TT 20: Transport: Spincaloric Transport (jointly with MA)

Results -partially also obtained in DFG Priority Program "Spin Caloric Transport" SPP1538 (www.spincat.info)- on spin-dependent transport phenomena initiated and controlled by thermal effects in magnetic nanostructures are discussed.

Time: Monday 15:00–18:45 Location: H22

TT 20.1 Mon 15:00 H22

Transverse magneto-thermoelectric effects in Permalloy films. — •Sasmita Srichandan, Maximilian Schmid, Michael Vogel, Christoph Strunk, and Christian Back — Institute of experimental and applied Physics, University of Regensburg, 93040 Regensburg, Germany

Thermally induced transversal magneto transport phenomena have been studied on 20 nm Py films deposited on MgO and GaAs substrates as well as on 100 nm thick SiN membranes. With an in plane thermal gradient ∇T, the transverse voltage V_T is measured on 10nm thick patterned Pt stripes on top of the Py films with respect to applied external magnetic field B at an angle θ where θ is the the angle between B and ∇T. The observed $\sin\theta\cos\theta$ dependence of V_T indicates the planar Nernst effect (PNE). Additionally we observe an asymmetry in the signal between the positive and negative B directions which is proportional to $\cos\theta$. This can be attributed to the anomalous Nernst effect (ANE) caused by a temperature gradient normal to the plane of the sample resulting from thermal radiation. The contribution of the transverse spin Seebeck effect (TSSE) which shares the same $\cos\theta$ symmetry as the ANE, has been separated and it turns out to be one order smaller than reported in the literature [1]. The above measurements have also been performed on SiN membranes and they result in Nernst signals being an order higher than for bulk samples owing to the large local T gradient.

[1] K. Uchida et.al, Observation of spin Seebeck effect. Nature **455**,778-781(2008).

TT 20.2 Mon 15:15 H22

Tunnel magneto-Seebeck effect in high temperature gradients — •Marvin Walter[1], J. C. Leutenantsmeyer[1], V. Zbarsky[1], T. Eggebrecht[1], M. Münzenberg[1], K. Rott[2], A. Böhnke[2], G. Reiss[2], A. Thomas[2], M. Czerner[3], and C. Heiliger[3] — [1]I. Phys. Inst., Universität Göttingen, Germany — [2]Dept. of Physics, Bielefeld University, Germany — [3]I. Phys. Inst., Universität Giessen, Germany

CoFeB/MgO/CoFeB devices showing a giant TMR effect are possible candidates for the generation of spin-currents by thermal heating and the tunnel magneto-Seebeck effect was already observed. It is theoretically predicted that for a 3 monolayer MgO barrier the torque of the spin-polarized tunneling electrons might be sufficient to observe thermal spin transfer torque (T-STT).

The samples presented in this work consist of a minimal pseudo-spin-valve stack with sputtered Ta and CoFeB layers and an e-beam evaporated MgO barrier with thicknesses down to 3 monolayers. The MTJs are heated by a Ti:Sa femtosecond laser to achieve high temperature gradients. The heating of the MTJ by a femtosecond laser is simulated using finite element methods. Using the parameters observed in the experimental setup, the simulations show temperature differences across the MgO barrier of more than 10K for a duration in the order of picoseconds. This temperature difference should be sufficient to achieve T-STT. Furthermore, the thermomagnetoelectric properties in high temperature gradients of MTJs with perpendicular magnetic anisotropy and switching current densities of $2 \cdot 10^5$ A/cm^2 are investigated.

