NEW PERSPECTIVES FOR SPIN-CALORITRONICS

PhD SpinCaT Workshop August 18th - 19th 2016
JGU-SPICE, Mainz, Germany

ORGANIZERS:
Jacob Gayles (Mainz)
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Image: 'Burning Windmill in Stege' by Johan Christian Claussen Dahl (1856). Poster design: SuperNova Studios . NL

KEYNOTE SPEAKERS:

Gerrit Bauer (Sendai/Delft)
Olena Gomonay (Mainz)
Mathias Kläui (Mainz)
Ajaya Nayak (Dresden)
Jairo Sinova (Mainz)
Thierry Valet (Mainz)

The Spin Phenomena Interdisciplinary Center aims to bring together scientists from diverse disciplines and of varying seniority in the broad area of spin related research. Its goal is to break down scientific barriers and foster emergent areas of research that combine the strengths of different fields.

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Contents

Tutorials **6**
Spin(calori)tronics with Magnons 6
Antiferromagnetic Spin-something-tronics: Phenomenological Models and Approaches 7
The Spin Seebeck Effect – The Role of the Bulk and of Interfaces 8
Tunable magnetic properties in Heusler materials 10

Career Talks **11**
But Nobody told me this! 11
Private Sector Career Opportunities for Physicists at a time of Industrial Innovation Disruptions 11

Contributed Talks **12**
Bulk Spin-Orbit Torques at finite temperatures in Bulk Half-Metallic Heuslers from First Principles 12
Comparison of laser induced and intrinsic tunnel magneto-Seebeck effect in 13
CoFeB/$MgAl_2O_4$ and CoFeB/MgO magnetic tunnel junctions 13
Probing non-integral spin magnons via spin current noise 14
Magnon accumulation in complex magnetic materials 15

Poster Abstracts **16**
Magneto-optic detection of spin Seebeck effect in Au/YIG and Cu/YIG bilayers at picosecond time-scale 16
Pure Anomalous Nernst Effect in Magnetic Thin Films 17
Spin-Caloritronic Transport in Superconductor-Ferromagnet TunnelStructures 18
Thermal spin transfer torque on MgO-based magnetic tunnel junctions using FMR microresonators 19
Towards low temperature measurements of thermal conductivity and thermal diffusivity of SiN membranes using the 3ω method 20
Thickness-dependent low-temperature enhancement of spin Seebeck effect in YIG films 21

List of Participants **22**

Campus Map **23**

LOCATION

Workshop Venue: Lorentz Room (05-127),
Poster Session: Minkowski Room (05-119)
Staudinger Weg 7
55128 Mainz

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PhD SpinCaT Workshop 2016

Timetable

TIME	Thu (18.08)	Fri (19.08)
8:30	Registration	
9:00	Introduction	
9:30	Gerrit Bauer	Olena Gomonay
10:00		
10:30	COFFEE BREAK	COFFEE BREAK
11:00	Ajaya Nayak (Claudia Felser)	Mathias Kläui
11:30		
12:00	LUNCH	LUNCH
12:30		
13:00		
13:30	Thierry Valet	Jairo Sinova
14:00		
14:30	Ulrike Ritzmann	Torsten Huebner
15:00	Akash Kamra	Jacob Gayles
15:30	POSTERS	**Discussion Time**
16:00		
16:30		Poster Award / Closing remarks
17:00		
17:30		
18:00		
18:30		
19:00	CONFERENCE DINNER	
19:30		
20:00		
20:30		

Legend:

green	theory
yellow	experiment
blue	career

website: http://www.spice.uni-mainz.de/phd-spincat-workshop-2016/

Tutorials

Gerrit Bauer Thursday 9:30-10:30

IMR & WPI-AIMR, Tohoku University & Kavli Institute of NanoScience Delft

Spin(calori)tronics with Magnons

Abstract: The high quality of thin films of the magnetic insulator yttrium iron garnet (YIG) allows the study of magnon physics in unprecedented detail.
This lecture addresses the basics and several recent theories and experiments that shed light on magnon transport in YIG films under optical, thermal, and electric excitation.

