MA 6: 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: Tuesday 13:30–16:45 Location: H5

Invited Talk MA 6.1 Tue 13:30 H5

Spin-charge interconversion with oxide 2-dimensional electron gases — •Manuel Bibes — Unité Mixte de Physique CNRS/Thales

Oxide 2-dimensional electron gases (2DEGs) display a wide range of functionalities including Rashba spin-orbit coupling (SOC), which offers exciting opportunities for spintronics. In this talk, I will show that the 2DEG that forms at the interface of SrTiO3 (STO) with LaAlO3[1] or reactive metals such as Al[2,3] may be exploited to efficiently interconvert spin and charge currents. By applying a gate voltage, we tune the position of the Fermi level in the complex multi-orbital structure of STO, which results in a strong variation of the conversion amplitude[4]. This can be related to the band structure through ARPES experiment and tight-binding calculations. I will present results from both spin-charge conversion where spins are injected by spin pumping in a FMR cavity and detected as a transverse voltage[5], and from charge-spin conversion probed through the bilinear magnetoresistance (BMR). Using a semi-classical model, the analysis of the BMR amplitude yields a good estimate of the Rashba coefficient[6]. In a second part, I will present gate-controlled, all-electrical spin current generation and detection in planar nanodevices only based on a STO 2DEGs[7].

[1] Ohtomo et al, Nature 2004, 427, 423. [2] Rödel et al, Adv. Mater. 2016, 28, 1976. [3] Vicente-Arche et al, PR Mater. 2021, 5, 064005. [4] Lesne et al, Nat. Mater 2016, 15, 1261. [5] Vaz et al, Nat. Mater. 2019, 18, 1187. [6] Vaz et al, PR Mater. 2020, 4, 071001. [7] Trier et al, Nano Lett. 2020, 20, 395.

Invited Talk MA 6.2 Tue 14:00 H5

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 optimize spin-to-charge conversion (SCC) in heavy metals. With this knowledge, we developed a novel and simple FM/Pt nanodevice to readout the in-plane magnetic state of the FM electrode using SHE [2]. 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].

Finally, I will present a radically different approach to further enhance SCC. By engineering a van der Waals heterostructure which combines graphene with a transition metal dichalcogenide, we first demonstrated SHE in graphene due to spin-orbit proximity [3]. The combination of long-distance spin transport and SHE in the same material gives rise to an unprecedented SCC efficiency, making graphene-based systems excellent candidates for MESO logic [1,2].

[1] Manipatruni et al., Nature 565, 35 (2019); [2] Pham et al., Nature Electron. 3, 309 (2020); [3] Safeer et al., Nano Lett. 19, 1074 (2019); Herling et al., APL Mater. 8, 071103 (2020).

Invited Talk MA 6.3 Tue 14:30 H5

Electrical and thermal generation of spin currents by magnetic graphene — •B.J van Wees[1], T.S. Ghiasi[1], A.A. Kaverzin[1], D.K. de Wal[1], A.H. Dismukes[2], and Bart Wees[2] — [1]Zernike Institute for Advanced Materials, Groningen, The Netherlands — [2]Department of Chemistry, Colombia University, New York, NY, USA

I will introduce proximity effects in Van der Waals heterostructures of graphene and materials with strong spin orbit interaction or magnetic 2D materials. Then I will discuss recent experiments [1] where we demonstrate with (non)local spin transport experiments that the proximity of the antiferromagnet CrSBr introduces a strong spin dependent conductivity (with a polarization of about 24%) in (bilayer) graphene. The strength of the exchange field is estimated to be about 170T, implying that the graphene has become magnetic by proximity. This also resulted in the observation of a spin-dependent Seebeck effect. These results were recently confirmed using non-magnetic injector/detector electrodes [2] Fimally I will indicate some new (device) functionalities made possible by this strong proximity inducedspin-charge coupling in graphene [1] T.S. Ghiasi et al., Nature Nanotech. 16, 788, Vol 18, 2021 [2] A.A. kaverzin et al., in preparation

15 min. break.

Invited Talk MA 6.4 Tue 15:15 H5

Ferroelectric switching of spin-to-charge conversion in GeTe — •Christian Rinaldi — Dipartimento di Fisica, Politecnico di Milano, 20133 Milano, Italy

Scalable and energy efficient magneto-electric spin-orbit (MESO) logic has been recently proposed by Intel as technologically suitable computing alternative to CMOS devices, towards attojoule electronics [1]. The MESO device comprises a magnetoelectric unit to drive a magnetic memory, while the read-out is perfomed exploiting spin-to-charge conversion in materials with large spin-orbit coupling.

Here we show that the ferroelectric Rashba semiconductor germanium telluride offers memory as well as spin-orbit read-out in a single material compatible with silicon, thus offering the opportunity for a great simplification of the MESO structure. Here we first demonstrate the robust control of ferroelectricity through gating. Then, by spin pumping measurements in Fe/GeTe, we reveal the ferroelectric control of its sizeable spin-to-charge conversion. These results pave the way to low power spin-orbit logic devices beyond-CMOS. [1] S. Manipatruni, Nature 565, 35 (2019); [2] S. Varotto et al., arXiv preprint, arXiv:2103.07646 (2021).

Invited Talk MA 6.5 Tue 15:45 H5

Theory of spin and orbital Edelstein effects in a topological oxide two-dimensional electron gas — •Annika Johansson[1], Börge Göbel[1,2], Jürgen Henk[1], Manuel Bibes[3], and Ingrid Mertig[1] — [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) spin Edelstein effect from a theoretical perspective by Boltzmann transport calculations within a multiorbital tight-binding model. Further, we report on the electrically induced magnetization originating from the orbital moments, known as orbital Edelstein effect [5]. At STO interfaces the orbital Edelstein effect exceeds the spin Edelstein effect by more than one order of magnitude.

[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)
[5] A. Johansson *et al.*, Phys. Rev. Research **3**, 013275 (2021)

Invited Talk MA 6.6 Tue 16:15 H5

Nonlinear magnetoresistance and Hall effect from spin-momentum locking — •Giovanni Vignale — University of Missouri

Surface states of topological insulators exhibit the phenomenon of spin-momentum locking, whereby the orientation of an electron spin is determined by its momentum. Recently a link has been discovered 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, it has been found that the nonlinear planar Hall effect, manifested as a transverse component of the nonlinear current, exhibits a Pi/2 phase shift with respect to the nonlinear longitudinal current, in marked contrast to the usual Pi/4 phase difference that exists between the linear planar Hall current and the linear longitudinal current in typical topological insulators and transition metal ferromagnets. In this talk I review the development of the theory vis-a-vis experiments done on the surface of topological insulator Bi_2Se_3 films and other materials.