TT 20.3 Mon 15:30 H22

Spin-filtering efficiency of ferrimagnetic spinels $CoFe_2O_4$ and $NiFe_2O_4$ — Nuala Caffrey[1], Daniel Fritsch[2], Tom Archer[1], Stefano Sanvito[1], and •Claude Ederer[3] — [1]School of Physics and CRANN, Trinity College Dublin, Ireland — [2]H. H. Wells Physics Laboratory, University of Bristol, United Kingdom — [3]Materials Theory, ETH Zurich, Switzerland

We assess the potential of the ferrimagnetic spinel ferrites $CoFe_2O_4$ and $NiFe_2O_4$ to act as spin-filtering barriers in magnetic tunnel junctions. Our study is based on the electronic structure calculated by means of first-principles approaches within different approximations for the exchange correlation energy. We show that, in agreement with previous calculations, the densities of states suggest a lower tunneling barrier for minority spin electrons, and thus a negative spin-filter effect. However, a more detailed analysis based on the complex band-structure reveals that both signs for the spin-filtering efficiency are possible, depending on the band alignment between the electrode and the barrier material.

TT 20.4 Mon 15:45 H22

Longitudinal spin Seebeck effect and anomalous Nernst effect in thin $NiFe_2O_4$/Pt films — •Daniel Meier[1], Timo Kuschel[1], Liming Shen[2], Arunava Gupta[2], Takashi Kikkawa[3], Ken-ichi Uchida[3], Eiji Saitoh[3], Jan-Michael Schmalhorst[1], and Günter Reiss[1] — [1]University of Bielefeld, Germany — [2]University of Alabama, Tuscaloosa, USA — [3]Tohoku University of Sendai, Japan

When a temperature gradient is applied along a ferromagnet/Pt system a spin current parallel to this temperature gradient is generated, which can be converted into an electromotive force (V_{Pt}) via the inverse spin Hall effect in the Pt. One can measure a voltage between the ends of the Pt film in a range of a few μV. In a ferromagnetic insulator/Pt system no regions are expected which are conductive and spin-polarized simultaneously. That is the reason why thermomagnetic effects like the anomalous Nernst effect could be neglected.

In this work we present data for the conductivity of the $NiFe_2O_4$ films and for V_{Pt} taken for $NiFe_2O_4$ films with a thin Pt film on top obtained in a setup for measurements at room temperature and in another one for investigations in a low temperature range. The $NiFe_2O_4$ films show semiconductive characteristics. Therefore, a detailed temperature dependence is studied as well as the influence of direction of an external magnetic field. The origin of the measured effects is discussed on the base of temperature dependent conductivity measurements in order to correlate the longitudinal spin Seebeck effect and the anomalous Nernst effect.

TT 20.5 Mon 16:00 H22

Dynamics of domains in thermal gradients — •Frank Schlickeiser, Denise Hinzke, and Ulrich Nowak — Universität Konstanz, 78457 Konstanz, Germany

Many of the recently proposed future magnetic storage devices are based on laser-pulse or current-induced writing schemes, as for example opto-magnetic writing [1]. An unavoidable by-product of these writing schemes are thermal gradients, so that the understanding of their interaction with magnetic structure becomes important. We investigate the dynamics of domains in thin ferromagnetic CoPd films triggered by thermal gradients by means of computer simulations, based on the Landau-Lifshitz-Bloch-equation. The latter describes the dynamics of a thermally averaged spin polarization on micro-magnetic length scales [2]. We show that in a Gaussian temperature profile the magnetic structure is modified towards a radial orientation of the domains. Our numerical results are compared with recently performed measurements. We acknowledge financial support by the DFG through SFB 767. [1] K. Vahaplar et al.,Phys. Rev. Lett. 103, 117201 (2009), [2] D. Hinzke and U. Nowak, Phys. Rev. Lett. 107, 027205 (2011).

TT 20.6 Mon 16:15 H22

Thermally excited magnonic spin currents probed by the longitudinal spin-Seebeck effect in YIG — •Andreas Kehlberger[1], René Röser[1], Gerhard Jakob[1], Benjamin Jungfleisch[2], Burkard Hillebrands[2], Ulrike Ritzmann[3], Denise Hinzke[3], Dong Hun Kim[4], Caroline Ross[4], Ulrich Nowak[2], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg-University Mainz, 55099 Mainz, Germany — [2]Department of Physics, Institute of Technology Kaiserslautern, 67663 Kaiserslautern, Germany — [3]Department of Physics, University of Konstanz, 78457 Konstanz, Germany — [4]Department of Materials Science and Engineering, MIT , Cambridge, MA 02139, USA

