements [1]. Reversible and consistent changes of the longitudinal resistance and planar Hall voltage of star-patterned epitaxial Mn2Au(001) thin films were generated by pulse current densities of 10^7 A/cm2. Consistent measurements of the anisotropic magnetoresistance (AMR) and the planar Hall effect (PHE) showed pulse current direction dependent reversible changes, providing direct evidence for Néel vector switching (Fig. 1). Easy read-out of the switching is provided by a large amplitude of the AMR of more than 6%, which is more than an order of magnitude higher than previously observed for other antiferromagnetic systems and one of the highest AMR amplitudes found for metallic magnetic thin films. We can reproduce the magnitude of the effect theoretically by including realistic disorder. The mechanism of the Néel vector manipulation is discussed in the framework of AFM domain wall motion.
[1] S.Yu. Bodnar, L. Šmejkal, I. Turek, T. Jungwirth, O. Gomonay, J. Sinova, A.A. Sapozhnik, H.-J. Elmers, M. Kläui, and M. Jourdan, Nature Commun. 9, 348 (2018).

SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 2

SP8.2.02

Dynamical spin-orbitronic effects in ferro- and antiferromagnets

F. Souza Mendes Guimarães, M. dos Santos Dias, S. Lounis

Text The interplay between charge and spin has been extensively studied in ferromagnetic structures, which are easy to detect and manipulate. Recently, the focus has shifted to antiferromagnets, presenting new features in the field of spin-orbitronics such as being insensitive to magnetic fields and offering faster dynamics. For a deep understanding of the mechanisms present in these complex structures, a microscopic material-specific *dynamical* theory, as the one we developed [1,2], is crucial. In this work, we investigate the different dynamical behavior of ferromagnetic FePt and antiferromagnetic PtMn. We demonstrate how the resonances, reaching the THz range, can be excited by electrical means and how they may enhance the currents flowing through the system. Combining the best of both worlds [3], we also build an idealized FePt/PtMn bilayer, coupled through the exchange bias, to identify how the ferromagnet/antiferromagnet interface contributes to the dynamical magnetization and transport properties. The layer-resolved magnetic interactions and spin-orbit torques can also be used to understand switching processes of this type of heterostructures.

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[3] S. Fukami *et al.*, Nature Materials **15**, 535 (2016)

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SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 2

SP8.2.04

Electrical control of antiferromagnetic domain walls

S. Reimers, P. Wadley, M. J. Grzybowski, C. Andrews, M. Wang, J. S. Chauhan, B. L. Gallagher, R. P. Campion, K. W. Edmonds, S. S. Dhesi, F. Maccherozzi, V. Novak, J. Wunderlich, T. Jungwirth

Text To date, antiferromagnets play only a passive role in spintronics applications, although they have a number of favourable properties as active elements including ultra-fast dynamics, zero stray fields and insensitivity to external magnetic fields[1]. Tetragonal CuMnAs is a testbed system in which the antiferromagnetic order parameter can be switched reversibly in ambient conditions using electrical currents[2]. Previous experiments used orthogonal in-plane current pulses to induce 90° rotations of antiferromagnetic domains and realize all-electrical memory bits in a multi-terminal geometry[3]. Here[4], we demonstrate that antiferromagnetic domain walls can be manipulated to realize stable and reproducible domain changes using only two electrical contacts. In this geometry, the polarity of the current is reversed in order to switch the sign of the current-induced magnetic fields. The resulting Néel spin orbit torque acts primarily on the domain wall. The resulting reversible domain and domain wall reconfigurations are imaged using x-ray magnetic linear dichroism in photoemission electron microscopy, and can also be detected electrically. The switching by domain wall motion can occur at much lower current densities than coherent domain switching.

