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SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 1

SP9 - Parallel Session 1

SP9.1.01

Characteristic switching temperature in spin-orbit torque switching in metallic/ferrimagnetic system

T. H. Pham, S.-G. Je, P. Vallobra, T. Fache, D. Lacour, G. Malinowski, M.-C. Cyrille, G. Gaudin, O. Boulle, M. Hehn, J.-C. Rojas-Sánchez, S. Mangin

Text Spin-orbit torque (SOT) induced perpendicular magnetization switching has attracted a great deal of interest due to its capability of manipulating magnetic moment orientation efficiently. Compelling questions arise regarding the reduction of critical current and the external in-plane field needed for switching to exploit its full potential in spintronics applications. So far however, the thermal contribution to this phenomena has not been completely elucidated. Besides, the use of transition metal - rare earth (TM-RE) ferrimagnetic materials start to draw large attention due to the potential advantages of tuning the net magnetization with composition or temperature.
Our work presents experimental results about spin-orbit-torque-induced magnetization switching in W/CoxTb1-x for different compositions and temperatures. We have observed the current-induced switching in all of samples for 0.72≤x≤0.86, including the compositions near the magnetization compensation point. The external in-plane field needed for switching is quite small (2mT) despite the strong perpendicular magnetic anisotropy of the samples.
We demonstrate that in these structures, the critical current density for switching is not a minimum at the nominal magnetic composition point but increases with Co concentration. We found that the devices have to reach a characteristic switching temperature (Tswitch) before the current generates the reversal and this Tswitch scales with the Curie temperature.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 1

SP9.1.02

Spin torque induced oscillations in fully perpendicular magnetic tunnel junction

V. Iurchuk, N. Lamard, J. Langer, J. Wrona, I.-L. Prejbeanu, L. Vila, R. Sousa, U. Ebels

Text Spin torque nano-oscillators (STNO) are nonlinear auto-oscillating systems known to produce steady state magnetization precession in the microwave range, when a spin-transfer torque balances the intrinsic Gilbert damping of a magnetic layer. Using strong interfacial perpendicular magnetic anisotropy, for either the polarizer or the free layer in magnetic tunnel junctions (MTJ) based STNOs, high output power, large tunability and zero-field operation [1–3] was demonstrated.

In contrast to this, here we report on the first experimental observation of STT-induced microwave generation in fully perpendicular MTJ-based STNO [4]. A non-zero magneto-resistive signal is detectable due to a tilted effective field as a combination of the applied in-plane field and the out-of-plane stray field, produced by the uncompensated synthetic antiferromagnetic multilayer. The frequencies of the oscillations range from 5 to 10 GHz and the frequency-current dispersion exhibits a redshifting behavior with a tunability factor df/dI=1.8 GHz/mA. This large df/dI factor is attributed to possible large intrinsic non-linearity of the STNO. The observation of such oscillations gives prospect to use the same magnetic stack for MRAM and rf functions.

Funding from the EU Horizon 2020 project GREAT No 687973 is acknowledged.

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SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 1

SP9.1.04

Spin pumping as a generic probe for linear spin fluctuations, irrespective of the magnetic and electrical nature of the spin-sink

O. Gladii, L. Frangou, G. Forestier, R. Lopes Seeger, S. Auffret, M. Rubio Roy, R. Weil, A. Mougin, C. Gomez, W. Jahjah, J.-P. Jay, D. Dekadjev, D. Spenato, S. Gambarelli, V. Baltz

Text We investigated the field of applicability of spin pumping as a probe of linear spin fluctuations. The spin pumping mechanism implies the injection of a spin current from a ferromagnetic spin-injector into an adjacent layer called the spin-sink, resulting in the loss of spin angular momentum[1]. The non-local contribution to the spin-injector damping is directly connected to the dynamical transverse spin susceptibility of the spin-sink[2,3]. Since the dynamical transverse spin susceptibility enhances around most ordering transitions, spin pumping should generically translate into a maxima in the temperature-dependence of spin-injector damping for fluctuating spin-sinks of all magnetic and electrical kind. We will discuss temperature-dependent relaxation in Py films and how it was affected by spin fluctuations in adjacent spin-sinks made of all kinds of ordering states: ferromagnetic (Tb), antiferromagnetic (IrMn exchange biased, IrMn not biased, NiO, NiFeOx, BiFeO3), and superconducting (NbN). We will also discuss to what extent the effect is independent on the metallic (Tb, IrMn), insulating (NiO, NiFeOx, BiFeO3), and superconducting (NbN) electrical nature of the spin-sink, i.e. to what extent the physical origin of the phenomenon disregards whether the spin current probe involves electronic or magnonic transport [4].

