HL 5: Topological insulators

Time: Monday 9:30–13:30 Location: H36

HL 5.1 Mon 9:30 H36

Mirror Chern number in the hybrid Wannier representation — •Tomáš Rauch[1,2], Thomas Olsen[3], David Vanderbilt[4], and Ivo Souza[2,5] — [1]Friedrich-Schiller-University Jena, Germany — [2]Centro de Física de Materiales, San Sebastián — [3]Technical University of Denmark, Kongens Lyngby, Denmark — [4]Rutgers University, Piscataway, New Jersey, USA — [5]Ikerbasque Foundation, Bilbao, Spain

We formulate the mirror Chern number (MCN) of a two-dimensional insulator with reflection symmetry $\hat{M}_z$ in terms of hybrid Wannier functions (the eigenfunctions of $\hat{P}\hat{z}\hat{P}$, the position operator projected onto the valence bands) localized perpendicular to the mirror plane. Because $\hat{P}\hat{z}\hat{P}$ and $\hat{M}_z$ anticommute, the spectrum of "Wannier bands" is symmetric about the mirror plane, and an excess of one mirror eigenvalue over the other in the occupied manifold leads to the appearance of flat bands on the mirror plane. In the absence of flat bands, pairs of dispersive bands may touch at isolated points on the mirror plane. These Dirac nodes are protected by reflection symmetry, and the MCN is given by the sum of their winding numbers. When flat bands are present the Dirac nodes are no longer protected, and the MCN is related instead to the Chern number of the flat bands. In some cases the magnitude of the MCN can be determined without constructing $\hat{M}_z$ explicitly. In three dimensions, the present formalism reveals a simple relation between the MCNs and the quantized axion angle θ, whose expression in the hybrid Wannier representation was previously obtained.

HL 5.2 Mon 9:45 H36

Nanoscale spectroscopy of surface states on a three-dimensional topological insulator — •Fabian Sandner[1], Fabian Mooshammer[1], Markus A. Huber[1], Martin Zizlsperger[1], Helena Weigand[1], Markus Plankl[1], Christian Weyrich[2], Martin Lanius[2], Jörn Kampmeier[2], Gregor Mussler[2], Detlev Grützmacher[2], Jessica L. Boland[1], Tyler L. Cocker[3], and Rupert Huber[1] — [1]Department of Physics, University of Regensburg, 93040 Regensburg, Germany — [2]PGI-9, Forschungszentrum Jülich, 52425 Jülich, Germany — [3]Department of Physics and Astronomy, Michigan State University, 48824 Michigan, USA

Massless Dirac fermions in topologically protected surface states (TSSs) make three-dimensional topological insulators (TIs) a promising material class for future high-speed electronics. However, recent reports outline the coexistence of the TSSs and an additional two-dimensional electron gas (2DEG) at TI surfaces due to band bending effects. Here, we use near-field microscopy in the mid-infrared spectral range to probe the local surface properties of $(Bi_{0.5}Sb_{0.5})_2Te_3$ structures with tomographic, three-dimensional precision on the nanoscale. Applying nano-spectroscopy, we retrieve the full complex-valued local dielectric function of the surface states without making *a priori* model assumptions on the spectral response. In this way, we identify a sharp Lorentzian resonance originating from intersubband transitions of the massive 2DEG, and a broadband absorption background in the dielectric function, which we attribute to transitions between the TSSs and the lowest 2DEG subband.

HL 5.3 Mon 10:00 H36

The quantum rectification sum rule in time reversal invariant materials — •Oles Matsyshyn and Inti Sodemann — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We derive a unifying fully quantum mechanical formula for the non-linear conductivity of metals and insulators. With this formula we establish a new sum rule for the frequency integrated rectified current which is controlled entirely by the non-abelian Berry connection and therefore depends purely on the quantum geometry of the ground state wave-function. For metals the sub-gap spectral weight contributing to this sum rule is exhausted by a sharp peak whose strength is proportional to the Berry curvature dipole introduced in Phys. Rev. Lett. 115, 216806 (2015). This offers a deeper insight into the meaning of the Berry curvature dipole as a kind non-linear analogue of the Drude weight in inversion breaking and time reversal invariant metals, which can be viewed as quantifying an acceleration of the electron liquid which is second order in electric fields. We apply our findings to understand the non-linear opto-electronic properties of Weyl semimetal materials.

