TT 6: TR: Nanoelectronics II: Spintronics and Magnetotransport

Time: Monday 14:00–18:15 Location: H19

TT 6.1 Mon 14:00 H19

Transport through an interacting quantum dot tunnel coupled to a ferromagnet with time-dependent magnetisation — •Nina Winkler[1], Michele Governale[2], and Jürgen König[1] — [1]Theoretische Physik and CeNIDE · Universität Duisburg-Essen — [2]School of Chemical and Physical Sciences · Victoria University of Wellington · New Zealand

We study adiabatic charge and spin pumping in an interacting quantum dot connected to one normal and one ferromagnetic lead. In general, this setup can work as a quantum pump when only the direction of the lead magnetisation is varied in time [1]. We focus on the adiabatic-pumping regime. To account for a time-dependent lead magnetisation, we generalise a diagrammatic real-time approach for adiabatic pumping through quantum dots with ferromagnetic leads [2, 3]. We perform a systematic expansion in both frequency and tunnel-coupling strength, treating the on-site Coulomb interaction on the quantum dot exactly. We investigate the adiabatic charge and spin transport through the structure when pumping by periodically changing the direction of the lead magnetisation up to second order in the tunnel-coupling strength.

[1] M.V. Costache *et al.*, Phys. Rev. Lett. **97**, 216603 (2006).
[2] J. Splettstoesser *et al.*, Phys. Rev. B **74**, 085305 (2006).
[3] J. Splettstoesser *et al.*, Phys. Rev. B **77**, 195320 (2008).

TT 6.2 Mon 14:15 H19

Kondo Effect in single wall carbon nanotubes with ferromagnetic contacts — •Markus Gaass, Andreas Hüttel, Dominik Preusche, Lorenz Herrmann, and Christoph Strunk — Universität Regensburg, Institut für Experimentelle und Angewandte Physik

We investigate the interplay of the Kondo effect and magnetic contacts in quantum dots formed by single wall carbon nanotubes. The regular spin-1/2 Kondo effect appears when the coupling between the electrodes and the quantum dot is high enough. If the leads are magnetized the Kondo resonance is exchange split at zero magnetic field. We fabricated single wall carbon nanotube transport devices with electric contacts made of PdNi which show a sufficient interface transparency to observe the Kondo effect. Without any applied field the Kondo resonance is indeed split. In some Coulomb valleys the splitting can be compensated by an external magnetic field on the order of 1 Tesla, in others it remains finite. In addition a fine structure in the spectra is observed which indicates a more complex level structure than expected for armchair carbon nanotubes.

TT 6.3 Mon 14:30 H19

A singlet - triplet T$_+$ based qubit — •Hugo Ribeiro[1], Jason Petta[2], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, D-78457, Konstanz, Germany — [2]Department of Physics, Princeton University, Princeton, NJ 08544, USA

We theoretically model a nuclear-state preparation scheme that increases the coherence time of a two-spin qubit in a double quantum dot. The two-electron system is tuned repeatedly across a singlet-triplet level-anticrossing with alternating slow and rapid sweeps of an external bias voltage. Using a Landau-Zener-Stückelberg model, we find that in addition to a small nuclear polarization that weakly affects the electron spin coherence, the slow sweeps are only partially adiabatic and lead to a weak nuclear spin measurement and a nuclear-state narrowing which prolongs the electron spin coherence. This resolves some open problems brought up by a recent experiment [1]. We also show that the electronic two-spin states singlet and triplet T$_+$ are promising candidates for the implementation of a qubit in GaAs double quantum dots (DQD). A coherent superposition of the two-spin states is obtained by finite time Landau-Zener-Stückelberg interferometry and the single qubit rotations are performed by means of an external magnetic field with a typical amplitude of about 100 mT, while coherent manipulation can be done within $\sim$ 1 ns. We also study the nuclear induced decoherence, mainly due to hyperfine contact coupling between the electronic and nuclear spins, and compute the decoherence time $T_2^* \sim 10$ ns.

[1] D. J. Reilly *et al.*, Science **321**, 817 (2008).