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SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 1

SP9.1.05

Magnon auto-oscillation under zero magnetic field

N. Nishida, T. Hache, P. Arekapudi, A. A. Awad, O. Hellwig, J. Fassbender, H. Schultheiss

Text Magnons are attractive for application in energy efficient information technology, because they propagate without any actual charge currents and they offer high frequencies up to THz range. Here we present a novel scheme for magnon generation using spin currents and domain walls.

When a charge current is applied to a heavy metallic/ferromagnetic bilayer, the spin currents originating from a spin Hall effect in the heavy metal apply a spin transfer torque on the magnetization. This allows driving efficiently auto-oscillations of magnetization [1]. We focused on domain walls as local magnon nano channels [2]. Since domain walls can be moved by electrical currents [3], they are attractive for reprogrammable nano circuits.

A 370 nm wide zigzag structure was fabricated from a Pt/CoFeB bilayer. A domain wall was generated at the apex by magnetic saturation. The magnon intensity on the remanent state was measured by Brillouin light scattering microscopy [4] with applying a dc current. The magnon excitation showed the dc current dependency. Magnons were detected only for positive dc currents. We succeeded to drive magnon auto-oscillation in the domain wall under zero magnetic field by spin transfer torque.

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SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 1

SP9.1.06

Phase locked loop operation of spin torque oscillators using custom integrated circuits

M. Kreissig, P. Sethi, S. Wittrock, A. Litvinenko, C. Murapaka, K. Merazzo-Jaimes, E. Jimenez-Romero, J. Hem, R. Lebrun, A. Jenkins, L. Vila, M.-C. Cyrille, R. Ferreira, P. Bortolotti, V. Cros, F. Ellinger, U. Ebels

Text Through spin-polarized transport properties spin torque oscillators (STO) can be implemented in electronic systems for signal generation. Efficient system implementation requires reduction of phase noise which can be achieved using a phase locked loop (PLL) [1]. Here, we discuss signal generation using STOs within a hybrid PLL [2], fabricated on 0.18µm BiCMOS. The PLL circuit components were designed for two types of STOs: vortex and uniform magnetized devices. They were assembled on two different PCBs with appropriate signal amplification and DC source. The PLL of vortex devices shows a reduction of phase noise of -50dBc at 100kHz offset frequency in a bandwidth of 2MHz. For uniform devices, temporary locking is also demonstrated within a bandwidth of 1MHz, while phase noise reduction is not yet complete due to instabilities of the free running signal. We also demonstrate prospect to use the PLL for frequency shift keying by shifting the PLL output frequency via variation of frequency divider. Improvements of the PLL operation such as locking via a field line will be discussed. The achieved results are a first step towards integration of spin torque oscillators for microwave applications.
Financial support is acknowledged from FP7-ICT-MOSAIC-317950, CNES (French space agency) for CM and PS, First-TF consortium for SW and ERC MagiCal N°669204 for AL and UE.
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SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 1

SP9.1.07

Ultrafast spin-dependent THz dynamics and high harmonic generation in semiconductor nanostructures

D. Schulze, J. Berakdar

Text Using a direct time propagation technique, we investigate the time-resolved charge and spin quantum dynamics of semiconductor based heterostructures subjected to THz laser pulses. Special attention is devoted to effects related to spin-orbital coupling due to structural or bulk inversion asymmetry. It is shown how the time and polarization-resolved emission spectrum can be controlled via the parameters of the driving field as well as by nanostructuring. It is pointed out how the footprints of the spin dynamics can be traced via monitoring in the emission spectrum.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 2

SP9 - Parallel Session 2

SP9.2.02

Spin–orbit torques and magnetization switching in epitaxial Pd/Co_2FeAl/MgO heterostructures

M. S. Gabor, T. Petrisor Jr., M. Nasui, M. Miron

Text Magnetization manipulation by current induced spin–orbit torques (SOTs) in non-magnetic/ferromagnetic/oxide structures showing perpendicular magnetic anisotropy is of great research interest for the development of electrically controlled spintronic devices. Here, we study the current induced SOTs and the magnetization switching in epitaxially sputtered MgO(001)//Pd(001)/Co_2FeAl(001)/MgO(001) heterostructures. Co_2FeAl (CFA) is an important Co based full Heusler alloy with relatively large spin polarization and low Gilbert damping. It shows structural matching with MgO(001), which is commonly used as a tunneling barrier in crystalline magnetic tunnel junctions. Epitaxial growth of the heterostructure was confirmed by x-ray diffraction experiments. Ferromagnetic resonance measurements indicated in-plane four-fold magnetic anisotropy for relative thick CFA films, as expected for cubic symmetry. By decreasing the thickness of the CFA films, the interface anisotropy dominates, and the magnetization turns out-of-plane with a saturation field of about 7 kOe. The SOTs, evaluated by harmonic Hall voltage measurements, show relatively large values which induce bipolar magnetization switching for charge current densities of the order of 10^7 A/cm^2. These values for the switching current densities are similar to the ones usually obtained for the more conventional Pt/Co structures which makes our system an interesting candidate for SOT driven spintronic devices.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 2