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SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 2

SP8.2.05

Field-Free Spin-Orbit Torque-Induced Magnetization Switching and Spin Hall Magnetoresistance in Exchange-Biased W/Co/NiO system

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Text Spin-orbit torque (SOT)-induced magnetization switching provides an alternative for non-volatile memory and logic devices. SOT-switching of perpendicular magnetization is usually observed in an external magnetic field collinear with the current, which however, is impractical in device applications. Here, we investigate the SOT generated by heavy metal (W), which induces switching of Co layer in perpendicularly magnetized exchange-biased (EB) multilayer structure: W(4.3)/Co(0.5 – 1.5)/NiO(10) (thickness in nm). W and Co layers were deposited by magnetron sputtering in Ar atmosphere, whereas the NiO layer was prepared in a separate chamber in O_2 atmosphere using pulsed laser deposition. The in-plane EB at the interface of ferromagnetic Co and antiferromagnetic NiO induces the effective in-plane magnetic field of +130 Oe and leads to deterministic SOT-driven field-free switching. In 10 x 100 μm^2 Hall bars with 0.81 nm thick Co the lowest critical current density of 7.6•1010 A/m^2 was measured that is four times smaller than in Pt(3)/CoFe(0.9)/IrMn(3)/Pt(1) structure - Ref [1]. In addition, we investigate the Spin Hall Magnetoresistance as a function of Co thickness and analyze the results with the spin drift-diffusion model taking into account different interfacial mechanisms.

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SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 2

SP8.2.06

Probing Pt/Ir_xMn_{1-x} Interface Magnetism via Spin Hall Magnetoresistance

T. K. H. Pham, M. Ribeiro, J. H. Park, T. H. Kim

Text Magnetic Pt/Ir_xMn_{1-x} (x = 0, 0.25) interfaces were studied as a function of their preparation conditions by measuring spin Hall magnetoresistance (SMR) in Pt. A systematic study of the SMR for different growth temperatures and thicknesses of antiferromagnetic Ir_xMn_{1-x} layer was carried out to obtain information of the interface magnetic properties, which is inaccessible by conventional magnetometers. Using UHV-MBE co-evaporation technique, Ir_xMn_{1-x} films with thickness ranging from 1.5 to 30 nm were grown on unetched Si wafers, and then followed by in situ deposition of a 3-nm-thick Pt through a meal shadow to fabricate laterally defined Hall bars. The evolution of IrMn film morphology and microstructure was characterized by AFM and XRR. The influence of growth conditions on surface roughness and ordered domains and their correlations to the SMR were carefully explored. The SMR appeared to be dramatically affected by the interface roughness. It was shown that the crystallographic part probes the increase in the interface roughness while the magnetic one clearly revealed a maximum in the in-plane magnetization of the interface. Zero-field-cooled and field-cooled resistivity versus temperature measurements of the patterned Hall bar Pt, grown on the IrMn films thinner than 5 nm, revealed clearly the existence of antiferromagnetic order at the interfaces below 150 K. Our results provide further insight into interfacial magnetic properties of ultrathin antiferromagnetic films.

SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 2

SP8.2.07

Parameters Controlling Switching of Antiferromagnetic CuMnAs Memory Cells

K. Olejnik, Z. Kašpar, V. Novák, T. Jungwirth

Text The manipulation of antiferromagnetically ordered magnetic moments using current induced staggered spin-orbit fields opened prospects for practical realization of antiferromagnetic spintronics devices [1][2]. In our recent study of terahertz writing speed in CuMnAs memory devices we have demonstrated the key advantage of antiferromagnetic memories: the writing speed limit in THz range which is significantly exceeding the GHz range of ferromagnetic memories [3]. We also found that the temperature plays an important role in the writing process for pulse lengths from nanosecond range down to picosecond range. Here we further investigate the role of the temperature in the writing process. In particular we focus on the separation of the effects of current induced Joule heating and staggered spin-orbit field by experiments with CuMnAs memory device equipped with an independent nanopatterned heater. The results point to the heat assisted nature of the writing process since the writing becomes effective only after reaching certain threshold temperature.

References:
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SP8 - Parallel Session 3

SP8 - Parallel Session 3

SP8.3.01

Magnetoelectronic properties of the non-collinear antiferromagnet $Mn_3Zn_{0.5}Ge_{0.5}N$

