TT 82: Topological Insulators II (joint session TT/MA)

Time: Thursday 9:30–13:00 Location: A 053

TT 82.1 Thu 9:30 A 053

Robust spin-polarized midgap states at step edges of topological crystalline insulators — •Domenico Di Sante[1], Paolo Sessi[2], Martin Greiter[1], Titus Neupert[3], Giorgio Sangiovanni[1], Tomasz Story[4], Ronny Thomale[1], and Matthias Bode[2] — [1]Institut fuer Theoretische Physik, Universitaet Wuerzburg — [2]Experimentelle Physik II, Universitaet Wuerzburg — [3]Physik Institut, Universitaet Zuerich, Switzerland — [4]Institute of Physics, Polish Academy of Sciences, Warsaw, Poland

Topological crystalline insulators are materials in which the crystalline symmetry leads to topologically protected surface states with a chiral spin texture, rendering them potential candidates for spintronics applications. In this talk, I report on the discovery of one dimensional midgap states at odd atomic surface step edges of the three dimensional topological crystalline insulator (Pb,Sn)Se. A minimal toy model and realistic tight-binding calculations identify them as spin polarized flat bands connecting two Dirac points. The midgap states inherit stability through the two dimensional Dirac metal from the three dimensional bulk insulator. This makes (Pb,Sn)Se the first example for a crystal symmetry protected hierarchy of one and two dimensional topological modes, which we experimentally prove to result in a striking robustness to defects, strong magnetic fields, and elevated temperature.

[1] P.Sessi, D. Di Sante et. al, Science 354 1269 (2016)

TT 82.2 Thu 9:45 A 053

Quantum capacitance measurements in $BiSbTeSe_2$ 3D topological insulators — •Jimin Wang[1], Zhiwei Wang[2], Yoichi Ando[2], and Dieter Weiss[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg, D-93040 Regensburg, Germany — [2]Physics Institute II, University of Cologne, Zülpicher Str. 77, 50937, Köln, Germany

We conducted low temperature quantum capacitance measurements in high quality bulk-insulating 3D topological insulators $BiSbTeSe_2$ flakes, with h-BN as protective capping layers. The density of states extracted from the gate voltage dependence of the quantum capacitance is asymmetric with respect its minimum, indicating a partly nonlinear energy dispersion. Our results can be well fitted using a linear dispersion with superimposed parabolic contributions, which are in agreement with literature [1, 2]. At magnetic fields higher than 10 T, we clearly resolve the zeroth Landau level, which can be observed at least up to 85 K. Due to impurity broadening, higher Landau levels cannot be resolved.

[1] A. A. Taskin, et al., PRL 107, 016801 (2011)
[2] T. Arakane et al., Nat. Commun. 3:636 (2012)

TT 82.3 Thu 10:00 A 053

Gate-Training Effects and Enhanced Transparency in HgTe Quantum Spin Hall Edge Channels — •Lukas Lunczer[1], Philipp Leubner[2], Hartmut Buhmann[1], and Laurens W. Molenkamp[1] — [1]Experimentelle Physik 3, Physikalisches Institut, Universität Würzburg — [2]Technische Universität Eindhoven

HgTe quantum wells are the most intensively studied 2D topological insulators. The key property of these systems is the existence of helical edge channels, which has been investigated in detail in various experiments [1,2,3]. However, the experimental observation of quantized conductance in these edge channels is limited to only very small sample dimensions (in the range of a few μm), which is not yet entirely understood. In this talk I will first discuss the influence of the size of the band gap to this limitation. One finds that an enlarged band gap does not result in a more stable quantization, as one would naively expect. We suggest that this the approach of gating affects our devices i.e. potential fluctuations prevent the sample from the bulk insulating state homogeneously. I will show that the non-quantized conductance in large samples can be influenced by hysteretic gate training and thus smoothening the potential landscape in the quantum well. On a 58 μm long pair of edge channels, this leads to a yet unseen conductance of 1.6 e^2/h, almost reaching the theoretically predicted value of 2 e^2/h.

