TT 26: Transport: Topological Insulators 3 (jointly with HL and MA)

Time: Wednesday 9:30–13:00 Location: BH 334

TT 26.1 Wed 9:30 BH 334

Spin-dependent thermoelectric transport in topological insulators — •Dietrich G. Rothe, Marine Guigou, Björn Trauzettel, and Ewelina M. Hankiewicz — Institut für Theoretische Phys. und Astrophys. Würzburg

We analyze spin-dependent thermoelectric transport of topological insulators based on (Hg,Cd)Te quantum wells using the non-equilibrium Green's function technique within the Bernevig-Hughes-Zhang model. The motivation for our work is to generate spin currents in a medium with strong spin orbit coupling by a gradient of temperature in the absence of magnetic fields. Furthermore, we would like to better understand to what extend the thermoelectric coefficients probe spectral properties of such devices.

We investigate specifically the spin Nernst effect, a transverse spin current induced by a longitudinal temperature gradient, in a four-terminal setup. Interestingly, we predict a peak in the spin Nernst signal when the device is operated in the topologically non-trivial regime. This peak is directly related to the minigap formed by overlapping edge states from opposite boundaries of our device. Hence, the spin Nernst effect is a powerful experimental tool to analyze the size and the structure of the minigap. Additionally, we see that the spin Nernst effect is rather sensitive to details of the band structure. We discuss how this effect can be used to distinguish the topologically trivial from the non-trivial regime and why the energy dependence of transport is markedly resolved in the experimental signatures of the spin Nernst signal.

TT 26.2 Wed 9:45 BH 334

Topological insulators in magnetic fields: Quantum Hall effect and edge channels with non-quantized θ-term — •Matthias Sitte[1], Achim Rosch[1], Ehud Altman[2], and Lars Fritz[1] — [1]Institute for Theoretical Physics, University of Cologne, Cologne, Germany — [2]Department of Condensed Matter Physics, The Weizmann Institute of Science, 76100 Rehovot, Israel

We investigate how a magnetic field induces one-dimensional edge channels when the two-dimensional surface states of three-dimensional topological insulators become gapped. The Hall effect, measured by contacting those channels, remains quantized even in situations, where the θ-term in the bulk and the associated surface Hall conductivities, σ_{xy}, are not quantized due to the breaking of time-reversal symmetry. The quantization arises as the θ-term changes by $\pm 2\pi n$ along a loop around n edge channels. Model calculations show how an interplay of orbital and Zeeman effects leads to quantum Hall transitions, where channels get redistributed along the edges of the crystal. The network of edges opens new possibilities to investigate the coupling of edge channels.

[1] M. Sitte, A. Rosch, E. Altman, and L. Fritz, arXiv:1110.1363

TT 26.3 Wed 10:00 BH 334

Fractional quantum Hall states in lattice models and their potential realization due to multiple orbitals — •Stefanos Kourtis, Jörn Venderbos, Jeroen van den Brink, and Maria Daghofer — Institute for Theoretical Solid State Physics, IFW Dresden, 01171 Dresden, Germany

It has been recently demonstrated that topologically non-trivial lattice models of interacting particles can lead to a fractional quantum Hall effect without a magnetic field as long as the band width is very narrow. This has triggered a search for possible realizations of such models in optical lattices or materials. One promising observation is that electronic orbital degrees of freedom can lead to the nearly flat bands needed for a fractional-quantum Hall ground state [1]. We map the topologically non-trivial band of such a multi-orbital system onto an effective lattice model [2]. We use exact diagonalization to obtain the ground state of the effective model taking into account Coulomb interactions and investigate its topological properties. In particular, we calculate the eigenvalue spectra, ground states and Chern numbers for a variety of filling fractions and obtain clear indications of a hierarchy of fractionally charged excitations.

[1] J. W. F. Venderbos, M. Daghofer and J. van den Brink, Phys. Rev. Lett. 107, 116401 (2011).
[2] Jörn W.F. Venderbos, Stefanos Kourtis, Jeroen van den Brink and Maria Daghofer, arXiv:1109.5955 (2011).

TT 26.4 Wed 10:15 BH 334

Quantum transport in nanostructures of Bi_2Se_3-topological insulator — •Joseph Dufouleur[1], Romain Giraud[1], Andreas Teichgräber[1], Silke Hample[1], Stephan Neuhaus[1], Barbara Eichler[2], Oliver G. Schmidt[2], and Bernd Büchner[1] — [1]Institute for Solid State Research - IFW Leibniz Institute, Helmholtzstr. 20, D-01069 Dresden, Germany — [2]Institute for Integrative Nanosciences - IFW Leibniz Institute, Helmholtzstr. 20, D-01069 Dresden, Germany

Three-dimensional topological insulators belong to a new class of semiconductors with a large spin-orbit coupling which have spin-polarized Dirac fermions at their surface. In theory, these materials are insulating in the bulk, so that charge transport is only due to electronic surface states. In pratice, the Fermi energy often stands above or below the bulk band gap, due to uncontrolled defects formed during the growth of single crystals, or of epitaxial thin films or nanostructures. This makes the electrical properties of topologically-protected surface states difficult to measure, unless ultra-thin flakes of these materials are prepared.

