TT 3: Topological Insulators (joint session TT/MA)

Time: Monday 9:30–13:00 Location: Theater

TT 3.1 Mon 9:30 Theater

Coexistence of trivial and topological edge states in two-dimensional topological insulators — T. L. van den Berg[1,2], M. R. Calvo[3,4], and •D. Bercioux[1,4] — [1]Donostia International Physics Center, Paseo Manuel de Lardizbal 4, E-20018 San Sebastián, Spain — [2]Centro de Física de Materiales (CFM-MPC) Centro Mixto CSIC-UPV/EHU,E-20018 Donostia-San Sebastián, Spain — [3]CIC nanoGUNE, 20018 Donostia – San Sebastián, Spain — [4]IKERBASQUE, Basque Foundation of Science, 48011 Bilbao, Spain

In this work, we show how the coexistence of trivial and topological edge states for the case of two-dimensional topological insulators (2DTIs) can occur in two different scenarios. In one case, we consider a space modulation of the gap parameter from topological to trivial. This scenario results in the so-called Volkov-Pankratov states (VPSs) [1]. In a second case, we consider the modulation of the chemical potential in an inverted gap 2DTI, similar to the traditional band pinning of semiconductors [2]. Also within this method, we obtain trivial edge states similar to the VPSs. In both cases, the trivial states lead to an enhancement of the edge conductance over the nominal maximum values of $2e^2/h$ expected in the presence of topological edge states. We propose several experiments that could demonstrate the presence of such trivial states in 2DTIs.

[1] B.A. Volkov & O.A. Pankratov, JETP Lett. **42**, 178 (1985).
[2] R. T. Tung, Appl. Phys. Rev. **1**, 011304 (2014).

TT 3.2 Mon 9:45 Theater

An anomalous higher-order topological insulator — •Selma Franca — Institute for Theoretical Solid State Physics, IFW Dresden, 01171 Dresden, Germany

Topological multipole insulators are a class of higher order topological insulators (HOTI) in which robust fractional corner charges appear due to a quantized electric multipole moment of the bulk. This bulk-corner correspondence has been expressed in terms of a topological invariant computed using the eigenstates of the Wilson loop operator, a so called "nested Wilson loop" procedure. We show that, similar to the unitary Floquet operator describing periodically driven systems, the unitary Wilson loop operator can realize "anomalous" phases, that are topologically non-trivial despite having a trivial topological invariant. We introduce a concrete example of an anomalous HOTI, which has a quantized bulk quadrupole moment and fractional corner charges, but a vanishing nested Wilson loop index. A new invariant able to capture the topology of this phase is then constructed. Our work shows that anomalous topological phases, previously thought to be unique to periodically driven systems, can occur and be used to understand purely time-independent HOTIs.

TT 3.3 Mon 10:00 Theater

Quantum Phase Transitions between $\mathbb{Z}_n \times \mathbb{Z}_n$ Symmetry Protected Topological Phases — •Julian Bibo[1], Ruben Verresen[1,2], and Frank Pollmann[1] — [1]Technische Universität München — [2]Max-Planck-Institut für komplexe Systeme, Dresden

Symmetry protected topological (SPT) phases are phases of matter without local order parameters. Instead, they are characterized by how a global symmetry G acts projectively on the edges. The projective transformations at the boundaries are in turn classified by the second cohomology group $H^2(G, U(1))$. Given this classification scheme, we can construct so called „fixed-point“ models describing the universal features of these phases. For $G = \mathbb{Z}_n \times \mathbb{Z}_n$, there are $n-1$ non-trivial SPT phases and hence $n-1$ „fixed-point“ models. For $n \leq 4$, it has been proven that the corresponding „fixed-point“ models have 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 use local symmetries to construct a path, proving that there are indeed direct transitions in cases, where n is divisible by 2, 3 or 4. We numerically confirm these arguments and show that these transitions are not fine-tuned.

TT 3.4 Mon 10:15 Theater

Quasiparticle interference and spin momentum locking of topological insulator surface states — •Henry Legg[1], Wouter Jolie[2], Timo Knispel[2], Nick Borgwardt[2], Zhiwei Wang[2], Markus Grüninger[2], Yoichi Ando[2], Thomas Michely[2], and Carsten Busse[2] — [1]Institut für Theoretische Physik, Universität zu Köln, Germany — [2]II. Physikalisches Institut, Universität zu Köln, Germany

In a normal Schrödinger material, with quadratic dispersion, the Fourier-transform of an STM quasi-particle interference (QPI) image is strongly enhanced close to momenta corresponding to $2k_F$ back-scattering. In constrast, the surface states of 3D topological insulators are protected from back-scattering due to spin-momentum locking and this protection suppresses the otherwise divergent QPI signal at $2k_F$.