[1] M. König et al., *Science* **318**, 766 (2007)
[2] A. Roth et al., *Science* **325**, 5938 (2009)
[3] C. Brüne et al., *Nature Physics* **8**, 485 (2012)

TT 82.4 Thu 10:15 A 053

Spectroscopy of 1D Edge States and Rashba-Split Valence Bands in Bismuthene on SiC(0001) — •Felix Reis[1], Gang Li[2,3], Raul Stühler[1], Lenart Dudy[1,4], Maximilian Bauernfeind[1], Stefan Glass[1], Werner Hanke[3], Ronny Thomale[3], Jörg Schäfer[1], and Ralph Claessen[1] — [1]Physikalisches Institut and Röntgen Research Center for Complex Material Systems, Universität Würzburg, D-97074 Würzburg, Germany — [2]School of Physical Science and Technology, ShanghaiTech University, Shanghai 201210, China — [3]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, D-97074 Würzburg, Germany — [4]Tempo Beamline, Synchtron Soleil, L'Orme des Merisiers, 91190 Saint-Aubin, France

Recently, the realization of bismuthene on the wide-gap substrate SiC(0001) was reported [1]. Theoretical analysis shows that Bi/SiC(0001) is a large-gap quantum spin Hall system, and demonstrates the pivotal role of the substrate not just for the stabilization of the monolayer film, but also for its topological properties. We investigate the spectroscopic properties with scanning tunneling spectroscopy (STS), photoemission and density-functional theory. We find a characteristic Rashba-split valence band due to the inversion symmetry breaking by the substrate. A metallic density of states exists at the bismuthene film edges near substrate steps. We will report STS investigations of the narrow 1D spatial confinement, and of the metallic spectra which show a zero-bias anomaly.

[1] F. Reis, G. Li, L. Dudy et al., *Science* **357**, 287 (2017).

TT 82.5 Thu 10:30 A 053

Probing the topological nature of SmB_6 by dynamical mean field theory — Patrik Thunström[1,2] and •Karsten Held[1] — [1]Institute of Solid State Physics, TU Wien, 1040 Vienna, Austria — [2]Department of Physics and Astronomy, Materials Theory, Uppsala University, 751 20 Uppsala, Sweden

Experiments on the presumptive topological insulator SmB_6 remain controversial and hotly debated, with largely conflicting physical interpretations. We present reliable density functional theory plus dynamical mean field theory calculations that yield a mixed valence ($4f^{5.5}$) state with a tiny bulk band gap and a $\Gamma_1+\Gamma_8$ ground state. The bulk states and the emerging topological surface states well agree with angular resolved photoemission spectra. Strong electronic correlations and the mixed valency severely modify the simple topological Kondo insulator picture, and explain, among others, the unusual spin texture of the topological surface states.

TT 82.6 Thu 10:45 A 053

Wigner oscillations and fractional Wigner oscillations in Luttinger liquids — •Niccolo Traverso Ziani and Bjoern Trauzettel — Institut für Theoretische Physik, Universität Würzburg

In finite electronic systems, when electron-electron interactions dominate over kinetic energy, electrons tend to form regular lattices, called Wigner molecules. While the study of the Wigner molecule in three and two spatial dimensions is most often carried out numerically, in one dimension the Luttinger liquid theory allows for analytical results. In one dimension, when interaction strength is increased from the noninteracting regime, a crossover between finite size Friedel oscillations (with wavevector $2k_F$) and Wigner oscillations (with wavevector $4k_F$) is found in the average density. Moreover, in a range of intermediate interactions, increasing temperature favours Wigner oscillations over Friedel ones. Importantly, for strong interactions, the Wigner molecule becomes an almost classical state and any dependence on the spin degree of freedom is lost. This behaviour is antithetical to the concept of spin-momentum locking characterizing the helical edges of two-dimensional topological insulators (helical Luttinger liquids). The compromise between strong interactions and spin-momentum locking leads, in helical systems, to a Wigner oscillation of fermions with fractional charge e/2. This fractional oscillation is also characterized by strongly anisotropic spin-spin correlations. In a finite size setup the fractional charges have a nontrivial interplay with Jackiw-Rebbi fractional solitons.