TT 6.4 Mon 14:45 H19

Charge ratchet from spin flip: Space-time symmetry paradox — •Sergey Smirnov[1], Dario Bercioux[2], Milena Grifoni[1], and Klaus Richter[1] — [1]Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany — [2]Freiburg Institute for Advanced Studies (FRIAS) and Physikalisches Institut, Universität Freiburg, D-79104 Freiburg, Germany

Traditionally the charge ratchet effect is considered as a consequence of either the spatial symmetry breaking engineered by asymmetric periodic potentials, or time asymmetry of the driving fields. Here we demonstrate that electrically and magnetically driven quantum dissipative systems with spin-orbit interactions represent an exception from this standard idea. In contrast to the so far well established belief, a charge ratchet effect appears when both the periodic potential and driving are symmetric. We show that the source of this paradoxical charge ratchet mechanism is the coexistence of quantum dissipation with the spin flip processes induced by spin-orbit interactions [1]. The queerness of the charge ratchet current consists in the fact that this current, in contrast to early predictions for systems without spin-orbit interactions, appears even when only one energy band provides electrons for transport and no harmonic mixing is present in the driving fields. Such purely spin-orbit charge currents are controlled by the gate voltage tuning the strength of the spin-orbit coupling. This peculiarity of the effect is very attractive from the experimental point of view.

[1] S. Smirnov, D. Bercioux, M. Grifoni and K. Richter, Phys. Rev. B 80, 201310(R) (2009).

TT 6.5 Mon 15:00 H19

Orbitally phase coherent spintronics — Cheryl Feuillet-Palma[1,2], Thomas Delattre[1,2], Pascal Morfin[1,2], Jean-Marc Berroir[1,2], Gwendal Feve[1,2], Christian Glattli[1,2,3], Bernard Placais[1,2], Audrey Cottet[1,2], and •Takis Kontos[1,2] — [1]Laboratoire Pierre Aigrain, Ecole Normale Supérieure, 24, rue Lhomond, 75231 Paris Cedex 05, France — [2]CNRS UMR 8551, Laboratoire associé aux universités Pierre et Marie Curie et Denis Diderot, France — [3]Service de physique de l'état Condensé, CEA, 91192

The scattering imbalance between up and down spins at the interface between a non-magnetic metal and a ferromagnetic metal is at the heart of the principle of the magnetic tunnel junctions or multilayers celebrated in the field of spintronics. Although these devices use the quantum mechanical spin degree of freedom and electron tunneling, they do not exploit a crucial degree of freedom involved in quantum mechanics: the phase of the electronic wave function. In most of the devices studied so far, this aspect has not been developed owing to the classical-like motion of charge carriers in the conductors used. In this work, we report on spin dependent transport measurements in carbon nanotubes based multi-terminal circuits. We observe a gate-controlled spin signal in non-local voltages and an anomalous conductance spin signal, which reveal that both the orbital phase and the spin can be conserved along carbon nanotubes with multiple ferromagnetic contacts. This paves the way for spintronics devices exploiting both these quantum mechanical degrees of freedom on the same footing.

TT 6.6 Mon 15:15 H19

Bulk transport properties of two-dimensional HgTe nanostructures — •Elena G. Novik[1], Patrik Recher[2], Ewelina M. Hankiewicz[2], and Björn Trauzettel[2] — [1]Physikalisches Institut (EP3), University of Würzburg, 97074 Würzburg — [2]Institut für Theoretische Physik und Astrophysik, University of Würzburg, 97074 Würzburg

The topologically non-trivial insulators realized in HgTe quantum wells (QWs) have recently attracted considerable attention because of their unique property: the existence of the gap in the bulk and the gapless edge states on the sample boundaries. Depending on the width of the HgTe QW the structure can be a trivial insulator with normal band structure when the QW width is smaller than 6.3 nm, or a topologically non-trivial insulator with inverted band structure for thicker QWs. Here we show that it is possible to distinguish the topologically trivial from non-trivial insulator states on the basis of bulk transport properties only. Using the effective four-band model [1], we have calculated the bulk conductance through the two-dimensional metal/HgTe insulator/metal structure. Whereas for the trivial insulator the conductance increases monotonically with decreasing distance between the electron reservoirs L, a non-monotonic behaviour of the bulk transport depending on L has been found for the insulator in the inverted regime. Interestingly, the bulk transport contribution can even exceed the quantized conductance caused by edge state transport and should be taken into account for the interpretation of future experiments.

[1] B. A. Bernevig et al., Science, 314, 1757 (2006).