HL 5.4 Mon 10:15 H36

Band structure of the 2D HgTe quantum well from the cyclotron resonance — •Jan Gospodaric[1], Alexey Shuvaev[1], Vlad Dziom[1], Andrei Pimenov[1], Alena Dobretsova[2], Elena Novik[3], Nikolay Nikolaevich Mikhailov[2], and Ze Don Kvon[2] — [1]Institute of Solid State Physics, Vienna University of Technology, 1040 Vienna, Austria — [2]Rzhanov Institute of Semiconductor Physics and Novosibirsk State University, Novosibirsk 630090, Russia — [3]Institute of Theoretical Physics, Technische Universität Dresden, 01062 Dresden, Germany

One of the most standardised and prominent methods to acquire the band structure of solids is provided by angle-resolved photoemission spectroscopy (ARPES). However, access to the electronic structure of thin film materials with a surrounding layered structure by ARPES is limited since the technique only allows investigation of the area close to the surface of the sample (typical depths in Ångström range). Here we present one the alternative method to obtain insight into the band dispersion of such samples by probing the cyclotron resonance of the free carriers in a thin film of three-dimensional topological insulator HgTe. Specifically, we applied our measuring procedure to a strained 80 nm thick HgTe quantum well, which is insulating in the bulk and is characterised by a 2D surface electron gas with a Dirac-like dispersion. With present technique we can map both the electron as well as the hole part of the band structure. The resulting band picture agrees reasonably well with theoretical predictions.

HL 5.5 Mon 10:30 H36

Topological crystalline insulators from stacked graphene layers — •Sanjib Kumar Das[1], Binghai Yan[2], Jeroen van den Brink[1,3], and Ion Cosma Fulga[1] — [1]Institute for Theoretical Solid State Physics, IFW Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [2]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot, 7610001, Israel — [3]Department of Physics, Technical University Dresden, 01062 Dresden, Germany

In principle the stacking of different two-dimensional (2D) materials allows the construction of 3D systems with entirely new electronic properties. Here we propose to realize topological crystalline insulators (TCI) protected by mirror symmetry in heterostructures consisting of graphene monolayers separated by two-dimensional polar spacers. The polar spacers are arranged such that they can induce an alternating doping and/or spin-orbit coupling in the adjacent graphene sheets. When spin-orbit coupling dominates, the non-trivial phase arises due to the fact that each graphene sheet enters a quantum spin-Hall phase. Instead, when the graphene layers are electron and hole doped in an alternating fashion, a uniform magnetic field leads to the formation of quantum Hall phases with opposite Chern numbers. It thus has the remarkable property that unlike previously proposed and observed TCIs, the non-trivial topology is generated by an external time-reversal breaking perturbation.

HL 5.6 Mon 10:45 H36

Superconductivity in MBE grown $In_xSn_{1-x}Te/Bi_2Te_3$ films — •Andrea Bliesener, Junya Feng, Alexey Taskin, and Yoichi Ando — Institute of Physics II, University of Cologne, Germany

$In_xSn_{1-x}Te$ is derived from the topological crystalline insulator SnTe which becomes superconducting when doped with Indium and it is one of the top candidates for topological superconductivity [1].

$In_xSn_{1-x}Te$ thin films have been grown by molecular beam epitaxy (MBE) on a Bi_2Te_3 buffer layer, which has a good lattice matching for the growth in the (111) direction [2]. Using in situ post-annealing procedures, we achieve robust superconductivity in the grown $In_xSn_{1-x}Te$ films.

To look for possible signatures of topological superconductivity in the grown films, we fabricated tunnelling junctions on the surface of the superconducting $In_xSn_{1-x}Te$ films. The tunnelling spectroscopy data shows a clear two-gap structure in the measured conductance spectra which points to the coexistence of bulk and surface superconductivity in the studied $In_xSn_{1-x}Te$ thin films.

References

[1] S. Sasaki et al; Physical Review Letters 109, 217004 (2012)

[2] A. A. Taskin et al; Physical Review B 89, 121302(R) (2014)

HL 5.7 Mon 11:00 H36

Topological band structures in electrical circuits — •Tobias Hofmann[1], Tobias Helbig[1], Ching Hua Lee[2,3], Martin Greiter[1], and Ronny Thomale[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Institute of High Performance Computing, A*STAR, Singapore, 138632 — [3]Department of Physics, National University of Singapore, Singapore, 117542

Topolectrical circuits present themselves as a platform to investigate fundamental topological states of matter realized in classical synthetic crystals. The manifold degrees of freedom unfolding as lattice connectivity and parameter choice in electric networks enable the implementation of arbitrary tight-binding models. We report on the design, measurement and engineering of admittance band structures in periodic circuits providing an extensive symmetry classification. We employ our approach on explicating several examples reaching from the Su-Schrieffer-Heeger and the graphene model over the implementation of the Chern state up to the realization of non-Hermitian physics in this classical environment.