Olena Gomonay Friday 9:30-10:30

JGU Mainz

Antiferromagnetic Spin-something-tronics: Phenomenological Models and Approaches

Abstract: Nowadays antiferromagnets compete with ferromagnetic materials in the fields of active spintronics devices. Antiferromagnets are faster, higher protected from noise and more scalable than their ferromagnetic counterparts. However, their magnetic dynamics differs from the magnetic dynamics of ferromagnets and in many cases seems counter-intuitive to "ferromagnetic community". In my lecture I will highlight the peculiarities of antiferromagnetic dynamics in the presence of spin currents (spintronics) and temperature gradients (caloritronics). I will also give and discuss several examples which illustrate differences and similarities of antiferro- and ferromagnetic spin-something-tronics.

Mathias Kläui Friday 11:00-12:00

JGU Mainz

The Spin Seebeck Effect – The Role of the Bulk and of Interfaces

Abstract: The spin Seebeck effect (SSE) allows for the generation of thermally excited spin waves and thus enables one to probe a broad frequency distribution of magnon spectra [1]. The occurring spin currents can be detected in an adjacent normal metal layer with the aid of the inverse spin Hall effect (ISHE).

By varying the bulk properties, it has been established that the origin of the measured signals are indeed thermally generated magnons originating in the bulk of the magnetic material [2]. In ferromagnetic insulator (FMI)/normal metal (NM) bilayers the temperature dependence of the SSE has been probed as a function of FMI thickness, different interfaces and detection materials [3]. At low temperatures, an enhancement of the SSE signal is observed, including the appearance of a peak in the amplitude (Fig. 1a). This enhancement clearly depends on the FMI thickness showing that bulk properties play a role. However the temperature dependence depends also strongly on the FMI/NM interface (Fig. 1b). This surprising dependence shows that different magnon modes have a different transmission probability depending on the interface. In order to obtain a better understanding of the influence of the FMI/NM interface, transmission electron microscopy (TEM) measurements combined with elemental analysis (EELS, EDS) are performed. We show that the atomistic structure of the interface depends strongly on the NM allowing us to correlate both [3]. Finally in ferrimagnets we can engineer the magnon modes and study their transmission probabilities into the NM showing semi-quantitatively how the different mode transmissions depend on the interface type and structure [4].

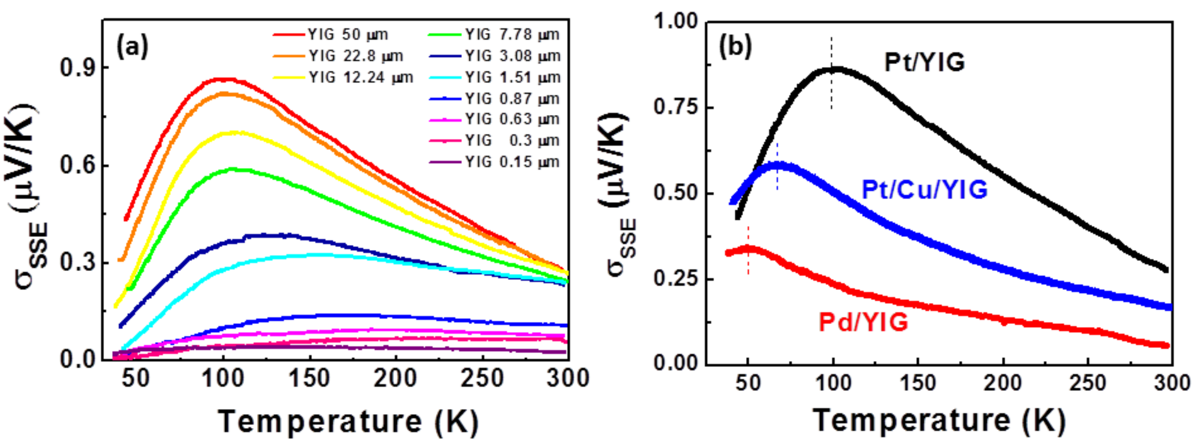

Figure 1. (a) Temperature dependent SSE coefficients (σ_{SSE}) of YIG thin films with a wide range of thicknesses. (b) Temperature dependent σ_{SSE} measured at Pt/YIG, Pt/Cu/YIG, and Pd/YIG hybrids. The thickness of YIG films is 50 μm.