S. Deng, G. Fischer, S. Srichandan, C. Sürgers

Text Antiferromagnetic perovskites often exhibit a non-collinear arrangement of magnetic moments giving rise to a number of interesting magnetic properties, including magnetocaloric effect, giant magnetoresistance, barocaloric and baromagnetic effect, negative or zero thermal expansion [1-3]. Here, we investigate the magnetoelectronic behavior of polycrystalline $Mn_3Zn_{0.5}Ge_{0.5}N$, a Mn-based antiperovskite with a Néel temperature T_N = 411 K. Neutron diffraction performed at room temperature reveals the existence of a Γ^{5g} non-collinear antiferromagnetic phase with triangularly arranged magnetic moments in the (111) plane. We further investigate the resistivity and the anomalous Hall effect for temperatures 1.8 - 300 K and in magnetic fields up to 8 T. The change of the anomalous Hall effect at low temperatures and its sensitivity to small changes of the magnetic texture indicates a structural distortion of the crystalline lattice and an accompanied modification of the magnetic structure generating a non-coplanar component. In contrast, the longitudinal magnetoresistance does not show strong changes with temperature or magnetic field. Magnetization and specific-heat measurements support the weak modification of the antiferromagnetic phase at low temperatures.

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SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 3

SP8.3.02

Angle dependent magnetoresistance in nonmagnet/antiferromagnet metallic heterostructures

S. DuttaGupta, A. Kurenkov, R. Itoh, S. Fukami, H. Ohno

Text Utilization of antiferromagnets (AFMs) as primary and active components of spintronic devices offers several unique advantages which can complement ferromagnet based devices [1, 2]. One of the pertinent questions concerns the manipulation and electrical detection of Néel vector (n) which governs magnetization dynamics in AFM. Experimental results have shown the prevalence of magneto-resistance (MR) studies as a robust tool for probing AFM dynamics [3, 4]. An investigation concerning the dynamics of n under applied magnetic field (H) and/or current in all-metallic AFM heterostructures have remained elusive. Here, we study MR effects in asymmetric (MgO/Pt0.38Mn0.62/Pt) and symmetric (Pt/Pt0.38Mn0.62/Pt) heterostructures.

Polycrystalline multilayers films are patterned into µm-sized devices by photolithography and Ar ion milling. We measure longitudinal and transverse components of MR using current reversal method for H rotations in x-y, y-z and x-z planes. A finite magnetoresistance is observed in all three planes indicating an interplay of anisotropic and spin Hall contributions leading to modulation of n. AFM thickness dependence of MR will also be discussed. Our results direct towards the potential of a new candidate material for AFM spintronics.

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SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 3

SP8.3.03

Broadband spintronics diodes for energy harvesting

B. Fang, M. Carpentieri, P. Khalili Amiri, G. Finocchio, Z. Zeng

Text Energy harvesting technologies offer a promising approach to capture energy from ambient sources. Among them, the ambient radio-frequency (RF) electromagnetic signals provide an attractive energy source for applications in self-powered portable electronics. However, currently available microwave detectors based on semiconductors do not meet the practical requirements for energy harvesting applications. We show a bias-field-free nanoscale spintronic diode (NSD) based on a MTJ and demonstrate that this NSD could be an efficient harvester of broadband ambient RF radiation, capable to efficiently harvest microwave powers of microWatt. We measured the rectified voltage in absence of magnetic field by applying an RF current to the device through a bias tee. The spin-polarized current excites a magnetization precession which creates a rectification voltage VDC across the MTJ that is highest near the FMR frequency. The frequency response of the NSD shows that a novel type of frequency behaviour, i.e. broadband response, is achieved. We see that for a RF input power PRF=10 μW, the NSD rectifies a constant voltage across a 100 to 550 MHz range [1]. Our results also demonstrate that the power generated by NSDs is sufficient to drive active devices for use in low-power electronic systems, showing their potential as self-powering devices for applications in wireless sensing and portable electronics in the emerging era of “internet of things”.

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SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 3

SP8.3.04

Quantum Anomalous Hall Effect and Anderson Chern Insulating Regime in noncollinear Antiferromagnetic 3Q State

P. B. Ndiaye, A. Abbout, A. Manchon

Text Anomalous Hall effect has been recently demonstrated to emerge in certain classes of co-planar antiferromagnets possessing spin-orbit coupling. In this work, we study the transport properties and the band structure of a non-trivial antiferromagnet characterized by a non-linear and non-coplanar spin texture on a triangular lattice in the absence of spin-orbit coupling. For this model, known as the 3Q state, we demonstrate the occurrence of both quantum anomalous Hall and disorder-induced Anderson Chern insulating phases. We show the emergence of a spin-polarized edge-localized current, calculate the non-Abelian Berry curvature and discuss the corresponding symmetries. A phase diagram due to the consideration of a second nearest neighbours is obtained and the conditions to get two-fold degenerate double Dirac cones are given.