Performing a self-consistent T-matrix calculation for several different scattering potentials, we demonstrate that spin-momentum locking leads to only a smooth dependence of QPI intensity as function of momentum, in particular no sharp features occur close to $2k_F$.

Our theory will be quantatively compared to measurements on compensated $BiSbTeSe_2$ allowing us to perform a detailed and precise characterisation of the topological insulator surface by extracting the full dispersion, scattering rates, and screening length of charged impurities. Intriguingly the experimental QPI intensity close to $2k_F$ shows a slight deviation from that expected due to perfect protection from backscattering, we will discuss the potential scattering mechanism that results in this effect.

TT 3.5 Mon 10:30 Theater

Topological insulator - ferrimagnet interface: Bi_2Te_3 on Fe_3O_4 — •Vanda M. Pereira[1], Chi-Nan Wu[1,2], Cariad Knight[1,3], Simone G. Altendorf[1], and Liu Hao Tjeng[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Department of Physics, National Tsing Hua University, Hsinchu, Taiwan — [3]University of British Columbia, Vancouver, Canada

Breaking the time reversal symmetry (TRS) of a topological insulator (TI) can lead to exotic phenomena such as the quantum anomalous Hall effect. In order to break the TRS, one can dope the system with transition metal elements. An alternative way to introduce magnetic order is to interface the TI with a magnetic layer, for instance a ferrimagnetic insulator (FI), making use of the proximity effect. This approach can be more advantageous, since it avoids the non-uniformity and disorder of the doping process. Here we present the study on the growth of TI/FI heterostructures, namely Bi_2Te_3/Fe_3O_4, making use of our expertise in growing high quality thin films of these materials [1,2]. The preparation of the films by molecular beam epitaxy and their *in-situ* structural and spectroscopic characterization will be discussed. We were able to achieve a good quality interface, indicated by the minimal chemical reaction observed by X-ray photoelectron spectroscopy. Furthermore, angle-resolved photoemission spectroscopy indicates the presence of a sharp Dirac cone and the consequent preservation of the top topological surface states of the TI layer.

[1] K. Hoefer *et al.* PNAS, **111(42)**, 14979 (2014)
[2] X.H. Liu *et al.*, Phys. Rev. B **90**, 125142 (2014)

TT 3.6 Mon 10:45 Theater

Transport properties of MBE grown Bi_2Te_3 on Fe_3O_4 thin film heterostructure — •Chi-Nan Wu[1,2], Vanda M. Pereira[1], Cariad Knight[1,3], Simone G. Altendorf[1], Minghwei Hong[4], Jueinai Kwo[2], and Liu Hao Tjeng[1] — [1]MPI CPfS, Dresden, Germany — [2]Dept. of Phys., NTHU, Hsinchu, Taiwan — [3]UBC, Vancouver, Canada — [4]Dept. of Phys., NTU, Taipei, Taiwan

Quantum anomalous Hall effect (QAHE) is expected to be observed when magnetic ordering is introduced in a topological insulator (TI) system. This effect is due to time reversal symmetry breaking and can be experimentally achieved by doping transition metals into the TI or by using the magnetic proximity effect (MPE) in TI/ferromagnetic insulator (FI) heterostructures to magnetize the topological surface state (TSS) at the interface. The MPE in TI/FIs has the advantage of less defects in the TI, and it might have a higher T_c to exhibit the QAHE. However, the QAHE has not yet been experimentally observed for TI/FI heterostructures. We have successfully grown heterostructures of Bi_2Te_3/Fe_3O_4 thin films by molecular beam epitaxy with minimum chemical reaction at the interface which is crucial for the short ranged MPE. In order to study the MPE induced gap opening of the TSSs, we conducted electrical transport measurements. The temperature dependent resistance shows a sharp Verwey transition of Fe_3O_4 at 122K indicating very good quality of the FI layer. From magnetoresistance measurement at low temperature, we observed the suppression of the weak antilocalization in the TI layer, indicating a TSS gap opening by the MPE.