[1] K. Uchida *et al.,* Nature **455**, 778 (2008); C. M. Jaworski *et al.*, Nature Mater. **9**, 898 (2010); G. Bauer *et al.*, Nature Mater. **11**, 391 (2012).
[2] U. Ritzmann *et al.,* Phys. Rev. B **89**, 024409 (2014); A. Kehlberger *et al.,* Phys. Rev. Lett. **115**, 096602 (2015).
[3] Er-Jia Guo *et al.,* Phys. Rev. X **6**, 031012 (2016).
[4] S. Geprägs *et al.,* Nature Commun. **7**, 10452 (2016).

Ajaya Nayak Thursday 11:00-12:00

MPI-Halle

Tunable magnetic properties in Heusler materials

Abstract: Heusler materials, X_2YZ (where X, Y are transition metals and Z is a main-group element), are well known for their potential application in spintronics, especially in TMR based devices. The presence of multiple magnetic sub-lattices in these materials provides a perfect platform for the design of anisotropic and acentric room-temperature magnets. We utilize this flexible magnetic configuration to design a compensated ferrimagnetic state by combining two oppositely aligned ferrimagnets. We show that this compensated magnetic state is an ideal recipe to achieve an extremely large exchange bias [1, 2]. In addition, these compensated magnetic materials are of large interest in antiferromagnetic (AFM) spintronics, since, in contrast to ferromagnets, they do not produce any unwanted stray field [3]. The possibility of AFM spintronics is further boosted with our recent finding of large anomalous Hall effect in a non-collinear antiferromagnets [4]. We also exploited the competing ferromagnetic and AFM interactions within the same crystal structure to realize a non-collinear magnetic states and skyrmions [5]. These non-collinear magnets are suitable candidates for generating skyrmion, a vortex like object with a circular spin configuration [6]. The skyrmions are excellent candidates for future spintronic devices as their motion can be accomplished in a small current density. In future, we will explore the possibility of skyrmion motion using heat current.

[1] A. K. Nayak et al., Nature Mater. 14, 679 (2015).
[2] A. K. Nayak et al., Phys. Rev. Lett. 110, 127204 (2013).
[3] B.G. Park et al., Nature Mater. **10**, 347 (2011).
[4] A. K. Nayak et al., Science Advances 2, e1501870 (2016).
[5] O. Meshcheriakova, S. Chadov, A. K. Nayak, U. Roessler, J. Kuebler, J. Kiss, G. Andre, A. A. Tsirlin, S. Hausdorf, A. Kalache, W. Schnelle, M. Nicklas, and C. Felser, Phys. Rev. Lett. 113, 087203 (2014).
[6] X. Z. Yu et al., Nature 465, 901 (2010).

Career Talks

Jairo Sinova Friday 13:30-14:30

JGU Mainz

But Nobody told me this!

Thierry Valet Thursday 13:30-14:30

JGU Mainz

Private Sector Career Opportunities for Physicists at a time of Industrial Innovation Disruptions

Someone once said that "experience is a candle that can only light up the path of the one who carries it". Accordingly, more than twenty five years as a physicist operating in the various, and at times overlapping, capacities of engineer, inventor, corporate R&D executive and entrepreneur, with my share of success, and failures, does not necessarily qualify me to inform your future career choices. Nevertheless, I will try to provide an informed/critical view of the opportunities offered to you in the private sector; answer the questions you may have in that respect, and hopefully give you some useful tools in case you want to further explore this path.

Contributed Talks

Jacob Gayles Friday 15:00-15:30

JGU Mainz

Bulk Spin-Orbit Torques at finite temperatures in Bulk Half-Metallic Heuslers from First Principles

We predict bulk spin-orbit torques in the half-metallic Heuslers NiMnSb and PtMnSb, using symmetry arguments in conjunction with first principle calculations. We present under uniaxial growth strain a linear dependence of the even torque and that can be tuned to zero while observing a sizable odd torque is independent of strain. Furthermore, these effects are seen to be two orders of magnitude larger in the PtMnSb. The even torque is strongly dependent on the temperature decreasing by 75% at room temperature where finite temperature is taken into account in the frozen phonon approximation. We show the equivalence of two widely used methods, the Landauer-Bütikker and the Kubo linear response formalism giving confidence in our result for experimental measurements in bulk magnetic Heusler compounds breaking inversion symmetry.