HL 5.8 Mon 11:15 H36

Haldane circuit — •Tobias Helbig[1], Tobias Hofmann[1], Ching Hua Lee[2,3], Martin Greiter[1], and Ronny Thomale[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Institute of High Performance Computing, A*STAR, Singapore, 138632 — [3]Department of Physics, National University of Singapore, Singapore, 117542

We propose an implementation of the Chern state in a topolectrical circuit network, featuring topologically protected, unidirectional propagation of voltage packages at its boundary. Recently, electrical circuit arrays have been established as an easily accessible and tunable environment to host synthetic topological states of matter. The breaking of reciprocity and time-reversal symmetry as well as minimizing dissipation effects constitute the central challenges arising in a circuit realization of the Chern state. In this talk, we present operational amplifiers in a negative-impedance converter configuration as the key component to master these challenges. We report on our results of a dissipation-corrected circuit implementation of the Haldane model.

15 min. break

HL 5.9 Mon 11:45 H36

Quantum oscillations of the Hall resistance in bulk Bi_2Se_3 at high temperatures — •Olivio Chiatti[1], Marco Busch[1], Sergio Pezzini[2], Steffen Wiedmann[2], Oliver Rader[3], Lada V. Yashina[4], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]High Field Magnet Laboratory, Radboud University Nijmegen, 6525ED Nijmegen, The Netherlands — [3]Helmholtz-Zentrum-Berlin für Materialien und Energie, 12489 Berlin, Germany — [4]Department of Chemistry, Moscow State University, 119991 Moscow, Russia

Bi_2Se_3 is one of the prototype three-dimensional (3D) topological insulators, where investigating transport by the two-dimensional (2D) topological surface states (TSS) has been hampered by residual bulk charge carriers. In recent work, the high-field Hall resistance and low-field magnetoresistance indicate that the TSS may coexist with a layered 2D electronic system [1]. We have investigated nominally undoped, bulk Bi_2Se_3 with a high electron density $n \approx 2{\cdot}10^{19}$ cm^{-3} and show quantum oscillations of the Hall resistance for temperatures up to 50 K. The angular and temperature dependence of the Hall resistance and the Shubnikov-de Haas oscillations show 3D and 2D contributions to transport. Angular-resolved photoemission spectroscopy proves the existence of TSS. We present a model for Bi_2Se_3 and suggest a coexistence of TSS and 2D layered transport stabilizing the quantum oscillations of the Hall resistance [2].

[1] Chiatti *et al.*, Sci. Rep. **6**, 27483 (2016).
[2] Busch *et al.*, Sci. Rep. **8**, 485 (2017).

HL 5.10 Mon 12:00 H36

Early onset of a '−1' quantized Hall plateau in HgMnTe / HgCdTe quantum wells close to charge neutrality — Saquib Shamim, •Wouter Beugeling, Andreas Budewitz, Pragya Shekhar, Philipp Leubner, Hartmut Buhmann, and Laurens W. Molenkamp — Physikalisches Institut (EP3), Würzburg University, Würzburg, Germany

Transport measurements of HgCdTe/HgMnTe/HgCdTe quantum wells indicate that the Hall conductivity quantizes at $-e^2/h$ already for remarkably small magnetic fields of $\sim$ 100 mT and remains quantized up to a few tesla. This phenomenology is reminiscent of a suggestion [1] that the quantum anomalous Hall effect could occur in this material. However, the suggested mechanism of closing the bulk gap for one spin component does not apply to our setup due to insufficient magnetization at small magnetic fields.

Comparing our data to predictions obtained from $k{\cdot}p$ theory, we find that the particle-hole asymmetric dispersion gives rise to a Landau-level fan with a $-e^2/h$ plateau that spans a large range of magnetic field values. The Mn doping favours the onset at small magnetic fields due to the effect of the exchange coupling. We confirm our theory by showing that it remains consistent with experiments performed in a tilted magnetic field and at different temperatures.

[1] C.-X. Liu *et al.*, Phys. Rev. Lett. 101, 146802 (2008).

HL 5.11 Mon 12:15 H36

Top-down fabrication of gate-tuneable bulk-insulating TI nanowires and their quantum transport — •Matthias Rössler, Dingxun Fan, Oliver Breunig, Andrea Bliesener, Gertjan Lippertz, Alexey Taskin, and Yoichi Ando — II. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, D-50937 Köln, Germany

With proximity-induced superconductivity, bulk-insulating topological insulator nanowires (TI NWs) are expected to serve as a robust platform for realizing Majorana bound states. When exploiting their non-Abelian exchange statistics, these could enable realizations of topological quantum computation schemes. In previous reports, however, manipulation of naturally- or MBE-grown TI NWs limited possible device layouts and finite bulk transport contribution yet showed potential for improvements.

We have been performing fabrication and optimization of bulk-insulating TI NWs based on a scalable approach, namely etching of MBE-grown high quality $(Bi_{1-x}Sb_x)_2Te_3$ thin films. Magneto-transport measurements have been carried out to characterize the NWs properties, showing that the quality of the pristine material can be maintained during fabrication. Using this technique, highly gate-tuneable bulk insulating TI NWs with a diameter of less than 100 nm can be prepared to form arbitrary networks, which will be utilized to study proximity-induced superconductivity in more complex devices layouts.