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SP8 - Parallel Session 3

Auto-oscillations in antiferromagnetic domain walls excited by spin currents

R. Khymyn, R. Ovcharov, J. Akerman, E. Galkina, B. Ivanov

Text Recently, it has been proposed to use antiferromagnets (AFM) as active layers of spin-torque nano-oscillators (STNO) due to their ability to operate at high frequencies, up to the THz range. In such STNOs, the spin current, flowing into an antiferromagnetic material (AFM) induces a torque on the AFM order parameter – so called "Neel vector". Wherein, the direction of spin current polarization defines the plane of Neel vector rotaion. To excite auto-oscillations the input current must overcome the threshold, created by the in-plane magnetocrystalline anisotropy and, as a result, only STNOs based on easy-plane AFMs are practically feasible. To overcome the problem, we propose here to employ the spin current induced dynamics in the aniferromagnetic domain walls (DWs). We show that the spin current can excite a precession of the Neel vector within a DW with a tunable frequency up to antiferromagnetic resonance, i. e. up to THz range. Moreover, the excitation of the auto-oscillations does not have a threshold in applied current for uniaxial AFM. We also demonstrate, that for the certain AFM materials, such as MnF2, the presence of Dzyaloshinskii-Moriya interaction (DMI) leads to a coupling of translational and precessional dynamics of such a DW. As a result, the excitation of precession creates oscillations of a DW position and vice versa. At the high-frequencies these oscillations can emit the spin waves into the surrounding AFM through the effect of Cherenkov radiation.

SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 3

SP8.3.06

Spin currents in non-collinear antiferromagnets

J. Železný

Text Antiferromagnets have recently attracted considerable attention in the spintronics community because they have some unique advantages over ferromagnetic materials and spintronics provides means of accessing and utilizing the antiferromagnetic order. Compared to ferromagnetic materials, however, the range of spintronic functionalities available in the most studied simple collinear antiferromagnets, is limited. In contrast, in non-collinear antiferromagnets, symmetry is lower and more spintronics effects can be present. The non-collinear antiferromagnets could thus combine the advantages of collinear antiferromagnets such as fast magnetic dynamics with the useful functionalities of ferromagnets.

Here, we discuss spin currents in non-collinear antiferromagnets of the Mn3X type. Our work [1] shows that a spin current flowing in the same direction as the charge current occurs in these antiferromagnets. This means that, like in ferromagnets, the charge current in the Mn3X is spin-polarized. In addition, we also show that a transverse spin currents occur in these antiferromagnets. This includes the conventional spin Hall effect, but also a new type of spin Hall effect, originating from the magnetic structure. We present microscopic calculations of torques resulting from spin currents in nanoscopic devices

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SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 3

SP8.3.07

Spin Hall effects in non-collinear antiferromagnetic Mn3X (X = Ir, Sn, Ge) thin-films

J. Taylor, E. Lesne, A. Markou, C. Felser, S. S. P. Parkin

Text Antiferromagnetic (AFM) materials have potential applications in spintronic devices operating without net magnetization. Non-collinear AFMs are of particular interest to antiferromagnetic spintronics because the topological character of their chiral spin texture drives novel phenomena such as a large anomalous Hall effect (AHE), and an intrinsic spin Hall effect (SHE).

In this work, we report the epitaxial growth of thin films of the non-collinear AFMs Mn3X (X = Ir, Sn, Ge) using magnetron sputtering, and on the investigation of their structural, magnetic and electrical properties by a combination of X-ray diffractometry, transmission electron microscopy, SQUID magnetometry, magnetotransport, and ferromagnetic resonance.

Magnetotransport, as a function of temperature and applied field angle, was measured in lithographically patterned devices. Temperature dependent AHE and anisotropic magnetoresistance (AMR) are explained in connection to the materials' magnetic properties. Finally, temperature dependent spin torque ferromagnetic resonance (ST-FMR) experiments in the Mn3X/ferromagnet bilayers are shown, in order to investigate SHE. A spin-orbit torque (SOT) generated by the AFM is detected, and its relationship to exchange bias explored. We discuss possible origins of this SOT, in terms of both bulk and interface antiferromagnetism. In addition, we present the first results of XLMD-PEEM experiments in an attempt to study the antiferromagnetic domain structure of these materials.