We acknowledge financial support by the DFG through SFB 173 and through SPP "Spin Caloric Transport".

Torsten Huebner Friday 14:30-15:00

Bielefeld University

Comparison of laser induced and intrinsic tunnel magneto-Seebeck effect in CoFeB/$MgAl_2O_4$ and CoFeB/MgO magnetic tunnel junctions

Abstract: We present a comparison of the tunnel magneto-Seebeck effect for laser induced and intrinsic heating. Therefore, Co40Fe40B20/MgAl2O4 and Co25Fe55B20/MgO magnetic tunnel junctions have been prepared. The TMS ratio of 3% in case of the MAO MTJ agrees well with ratios found for other barrier materials, while the TMS ratio of 23% of the MgO MTJ emphasizes the influence of the CoFe composition. We find results using the intrinsic method that differ in sign and magnitude in comparison to the results of the laser heating. The intrinsic contributions can alternatively be explained by the Brinkman model and the given junction properties. Especially, we are able to demonstrate that the symmetric contribution is solely influenced by the barrier asymmetry. Thus, we conclude that the symmetry analysis used for the intrinsic method is not suitable to unambiguously identify an intrinsic tunnel magneto-Seebeck effect.

Akashdeep Kamra Thursday 15:00-15:30

University of Konstanz

Probing non-integral spin magnons via spin current noise

Abstract: The charge currents which underlie the modern electronic devices are typically mediated by electrons. A novel technological paradigm based on magnets relies upon spin currents carried by fundamentally different particles - magnons, carrying a quantum of spin. In this work, we show that interactions lead to a new exotic particle called squeezed-magnon, consisting of a quantum conglomerate of several magnons and, thus, carrying an angular momentum greater than the fundamental quantum $\hbar$. Non-equilibrium spin current fluctuations are predicted to carry the information about the squeezed magnons. Hence, we show that the experimentally feasible investigation of the spin current fluctuations in a spin pumping setup might be the key to reveal the quantum nature of exotic quasiparticles like the squeezed magnon.

The magnetization of a ferromagnet (F) driven out of equilibrium injects pure spin current into an adjacent conductor (N). We evaluate the shot noise of the spin current traversing the F|N interface when F is subjected to a coherent microwave drive. We find that the noise spectrum is frequency independent up to the drive frequency, and increases linearly with frequency thereafter. The low frequency noise indicates super-Poissonian spin transfer, which results from quasi-particles with effective spin $\hbar^* = \hbar(1 + \delta)$. For typical ferromagnetic thin films, $\delta \sim 1$ is related to the dipolar interaction mediated squeezing of F eigenmodes.

References:
[1] A. Kamra and W. Belzig, Phys. Rev. Lett. 116, 146601 (2016).
[2] Ya. M. Blanter and M. B□uttiker, Phys. Rep. 336, 1 (2000).

Ulrike Ritzmann Thursday 14:30-15:00

JGU Mainz

Magnon accumulation in complex magnetic materials

It was shown experimentally that in a magnetic insulator, spin currents can be created by applying temperature gradients [1]. These spin currents are due to a net magnon current that propagates from the hotter towards to cooler region of the magnetic material.

Using atomistic spin model simulations with the stochastic Landau-Lifshitz-Gilbert equation, we study thermally induced magnonic spin currents and their characteristic length scales in magnetic materials with different temperature profiles [2,3,4]. The magnon accumulaton in ferromagnets created by linear temperature gradients is first increasing with increasing length of the gradient and saturates in agreement with experimental measurements [3]. Moreover, the excited spin current can be controled by applying external magnetic fields, which cause a suppression of the thermally excited spin currents [4]. A frequency dependent study of the magnon accumulation is used to explain the observed thickness dependence of the suppression effect.