In the research field of spin caloric transport one of most the prominent and still not understood effects is the spin-Seebeck effect (SSE) in magnetic insulators [1]. Many explanations consider thermally excited magnons as the underling mechanism, for which direct evidence is missing so far. We present a systematic study of the SSE in Yttrium

Iron Garnet (YIG) films of different thicknesses. From the thickness dependence of the measured inverse spin Hall effect we can unambiguously identify the SSE effect . Corresponding simulations on atomistic length scales allow us to deduce the propagation length of the thermally excited magnons, which could be used to manipulate domain walls [2]. [1] K. Uchida et al., Nature Mater. 9, 894 (2010) [2] D. Hinzke et al., Phys. Rev. Lett. 107, 027205 (2011)

TT 20.7 Mon 16:30 H22

Laser induced magneto-Seebeck effect on different substrate materials — •Alexander Böhnke[1], Marvin Walter[2], Karsten Rott[1], Andy Thomas[1], Markus Münzenberg[2], and Günter Reiss[1] — [1]Thin Films and Physics of Nanostructures, Bielefeld University, Germany — [2]I. Physikalische Institut, Georg-August-Universität Göttingen, Germany

Since the discovery of the magneto-Seebeck effect [1,2,3] (TMS, *tunnel magneto-Seebeck*) a proper interpretation of the time-resolved voltage traces has been missing [1]. Improvements in the time resolution of the TMS setup now give access to the investigation of the origin of the Seebeck voltage.

Further, we investigated magnetic tunnel junctions (MTJs) on two different substrate materials: Insulating MgO and semiconducting p-doped Si covered by 50 nm of SiO_2. TMS measurements on both sample types lead to same results. However, the time-resolved voltage traces in the case of silicon substrate showed a sharp peak when the laser is turned on. On MgO substrate this peak is not found. SPICE simulations of comparable MTJs on both substrates were performed and can give a first glance on thermal voltages occurring in the layer stacks and the substrates due to laser heating and capacitive coupling.

[1] M. Walter et al., Nat. Mater. 10 (2011), 742.
[2] C. Heiliger et al., Phys. Rev. B 83 (2011), 1.
[3] N. Liebing et al., Phys. Rev. Lett. 107 (2011), 177201.

15 min. break

TT 20.8 Mon 17:00 H22

Ab initio investigations on the magnetothermopower of thin Co/Cu multiple spin-valves — •Voicu Popescu and Peter Kratzer — Faculty of Physics, University Duisburg-Essen, Duisburg, Germany

We have modelled multiple spin-valve configurations by stacking Co and Cu layers of various thickness and number of repetitions. Theoretical investigations on their magneto-thermoelectric properties were performed by calculating the conventional and magnetic Seebeck coefficient using a spin-polarized relativistic implementation of the Landauer-Büttiker conductance formula within the framework of Korringa-Kohn-Rostoker method.

In line with experimental expectations, we find that the anti-parallel (AP) alignment of the adjacent Co layers is characterized by a much larger Seebeck coefficient than the parallel (P) configuration: from $1-2\ \mu$V/K in the P-case, the AP Seebeck coefficient can reach as much as 10 μV/K at room temperature. A correspondence between these values and the giant magneto-resistance characteristic to the Co/Cu spin valves could thus be established.

We show that an increase in the thickness of the Co layer further enhances the magnetothermopower whereas the Cu layer thickness variation has a negligible effect. In addition, we investigate the magnetic anisotropy in the Seebeck coefficient for these systems, by changing the magnetization orientation from parallel to perpendicular to the current. Our results suggest that a strong Seebeck magnetic anisotropy could be detected in typical GMR elements.

TT 20.9 Mon 17:15 H22

Altering the thermopower by magnetic fields — •Steven Achilles[1], Volodymyr V. Maslyuk[2], and Ingrid Mertig[1] — [1]Institute of Physics, Martin Luther University Halle-Wittenberg, D-06120 Halle, Germany — [2]Institute of Electron Physics, National Academy of Sciences of Ukraine, 88017 Uzhgorod, Ukraine

Transport properties of nanocontacts are unusual and determined by quantum effects as soon as the characteristic diameter decreases towards the nanometer scale. Besides the investigation of transport properties under low temperature conditions, temperature induced transport becomes more and more important [1].