TT 6.7 Mon 15:30 H19

Magneto-resistance of atomic-sized contacts of magnetic metals — •Stefan Egle[1], Hans-Fridtjof Pernau[1], Cécile Bacca[1], Magdalena Huefner[2], and Elke Scheer[1] — [1]Department of Physics, University of Konstanz, Germany — [2]Solid State Physics Laboratory, ETH Zurich, Switzerland

In this talk, a comprehensive study of the magneto resistance (MR) behavior of atomic-size contacts is given, where two macroscopic electrodes are connected to a central nanobridge. An atomic contact can be adjusted by means of mechanically controllable break junction (MCBJ) technique. In order to separate the influence of the electrodes from the effect of the nanobridge itself, we employ different material systems. Namely, ferromagnetic cobalt electrodes are connected to a non-magnetic gold bridge and vice versa. The shape of the electrodes can be chosen symmetric or asymmetric and the nanobridge region can be suspended or non-suspended. Furthermore, we investigate the MR for different orientations of the magnetic field. The curves show a very rich behavior with magneto resistance ratios (MRR) up to 100% and more in the atomic contact regime, reaching up to a few 1000% in the tunneling regime. For all geometries used, the MRR values are of comparable size. Moreover, we study the possible influence of the micromagnetic order of the domains in the vicinity of the contact region as well as ballistic MR, GMR, TMR, atomically enhanced anisotropic MR (AAMR) and magnetostriction. We conclude that the AAMR is the most important contribution of the MR at large magnetic fields, while magnetostriction, TMR and GMR govern the low-field regime.

TT 6.8 Mon 15:45 H19

Oscillatory crossover from two dimensional to three dimensional topological insulators — •Chao-Xing Liu[1], HaiJun Zhang[2], Binghai Yan[3], Xiao-Liang Qi[4], Thomas Frauenheim[3], Xi Dai[2], Zhong Fang[2], and Shou-Cheng Zhang[4] — [1]EP3 and Institute for Theoretical Physics and Astrophysics, University of Würzburg, 97074 Würzburg, Germany — [2]IOP, Chinese Academy of Sciences, Beijing 100190, China — [3]Bremen Center for Computational Materials Science, Universität Bremen, 28359 Bremen, Germany — [4]Department of Physics, Stanford University, Stanford, CA 94305-4045

Topological insulators (TIs) are new states of quantum matter with the surface states protected by time-reversal symmetry, which can exist both in two-dimensional (2D) system and three-dimensional (3D) system. In this work, we would like to investigate the crossover regime from 3D TIs to 2D TIs when the sample thickness is reduced. Based on the four band effective model, we find that the crossover occurs in an oscillatory fashion as a function of the film thickness, alternating between topologically trivial and non-trivial 2D behavior. A physical picture is provided to understand the origin of the oscillation. Furthermore *ab initio* calculation is performed to study the realistic Bi_2Se_3 and Bi_2Te_3 thin film and confirm the analytical results. These results not only establisch the relation between the TIs with the different dimensions, but also provide a new path to search for new TIs.

15 min. break

TT 6.9 Mon 16:15 H19

Spin accumulation with spin-orbit interaction — •Henri Saarikoski[1,2,3] and Gerrit E. W. Bauer[1] — [1]Kavli Institute of Nanoscience, Delft University of Technology, 2628-CJ Delft, The Netherlands — [2]Mathematical Physics, Lund Institute of Technology, SE-22100 Lund, Sweden — [3]Present address: University of Regensburg, 93040 Regensburg

Spin accumulation is a crucial but imprecise concept in spintronics. In metal-based spintronics it is characterized in terms of semiclassical distribution functions. In semiconductors with a strong spin-orbit coupling the spin accumulation is interpreted as a superposition of coherent eigenstates. We show that both views can be reconciled by taking into account the electron-electron interaction: a sufficiently strong self-consistent exchange field reduces a spin accumulation to a chemical potential difference between the two spin bands even in the presence of spin-orbit coupling. We demonstrate the idea on a clean two-dimensional electron gas (2DEG) by showing how the exchange field protects a spin accumulation from dephasing and introduces an easy-plane anisotropy. Spin can be injected either adiabatically, e.g. by a ferromagnetic contact with small electric bias, or diabatically, e.g. by pulsed optically induced excitation. We discuss spin-accumulation eigenstates that are accessible by adiabatic excitation as well as spin accumulation dynamics of rapidly excited states. We illustrate the general ideas at the hand of a 2DEGs with Rashba SOI, in which the disorder-scattering lifetime broadening is much smaller than the spin-orbit splitting at the Fermi-level.

