SP 17 Spin caloritronics

SP17 - Parallel Session 1

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SP17.1.01

Longitudinal spin Seebeck effect in a magnetic insulator induced by ballistic transport of quasi-acoustic thermal magnons

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Text The observation of the longitudinal spin Seebeck effect (LSSE) in magnetic insulators confirms the crucial role of magnons in spin caloric processes. In the case of the LSSE, the spin current carried by magnons is flowing along an applied thermal gradient. It can be measured as an electric signal in an adjacent nonmagnetic metal by means of the inverse spin Hall effect. Since the number of thermal magnons decays exponentially within an effective propagation length, a strong dependence of the LSSE temporal dynamics on the magnetic layer thickness is expected. We studied the transient behavior of the spin current generated by the LSSE in a set of platinum-coated yttrium iron garnet (YIG) films of different thicknesses from 150 nm to 53 µm. A microwave pulse applied to the samples resulted in Joule heating of the Pt layer. The subsequent thermal gradient through the YIG thickness gives rise to a LSSE-voltage pulse. We found that the time evolution of the LSSE is determined by the temporal dynamics of the gradient triggering the flux of thermal magnons in the vicinity of the YIG/Pt interface. The measured data have been fitted using a model that assumes ballistic motion of thermal magnons in a gradient. The average magnon propagation length of about 425 nm was found to be almost independent of the YIG film thickness. We consider this fact as a manifestation of the ballistic propagation of quasi-acoustic thermal magnons having almost linear dispersion in room temperature YIG.

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SP17.1.02

Thermodynamic reciprocity of the spin Seebeck and spin Peltier effects

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Text The longitudinal spin Seebeck [1] and spin Petier [2] effects are two thermomagnetic effects resulting from the passage of a magnetic moment current (spin current) on a ferromagnetic insulator like YIG. These effects are revealed by employing the spin Hall effect of a side metallic layer, like Pt. The reciprocity is not so evident, as in the case of thermoelectric materials, because the magnetic moment is a non conserved quantity. In the present paper we will present both theoretical thermodynamic aspects as well as experiments on the two effects. From non-equilibrium thermodynamics we derive the reciprocal relations evidencing the role played by the parameter epsilon M, the absolute thermomagnetic power coefficient of YIG [3]. Experiments performed by controlling the heat flux traversing the device will be discussed and the coefficient epsilon M will be derived [4].

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SP17.1.04

Role of the Magnon Dispersion in the Spin Seebeck Effect in Fe_3O_4 Thin Films

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Text The spin Seebeck effect (SSE) is a recently discovered phenomena where a spin current, J_s, arises when a thermal gradient is applied to a magnetised layer [1]. This spin polarised current can be detected via the inverse spin Hall effect (ISHE) if a paramagnetic contact such as Pt is deposited on top of the magnetic layer [2]. Recent work on thin films have shown that there is a characteristic length scale t_{FM} at which the observed ISHE voltage saturates. This has been shown in thin film YIG where values of $t_{FM} \sim 90$ nm [3] and $t_{FM} \sim 300$ nm [4], were obtained by experiment and theory, respectively. In thin film Fe_3O_4, t_{FM} was found experimentally to be 100 nm [5].

In this study, we present measurements of the SSE normalised to the heat flux, J_Q, of FeO_x/Pt bi-layers as the Fe_3O_4 thickness was increased. Whilst we find that the coefficient reaches a maximum at around t$_{\text{Fe}}$_{$_3$O$_4$}=80 nm, instead of saturating it starts to decrease slightly. To investigate whether the observed trend is due to the magnon diffusion length or a complex function of several variables we compare this work to complementary magnetometry as well as measurement of the magnon dispersion curves in single crystal Fe_3O_4.

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SP17.1.05

Spin Seebeck effect and phonon energy transfer in heterostructures containing layers of a normal metal and a ferromagnetic insulator

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Text In the framework of the kinetic approach based on the Boltzmann equation for the phonon distribution function, we analyzed phonon heat transfer in a heterostructure containing a layer of a normal metal (N) and a layer of a ferromagnetic insulator (F). Two real methods for creating a temperature gradient in such a heterostructure are considered: the heating of an N-layer by an electric current and the placement of an N/F-bilayer between massive dielectrics with different temperatures. The electron temperature Te in the N-layer and the magnon temperature Tm in the F-layer are calculated. The difference in these temperatures determines the voltage VISHE on the N-layer in the spin Seebeck effect regime. The dependence of VISHE on the bath temperature and on the thickness of the N and F layers is compared with the experiment.

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SP17.1.06

Temperature dependence of the non-local spin Seebeck effect in YIG/Pt nanostructures

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Text Solid-state information processing is commonly realized by the motion and storage of quantized entities such as electric charge, spin or magnetic flux. Nowadays, non-charge based devices are studied intensively due to their possibly lower power dissipation. To this end, spin waves (magnons) in ferromagnets have attracted particular interest, as they may constitute a new pathway for information processing beyond charge-based semiconductor technology.