TT 82.7 Thu 11:00 A 053

Magnetotransport properties of 3D topological insula-

tor (TI) nanowire structures — •Kristof Moors[1], Peter Schüffelgen[2,3], Daniel Rosenbach[2,3], Tobias Schmitt[2], Thomas Schäpers[2,3], and Thomas Schmidt[1] — [1]University of Luxembourg, Luxembourg, Luxembourg — [2]Peter Grünberg Institut, Jülich, Germany — [3]Helmholtz Virtual Institute for Topological Insulators (VITI), Jülich, Germany

3D TIs host gapless spin-momentum locked surface states with great potential for applications in spin electronics or quantum computing. When confined to the surface of a straight nanowire however, a confinement-induced gap appears and the topological protection is lost. Interestingly, this protection can be restored by a magnetic field with a half-integer magnetic flux piercing the cross section of the wire. To further explore the magnetotransport properties of nanowire structures, e.g. kinks or Y-junctions, we present a 3D tight-binding model, based on the $k \cdot p$ Hamiltonian introduced by Zhang. This model allows us to study structures made of different TI materials with a potentially anisotropic and/or particle-hole asymmetric surface state spectrum. Based on band structure and ballistic transport simulations, we demonstrate a rescaling of the magnetoconductance oscillations as a function of the surface state thickness, the protection of gapless surface states from a perpendicular magnetic field and special angles of the magnetic field for which nanowire kinks and Y-junctions feature conductance resonances. These properties could be relevant in future quantum transport experiments of TI nanowire structures.

15 min. break.

TT 82.8 Thu 11:30 A 053

Direct phase transitions between $Z_n \times Z_n$ bosonic topological phases in 1+1D — •Julian Bibo[1], Ruben Verresen[1,2], and Frank Pollmann[1] — [1]Technische Universiät München — [2]Max-Planck-Institut für komplexe Systeme, Dreseden

Symmetry protected topological (SPT) phases are phases of matter without local order parameters. Instead, they are classified by how a global symmetry G acts projectively on the edges. For $G = Z_n \times Z_n$, there are $n-1$ non-trivial SPT phases. For $n \leq 4$, it has been proven that within a certain class of models there are direct transitions between adjacent phases. For $n \geq 5$, however, the expectation was that there are intermediate gapless phases instead of direct transitions. Contrary to this expectation, we argue analytically that there are direct transitions in case n is divisible by 2, 3 or 4. We numerically confirm that these transitions are not fine-tuned.

TT 82.9 Thu 11:45 A 053

Signatures of hydrodynamic transport in ribbons of Dirac material — •Oleksiy Kashuba[1], Laurens Molenkamp[2], and Björn Trauzettel[1] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, D-97074 Würzburg — [2]Physikalisches Institut (EP3), Universität Würzburg, D-97074 Würzburg

Charge transport in ribbon-shaped 2D Dirac systems is studied employing the Boltzmann equation. The dependence of the resistivity on temperature and bias is investigated. An accurate understanding of the influence of electron-electron interaction and material disorder allows us to identify a parameter regime, where the system reveals hydrodynamic transport behaviour. We point out the conditions for three Dirac fermion specific features: two-liquid hydrodynamics, pseudo-diffusive transport, and the electron-hole scattering dominated regime. It is demonstrated that for the very clean samples the Gurzhi effect, a definite indicator of hydrodynamic transport, can be observed.

TT 82.10 Thu 12:00 A 053

Helical Andreev bound states and non-sinusoidal current-phase relationship at the surface of topological insulators — •Niklas Krainovic, Grigory Tkachov, and Ewelina Maria Hankiewicz — Institute for Theoretical Physics and Astrophysics, University of Würzburg, D-97074 Würzburg, Germany

When a conventional superconductor is brought in close proximity to a three-dimensional topological insulator (3D TI), an unconventional triplet pairing is generated at the TI surface. Josephson junctions based on such hybrids support Andreev bound states (ABSs) that inherit the helical spin polarization of the normal TI, resulting in the non-sinusoidal Josephson current-phase relationship (CPR) [1,2]. Here, we present detailed analytic calculations of the non-sinusoidal CPR in the metallic regime and close to the Dirac point. The CPR exhibits strong forward skewness caused by a reflectionless transport channel perpendicular to the junction interface.