TT 3.7 Mon 11:00 Theater

Towards Topological Quasi-Freestanding Stanene via Substrate Engineering — •Philipp Eck[1], Domenico Di Sante[1], Maximilian Bauernfeind[2], Marius Will[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) Kane-Mele-type 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. Utilizing heavy atoms (Sn, Pb) increases the SOC strength and stabilizes the non-trivial phase but comes at the prize of low-buckled structurally unstable monolayers. Here we present a systematic density functional study of stanene (Sn) on group-III and -V adatom buffered SiC(0001) and shed light on the buffer-stanene interaction physics by investigating the impact of covalent and Van-der-Waals-type bonding on the topological phase of stanene and its structural stability. We find for some buffer layers weakly interacting configurations which preserve the freestanding stanene geometry and its non-trivial phase while rendering the low-buckled structure stable. The theoretical study is supported by experimental data on an Al buffer.

[1)] D. Di Sante et al., arXiv:1807.09006

15 min. break.

TT 3.8 Mon 11:30 Theater

VLS-Growth and characterization of bulk-insulating topological insulator nanowires — •Felix Münning[1], Oliver Breunig[1], Zhiwei Wang[1], Mengmeng Bai[1], Stefan Roitsch[2], Klaus Meerholz[2], Thomas Fischer[3], Sanjay Mathur[3], and Yoichi Ando[1] — [1]Physics Institute II, University of Cologne — [2]Institute of Physical Chemistry, University of Cologne — [3]Institute of Inorganic Chemistry, University of Cologne, Germany

We report on the growth of $Bi_2Te_xSe_{3-x}$ and $Bi_xSb_{2-x}Te_3$ nanowires and their characterization in terms of morphology, material composition and electronic transport at low temperatures. Growth is performed using the vapour-liquid-solid (VLS) method on Si/SiO_2 substrates decorated with 20-nm Au nanoparticles. Growth parameters such as temperature distribution, mass and ratio of source materials, inert gas flow, pressure and growth time are optimized and the results are examined using scanning and transmission electron microscopy (SEM, TEM) and electron dispersive X-ray spectroscopy (EDX). Devices featuring ohmic contacts to the nanowires are fabricated using electron-beam lithography. Subsequently, the electronic transport properties of the nanowires are measured for their dependencies on temperature, magnetic field and electrostatic gating at temperatures down to 1.7 K.

TT 3.9 Mon 11:45 Theater

Crossed Andreev reflection in Superconductor-TI nanowire junctions — •Michael Barth, Jacob Fuchs, Cosimo Gorini, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

Topological Insulators (TIs) are materials with an ordinary bulk band gap and metallic surface/edge states. The latter are helical, meaning that we have spin-momentum-locking, and they are topologically protected by time-reversal symmetry [1]. Topologically non-trivial superconducting states can be obtained by putting a TI in close proximity to a normal superconductor. This kind of system is characterized by modifications of phenomena such as crossed Andreev reflection [2], which for example can be fully suppressed in 2-dimensional TIs [3]. We consider instead a hybrid 3-dimensional TI - superconductor T-junction, where crossed Andreev reflection is in principle tunable via external magnetic fields. This is confirmed by our 3D numerical simulations for T-junctions, showing clear signatures of tunable crossed-Andreev reflection.

[1] X.-L. Qi and S.-C. Zhang, Rev. Mod. Phys. 83, 1057 (2011)
[2] G. Falci, D. Feinberg, and F. W. J. Hekking, EPL 54, 255 (2001)
[3] P. Adroguer et al., Phys. Rev. B 82, 081303 (2010)

TT 3.10 Mon 12:00 Theater

Coulomb Blockade in Topological Insulator Quantum Dots — Klaus Richter, Cosimo Gorini, Raphael Kozlovsky, •Ansgar Graf, and Andreas Hackl — Universität Regensburg, Institut für Theoretische Physik, 93053 Regensburg

Three-dimensional topological insulator (3DTI) nanowires host topologically non-trivial surface states wrapped around an insulating bulk. We model these states by two-dimensional effective Dirac Hamiltonians. A coaxial magnetic field is known to produce Aharonov-Bohm (AB) type oscillations in the conductance. The corresponding AB phase and a Berry phase originating from spin-momentum locking affect the angular momentum wave number. We investigate 3DTI nanowires where additionally the longitudinal wave number gets quantized by size confinement, such that a '3DTI quantum dot' exhibiting a fully discrete energy spectrum is obtained. Such confinement is not possible by electrostatic means (Klein tunneling) but can be achieved via the interplay between non-trivial geometry (shaped nanowire) and a homogeneous coaxial magnetic field. We are looking for signatures of Berry phase and Dirac states in the single-electron transport regime (in particular in the Coulomb diamonds) of such a 3DTI quantum dot.