SP9.2.03

Resonant expulsion of a magnetic vortex core excited by RF torques: towards real time threshold RF detectors

S. Menshawy, A. Jenkins, P. Bortolotti, J. Kermorvant, U. Ebels, M.-C. Cyrille, L. Vila, R. Ferreira, P. Freitas, D. Costa, V. Cros

Text Spin transfer dynamics in the last decade have led to advances in spintronics, including opportunities for new features in radiofrequency devices (RF), such as signal generation using spin transfer nano-oscillators (STNOs). Among the different configurations studied, the precession of a vortex core induced by spin transfer, that yield to rf emission in the range of a few 100 MHz is of particular interest because vortex based STNOs have excellent signal characteristics, i.e. large output power and small linewidth. A potential new functionality of STNO is the detection of a rf signal with better sensitivity compared to standard rf diode. Here we are interested in studying the vortex based STNO's response when a dc current is applied together with a rf field from an antenna. When the frequency of the RF field approaches the frequency of the vortex gyrotropic mode, the magnetic configuration of the free layer changes drastically as the vortex core is expulsed out of the STNO. Varying the injected DC current and/or the external magnetic field allows us to identify several regimes of the expulsion scheme. The large variation of the dc resistance associated with the core expulsion provides a new approach for developing a rf threshold detector. To determine the real-time response of the detector but also to better understand the mechanism of the vortex core expulsion, we will finally present time domain measurements using a high frequency oscilloscope.
SM acknowledges DGA for support.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 2

SP9.2.04

Imaging spin diffusion in germanium at room temperature

F. Bottegoni, C. Zucchetti, C. Vergnaud, F. Ciccacci, G. Isella, L. Ghirardini, M. Celebrano, F. Rortais, A. Ferrari, A. Marty, M. Finazzi, M. Jamet

Text Germanium is one of the most promising candidates for spintronic applications, thanks to its compatibility with the Si-based microelectronic devices, the long electron spin lifetime and the optical properties matching the conventional telecommunication window. Furthermore, the possibility to optically inject spins in the conduction band of Ge with a very high spin polarization can pave the way for the integration of spintronic and photonic devices on the same platform. Here, we implement a nonlocal spin injection/detection scheme in germanium at room temperature, where the spin is optically injected and electrically detected. The nonlocal geometry is particularly interesting in spintronics since it allows, in principle, spin manipulation in the channel between the spin injector and detector. By performing optical spin injection through a set of lithographically-defined metal microstripes, we demonstrate lateral spin transport in a lightly n-doped bulk Ge sample. Nonlocal spin detection is achieved using either magnetic tunnel junction or the inverse spin-Hall effect (ISHE) in a thin Pt stripe, thus mapping the spin diffusion in Ge and directly estimating the electron spin diffusion length. Notably, by combining optical spin injection and the ISHE in Pt, we build a nonlocal spin-injection/detection scheme without the use of any ferromagnetic metal.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 2

SP9.2.05

Spin-orbitronics in graphene/Transition Metal Dichalcogenide heterostructures

J. H. Garcia, M. Vila, A. W. Cummings, S. Roche

Text One of the key properties of graphene for spintronics is its capability to transport spins over long distances unaltered. This property originates from its small spin-orbit coupling that concomitantly prevents the electrical manipulation of spins. The heterostructures composed of graphene and transition metal dichalcogenides are recently being used to increase, by order of magnitudes, graphene's spin-orbit coupling, while preserving its extraordinary transport properties. Moreover, these heterostructures induce a special type of spin-orbit interaction that couples the spin and valley degrees of freedom, termed valley-Zeeman.