HL 5.12 Mon 12:30 H36

Higher-order topology in two-dimensional crystals — Frank Schindler[1], Wladimir A. Benalcazar[2,3], Marta Brzezinska[1,4], Mikel Iraola[5,6], Adrien Bouhon[7,8], •Stepan S. Tsirkin[1], Maia G. Vergniory[5,9], and Titus Neupert[1] — [1]University of Zürich, Switzerland — [2]Pennsylvania State University, USA — [3]University of Illinois at Urbana-Champaign, USA — [4]Wroclaw University of Science and Technology, Poland — [5]Donostia International Physics Center, Donostia - San Sebastian, Spain — [6]University of the Basque Country UPV/EHU, Bilbao, Spain — [7]Uppsala University, Sweden — [8]NORDITA, Stockholm, Sweden — [9]IKERBASQUE, Basque Foundation for Science, Bilbao, Spain

We study two-dimensional spinful topological phases of matter protected by time-reversal and crystalline symmetries. To define the topology we employ the concept of corner charge fractionalization: We show that corners in a higher-order topological phase can carry charges that are fractions of even multiples of the electric charge. These charges are quantized and topologically stable as long as all symmetries are preserved. We classify the topologies corresponding to different corner charge configurations for all 80 layer groups, and present their bulk topological indices. These can be calculated from the symmetry data and Brillouin zone Wilson loops. To corroborate our findings, we present tight-binding models and density functional theory calculations for various material realizations.

HL 5.13 Mon 12:45 H36

Topological Crystalline Protection in the BHZ and Kane-Mele models — •Fernando Dominguez, Benedikt Scharf, and Ewelina M. Hanckiewicz — Wuerzburg University, Wuerzburg, Germany

We investigate the topological crystalline protection against in-plane magnetic fields that naturally appears in two general quantum spin Hall models: the BHZ and and the Kane-Mele models [1]. This protection avoids the mixing of counter propagating modes and arises through the combination of particle-hole and reflection symmetries. Indeed, a gap can be opened in the presence of terms that break one of the mentioned symmetries. Therefore, we explore the impact on the gap opening of different coupling terms that break particle-hole symmetry, such as, Rashba spin-orbit coupling, a staggered potential, next-nearest neighbor hopings, anisotropic g-factor and lattice strain.

[1] F. Dominguez, B. Scharf, G. Li, J. Schäfer, R. Claessen, W. Hanke, R. Thomale, and E. M. Hankiewicz, Phys. Rev. B 98 , 161407 (2018).

HL 5.14 Mon 13:00 H36

Interplay of disorder and interactions in 3d tilted Weyl cones — •Tycho Sikkenk[1] and Lars Fritz[2] — [1]Utrecht University, Utrecht, The Netherlands — [2]Utrecht University, Utrecht, The Netherlands

"Weyl semi-metals (WSMs) are characterised by a non-degenerate touching point in a linear dispersion where the density of states vanishes. This cone-like behaviour strongly affects the reaction of these materials to disorder and interactions, which we investigate within an RG framework.*In a less idealised case the cones in the dispersion can be tilted, which destabilises the fixed points of the upright model in favour of others that are associated with potentially different critical exponents."

HL 5.15 Mon 13:15 H36

Majorana bound states in Phase-Controlled Josephson Junctions with Strong Spin-Orbit Coupling — •Benedikt Scharf[1], Falko Pientka[2], Hechen Ren[3], Amir Yacoby[4], Bertrand I. Halperin[4], and Ewelina M. Hankiewicz[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Würzburg, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]California Institute of Technology, Pasadena, California 91125, USA — [4]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

Topological superconductors based on Josephson junctions in two-dimensional electron gases (2DEGs) with strong Rashba spin-orbit coupling (SOC) offer an attractive alternative to wire-based setups [1,2]. Here, we elucidate how phase-controlled Josephson junctions with an arbitrary combination of Rashba and Dresselhaus SOC can also host Majorana bound states (MBS) for a wide range of parameters as long as the magnetic field is oriented appropriately. Hence, MBS based on Josephson junctions can appear in a wide class of 2DEGs. We study the effect of SOC, the Zeeman energies, the superconducting phase difference and normal reflection to create a full topological phase diagram and find the optimal stability region to observe MBS. Finally, we study the role of the Doppler effect that can arise due to the magnetic-field-induced local gradient of the superconducting phase in these junctions. [1] F. Pientka, et al. Phys Rev X 7, 021032 (2017). [2] H. Ren, et al. arXiv:1809.03076.