SP 8 Antiferromagnets and antiferromagnetic spintronics

SP8 - Parallel Session 3

SP8.3.08

Spin Hall magnetoresistance in antiferromagnetic NiO/Pt bilayers

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Text Antiferromagnetic materials promise improved performance for spintronic applications, as they are robust against external magnetic field perturbations and allow for faster magnetization dynamics compared to ferromagnets. However, the direct observation of the antiferromagnetic state is challenging due to the lack of magnetization. Here, we probe the antiferromagnetic insulator NiO by investigating the spin Hall magnetoresistance (SMR) effect in a heavy metal electrode of Pt in a NiO/Pt bilayer heterostructure. While we rotate an external magnetic field in the easy plane of NiO and record the longitudinal and the transverse resistivity of Pt, we observe an amplitude modulation consistent with the SMR. In comparison to Pt on collinear ferrimagnets, the modulation is phase shifted by 90° and its amplitude quadratically increases with the magnitude of the magnetic field [1]. We explain the observed magnetic field dependence of the SMR in a comprehensive model taking into account magnetic field-induced modifications of the domain structure and magnetoelastic effects in the antiferromagnetic layer [1]. Our detailed study shows that the SMR is a versatile tool to gain understanding of the magnetic spin configuration and to investigate magnetoelastic effects in antiferromagnetic multi-domain materials. With our generic model, we are further able to estimate the strength of the magnetoelastic coupling.

[1] J. Fischer et al., Phys. Rev. B 97, 014417 (2018).

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SP8.4.01

Synthetic antiferromagnetic coupling between ultra-thin insulating garnets

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Text The use of ferromagnetic insulators (FMIs) is attracting a lot of interest due to a rich variety of spin dependent phenomena with potential applications to spintronics devices. Downscaling is an important factor for these devices and so maintaining magnetic properties of the FMI at reduced dimensions is considered key for deterministic magnetization reversal due to spin-orbit torque[1] or for guiding magnons[2].
In this work, we fabricate ultra-thin yttrium iron garnet (YIG) / gadolinium iron garnet (GdIG) insulating bilayer epitaxially grown on gadolinium gallium garnet (GGG), confirmed with structural and compositional characterization by transmission electron microscopy. From spin Hall magnetoresistance[3], a powerful tool to to study the surface magnetization of FMIs, and X-ray magnetic circular dichroism measurements, we show the presence of a negative exchange interaction between YIG and GdIG that constitutes a novel insulating synthetic antiferromagnetic state[4]. This realization could open new venues for insulators in magnetic devices[5]. For instance, we show that the complex interplay between the negative exchange interaction and the demagnetizing fields of the layers induce a memory effect that could be exploited[4].

1. C. O. Avci et. al., Nat. Mater. 16 (2016)
2. A. V. Chumak et. al., Nat. Phys. 11 (2015)
3. H. Nakayama et. al., Phys. Rev. Lett. 110 (2013)
4. J. M. Gomez-Perez et al., arXiv: 1803.05545
5. R. A. Duine et. al., Nat. Phys. 14 (2018)

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SP8.4.02

Spin pumping and enhanced damping in the vicinity of the antiferromagnetic-ferromagnetic phase transition of FeRh

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Text As a promising candidate in thermally assisted magnetic recording and recently emerged antiferromagnetic (AFM) spintronics, FeRh attracts great interest due to its first-order phase transition from AFM to ferromagnetic (FM) phase upon heating. In this work, we focus on the spin pumping near the phase transition of FeRh. Ultrathin FeRh films of 5 nm and 10 nm capped with Pt or Al were investigated via inverse spin Hall effect, using a coplanar waveguide. In addition to the observed spin pumping in FeRh capped with Pt, an enhancement of damping and broadened linewidth are detected during the AFM-FM transition of FeRh for all samples. Both of the spin pumping voltages and calculated damping by sweeping *T* display hysteretic windows, in analogy to the hysteretic *T*-dependent magnetization loops. Based on the field rotation and frequency-dependent measurements at different temperatures, it reveals that the dominated origin is probably from the enhanced two-magnon scattering during the phase transition, with regard to the AFM domain nucleation and growth. In contrast, the effect of intrinsic damping including lateral spin pumping on the enhancement of damping might be negligible, due to the constant orbital to spin moment ratios for FeRh during its first-order phase transition. These findings would provide scientific insight into the spin dynamics of a single material with coexistence of AFM and FM domains, and would also advance their practical application.

