HL 13: Focus Session: Spin-Charge Interconversion (joint session MA/HL)

While classical spintronics has traditionally relied on ferromagnetic metals as spin generators and spin detectors, a new approach called spin-orbitronics exploits the interplay between charge and spin currents enabled by the spin-orbit coupling (SOC) in non-magnetic systems. Efficient spin-charge interconversion can be realized through the direct and inverse Edelstein effects at interfaces where broken inversion symmetry induces a Rashba SOC. Although the simple Rashba picture of split parabolic bands is usually used to interpret such experiments, it fails to explain the largest conversion effects and their relation to the actual electronic structure.

Organizer: Ingrid Mertig (University Halle-Wittenberg)

Time: Monday 15:00–18:15 Location: HSZ 04

Invited Talk HL 13.1 Mon 15:00 HSZ 04
SrTiO3-based 2-dimensional electron gases for ultralow power spintronics — •Manuel Bibes — CNRS/Thales, Palaiseau, France

The MESO transistor is a spin-based non-volatile device proposed by Intel in which magnetic information is written by a magnetoelectric element and read out by a spin-orbit element through the inverse spin Hall effect or the inverse Edelstein effect (IEE). In this talk, I will show that the 2DEG that forms at the interface of SrTiO3 (STO) with LaAlO3 or reactive metals such as Al may be exploited to interconvert spin and charge currents through the direct and inverse Edelstein effects with high efficiencies. I will first present spin to charge conversion experiments using the spin-pumping technique to inject a spin current in the 2DEG. By applying a gate voltage, we tune the position of the Fermi level in the multi-orbital electronic structure of STO, which results in a strong variation of the IEE amplitude with sign changes. This can be modelled through a tight-banding modelling of the band structure measured by ARPES. Importantly, a finite conversion effect persists at room temperature, with a figure-of-merit competitive for MESO-based electronics. In a second part, I will present gate-controlled, all-electrical spin current generation and detection in planar nanodevices free from ferromagnets and only based on a STO 2DEG. Here, the spin current is generated by the direct 2D spin Hall effect from a charge current running in the 2DEG, transported through the device over several microns and reconverted into a charge current by the inverse 2D spin Hall effect.

Invited Talk HL 13.2 Mon 15:30 HSZ 04
Spin-to-charge current conversion for logic devices — •Felix Casanova — CIC nanoGUNE, San Sebastian, Basque Country, Spain

The integration of logic and memory in spin-based devices, such as the recent MESO proposal by Intel [1], could represent a post-CMOS paradigm. A key player is the spin Hall effect (SHE), which allows to electrically create or detect pure spin currents without using ferromagnets (FM). Understanding the different mechanisms giving rise to SHE allows to find and optimize promising materials for an efficient spin-to-charge conversion (SCC). We unveiled these mechanisms in prototypical materials Pt and Ta [2]. A radically different approach is by engineering a van der Waals heterostructure which combines graphene with a transition metal dichalcogenide. We recently demonstrated SHE in graphene due to spin-orbit proximity with MoS2 [3]. The combination of long-distance spin transport and SHE in different parts of the same material gives rise to an unprecedented SCC efficiency.

Finally, I will present a novel and simple FM/Pt nanodevice to readout the in-plane magnetic state of the FM electrode using SHE [4]. The spin-orbit based detection allows us to independently enhance the output voltage (needed to read the in-plane magnetization) and the output current (needed for cascading circuit elements) with downscaling of different device dimensions, which are necessary conditions for implementing the MESO logic [1].

[1] Manipatruni et al., Nature 565, 35 (2019); [2] Sagasta et al., PRB 94, 060412 (2016); ibid. 98, 060410 (2018); [4] Safeer at al., Nano Lett. 19, 1074 (2019); [5] Pham et al., submitted.

Invited Talk HL 13.3 Mon 16:00 HSZ 04
Spin-charge interconversion in graphene/TMD Van der Waals heterostructures — •Bart Van Wees — Zernike Institute for Advanced materials, University of Groningen, The Netherlands

I will give an introduction into spin transport, spin relaxation and spin-charge conversion in Van der Waals heterostructures made of (single) layer graphene and (single layer) transition metal dichalcogenides (TMDs). Due to their proximity, the strong anisotropic spin orbit interaction in the TMD results in anisotropic, valley-Zeeman and Rashba type spin orbits field in the graphene . As a result the spin relaxation in graphene becomes strongly anisotropic, with out-of-plane oriented spins having a factor 10 or more longer spin life times than in-plane oriented spins [1,2]. The proximity induced spin orbit interaction also gives the possibility of gate tuneable spin change interconversion mechanisms such as spin Hall effect (and its inverse) and Rashba Edelstein effect (and its inverse). I will explain how these effects are observed experimentally [3,4,5], and how they can be optimized for future 2D spintronics applications.

1] T.S. Ghiasi et al., Nano Lett. 17, 7528-7532 (2017)
2] L.Benitez et al., Nature Physics 14, pages303-308(2018)
3] C.K. Safeer et al., Nano Lett. 19, 2, 1074-1082 (2019)
4] T.S. Ghiasi et al., Nano Lett. 19,9, 5959-5966 (2019)
5] L. A. Benítez et al, https://arxiv.org/abs/1908.07868

15 min. break.