TT 6.10 Mon 16:30 H19

Suppression of the Spin-Hall Effect by Magnetic Fields in Nanostructures — •Dietrich Rothe and Ewelina M. Hankiewicz — Institut für Theoretische Physik und Astrophysik, Würzburg, Germany

The spin-Hall effect (SHE) is the generation of the transverse spin-imbalance in semiconductors with strong spin-orbit interactions in the conducting ("metallic") regime. Although the SHE is caused by spin-orbit interaction and the time symmetry breaking perturbation should destroy the phenomenon, the influence of magnetic field was not so far discussed in detail.

In this contribution, we will analyze the influence of magnetic field on the magnitude of spin signal in the H-shaped structures where the spin signal can be excited and detected electrically [1,2].

We will show, within the non-equilibrium Green function formalism, that the magnetic field destroys the spin signal effectively in perpendicular magnetic fields while the signal is much less affected in parallel fields where only the Zeeman part of the field is present. The connection with experimental results will be discussed [1].

[1] C. Bruene, A. Roth , E. G. Novik, M. Koenig, H. Buhmann, E. M. Hankiewicz, W. Hanke, J. Sinova and L. W. Molenkamp, arXiv:0812.3768 (2008).

[2] E. M. Hankiewicz, L. W. Molenkamp, T. Jungwirth, and Jairo Sinova, Phys. Rev. B 70, 241301(R) (2004).

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TT 6.11 Mon 16:45 H19

Interference spin-blockade in symmetric nanojunctions — •Andrea Donarini, Georg Begemann, and Milena Grifoni — Institut für Theoretische Physik, Universität Regensburg

Nanojunctions with a high degree of spatial symmtry, like molecular junctions, but also specially designed multiple quantum dot structures, have a degenerate many body spectrum. The degeneracy is in fact protected by symmetry. The interference between the degenerate states causes a novel current blocking mechanism that allows, in presence of polarized leads, the all electric control of the spin and orbital degree of freedom on the junction. We present here a general formalism to give necessary and sufficient conditions for interference blockade. As an example we analyze a triple dot single electron transistor (SET) [1]. In particular, we show how to prepare the system in each of the three spin states of the excited 2-electrons triplet state without application of any external magnetic field.

[1] Nano Letters, **9**, 2897 (2009).

TT 6.12 Mon 17:00 H19

Influence of Different Spin-Orbit Terms on Spin Transport in HgTe Quantum Wells — •Rolf W. Reinthaler[1], Dietrich Rothe[1], Chao-xing Liu[2], Laurens W. Molenkamp[2], and Ewelina M. Hankiewicz[1] — [1]Institut für Theoretische Physik und Astrophysik, Würzburg, Germany — [2]Physikalisches Institut (EP3), Würzburg, Germany

We derive, within kp theory, an effective four band model (conduction/heavy hole bands) describing physics of HgTe quantum wells with the Dirac-like and Rashba types spin-orbit interactions.

The physics of both contributions is discussed using the Landauer-Büttiker approach and with the semiclassical equations of motions within the wave packet formalism. We find that the spin-Hall conductance originating from the Rashba spin-orbit interaction scales quadratically with spin-orbit coupling strength and shows a precession pattern. On the other hand, the term obtained from Dirac part scales linearly with the spin-orbit strength and conserves the z-component of the spin.

The competition between the Dirac-like and Rashba spin-orbit terms is of particular interest. We find that for realistic material parameters the Dirac-like terms can influence the action of Rashba spin-orbit interactions and lead to the enhancement of the spin-Hall conductance.

We acknowledge the financial support by German DFG grant HA 5893/1-1.

TT 6.13 Mon 17:15 H19

Hyperfine mediated triplet-singlet transition probability in a double-quantum-dot system: Analogy with the double-slit experiment — •Fernando Dominguez, Carlos López-Monís, and Gloria Platero — Instituto de ciencia de los materiales de Madrid (ICMM)

Recent experiments and theoretical works have been devoted to the analysis of transport through double quantum dots in the spin blockade regime. There, the current is blocked unless spin scattering induces electron spin-flip, giving rise to electronic triplet-singlet transition. Hyperfine interaction is the main mechanism responsible for spin-flip and it will be considered in the present work. We present an elementary measurement theory scheme in order to analyze the electronic triplet-singlet transition mediated by the hyperfine interaction in a double quantum dot. We show that the local character of the hyperfine interaction and the nuclear back-action process (flip-flop) are crucial for canceling destructive interferences of the triplet-singlet transition probability. It is precisely this cancellation which distinguishes the transition probability mediated by hyperfine interaction from the effect due to an anisotropic magnetic field.