TT 3.11 Mon 12:15 Theater

On-demand thermoelectric generation of equal-spin Cooper pairs — •Felix Keidel[1], Pablo Burset[2], Sun-Yong Hwang[3], Björn Sothmann[3], and Björn Trauzettel[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, D-97074 Würzburg, Germany — [2]Department of Applied Physics, Aalto University, 00076 Aalto, Finland — [3]Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany

A central goal for the application of superconductors in spintronics is the on-demand generation of spin-polarized supercurrents or, analogously, of equal-spin Cooper pairs. Most proposals rely on a careful manipulation of magnetic materials to electrically generate equal-spin Cooper pairs in ferromagnet (F)-superconductor (S) hybrid junctions.

Here, we propose a quantum heat engine that utilizes the helicity of the edge states of a quantum spin Hall insulator instead, where nonlocal transport necessarily takes place through equal-spin channels. We demonstrate that a temperature bias applied to an S-F-S junction can drive a nonlocal polarized supercurrent, while the normal contribution from electron tunneling is suppressed. Remarkably, the relative phase between the superconductors serves as a switch to turn the thermoelectric current on and off, allowing for the creation of equal-spin Cooper pairs on demand.

TT 3.12 Mon 12:30 Theater

Edge plasmons in topological 2D materials — •Luca Vannucci[1], Nicola Marzari[2], and Kristian S. Thygesen[1] — [1]CAMD, Technical University of Denmark, 2800 Kongens Lyngby, Denmark — [2]THEOS, École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

We discuss topologically-protected collective excitations in 1D systems formed at the edge of novel 2D materials, combining both theoretical models and first-principles simulations. With the help of newly-developed computational 2D materials databases [1, 2], containing thousands of 2D materials and forming the ideal starting point for the investigation of unexplored topological materials, we focus both on known quantum spin Hall systems and new interesting candidates [3]. We then explore the electronic and plasmonic band structures in different nanoribbon geometries, highlighting the emergence of plasmonic excitations from the inspection of the dielectric function and discussing the influence of topological protection on their properties. This topological plasmonics [4] may lead to several important applications in the context of opto-electronics, where the coupling of electromagnetic fields to collective edge excitations of topological 2D materials could pave the way to new and innovative recipes for transmitting information in a robust, protected way.

[1] N. Mounet et al., Nat Nanotechnol. 13, 246 (2018)
[2] S. Haastrup et al., 2D Mater. 5, 042002 (2018)
[3] A. Marrazzo et al., Phys. Rev. Lett. 120, 117701 (2018)
[4] D. Jin et al., Phys. Rev. Lett. 118, 245301 (2017)

TT 3.13 Mon 12:45 Theater

Topological Devil's staircase in atomic two-leg ladders — Simone Barbarino[1,2], Davide Rossini[3], •Matteo Rizzi[4], Rosario Fazio[5,6], Giuseppe E. Santoro[1,5,7], and Marcello Dalmonte[1,5] — [1]SISSA, Trieste, Italy — [2]Technische Universität Dresden, Germany — [3]Università di Pisa and INFN, Italy — [4]Johannes Gutenberg-

Universität, Mainz, Germany — [5]ICTP, Trieste, Italy — [6]NEST, SNS & Istituto Nanoscienze-CNR, Pisa, Italy — [7]CNR-IOM Democritos, Trieste, Italy

We show that a hierarchy of symmetry-protected topological (SPT) phases in 1D –a topological Devil's staircase – can emerge at fractional filling fractions in interacting systems, whose single-particle band structure describes a (crystalline) topological insulator. Focusing on a specific example in the BDI class, we present a field-theoretical argument based on bosonization that indicates how the system phase diagram, as a function of the filling fraction, hosts a series of density waves. Subsequently, based on a numerical investigation of spectral properties, Wilczek-Zee phases, and entanglement spectra, we show that these phases can support SPT order. In sharp contrast to the non-interacting limit, these topological density waves do not follow the boundary-edge correspondence, as their edge modes are gapped. We then discuss how these results are immediately applicable to models in the AIII class, and to crystalline topological insulators protected by inversion symmetry. Our findings are immediately relevant to cold atom experiments with alkaline-earth atoms in optical lattices, where the band structure properties we exploit have been recently realized.