This work has been supported by the DFG Grant No TK60/4-1, by SFB 1170 8220 ToCoTronics 8221 and the ENB Graduate School on Topological Insulators.

[1] G. Tkachov, E. M. Hankiewicz, Phys. Rev. B 88, 075401 (2013).
[2] I. Sochnikov, L. Maier, C. A. Watson, J. R. Kirtley, C. Gould, G. Tkachov, E. M. Hankiewicz, C. Bruene, H. Buhmann, L. W. Molenkamp, and K. A. Moler, Phys. Rev. Lett. 114, 066801 (2015).

TT 82.11 Thu 12:15 A 053

Electrically induced quantum vortices and anyons in three-dimensional topological insulators — •Flavio Nogueira and Jeroen van den Brink — IFW Dresden

The electromagnetic response of a three-dimensional topological insulator is well known to be given by a so called axion electrodynamics, which features a magnetoelectric topological term $\alpha\theta/(4\pi^2)\mathbf{E}\cdot\mathbf{B}$ in the Lagrangian density, where θ is a 2π-periodic parameter and α the fine-structure constant. We show that a point electric charge induces a quantized vortex on the surface of a topological insulator, even if the system is not a superfluid. We derive the exact expressions for the electrically induced magnetic field and angular momentum. It is shown that the dynamics of charged particles on the surface obeys fractional statistics. We briefly discuss different experimental probes to detect this behavior.

TT 82.12 Thu 12:30 A 053

Controlling the Topological Properties of Stanene by Substrate Engineering: Realistic Modelling and Experimental Approaches — •Philipp Eck[1], Maximilian Bauernfeind[2], Marius Will[2], Domenico Di Sante[1], Lenart Dudy[2], Ronny Thomale[1], Jörg Schäfer[2], Ralph Claessen[2], and Giorgio Sangiovanni[1] — [1]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, D-97074 Würzburg — [2]Physikalisches Institut and Röntgen Research Center for Complex Material Systems, Universität Würzburg, D-97074 Würzburg

Although two-dimensional (2D) group IV (C-, Si-, Ge-, Sn-) honeycomb lattices have been successfully grown on a vast number of substrates, strain, deformation and/or hybridization often destroy their topological properties. Focusing on stanene, a promising strategy is the growth on passivated SiC(0001) with a buffer layer saturating the SiC dangling bonds. We present a systematic density functional theory study of group III and V buffer layers and shed light on the buffer-stanene hybridization physics influencing the vertical stanene distance and the stanene deformation. We find for some buffer layers large equilibrium distances leading to a freestanding-stanene-like topological band structure. The theoretical study will be supported by experimental data on an Al buffer layer.

TT 82.13 Thu 12:45 A 053

Magnetization current and anomalous Hall effect for massive Dirac electrons — •Peter Silvestrov[1] and Patrik Recher[1,2] — [1]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology Braunschweig, 38106 Braunschweig, Germany

Existing investigations of the anomalous Hall effect, *i.e.* a current flowing transverse to the electric field in the absence of an external magnetic field, are concerned with the transport current. However, for many, *e.g.* optical, applications one needs to know the total current, including its pure magnetization part. In this paper, we employ the two-dimensional massive Dirac equation to find the exact universal total current flowing along a potential step of arbitrary shape. For a slowly varying electric field, we find the current density $\mathbf{j}(\mathbf{r})$ and the energy distribution of the current density $\mathbf{j}^{\varepsilon}(\mathbf{r})$. The latter turns out to be unexpectedly nonuniform, behaving like a δ-function at the border of a classically accessible area at energy ε. To demonstrate explicitly the difference between the magnetization and transport currents, we consider the transverse shift of an electron ray in an electric field.