In this work, we show that the valley-Zeeman spin-orbit coupling effectively enhances the spin Hall and Rashba-Edelstein effects when compared to graphene with traditional spin-orbit interaction such as Rashba or Intrinsic. Additionally, we show that due to the coupling between valley and spin, such enhancement is modulated by the intervalley scattering, a parameter that is generally overlooked when designing devices. Therefore, we will also propose indirect ways to determine it.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 2

SP9.2.06

Unveiling the mechanisms of the spin Hall effect in Ta

E. Sagasta, Y. Omori, S. Vélez, R. Llopis, M. Gradhand, C. Tollan, A. Chuvilin, L. E. Hueso, Y. Otani, F. Casanova

Text Spin-to-charge conversions (SCCs) originating from the spin Hall effect (SHE), or its inverse (ISHE), are now widely exploited in the field of spintronics and there is a major interest in enhancing SCC efficiencies for future spin-orbit-based technological applications, such as spin-orbit torque [1] or spin-orbit logic [2]. The contribution of each mechanism behind the SHE reveals the potential of the material for SCC. In this work, we experimentally demonstrate the dominance of the intrinsic mechanism of the SHE in Ta. 10 to 15 nm of Ta is grown by magnetron sputtering and structural characterization by electron diffraction indicates coexistence of α -Ta and β -Ta phases. From spin absorption experiments in a large set of lateral spin valve devices, we obtain an intrinsic spin Hall conductivity (SHC) for Ta of -820±120 (ħ/e) $\Omega^{-1}cm^{-1}$. The obtained intrinsic SHC is larger than the reported theoretical values for both α-Ta (from -80 to -240 (ħ/e) $\Omega^{-1}cm^{-1}$ [3, 4]) and β-Ta (-378 (ħ/e) $\Omega^{-1}cm^{-1}$ [4]). The predominance of the intrinsic mechanism in Ta allows us to linearly enhance the spin Hall angle by tuning the resistivity of Ta. We reach up to -35±3 %, the largest reported value for a pure metal, demonstrating the intrinsic potential of Ta as a spin-to-charge transducer.

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SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 2

SP9.2.07

Observation of the conversion between charge and spin in a Rashba channel

H. C. Koo, J.-h. Lee, W. Y. Choi, H.-j. Kim, J. Chang, S. H. Han, S. Hong, S. Sayed, S. Datta

Text In a strong Rashba system, both charge-to-spin and spin-to-charge conversions were observed. Using an InAs quantum well channel, the existence of three resistance states were detected when two ferromagnetic (FM) electrodes were used as current terminals while a separate normal metal contact pair was used as voltage terminals. This spin-to-charge conversion result is strikingly different from ordinary spin valve or magnetic tunnel junction devices, which have only two resistance states corresponding to parallel and antiparallel alignments of the FM contacts. Surprisingly, the non-magnetic contacts to the Rashba channel reads the magnetization state of the ferromagnetic electrodes located millimeter away from the detector. From the reciprocal set-up, the ferromagnetic electrode detected a spin voltage induced by the current driven Rashba spin splitting, which confirmed charge-to-spin conversion. The temperature dependence of these experiments showed the Rashba effect induced separation of the spin-up and down electrochemical potentials up to room temperature. In this system, we also observed direct and inverse spin Hall effects using the FM electrode magnetized along the in-plane. Without a perpendicular magnetization, spin Hall voltage was detected via the Rashba spin precession. We can explain our results by the experimentally well-established Onsager reciprocity relation.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 3

SP9 - Parallel Session 3

SP9.3.01

Spin-Orbit Torques At Disordered Interfaces

D. Prychynenko, V. P. Amin, B. Dupé, J. Sinova, M. D. Stiles

Text While considerable theoretical progress has been made towards understanding spin-orbit torques at ideal interfaces, very little work has been done about the role that disorder can play at such interfaces. Given high resistivities of the bulk materials forming the bilayers and a large lattice mismatch between the materials, the interfaces are likely to be highly disordered. We consider how electron transport and spin-orbit torques are affected by disorder at the interface. We consider delta function impurity scattering at the interfaces. We find that impurity scattering does not play a dominant role for spin-orbit torques derived from the spin Hall effect.
For interfacial contributions to the spin-orbit torque, interfacial impurity scattering on the one hand enhances the effects of interfacial spin-orbit coupling and on the other hand it suppresses the in-plane current flow due to the additional contributions to the local resistivity.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 3

SP9.3.02

Study of Low offset frequency noise in vortex spin torque nano-oscillators

S. Wittrock, S. Tsunegi, K. Yakushiji, A. Fukushima, H. Kubota, P. Bortolotti, U. Ebels, S. Yuasa, G. Cibiel, S. Galliou, V. Cros

Text The key property of spintorque nano-oscillators (STNOs) is their high nonlinearity which gives rise to manifold phenomena as well as to their relatively poor spectral coherence and coupled noise behavior. While the noise distribution far from the carrier frequency is reasonably well understood and described by the general nonlinear autooscillator theory, low frequency noise close to the carrier remains under investigation as it limits the frequency stability of the oscillator.
Extensively studied in GMR and TMR sensors, this work addresses the flicker noise of a TMR based spin-torque vortex oscillator in the regime of large amplitude steady oscillations. We investigate the noise dependence on the active magnetic volume of the oscillation, reflected by the Hooge-formula, under various field and current conditions as well as its link to nonlinearity. We also develop a phenomenological theory aiming to describe the flicker noise in these vortex STNOs. Noteworthy, we find that our theoretical predictions agree well to our experimental results for the gyrotropic mode.
As a main result, we find a strong dominance of the nonlinear properties against the Hooge-proportionality and identify the low frequency noise level as proportional to $\alpha/(p_0\, f_p^2)$ for the amplitude and α/p_0 for the phase noise, with α the Hooge-parameter, p_0 the oscillator's output power and f_p the damping rate for small power deviations.