In this work, we present an ab-initio study of both conductance and thermopower in a non-collinear magnetic system. We focus on an organometallic vanadium-benzene (V_4Bz_5) molecule attached to two Co electrodes oriented in fcc (001) direction with non-collinear magnetic order. Such vanadium-benzene complexes were synthesized and remain stable up to room temperature [2].

We show that, besides the formation of a non-collinear magnetization through the molecule, the sign and magnitude of the thermopower can be addressed directly altering the orientation of the leads magnetization. Furthermore, a non-monotonous behavior of the thermopower as a function of angle between the lead magnetization directions is found [3].

[1] Reddy et al., Science **315 (5818)**, 1568 (2007).
[2] K. Miyajima et al., Eur. Phys. J. D **34**, 177-182 (2005).
[3] V. V. Maslyuk et al., submitted.

TT 20.10 Mon 17:30 H22

Thermal spin-transfer torques in magnetic tunnel junctions — Michael Czerner, Christian Franz, and •Christian Heiliger — I.Physikalisches Institut, Justus Liebig University Giessen, D-35392, Germany

The emerging research field of spin caloritronics combines the spin-dependent charge transport with energy or heat transport. In comparison to thermoelectrics the spin degree of freedom is considered as well. We present ab initio calculations based on density functional theory using a Green's function KKR method. We compute the non-equilibrium density in a non-collinear regime, which allows us to calculate the spin-transfer torque. In our investigation we focus on the material dependence of the thermal spin-transfer torque in MgO based tunnel junctions. In particular, we investigate Fe, Co, and FeCo alloys as lead materials. The FeCo alloy is described by the coherent potential approximation (CPA) including vertex corrections for the non-equilibrium density. The thermal spin-transfer torque is calculated for several barrier thicknesses. It turns out that the size of the thermal spin-transfer torque is orders of magnitude smaller than spin-transfer torque at an applied bias voltage. Consequently, the thermal spin-transfer torque can be utilized only for very thin barrier thicknesses.

TT 20.11 Mon 17:45 H22

Quantum Isobaric Process and Thermodynamic Diesel Cycle in Ni_2 — •Chuanding Dong, Georgios Lefkidis, and Wolfgang Hübner — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Box 3049, 67653 Kaiserslautern, Germany

Building thermodynamic cycles with magnetic molecules extends quantum thermodynamics to real systems [1,2] and provides a unique opportunity to explore the thermodynamic properties of the spin degree of freedom. Here we propose a quantum isobaric process in the Ni_2 dimer, and build a quantum Diesel engine [3]. The level scheme of Ni_2 is obtained using *ab-initio* calculation and the perturbative inclusion of an external magnetic field. Our isobaric process is realized by adjusting the bath temperature in dependence on the interatomic distance. The boundary condition of keeping the pressure constant imposes a limitation on the allowed bond lengths, which we call isobaric range.

In the quantum Diesel cycle, since the preceding adiabatic process brings the Ni_2 dimer to a nonequilibrium state, the isobaric process is realized through a modified Boltzmann distribution. Due to its strong effect on the distribution profile, novel features, such as the crossing of the two adiabatic strokes, can appear on the projection on the two-dimensional $P-V$ diagram.

[1] H. T. Quan, Phys. Rev. E **79**, 041129 (2009).
[2] T. D. Kieu, Phys. Rev. Lett. **93**, 140403 (2004).
[3] C. D. Dong, G. Lefkidis, and W. Hübner, J. Supercond. Nov. Magn (in press).