To overcome this difficulty, we performed quantum transport measurement in ultra-thin Bi_2Se_3 flakes grown by CVD. We used e-beam litography technics to pattern Hall bars in the topological insulator. The measurements were done at low temperature and in an in-plane and perpendicular magnetic field up to 15 T.

TT 26.5 Wed 10:30 BH 334

Interaction and disorder effects in 3D topological insulator thin films — •Elio Koenig[1], Pavel Ostrovsky[2], Ivan Protopopov[2], Igor Gornyi[2], and Alexander Mirlin[1,2] — [1]Institut für Theorie der Kondensierten Materie Karlsruher Institut für Technologie Wolfgang-Gaede-Str. 1 D-76131 Karlsruhe — [2]Institut für Nanotechnologie Hermann-von-Helmholtz-Platz 1 76344 Eggenstein-Leopoldshafen

It has been recently predicted that Coulomb interaction drives a surface of a 3D topological insulator into a critical state. We employ the sigma-model formalism to investigate the effect of electron-electron interaction on the transport by surface states in topological insulator thin films. We take into account the interaction of electrons on different surfaces and also the top-bottom asymmetry of the film (different densities of states and strength of disorder on top/bottom surface). This asymmetry is naturally present in experiments where the electronic densities on the surfaces are controlled independently by means of electrostatic gates. The lack of symmetry between top and bottom surfaces is shown to have strong effect on the film conductivity. The interplay of weak antilocalization, Coulomb interaction within and between surfaces and topological protection leads to a rich flow diagram representing the low temperature behavior of the system. The connection with recent experiments on Bi_2Se_3 films is discussed.

TT 26.6 Wed 10:45 BH 334

Rashba spin-orbit interaction in the superconducting proximity effect in helical Luttinger liquid — •Pauli Virtanen and Patrik Recher — Institute for Theoretical Physics and Astrophysics, University of Würzburg, 97074 Würzburg, Germany

We consider the superconducting proximity effect in a helical Luttinger liquid at the edge of a 2D topological insulator. In addition to correlations between the left and right moving modes, coupling to a s-wave superconductor can also induce correlations inside a single mode, as the spin axis of the edge modes is not necessarily constant. This can be induced controllably in HgTe/CdTe quantum wells via the Rashba spin-orbit coupling. We discuss the consequent transport signatures, and point out a long-ranged feature in a dc conductance measurement that can be used to distinguish the two types of correlations present.

TT 26.7 Wed 11:00 BH 334

Bloch–Zener Oscillations in Graphene and Topological Insulators — •Viktor Krueckl and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

Conventional free electrons in a superlattice subject to an accelerating drift potential feature a periodic motion known as Bloch oscillations. This physical phenomenon is enriched for topological insulators and graphene, since the electronic structure of those materials close to the Fermi energy is governed by a linear dispersion with a vanishing bandgap between electron and hole states. As a consequence superlattices based on zero-gap semiconductors exhibit characteristic Bloch–Zener oscillations that emerge from the coherent superposition of Bloch oscillations and multiple Zener tunneling between the electron and hole branch [1]. We demonstrate this mechanism by means of wave packet dynamics in various spatially periodically modulated nanoribbons subject to an external bias field. The associated Bloch frequencies exhibit a peculiar periodic bias dependence which we explain within a two-band model. Supported by extensive numerical transport calculations, we show that this effect gives rise to distinct current oscillations observable in the *I-V* characteristics of graphene and mercury telluride superlattices.

[1] Viktor Krueckl and Klaus Richter, arXiv:1109.5541v1 (2011)

15 min. break.

TT 26.8 Wed 11:30 BH 334

Generalized string order in 1D symmetry protected topological phases — •Frank Pollmann[1], Ari Turner[2], and Erez Berg[3] — [1]Max-Planck-Institut für Physik komplexer Systeme, 01187 Dresden, Germany — [2]University of Amsterdam, 1090 GL Amsterdam, The Netherlands — [3]Department of Physics, Harvard University, Cambridge, MA 02138, USA

A topological phase is a phase of matter which cannot be characterized by a local order parameter. It has been shown that gapped phases in 1D systems can be completely characterized using tools related to projective representations of the symmetry groups. An example of a symmetry protected topological phase is the Haldane phase of S = 1 chains. Here the phase is protected by any of the following symmetries: dihedral group of π-rotations about two orthogonal axes, time-reversal symmetry, or bond centered inversion symmetry. We introduce non-local order parameters as generalization of string order for each case which can be simply calculated using numerical methods such as Density-Matrix Renormalization Group (DMRG). These non-local order parameters provide a practical tool for numerically detecting different phases.