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SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 3

SP9.3.03

Large unidirectional spin Hall magnetoresistance induced by highly spin-polarised Heusler compounds

C. Lidig, J. Cramer, L. Weißhoff, M. Kläui, M. Jourdan

Text The unidirectional spin Hall magnetoresistance (USMR) [1,2] appears in heavy metal/ ferromagnetic metal bilayer systems. It probes the magnetic state at the interface and scales, similar to the current in-plane giant magnetoresistance effect, with the spin polarization of the ferromagnet [3]. Correspondingly, highly spin polarized materials as half metallic Heusler compounds should enable larger USMR effects.
Here, we investigate the USMR of Co2MnSi(001)/Pt bilayer systems using a Heusler compound for which our spin resolved photoemission spectroscopy showed close to 100% spin polarization at the Fermi energy [4]. The investigated bilayer systems show a relatively large unidirectional resistance effect, with a magnetic field angular dependence consistent with the USMR effect. However, it is in general challenging to separate the USMR effect from thermal effects such as the planar Nernst effect. As Co2MnSi and Pt have a different specific conductivities, we expect a temperature gradient perpendicular to the film plane generated by the probing current. Thus to separate thermal effects from the USMR we additionally investigate Co2MnSi/ Cu reference systems, which exhibit no USMR due to the small spin-Hall effect in Cu.

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SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 3

SP9.3.04

Dispersion relation of the interlayer exchange coupled tailored ferrimagnets

S. Sorokin, C. Fowley, G. Atcheson, G. S. Dennehy, J. Duan, A. Khudorozhkov, K. Rode, P. Stamenov, J. Lindner, J. Fassbender, A. M. Deac

Text Here we present a study of different ferromagnetic resonance (FMR) modes in micron-sized antiferromagnetically interlayer exchange coupled SiO_2/Ta(5nm)/Py(t)/Ru(0.85 nm)/Py(3nm)/Ru(3nm) structures, with t = 3, 6 and 9 nm, by means of the electrically detected ferromagnetic resonance (ED-FMR). The main magnetoresistance effect used in ED-FMR was anisotropic magnetoresistance (AMR). Bilinear and biquadratic coupling strengths for each sample were determined by fitting SQUID-VSM measurements on 4×4 mm^2 thin films, using equilibrium total energy minimization. The existence of two different resonance modes (in-phase (acoustic) and out-of-phase (optic)) is shown for asymmetric samples. For the symmetric sample only the acoustic mode was observed, due to the compensation of AMR response from Py layers for the out-of-phase mode. The obtained dispersion relations show a clear dependence of the acoustic mode frequency minimum on the bilinear coupling strength. For asymmetric samples, mode intermixing occurs for certain resonance fields, accompanied by abrupt jumps in both mode frequencies. Such behavior is not observed for symmetric samples, in accordance with predictions based on VNA-FMR experiments and simulations performed elsewhere **[1]**.

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SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 3

SP9.3.05

Optimization of the spin-to-charge conversion signal in CoFe/Pt local spin injection devices

I. Groen, V. T. Pham, E. Sagasta, C.-C. Lin, S. Manipatruni, T. Gosavi, I. A. Young, L. Hueso, F. Casanova

Text Spin-orbitronic devices exploit the coupling between spin and orbital momentum of electrons.[1] A well-established device is a non-local spin valve with spin absorption that can be used to generate and detect pure spin currents.[2] Here, we present a local spin injection device which allows for conversion of a spin-polarized state into an electric signal, utilizing spin-orbit coupling (SOC). The advantage of these devices compared to non-local devices is the increase of the signal strength. Our approach opens up exciting opportunities towards the implementation of spin-orbit-based logic circuits.[3]

The local spin injection device consists of (1) a ferromagnetic (FM) electrode, allowing for the injection of a spin-polarized current, and (2) a T-shaped electrode made of a material with strong SOC, realizing the spin-to-charge conversion through the inverse spin Hall effect.[4] Our devices are vertical junctions composed of CoFe (FM) and Pt (SOC), forming a cross-shaped geometry. In this study, the width dependence of the injection and detection electrodes is investigated to optimize both the spin injected signal as well as the spin-to-charge efficiency.