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SP8.4.03

Interface proximity effects near a domain wall in antiferromagnet/superconductor heterostructures

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Text While antiferromagnetic textures show some advantages over ferromagnetic analogs [1], because they lack net magnetization they are difficult to detect [2]. We demonstrate transport singularity near antiferromagnetic domain walls due to interface proximity effects in antiferromagnet/superconductor heterostructures. Thus far, most such studies have utilized ferromagnet/superconductor heterostructures, where Cooper pair quasiparticles made of opposite spins experience the exchange field averaged over the superconducting coherence length and induce superconductivity into the magnetic layer over a finite length [3]. A magnetic domain wall with opposite spins on either side of the wall lowers the averaged exchange field and provides an additional and more efficient superconducting pathway in the magnetic layer. We discuss in this work series of experimental results for antiferromagnet/superconductor heterostructures. We created domains in the antiferromagnet and varied the antiferromagnetic configuration from multi- to single-domain. The gradual enhancement of the superconducting critical temperature with the amount of domain walls in the antiferromagnet demonstrates that the length scales into play allow for the electrical detection of antiferromagnetic domain walls via the localized penetration of superconducting states [4].

[1] O. Gomonay et al, PRL 117, 017202 (2016)
[2] V. Baltz et al, RMP 90, 015005 (2018)
[3] A. I. Buzdin, RMP 77, 935 (2005)
[4] G. Forestier et al, to be pub.

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SP8.4.04

Thermally induced ultrafast magnetization dynamics; ferromagnets vs antiferromagnets

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Text Antiferromagnetic materials are in the focus of current research in magnetism because of their potential for applications in spintronics. Antiferromagnetic spin dynamics are proposed to beat ferromagnetic dynamics both in speed and efficiency. However, little is known about their dynamics in a wide range of relevant timescales, such as i) thermally activated magnetic reversal, and ii) femtosecond laser induced sub-picosecond magnetic order relaxation.

First, as for ferromagnets, their magnetic stability in nanostructures will be limited by thermal excitations. Here, we investigate the superparamagnetic limit of antiferromagnetic nanoparticles theoretically, focusing on a comparison to the known properties of ferromagnetic particles. We find a drastically reduced stability because of the exchange enhancement of the attempt frequencies and the effective damping during the antiferromagnetic switching process.

Second, we investigate the relaxation time of the antiferromagnetic order parameter under the application of an ultrafast heat pulse, and find that indeed antiferromagnets can respond up to one order of magnitude faster than ferromagnets. We find theoretical expressions for the relaxation times, and that the reason behind this strong difference relies in the effective damping of the system caused by the exchange coupling between sublattices, absent in ferromagnets. These findings have strong implications for ultrafast control of magnetic states in antiferromagnets.

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SP8.4.05

Thin Film Granular Magnetoelectric Antiferromagnets

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Text Antiferromagnetic thin films have recently shown their promise for applications [1]. Beside metallic antiferromagnets [2], oxide based magnetoelectric materials like BFO [3] and Cr_2O_3 [4] are promising for the realization of RAM. In Cr_2O_3 thin films, several extrinsic effects can influence the behavior of the material including the emergent ferrimagnetism [4], granularity, interface states [4-6] and interaction with metal electrodes [5,6].
In this context, we present a comprehensive study of these effects and evaluate their effect on device performance. We exploit extremely sensitive Zero-Offset Hall measurements [5] of the non-zero magnetization as well as Nitrogen Vacancy Magnetic Microscopy [4,7] of the domain patterns for Cr_2O_3 thin films. We can track the magnetic ordering and derive important quantities such as pinning of antiferromagnetic domain walls and the intergranular exchange. Furthermore, we will focus on the physics of electron transport in Cr_2O_3/Metal bilayers.