As a next step, we explore the thermally excited spin currents in antiferromagnetic materials. We study the magnon accumulation due to a temperature step and its characteristic length scale. Furthermore, we investigate the different antiferromagnetic modes that are excited and discuss their propagation length using a one-dimensional analytical model.

These methods can be extended for ferrimagnetic materials. In a two-sublattice ferrimagnet, we determine the thermally excited magnon accumulation excited by a temperature step. We study the temperature dependence of the magnon accumulation in ferrimagnets and investigate under which condition the magnon accumulation in such systems vanishes [5].

We acknowledge financial support by the DFG through SFB 767 and through SPP "Spin Caloric Transport".

[1] K. Uchida et al, Appl. Phys. Lett. **97**, 172505 (2010)
[2] U. Ritzmann et al., Phys. Rev. B **89,** 024409 (2014)
[3] A. Kehlberger et al.,Phys. Rev. Lett. **115**, 096602 (2015)
[4] U. Ritzmann et al., Phys. Rev. B **92**, 174411 (2015)
[5] U. Ritzmann et al., submitted

Poster Abstracts

Magneto-optic detection of spin Seebeck effect in Au/YIG and Cu/YIG bilayers at picosecond time-scale

J. Kimling[1], G.-M. Choi[2], J. T. Brangham[3], T. Matalla-Wagner[4], T. Huebner[4], T. Kuschel[4;5], F. Yang[3], D. G. Cahill[1]

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Application of a temperature gradient perpendicular to the plane of $Y_3Fe_5O_{12}$ (YIG) / Pt bilayers create a voltage in the Pt layer. The established explanation is, that the temperature gradient in the YIG drives a spin current which is injected into the Pt where the inverse spin Hall effect (ISHE) converts the spin current into a charge current and thus a voltage can be measured [1]. The initial generation of the spin current by a temperature gradient has been termed as the longitudinal spin Seebeck effect (LSSE) [2]. In addition, a magnetic proximity effect (MPE) in Pt can occur, that allows for the anomalous Nernst effect (ANE), which has the same symmetry as the LSSE [3]. The MPE in Pt has been initially investigated by two groups using x-ray magnetic circular dichroism (XMCD). Geprgs et al. have seen no evidence for a signifcant MPE in YIG / Pt bilayers [4], while Lu et al. can not exclude the MPE induced ANE in YIG / Pt bilayers as a parastitic side effect [5]. A more interface-sensitive method to investigate the MPE is the x-ray resonant magnetic reflectometry (XRMR), which has been used by Kuschel et al. to investigate $NiFe_2O_4$ (NFO) / Pt bilayers, excluding the MPE for those systems [6]. To corrobate the spin current hypothesis and to reliably detect the LSSE without any MPE side effects, additional techniques such as magneto-optic means are required.
Here, we present LSSE measurements using the time-resolved magneto-optical Kerr effect (TR-MOKE). Our results indicate angular-momentum transfer across YIG / Cu and YIG / Au interfaces on a picosecond time scale [7].

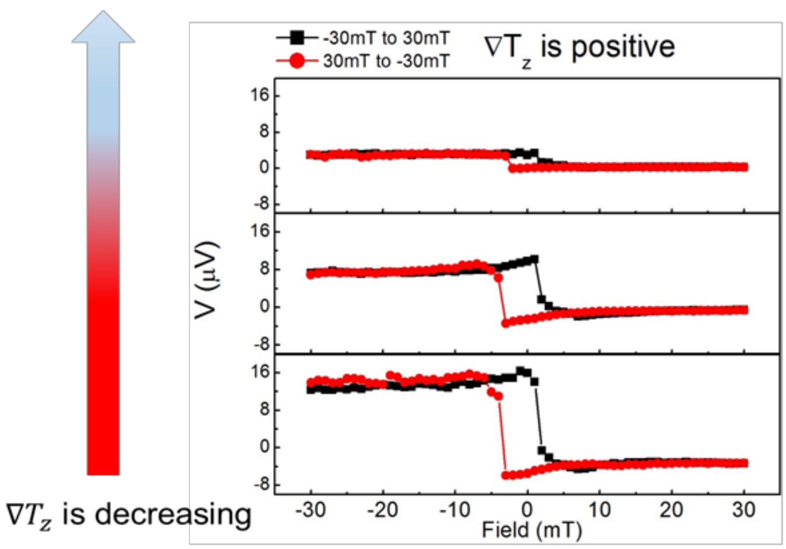
[1] E. Saitoh et al., Appl. Phys. Lett. 88, 182509 (2006)
[2] K. Uchida et al., Appl. Phys. Lett. 97, 172505 (2010)
[3] S. Y. Huang et al., Phys. Rev. Lett. 109, 107204 (2012)
[4] S. Geprgs et al., Appl. Phys. Lett. 101, 262407 (2012)
[5] Y. M. Lu et al., Phys. Rev. Lett. 110, 147207 (2013)
[6] T. Kuschel et al., Phys. Rev. Lett. 115, 097401 (2015)
[7] J. Kimling et al., arXiv.org/abs/1608.00702 (2016)