TT 20.12 Mon 18:00 H22

Ab-initio study of the temperature dependent electron transport through magnetic nanostructures — •Roman Kováčik, Phivos Mavropoulos, Daniel Wortmann, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Recent developments in the field of the spin caloritronics have triggered many questions about the origin and character of the observed phenomena (e.g., spin-dependent Seebeck versus spin Seebeck effect [1]). To contribute to the understanding of the underlying mechanisms at the microscopic level, we investigate spin-dependent electron transport through various magnetic nanostructures between non-magnetic leads as a function of the temperature. The electronic structure of the studied systems is calculated within the multiple scattering screened

Korringa-Kohn-Rostoker (KKR) Green function framework [2]. The Monte-Carlo methodology is then used to simulate the effect of temperature on the magnetic configurations with the exchange coupling parameters calculated according to [3]. Finally, the Landauer-Büttiker approach for the ballistic transport within the KKR framework [4] is extended to account for the non-collinear magnetic effects. Support from the DFG (SPP 1538) is gratefully acknowledged.

[1] G.E.W. Bauer *et al.*, Nature Mater. 11, 391 (2012).
[2] N. Papanikolaou *et al.*, J. Phys. Condens. Matter 14, 2799 (2002), also see: www.kkr-gf.org.
[3] A.I. Liechtenstein *et al.*, J. Magn. Magn. Mater. 67, 65 (1987).
[4] Ph. Mavropoulos *et al.*, Phys. Rev. B 69, 125104 (2004).

TT 20.13 Mon 18:15 H22

Origin of the spin Seebeck effect in thin films — •Michael Schreier[1], Akashdeep Kamra[2], Mathias Weiler[1], Rudolf Gross[1], and Sebastian T.B. Goennenwein[1] — [1]Walther-Meißner-Institut, Garching, Germany — [2]Kavli Institute of Nanoscience, Delft University of Technology, The Netherlands

The spin Seebeck effect (SSE) originates from a finite temperature difference ΔT between the magnons in a ferromagnet (FM) and the electrons in a normal metal (NM) which supposedly stems from weak magnon-phonon interaction and different boundary conditions on phonon and magnon mediated heat currents. Also, recent experiments [1] suggest that the magnon-phonon interaction is much stronger than originally assumed, which again reduces the expected SSE [2]. Hence the established theory can not account quantitatively for the longitudinal SSE signals in thin films. A factor that has, however, been neglected so far is the Kapitza resistance which leads to an additional contribution to ΔT by introducing a discontinuity in the phonon temperature distribution at the FM/NM interface. This has been modelled using an analytical model and 3D finite elements simulations which show that, for thin layers, the contribution to ΔT originating from the Kapitza resistance is indeed of the same order of magnitude as the one from the original model. Hence the acoustic properties of the FM and NM play an important role in the origin of the SSE. This work is supported by the DFG via SPP1538.

[1] M. Agrawal et al., arXiv (2012)
[2] M. Weiler et al., Phys. Rev. Lett. 108, 106602 (2012)

TT 20.14 Mon 18:30 H22

Scattering-Independent Contribution to the Anomalous Nernst Effect — •Jürgen Weischenberg, Frank Freimuth, Stefan Blügel, and and Yuriy Mokrousov — Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

In analogy to the electric conductivity tensor [1], the thermoelectric- or Peltier conductivity tensor may be decomposed into a scattering-dependent and a scattering-independent term. Using the full-potential linearized augmented plane-wave method within the density functional theory, we compute all the contributions to the scattering-independent term, namely the intrinsic contribution and the side-jump contribution, and show that in ferromagnetic materials they are both of equal importance. In particular, the comparison of our theoretical values with experiments suggests that the anomalous Nernst effect in Fe, Co, Ni, FePd and FePt is largely caused by the scattering-independent term [2]. Moreover, the consequences of magnetic disorder on thermoelectric transport phenomena are also discussed. Financial support by the HGF-YIG Programme VH-NG-513 is gratefully acknowledged. J. W. was supported under grant SPP 1538 SpinCaT by the German Science Foundation.

[1] J. Weischenberg, F. Freimuth, J. Sinova, S. Blügel and Y. Mokrousov, PRL **107**, 106601 (2011)
[2] J. Weischenberg, F. Freimuth, S. Blügel and Y. Mokrousov, arXiv:1210.8283 [cond-mat.mtrl-sci]