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SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 3

SP9.3.06

Spin transport through interfaces: how temperature matters

K. Gupta, R. J.H. Wesselink, Z. Yuan, P. J. Kelly

Text The discontinuity of spin currents at an interface is a direct consequence of (interface-enhanced) spin-orbit splitting and can contribute significantly in a variety of experiments dealing with multilayer ferromagnetic(F)|nonmagnetic(N) geometries. However, it is usually neglected in analyzing experiments to avoid introducing too many parameters; this leads to bulk spin transport properties that are "contaminated" with interface effects. Our knowledge of interface parameters is limited to low temperatures where scattering is dominated by extrinsic mechanisms. From an application perspective, finite temperature studies are more relevant, thus it is essential to understand the role of intrinsic scattering for interfaces.
To quantify the effect of interfaces on spin transport at finite temperatures, we determine the spin-memory loss (SML), interface spin-Hall angle (SHA) and interface resistances (spin-dependent for F|N) for F|N and $N_1|N_2$ interfaces. Using first-principles scattering theory, we calculate the conductance as well as local charge and spin currents modeling temperature induced disorder within the adiabatic approximation with frozen thermal lattice and spin disorder. Our results for the longitudinal spin currents are interpreted in terms of a Valet-Fert model generalized to extract the SML. The transverse currents generated by the inverse spin-Hall effect are used to extract interface SHAs. We find a significant temperature dependence for all of these parameters.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 3

SP9.3.07

Spin pumping in ferrimagnets: Bridging ferro- and antiferromagnets

A. Kamra, W. Belzig

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

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SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 3

SP9.3.08

Strongly anisotropic spin relaxation in graphene– transition metal dichalcogenide heterostructures at room temperature

L. A. Benítez, J. F. Sierra, W. Savero Torres, A. Arrighi, F. Bonell, M. V. Costache, S. O. Valenzuela

Text In graphene spin information can be transported over long distances and, in principle, can be manipulated by using magnetic correlations or large spin-orbit coupling (SOC) induced by proximity effects [Phys. Rev. B 92, 155403 (2015)]. Such SOC has been predicted when interfacing graphene with semiconducting transition metal dichalcogenides. Signatures of such an enhancement have been reported, but the nature of the spin relaxation in these systems remains unknown.

We recently demonstrated anisotropic spin dynamics in bilayer heterostructures comprising graphene and different transition metal dichalcogenides such as tungsten and molybdenum disulphide at room temperature. Using our pioneering technique [Nat. Commun. 7, 11444 (2016)], we demonstrate that the spin lifetime varies over one order of magnitude depending on the spin orientation, being largest when the spins point out of the graphene plane [Nature Phys 14, 303 (2018)]. Similar results have been reported for graphene molybdenum diselenide heterostructures at low temperatures [Nano Lett. 17, 7528 (2017)]. This indicates that the strong spin–valley coupling in the transition metal dichalcogenide is imprinted in the bilayer and felt by the propagating spins. Our findings provide a rich platform to explore coupled spin–valley phenomena and offer novel spin manipulation strategies based on spin relaxation anisotropy in two dimensional materials.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 4

SP9 - Parallel Session 4

SP9.4.01

Spin transfer torque ferromagnetic resonance in the magnetic heterostructures: interface transparency and spin memory loss

A. Kumar, R. Gupta, S. Akansel, V. Kapaklis, R. Brucas, P. Svedlindh

Text The interfacial parameters in FM/NM systems i.e., spin memory loss, magnetic proximity, and transparency, affect the precise estimation of spin Hall angle (SHA) and spin current transmission efficiency across the FM/NM interface, and therefore, a unifying consensus about the role of interfacial properties in governing spin-transportation in FM/NM systems is largely missing. To study the role of interfacial transparency and spin memory loss on spin transportation across bilayer interfaces we have chosen bilayer combinations of Fe/Pd and CFA/β-Ta bilayer system.
In the first set of samples; polycrystalline Si(100)/Fe(10nm)/Pd(2,4,6,8nm), in-plane FMR measurements and simultaneous detection of SHE and ISHE were performed using ST-FMR setup. In this work we have studied interfacial parameter contributions in measured values of the spin current. In the second set of samples; epitaxial MgO(100)/Fe(tFM)/Pd(5nm) samples, the role of interface roughness (ranges from 0.2 to 1.2 nm) on the spin angular momentum transportation across the Fe/Pd interface has been studied in terms of interface transparency and spin memory loss. The third set of samples; CFA/Cu(0,10nm)/β-Ta systems, was studied for SHA dependency on interfacial spin memory loss and transparency. Our findings suggest that the effect of the interface parameters on spin-mixing conductance depends on choice of materials in the heterostructures which is in contradiction to W. Zhang et al., Nature Physics, 11, 496(2015), report.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 4