[1] Phys. Rev. B 80, 201301 R (2009)

TT 6.14 Mon 17:30 H19

Ballistic transport in 1D magnetic systems based on the FLAPW Method and Wannier functions — •Björn Hardrat[1], Neng-Ping Wang[2], Yuriy Mokrousov[3], Frank Freimuth[3], and Stefan Heinze[1] — [1]Institut für Theoretische Physik und Astrophysik, Christian-Albrechts-Universität zu Kiel, Leibnizstr. 15, D-24098 Kiel, Germany — [2]Physics Departement, Ningbo Univeristy, Fenghua Road 818, 315211 Ningbo, P.R. China — [3]Institut für Festkörperforschung, Forschungszentrum Jülich, D-52435 Jülich, Germany

We report the development of a ballistic transport code for one-dimensional magnetic systems based on Wannier functions (WF) constructed within the full-potential linearized augmented plane-wave (FLAPW) method. We describe the details of the construction of first-shot (fsWF) or maximally localized (MLWF) WFs from the FLAPW wavefunctions choosing a monoatomic Pt chain as a model system. For the calculation of ballistic transport, we apply the Landauer formalism using Green's functions, which allows us to obtain the conductance of the system. As first applications of the approach, we study the transition from the contact to the tunneling regime in monoatomic Pt wires, with and without spin-orbit coupling (SOC), as well as in ferromagnetic Co wires, for which we calculated the tunneling magneto resistance (TMR). Furthermore we investigate the effect of single defect Pt and Co scatterers on the transmission through such monowires.

TT 6.15 Mon 17:45 H19

Dynamic spin-Hall effect and driven spin helix for linear spin-orbit interactions — •Mathias Duckheim[1], Dmitrii L. Maslov[2], and Daniel Loss[1] — [1]Department of Physics, University of Basel, CH-4056 Basel, Switzerland — [2]Department of Physics, University of Florida, Gainesville, FL 32611 -8440, USA

We derive boundary conditions for the electrically induced spin accumulation in a finite, disordered 2D semiconductor channel. While for DC electric fields these boundary conditions select spatially constant spin profiles equivalent to a vanishing spin-Hall effect, we show that an in-plane ac electric field results in a non-zero ac spin-Hall effect, i.e., it generates a spatially non-uniform out-of-plane polarization even for linear intrinsic spin-orbit interactions. Analyzing different geometries in [001] and [110]-grown quantum wells, we find that although this out-of-plane polarization is typically confined to within a few spin-orbit lengths from the channel edges, it is also possible to generate spatially oscillating spin profiles which extend over the whole channel. The latter is due to the excitation of a driven spin-helix mode in the transverse direction of the channel. We show that while finite frequencies suppress this mode, it can be amplified by a magnetic field tuned to resonance with the frequency of the electric field. In this case, finite size effects at equal strengths of Rashba and Dresselhaus SOI lead to an enhancement of the magnitude of this helix mode. We comment on the relation between spin currents and boundary conditions.

TT 6.16 Mon 18:00 H19

Frequency-Dependent Spin Conductance and Spin Noise of Quantum Dots in the Kondo Regime — •Ireneusz Weymann[1,2], Catalin Pascu Moca[3], and Gergely Zarand[3] — [1]Physics Department, ASC, and CeNS, Ludwig-Maximilians-University, Theresienstrasse 37, 80333 Munich, Germany — [2]Physics Depertement, Adam Mickiewicz University, Umultowska 85, 61-614 Poznan, Poland — [3]Department of Theoretical Physics, Institute of Physics, Budapest University of Technology and Economics, H-1521 Budapest, Hungary

We analyze the equilibrium and non-equilibrium frequency-dependent spin noise and spin conductance of a quantum dot in the Kondo regime. The equilibrium spin noise is characterized by two universal functions that we determine perturbatively for large frequencies, and compute numerically at zero temperature using numerical renormalization group.

The parallel and antiparallel noise components show markedly different frequency dependence. The antiparallel spin conductance develops a resonance for frequencies of the order of the Kondo temperature as a result of dynamical spin accumulation. For temperatures well above the Kondo scale, a low-frequency anomaly appears in the spin current correlations below the Korringa relaxation rate.