In this study, the transport of thermally excited non-equilibrium magnons in the ferrimagnetic insulator yttrium iron garnet (YIG) is investigated, utilizing two electrically isolated Pt stripe electrodes deposited on the YIG surface. Magnons are excited via current-induced heating at the injector strip and their diffusion to a nearby detector strip generates a finite voltage via the inverse spin Hall effect. This formally can be viewed as a non-local spin Seebeck effect (SSE). We measure this non-local SSE as a function of temperature and strip separation d. In experiments at room temperature we observe a sign change of the non-local SSE voltage at a characteristic value $d = d_0$, in agreement with previous investigations. For low temperatures we find a strong temperature dependence of d_0. This suggests that both the angular momentum transfer across the YIG/Pt interface as well as the transport mechanism of the magnons in YIG as a function of temperature must be taken into account to describe the non-local SSE.

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SP17 - Parallel Session 1

SP17.1.07

Observation of an interface-induced anomalous Nernst effect in Fe_3O_4/Pt-based heterostructures

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Text We report recent progress on the study of the spin thermoelectric properties of highly crystalline [Fe_3O_4/Pt]-based hetero-structures. We measured the anomalous Nernst effect (ANE) by application of a magnetic field oriented in the out-of-plane direction, in the perpendicular magnetized configuration where only the ANE is detected.

We observed a non-negligible ANE-driven electric field in $[Fe_3O_4/Pt]_n$ multilayers that scales with the number of interfaces. Quantitative comparison between the ANE and spin Seebeck effects (SSE) in the multilayers shows that the magnitude of the ANE is significantly smaller than that of the SSE. Thus, indicating that the SSE dominates the transverse thermoelectric voltage response for in-plane magnetic fields in Fe_3O_4/Pt system.

We further investigated the observed ANE by performing measurements in [Fe_3O_4/Pt/Fe_3O_4] trilayers as a function of the Pt interlayer thickness. The obtained thickness dependence cannot be simply understood by the shunting effect of the ANE of the Fe_3O_4 layers, and the presence of an additional ANE component from the Fe_3O_4-Pt interface must be considered. Measurements of the ANE as a function of the Pt deposition temperature show that the effect only appears for Pt deposited at high temperature, suggesting that the origin of the interface-driven ANE might be related to a subnanometer Fe-Pt interdiffusion, which can affect the Fe coordination and/or elemental composition at the interface.

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SP17.2.02

Thermally activated Domain Wall Motion

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Text The investigation and control of domains and domain walls in magnetic materials plays a crucial role for a deeper understanding of magnetic thin film physics and in the development of future spintronic devices. Lately the interaction between heat transport, charge and spin degrees of freedom has been attracting considerable attention.

In this project we are investigating the influences of thermal gradients on magnetic systems. Specially the role of thermal gradients interacting with magnetic domain walls. It was predicted by various authors e.g. [1], that a magnetic domain wall should interact with a heat source by means of the thermal gradient and the resulting magnon currents (magnonic spin seebeck effect). This prediction states, that a magnetic domain wall should move towards a heating site, in order to minimize the internal free energy.

We hereby report for the very first time a domain wall motion purely induced by an applied thermal gradient. To apply this gradient, we use a frequency doubled Nd:YAG in continuous wave mode. The laser beam is focused down, thus giving us control of the magnitude of the thermal gradient by controlling the incoming laser power and the size of the focal spot. The threshold temperature gradient is about 75mK/nm. The samples in study are amorphous TbFe thin films with an out-of-plane magnetization direction.

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SP17 - Parallel Session 2

SP17.2.03

Domain wall dynamics of ferrimagnets in temperature gradients

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Text Previous studies in ferromagnets have predicted that a domain wall (DW) in a temperature gradient will move towards the hotter region, not only due to angular momentum exchange with the magnons passing through the DW, but also in order to minimize the DW free energy [1]. Later works found a similar DW motion in antiferromagnets [2]. Here, we examine the DW dynamics of ferrimagnets in thermal gradients, which, depending on temperature, can exhibit both, ferro- or antiferromagnetic-like properties.
We model a typical rare earth-transition metal alloy using an atomistic spin model based on the stochastic Landau-Lifshitz-Gilbert equation. Surprisingly, our simulations reveal that a precessing DW below the angular momentum compensation point T_A will move towards the colder sample region, i.e. against the direction implied by free energy minimization [3]. In related works, this behavior has been attributed to linear momentum transfer from reflected magnons [4,5]. Furthermore, we predict a torque compensation point $T_\mathrm{T} > T_\mathrm{A}$, at which the DW precession stops and eventually changes its sign as well. This torque compensation can efficiently suppress the Walker breakdown in its vicinity, even for comparably low magnetic anisotropy and large thermal gradients.