SP9.4.02

Atomistic spin- and lattice-dynamics simulations: Method and applications

J. Hellsvik, D. Thonig, K. Modin, P. Bessarab, D. Iusan, A. Bergman, O. Eriksson, L. Bergqvist, A. Delin

Text We present a computationally efficient general first-principles based method for spin-lattice simulations for solids. Our method is based on a combination of atomistic spin-dynamics and molecular dynamics, expressed through a spin-lattice Hamiltonian where the bilinear magnetic term is expanded to first order in displacement, and all parameters are computed using density functional theory [1]. The effect of spin-lattice coupling on the magnon and phonon dispersion in bcc Fe is reported, and is seen to be in good agreement with previous simulations performed with an empirical potential approach [2,3]. In addition, we also illustrate the abilities of our method on a more conceptual level, by exploring dissipation-free spin and lattice motion in the Fe dimer, trimer and quadmer. Our method opens the door for quantitative description and understanding of the microscopic origin of many fundamental phenomena of contemporary interest, such as ultrafast demagnetization, magnetocalorics, and spincaloritronics.

[1] Atomistic spin-dynamics foundations and applications, O. Eriksson, A. Bergman, L. Bergqvist, and J. Hellsvik (Oxford University Press, 2017).
[2] P.-W. Ma, C. H. Woo, S. L. Dudarev, Phys. Rev. B 78, 024434 (2008).
[3] D. Perera et al., Phys. Rev. B 95, 014431 (2017).

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 4

SP9.4.03

Spin-orbit phenomena in single crystalline Fe/GaAs (001) hybrid structures

L. Chen

Text Experiments in single crystalline Mn-doped GaAs have shown that current induced spin-orbit fields, arising from broken inversion symmetry, can produce spin-orbit torques which act on the magnet's magnetization, thus offering an efficient way for its manipulation [1]. However, the Curie temperature of Mn-doped GaAs is still far below room temperature, which hinders its practical applications. Here, I will show that depositing a layer of single crystalline Fe on top of GaAs results in the emergence of Rashba- and Dresselhaus-like spin-orbit interaction at the Fe/GaAs (001) interface due to the lack of space inversion symmetry (C2v), which can also lead to mutual conversion of spin and charge currents at room temperature [2]. The interplay of Rashba and Dresselhaus spin-orbit interaction leads to the first observation of anisotropic Gilbert damping in ultra-thin Fe films [3]. Morever, I will show a new scheme for electric-field control, i.e., by using the electric-field in a Schottky barrier between Fe and GaAs to control the interfacial spin-orbit field-vector [4].

[1] A. Chernyshov, et al., Nature Phys. 5, 656-659 (2009).
[2] L. Chen, et al., Nature Commun. 7, 13802 (2016).
[3] L. Chen, et al., Nature Phys. http://doi.org/10.1038/s41567-018-0053-8
[4] L. Chen, et al., arXiv 1803.01656.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 4

SP9.4.04

Explicit proof of hole transport across a MgO-based magnetic tunnel junction due to oxygen vacancies

F. Schleicher, B. Taudul, U. Halisdemir, K. Katcko, E. Monteblanco, D. Lacour, S. Boukari, F. Montaigne, E. Urbain, L. M. Kandpal, J. Arabski, W. Weber, E. Beaurepaire, M. Hehn, M. Alouani, M. Bowen

Text The quantum mechanical tunneling process conserves the quantum properties of the particle considered. As applied to solid-state tunneling, this physical law was verified, within the field of spintronics, regarding the electron spin in early experiments across Ge tunnel barriers, and in the 90s across Al2O3 barriers. The conservation of the quantum parameter of orbital occupancy, as grouped into electronic symmetries, was observed in the ‘00s across MgO barriers, followed by SrTiO3. Barrier defects, such as oxygen vacancies, only partly conserve this electronic symmetry. In the solid-state, an additional subtlety is the sign of the charge carrier: are holes or electrons involved in transport? We demonstrate that solid-state tunneling across MgO magnetic tunnel junctions involves holes by examining how shifting the junction's Fermi level alters the ensuing barrier heights defined by the barrier’s oxygen vacancies. In the process, we consolidate the description of tunnel barrier heights induced by specific oxygen-vacancy induced localized states. This should provide important insight into spin transfer torque physics across MgO.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 4

SP9.4.05

Geometric Phase Contributions to the Anomalous Nernst and Hall Effect in the Chiral Double Helimagnetic System