Pure Anomalous Nernst Effect in Magnetic Thin Films

Junfeng Hu[1,2], Ping Che[1], and Haiming Yu[1,2]

[1] *Fert Beijing Institute, Spintronics interdisciplinary center, Univ. Beihang, 100191, Beijing, China*
[2] *School of Electronics and information engineering, Beihang university*

We use thin films (Py, CoFeB, CoGd) to study the anomalous Nernst effect (ANE). In order to eliminate the influence of other effects, such as the spin Seebeck effect [1] and the magnetic proximity effect [2], the thin films we used are covered by very thin aluminum. In this poster, we will show some ANE measurements based on different thin films. We have investigated three different thin films which showed a bit different results, namely the CoGd shows an inverse sign of signal and much bigger amplitude compared to both Py and CoFeB at the same condition. But the accurate value of the anomalous Nernst coefficients for CoFeB and CoGd sample are not available, since we cannot get a precise value of the out of plane temperature gradient yet.
ANE on CoGd(20nm) / Si thin film with out of plane temperature gradient.



ANE on CoGd(20nm) / Si thin film with out of plane temperature gradient

[1] K. Uchida et al. Observation of the spin Seebeck effect. Nature 455, 778–781 (2008).
[2] S.Y. Huang et al. Transport Magnetic Proximity Effects in Platinum. PRL 109, 107204 (2012).

Spin-Caloritronic Transport in Superconductor-Ferromagnet TunnelStructures

Ali Rezaei, Akashdeep Kamra, Peter Machon, Wolfgang Belzig

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We investigate the effect of an exchange field ($\boldsymbol{H}_{\mathrm{ex}}$) and spin-flip scattering (τ_{sf}) on the pair potential (Δ) and the spin Seebeck coefficient ($\boldsymbol{S}$) of superconductor (S)-ferromagnet (F) hybrid structures using the Green's function method. Such structures have been predicted to show giant charge Seebeck coeficient [1, 2]. In the absence of spin-flip scattering, the pair potential of the S has been studied for different values of the exchange field. We show that when $\boldsymbol{H}_{\mathrm{ex}} = 0.9\Delta_{\mathbf{0}}$, where $\Delta_{\mathbf{0}}$ is the pair potential at zero temperature, there is a first order phase transition in BCS self-consistency relation. The density of states in energy, and spin Seebeck coefficient as a function of temperature have been computed for several values of the inverse collision time for spin-flip scattering ($\Gamma = 1/\tau_{\mathrm{sf}}$). We show that spin-flip scattering limits the enhanced spin Seebeck coefficient in realistic settings.

[1] P. Machon, M. Eschrig, and W. Belzig, Phys. Rev. Lett. **110**, 047002 (2013).
[2] A. Ozaeta, P. Virtanen, F. S. Bergeret, and T. T. Heikkilä, Phys. Rev. Lett. **112**, 057001 (2014).