TT 26.9 Wed 11:45 BH 334

Tunable quantum spin Hall effect in double quantum wells — •Paolo Michetti[1], Jan C. Budich[1], Elena G. Novik[2], and Patrik Recher[1,3] — [1]Institute of Theoretical Physics and Astrophysics, University of Würzburg, D-97074 Würzburg, Germany — [2]Physical Institute, University of Würzburg, D-97074 Würzburg, Germany — [3]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany

The field of topological insulators (TIs) is rapidly growing. The quantum spin Hall effect, characterized by a single pair of helical edge modes protected by time-reversal symmetry, has been demonstrated in HgTe-based quantum wells (QWs) with an inverted bandgap. Concerning possible applications, the quest for materials with an easily controllable TI phase is a key issue.

We analyze, employing an extended version of the Bernevig-Hughes-Zhang model, the topological properties of a generically coupled HgTe-based double QW (DQW). In particular we show how in such a system a TI phase can be driven by an inter-layer bias voltage, even when the individual layers are non-inverted. We also provide a numerical estimate of the system parameters, based on k.p calculations, suggesting the experimental feasibility of the present proposal.

Consequently, a DQW composed of non-inverted QWs, which could be in principle made of suitable narrow gap semiconductors different from HgTe, can be driven into a topologically non-trivial phase with the application of a gate bias.

TT 26.10 Wed 12:00 BH 334

Strong Correlations in a Generic Topological Insulator: The Transition-Metal Oxide Na_2IrO_3 — •Manuel Laubach[1], Ronny Thomale[2], Stephan Rachel[3], and Werner Hanke[1] — [1]Theoretical Physics, University of Würzburg, D-97074 Würzburg — [2]Department of Physics, McCullough Building, Stanford University, Stanford, California 94305-4045 — [3]Department of Physics, Yale University, New Haven, CT 06520, USA

A key recent advancement in condensed-matter physics is to study the interplay between nontrivial topology and electronic correlations. In 5d transition-metal oxides, both the spin-orbit interaction and the electron correlation emerge at comparable orders of magnitude. In these systems, a variety of specifically tailored crystal structures are available, enabling the design of robust topological insulators. In this work, we study theoretically a monolayer of the 5d-compound Na_2IrO_3, modeled by a Hubbard-type of Hamiltonian on a honeycomb lattice where the spin symmetry is not conserved. Based on a variational cluster approach (VCA), the zero temperature phase diagram is obtained. We can identify, through an increase of the Hubbard U, the transition from a quantum spin Hall insulator to either a spin liquid phase or an antiferromagnetic insulating phase, depending on the strength of the spin-orbit coupling. We illustrate the evolution of the quasiparticle spectral function for bulk and edge-states upon variation of system parameters.

TT 26.11 Wed 12:15 BH 334

A quantum dot in a quantum spin Hall edge: Interaction effects — •Carsten Timm — Technische Universität Dresden, Germany

The edge states of a quantum spin Hall system are topologically protected but can be gapped by a magnetic field. A quantum dot realized by two magnetic tunneling barriers in a quantum spin Hall edge is proposed and transport through this device is analyzed. The analysis goes beyond linear response and incorporates electron-electron interaction in a combination of Green-function and master-equation approaches. A partial recurrence of non-interacting behavior is found for strong interactions. The possibility of controlling the magnetization of the edge by a locally applied gate voltage is proposed.

TT 26.12 Wed 12:30 BH 334

Inelastic electron backscattering in a generic helical edge channel — •Thomas L. Schmidt[1,2], Stephan Rachel[1], Felix von Oppen[3], and Leonid I. Glazman[1] — [1]Department of Physics, Yale University, 217 Prospect Street, New Haven, CT 06520, USA — [2]Department of Physics, University of Basel, 4056 Basel, Switzerland — [3]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universitaet Berlin, 14195 Berlin, Germany

We calculate the low-temperature conductance of a generic one-dimensional helical liquid which exists at the edge of a two-dimensional topological insulator (quantum spin Hall insulator). In a generic case, the S_z spin-symmetry is absent, which opens a possibility of single-particle inelastic electron backscattering. We show that although time-reversal invariance is preserved, inelastic backscattering gives rise to a temperature-dependent deviation from the quantized conductance, $\delta G \propto T^4$. In addition, δG is sensitive to the position of the Fermi level in the gap of the insulator. We present an effective model for this type of helical liquid and determine its parameters explicitly from numerical solutions of microscopic models for two-dimensional topological insulators in the presence of Rashba spin-orbit coupling.

TT 26.13 Wed 12:45 BH 334

Magnetoconductance of disordered HgTe strips — •Sven Essert and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany

Quantum wells of HgTe show the fascinating phenomenon of edge state transport which leads to a finite conductance in an energy window where the bulk material is insulating. This edge conductance exhibits special properties. One is, that it is expected to be stable against non-magnetic disorder because of a topological protection by time-inversion symmetry.

Inspired by this, we numerically investigate how the conductance of disordered HgTe strips of finite width changes under the application of a time-reversal symmetry breaking external magnetic field. We compare our results for different disorder models to experimental data.

Additionally, we study how the so-called "topological Anderson insulator" phase of HgTe strips, i.e. the phenomenon that finite disorder drives the metallic system into a quantum spin hall state with quantized edge conductance, is affected by the application of an external magnetic field.