Invited Talk HL 13.4 Mon 16:45 HSZ 04
Ferroelectric control of the spin-to-charge conversion in the ferroelectric Rashba semiconductor GeTe — Sara Varotto[1], Luca Nessi[1], Stefano Cecchi[2], Paul Noel[3], Simone Petrò[1], Alessandro Novati[1], Raffaella Calarco[2], Matteo Cantoni[1], Laurent Vila[3], Jean-Philippe Attané[3], Riccardo Bertacco[1], and •Christian Rinaldi[1] — [1]Dipartimento di Fisica, Politecnico di Milano, via Colombo 81, 20133 Milano, Italy — [2]Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany — [3]Univ. Grenoble Alpes, CNRS, CEA, Grenoble INP, IRIG-SPINTEC, F-38000 Grenoble, France

Scalable and energy efficient spin-orbit logic has been very recently pointed out by Intel as technologically suitable computing alternative to CMOS devices [1]. It comprises an electrically driven memory element, with the spin-orbit-based detection of the state performed by spin-to-charge conversion. In this talk, we show that the ferroelectric Rashba semiconductor Germanium Telluride offers memory as well as spin-orbit readout in a silicon-compatible semiconductor. GeTe possesses a giant bulk Rashba-like spin texture, which can be reversed by its non-volatile ferroelectricity [2]. Here we demonstrate the switchability of bulk GeTe through gate electrodes, enabling the electric control of spin textures. Spin pumping measurements in Fe/GeTe heterostructures revealed the ferroelectric control of the spin to charge conversion, paving the way to single-compound spin-orbit logic devices.

[1] S. Manipatruni, Nature 565, 35 (2019); [2] C. Rinaldi et al., Nano Letters 18, 2751 (2018)

Invited Talk HL 13.5 Mon 17:15 HSZ 04
Theory of spin-to-charge conversion in a topological oxide two-dimensional electron gas — •Annika Johansson[1], Börge Göbel[1,2], Ingrid Mertig[1], and Manuel Bibes[3] — [1]Martin Luther University Halle-Wittenberg, Halle, Germany — [2]Max Planck Institute of Microstructure Physics, Halle, Germany — [3]Unité Mixte de Physique CNRS/Thales, Université Paris-Sud, Université Paris-Saclay, Palaiseau, France

$SrTiO_3$ (STO)-based two-dimensional electron gases (2DEGs) provide a highly efficient spin-to-charge conversion [1], also known as inverse Edelstein effect [2,3]. Recently, an extremely large spin-to-charge conversion efficiency was demonstrated in the 2DEG at the interface between STO and Al [4]. The application of a gate voltage leads to a strong variation and even sign changes of the spin-to-charge conversion.

We explain this unconventional gate dependence of the (inverse)

Edelstein effect from a theoretical perspective by Boltzmann transport calculations within a multiorbital tight-binding model. By a band-resolved analysis of the Edelstein signal we relate the experimentally observed spin-to-charge conversion to the band structure as well as the topological character and the spin texture of the 2DEG.

[1] E. Lesne *et al.*, Nat. Mater. **15**, 1261 (2016)
[2] V. M. Edelstein, Solid State Commun., **73**, 233 (1990)
[3] K. Shen *et al.*, Phys. Rev. Lett. **112**, 096601 (2014)
[4] D. Vaz *et al.*, Nature Materials **18**, 1187 (2019)

Invited Talk HL 13.6 Mon 17:45 HSZ 04

Nonlinear magnetoresistance from surface states of a topological insulator — •Giovanni Vignale[1], Pan He[2], Dapeng Zhu[2], Shuyuan Shi[2], Hyunsoo Yang[2], Steven S.-L Zhang[3,4], and Olle Heinonen[3] — [1]Department of Physics and Astronomy, University of Missouri-Columbia, Missouri 65211, USA — [2]1Department of Electrical and Computer Engineering, and NUSNNI, National University of Singapore, 117576, Singapore — [3]2Materials Science Division, Argonne National Laboratory, Lemont, Illinois 60439, USA — [4]3Department of Physics, Case Western Reserve University, Cleveland, Ohio 44106, USA

Surface states of topological insulators exhibit the phenomenon of spin-momentum locking, whereby the orientation of an electron spin is determined by its momentum. We have discovered a close link between the spin texture of these states and a new type of nonlinear magnetoresistance, which depends on the relative orientation of the current with respect to the magnetic field as well as the crystallographic axes, and scales linearly with both the applied electric and magnetic fields. The nonlinear magnetoresistance originates from the conversion of a non-equilibrium spin current into a charge current under the application of an external magnetic field. Additionally, we find that the transverse component of the nonlinear resistance exhibits a pi/2 phase shift with respect to its longitudinal counterpart, in marked contrast to the usual pi/4 phase difference that exists between the linear planar Hall effect and the anisotropic magnetoresistance in typical topological insulators and transition metal ferromagnets.