Thermal spin transfer torque on MgO-based magnetic tunnel junctions using FMR microresonators

Hamza Cansever[1,2], Ciaran Fowley[1], Rysard Narkowicz[1] Ewa Kowalska[1,2],, Yuriy Aleksandrov[1,2], Oguz Yildirim[1], AlexandraTitova[1,2], Kilian Lenz[1], Jürgen Lindner[1], Jürgen Fassbender[1,2], Alina M. Deac[1]

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MgO-based magnetic tunnel junctions are commonly used in spintronic device applications, such as recent spin transfer torque random access memory (STT-RAM) because of their non-volatility, fast switching and high storage capacity. Spin transfer torque is defined as a spin polarized current flowing through a ferromagnet exerting a torque on the local magnetization. With thermal spin transfer torque (T-STT), thermally excited electron transport is used instead of spin polarized charge current and provides an interesting way of using thermoelectric effects in magnetic storage applications. Our study focuses on fundamental experimental research aimed at demonstrating that thermal gradients can generate spin-transfer torques in MgO-based magnetic tunnel junctions (MTJs). We use microresonators in order to analyze how the ferromagnetic resonance signal corresponding to the free layer of an in-plane MgO-based tunnel junction device is modified in the presence of a temperature gradient across the barrier.

This work is supported by DFG-SPP**1538**

Towards low temperature measurements of thermal conductivity and thermal diffusivity of SiN membranes using the 3ω method

Sofia Blanter[1], Sasmita Srichandan[1], Denis Kochan[1], and Christoph Strunk[1]

[1] *Institute of Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany*

We present measurements of thermal conductivity and thermal diffusivity for thin suspended membranes. The measurements are performed on 500 nm thick SiN membranes using the 3ω method [1]. We pass an AC current at a frequency ω through a metal heater, which is simultaneously used as a thermometer, located on top of the membrane. This applied current generates an oscillating heat flux through the membrane. This will create a modulation on top of the measured voltage through the heater, at a frequency of 3ω.
We use two different theoretical models, derived from the 1D and 2D heat diffusion equations, that allow us to extract the thermal conductivity and thermal diffusivity of our membranes. Both models give similar SiN thermal conductivity values to the ones found in literature [2–4].

[1] D. Cahill and R. Pohl, *Thermal conductivity of amorphous solids above the plateau*, Physical Review B **35** (1987): 4067.

[2] D.R. Queen and F. Hellman, *Thin film nanocalorimeter for heat capacity measurements of 30 nm films,* Review of Scientific Instruments **80** (2009): 063901.

[3] A. Sikora, H. Ftouni, J. Richard, C. Hébert, D. Eon, F. Omnès and O. Bourgeois *Highly sensitive thermal conductivity measurements of suspended membranes (SiN and diamond) using a 3ω-Völklein method,* Review of Scientific Instruments **83** (2012): 054902.

[4] R. Sultan, A.D. Avery, J.M. Underwood, S.J. Mason, D. Bassett and B.L. Zink, *Heat transport by long mean free path vibrations in amorphous silicon nitride near room temperature,* Physical review B **87** (2013): 214305.

Thickness-dependent low-temperature enhancement of spin Seebeck effect in YIG films

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The spin Seebeck effect (SSE) allows for the generation of thermally excited spin waves and thus enables one to probe a broad frequency distribution of magnon spectra [1, 2]. The occurring spin currents can be detected in an adjacent normal metal layer with the aid of the inverse spin Hall effect (ISHE).
In ferromagnetic insulator (FMI)/normal metal (NM) bilayers the temperature dependence of the SSE has been probed as a function of FMI thickness, different interfaces and detection materials [3]. At low temperatures, an enhancement of the SSE signal is observed, including the appearance of a peak in the amplitude. This enhancement clearly depends on the FMI thickness, as it is more pronounced for thicker films and vanishes for film thicknesses below 600 nm. In addition to that, the maximum position Tpeak strongly depends on the FMI thickness as well as on the FMI/NM interface. The thickness dependence can be well explained by considering a model of a magnon-driven SSE, which takes into account the frequency dependent propagation length of thermally excited magnons inside the bulk material. The NM dependence, however, indicates that previously neglected interface effects play a major role in the observed signal. In order to obtain a better understanding of the influence of the FMI/NM interface, transmission electron microscopy (TEM) measurements combined with elemental analysis (EELS, EDS) are performed to correlate the interface structure with the resulting spin current transmission.