[1] T. Jungwirth et al., Nat. Nano. 11.3 (2016): 231.
[2] P. Wadley et al., Science 351.6273 (2016): 587-590.
[3] J. T. Heron et al., Nature 516.7531 (2014): 370.
[4] T. Kosub et al., Nat. Comm. 8 (2017): 13985.
[5] T. Kosub et al., Phys. Rev. Lett. 115 (2015): 097201.
[6] R. Schlitz et al., Appl. Phys. Lett. 112 (2018): 132401.
[7] I. Gross et al., Nature 549.7671 (2017): 252.

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SP8.4.06

Growth and characterization of non-collinear antiferromagnetic Mn_3Sn films

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Text Non-collinear hexagonal antiferromagnets (AFMs) Mn_3Z (Z = Ge and Sn) have received much attention in recent years, due to their remarkable structural, magnetic and magnetotransport properties. Non-collinear AFMs are particularly promising, with the topological character of their chiral spin texture yielding novel phenomena, such as giant anomalous Hall effect (AHE) [1], driven by non-vanishing Berry curvature. Until now, the only reports on these materials study bulk polycrystalline or single crystal samples.
Here, we report the growth of the Mn_3Sn compound in thin film form. Mn_3Sn films with different thicknesses were heteroepitaxially grown on ZrO_2 substrates with a Ru underlayer. The films crystallize in the hexagonal $D0_{19}$ structure with (0001) preferred orientation. TEM analysis confirms the crystal structure of the films, while at the same time reveals a nearly perfect heteroepitaxy of the epilayers. Chemical mapping shows that the films are homogeneous and there is no intermixing between the film and the underlayer. The Mn_3Sn films exhibit a small in-plane net magnetization. Additionally, we have studied the exchange bias effect in a Mn_3Sn/Py bilayer. Exchange bias fields of H_{EB}=14 mT can be achieved, with a blocking temperature very close to room temperature. The exchange bias can be used to investigate spin transfer phenomena applicable to the developing field of antiferromagnetic spintronics.

[1] A. K. Nayak et al., Sci. Adv. 2, e1501870 (2016)

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SP8.4.07

Ultrafast dynamics of antiferromagnets induced by spin-orbit torques

O. Gomonay

Text Searching for optimal ways to manipulate the states of antiferromagnets (AFs), we focus on ultrafast dynamics of AFs induced by the electrically-created spin-orbit torques of different types and their combinations. We show that simultaneous application of the field-like Néel spin orbit torque (NSOT) and the antidamping spin orbit torque (SOT) induces fast and reach dynamics with multiple regimes which can be attained by tuning amplitudes and time dependence of the torques. For example, while the NSOT by itself induces switching between the different AF states, combining the NSOT with the SOT allows to reduce the threshold current necessary for reliable switching. Moreover, ultrashort pulses of the SOT-creating spin current facilitate the NSOT-induced switching and result in noticeably shortening of the switching time. We also show that depending on the spin current parameters, the SOT by itself can produce different effects on an AF: static tilting of the Néel vector, forced oscillations, or autooscillations at THz frequency. Combining the SOT with the oscillating NSOT allows to stabilize and control the frequency of autooscillations via the phase locking effect. Our results are summarized in the phase diagram of static and dynamical states of an AF depending on the amplitudes of the NSOT and SOT. These results can be used for tailoring of new spintronic devices and optimization of their working regimes.

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SP8.4.08

Electrical conductivity of antiferromagnetic Dirac quasi-particles

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Text We study the influence of a change in Neel vector orientation on electrical conductivity in antiferromagnetic Dirac nodal-point and nodal-line semimetals. In certain PT symmetric antiferromagnetic materials, such as CuMnAs, protected anti-crossings occur when the Neel vector is oriented along a crystallographic high-symmetry axis [L. Šmejkal et al. PRL 118, 106402 (2017)]. By an explicit computation for model tight-binding Hamiltonians, we demonstrate that the transition between gapless and gapped phases mediated by the rotation of Neel vector manifests itself in a strong orientation dependence of electrical conductivity. Both crystalline and non-crystalline components of the anisotropic conductivity become enhanced due to the interplay between the s-d exchange and a strong spin-orbit interaction. This represents an extreme example of charge transport control via spin-orbit interactions.