J. Gayles, J. Noky, Y. Sun, C. Felser

Text We use first principle calculations to show that the anomalous Hall and Nernst effect are enhanced in MnP and FeP due to geometric phase contributions. At ambient pressure the inversion breaking crystals shows a transition from a double-spiral helimagnetic phase to a trivial magnetic phase. This helimagnetic structure is determined by exchange frustration and the Dzyaloshinkii-Moriya interaction. The electronic structure, i.e. band crossings near the Fermi energy, depends intimately on the helical spiral length. We show the contributions to the anomalous Hall and Nernst effect phenomena have different dependence on disorder than normal ferromagnetic which is rooted in the topology of the band structure at the Fermi energy. Due to the non-collinear nature of the spin-spiral contributions to the anomalous Hall and Nernst conductivity arise from both the even and odd in magnetization direction.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 4

SP9.4.06

Large spin mixing conductance in Bi-doped Cu/YIG interfaces

S. Ruiz-Gomez, M. Muñoz, R. Guerrero, M. Foerster, L. Aballe, M. Amado, J. W. A. Robinson, A. Mascaraque, L. Pérez

Text In the field of spintronics, the Spin Hall Effect provides an efficient tool for the conversion of a charge current into a spin current without the need of ferromagnets [1]. Recently, a Spin Hall Angle of 0.25 has been measured in Cu doped with 0.25% Bi [2] and larger values of are expected for larger Bi doping according to theoretical calculations [3].

In this work we incorporate up to 10% of Bi atoms into the Cu structure without evidence of Bi surface segregation of cluster formation, as studied by several microscopic and spectroscopic techniques. We investigate the spin pumping effect in a series of yttrium-iron-garnet (YIG)–Cu(Bi) bilayers by the measurement of broadband ferromagnetic resonance (FMR). We determine the effective spin-mixing conductance as a function of Bi concentration by comparing the FMR response of pure YIG layers and Cu(Bi)/YIG bilayers in a frequency range from 2-10 GHz. With a Cu(Bi) layer on top of the YIG the Hilbert damping is significantly enhanced (up to 40%). The effective spin-mixing conductance extracted from the ferromagnetic resonance experiments increase with the Bi concentrations up to a value of $G_{eff} = 7.3 \times 10^{18}$ m^{-2}.

[1] J. Sinova et al. Rev. Mod. Phys. 87, 1213 (2015)
[2] Y. Niimi et al. Phys. Rev. Lett. 109, 156606 (2012)
[3] B. Gu, et al. J. Appl. Phys. 117, 17D503, (2015).

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 4

SP9.4.07

Unconventional Superfluidity in Yttrium Iron Garnet Films

T. Nattermann, V. Pokrovsky, C. Sun

Text We argue that the magnon condensate in yttrium iron garnet may display experimentally observable superfluidity at room temperature despite the 100 times dominance of the normal density over superfluid ones. The superfluidity has a more complicated nature than in known superfluids since the U(1) symmetry of the global phase shift is violated by the dipolar interaction leading to the exchange of spin moment between the condensate and the crystal lattice. It produces periodic inhomogeneity in the stationary superfluid flow.We discuss the manner of observation and possible applications of magnon superfluidity. It may strongly enhance the spin-torque effects and reduce the energy consumption of the magnonic devices.

SP 9 Spin transport and spin dynamics

SP9 - Parallel Session 4

SP9.4.08

Hydrodynamics and topological spin currents in amorphous magnets

H. Ochoa, R. Zarzuela, Y. Tserkovnyak

Text Spin superfluidity, understood as the coherent transport of spin mediated by topologically stable textures, offers promising perspectives for the design of energetically efficient spintronic devices. In magnetic systems it relies on the orientational dynamics of the magnetic order, which can be triggered by spin-orbit torques at the interface and detected via the reciprocal pumping effects. Potential platforms for spin superfluidity are built upon the insulating easy-plane (anti)ferromagnet paradigm, for which the stability of the superfluid relies on the underlying U(1) symmetry. However, in the presence of parasitic planar anisotropies (arising, e.g., due to the fabrication process) this symmetry breaks down and coherent spin transport can only occur above certain current threshold.

In this talk we show how structural disorder in amorphous magnets can eventually frustrate these parasitic anisotropies in the exchange-dominated limit for magnetic interactions, allowing for long-range spin drag signals between metal reservoirs even in the presence of damping. We describe the spin hydrodynamics of these systems in terms of coherent rotations of a noncollinear texture. We determine the salient features of this coherent spin transport in nonlocal magneto-transport measurements and discuss the topological stability of the resultant spin currents. Our work paves the way for future studies on macroscopic spin dynamics in materials with frustrated interactions.