[1] A. Kehlberger et al. Phys. Rev. Lett. 115, 096602 (2015)
[2] U. Ritzmann et al. Phys. Rev. B 89, 024409 (2014)
[3] Er-Jia Guo et al., Phys. Rev. X **6**, 031012 (2016)

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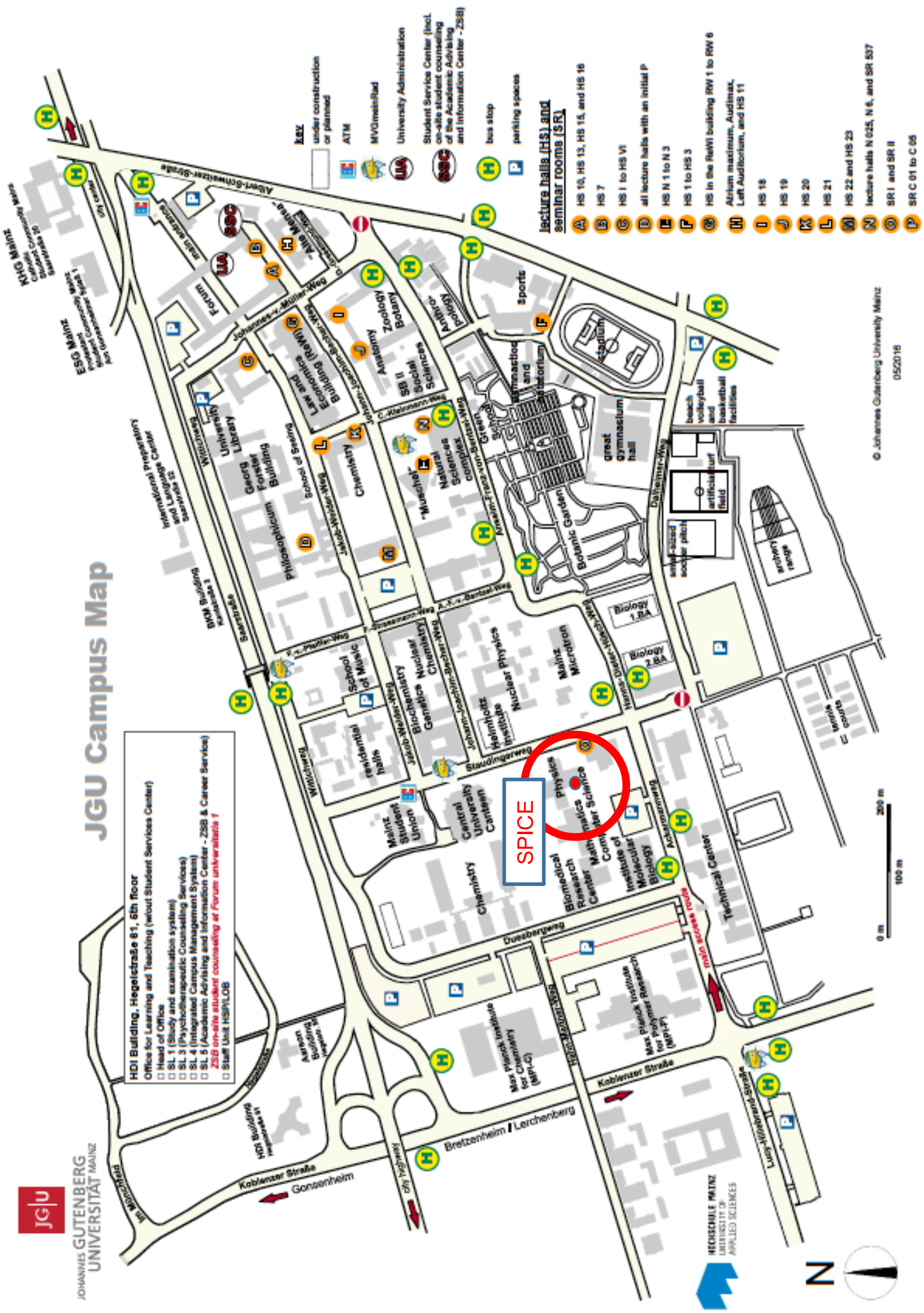
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