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SP17 - Parallel Session 2

SP17.2.04

Thermoelectrical detection of magnetization reversal in Pt/Ir/Co nanowires with interfacial Dzyaloshinskii–Moriya interaction

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Text In Pt|Co|Ir multilayers sub-100 nm skyrmions can be stabilized at room temperature by interfacial Dzyaloshinskii–Moriya interaction (DMI) [1,2]. Recently it was shown that in patterned sub-micronic strips, individual skyrmions can be electrically detected by their signature to the anomalous Hall effect (AHE) [3]. While AHE detection is intrinsically limited to Hall crosses it was recently shown that the anomalous Nernst effect (ANE), the thermoelectric analogue of the AHE, allows sensitive nano-scale characterization of the magnetization also in various nanowire geometries [4].

Here we compare ANE and AHE for the characterization of out-of-plane magnetization reversal loops in nanowires (ANE) and nanopatterned Hall crosses (AHE) of typical multilayers, consisting of Ta 15|Co 0.8|(Pt 1|Ir 1|Co 0.8)5|Pt 3. Both ANE and AHE loops show similar characteristics proving the suitability of ANE as an electrical detection scheme. Comparison to magnetic force microscopy allows to correlate the loop features to the presence of stripe domains and skyrmions in the nano structures. The prospects for ANE detection of individual skyrmions inside the nanostructures will be discussed.

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SP17 - Parallel Session 2

SP17.2.05

Coherent control of acoustic-wave-induced magnetization dynamics in magnetic tunnel junctions

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Text Manipulating the angular momentum of spins with external stimulus is a key issue in the field of spintronics with the aim to boost logic and memory applications. Such a manipulation can be achieved by different physical effects, employing photons, electrons, heat flux, THz radiation, as well as phonons. In particular, the interaction of acoustic pulses with spin structures provides interesting prospects.
We experimentally study magnetization dynamics in magnetic tunnel junctions (MTJ) driven by femtosecond-laser-induced surface acoustic waves. The acoustic pulses induce a magnetization precession in the free layer of the magnetic tunnel junction through the magnetoelastic coupling. The frequency and amplitude of the precession shows a pronounced dependence on the applied magnetic field and the laser excitation position. We are able to identify acoustic-wave-induced magnetization precession modes from a comparison with charge-current-induced magnetization dynamics. The experimental scheme even allows us to coherently control the magnetization precession using two acoustic pulses. This might prove important for future applications requiring ultrafast spin manipulation. Additionally, our results directly pinpoint the importance of acoustic pulses for the investigation of optically induced temperature effects in magnetic nanostructures.

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SP17.2.06

Controlling three-dimensional temperature gradients in magnetic tunnel junctions: Anomalous Nernst effect

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Text We present a systematic investigation of thermomagnetic voltages generated by three-dimensional temperature gradients created by localized laser heating in magnetic devices.
We measure the tunnel magneto-Seebeck effect (TMS) and the anomalous Nernst effect (ANE) generated on a nanometer length scale by micrometer sized temperature gradients in magnetic tunnel junctions (MTJs). The ANE is extracted by analyzing the influence of in-plane temperature gradients on the TMS in in-plane magnetized pseudo spin valve MTJs based on CoFeB electrodes with uniaxial magnetic anisotropy (UMA) and an MgO tunnel barrier. The direction controlled temperature gradients are created by a focused cw diode laser spot. The spatial extent of the measured effects is defined by the elliptically shaped MTJ sized 6 µm x 4 µm, while the spatial resolution is given by the laser spot size and the step size of its lateral translation. We investigate the influence of the CoFeB electrodes UMA on the generated ANE voltage in a systematic study.
The measurement method is highly sensitive to low voltages and yields an ANE coefficient of $K_N \approx 1.6 \cdot 10^{-8}$ V/TK for CoFeB, which is slightly lower, than for other CoFeB compositions. At such a high sensitivity, the generated ANE effect allows to expand the MTJs' functionality from simple memory storage to nonvolatile logic devices and in combination with the UMA opens new application fields, for example direction dependent temperature sensing.

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SP17 - Parallel Session 2

SP17.2.07

Thermoelectric Spin Voltage in Graphene

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Text Spin-caloritronics, a field that exploits the interaction between spin and heat currents in solid-state devices, has spawned a vast literature in recent years, complete with beautiful and elaborate experiments [1]. Amongst the most intriguing phenomena is the spin Seebeck effect, in which a thermal gradient in a ferromagnetic material gives rise to spin current. Non-magnetic materials are also relevant for spin caloritronics. Graphene, for example, exhibits efficient spin transport, energy-dependent carrier mobility and a unique density of states, which make it an ideal platform for the observation of novel spin-caloritronic effects. However, decisive observations of the spin-heat interaction in graphene are scarce to non-existent. We have recently predicted and experimentally demonstrated that a carrier thermal gradient in a graphene lateral device leads to a large increase of the spin voltage around the graphene charge neutrality point [2]. This increase results from a thermoelectric spin voltage, analogous to the voltage in a thermocouple, which can be further enhanced by the presence of hot carriers generated by an applied current. These results could prove crucial for graphene spintronic devices, in particular, to sustain pure spin signals with thermal gradients and tune the remote spin accumulation by varying the spin injection.

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