TT 8: Topological Insulators I (joint session HL/TT)

Time: Monday 9:30–13:00 Location: A 151

TT 8.1 Mon 9:30 A 151

Model for ferromagnetic Weyl and nodal line semimetals: topological invariants, surface states, anomalous and spin Hall effect — Tomáš Rauch[1,2], Huong Nguyen-Minh[1], •Jürgen Henk[1], and Ingrid Mertig[1,3] — [1]Institute of Physics, Martin Luther University Halle-Wittenberg, Halle, Germany — [2]Berc Materials Physics Center, Donostia–San Sebastián, Spain — [3]Max Planck Institute for Microstructure Physics, Halle, Germany

By adding a Zeeman term to the extended Dirac equation [1] we show that this equation describes not only topological insulators but also models the electronic properties of ferromagnetic Weyl and nodal line semimetals [2], both of which arise for specific parameter sets. We confirm the topological nontriviality of the nodal objects by calculating the topological invariants as well as by demonstrating the existence of characteristic topological surface states of the associated semi-infinite systems. Moreover, Weyl points and nodal lines produce notable features in the anomalous and in the spin Hall conductivity.

[1] S.-Q. Shen, W.-Y. Shan, and H.-Z. Lu, Spin **1**, 33 (2011).
[2] T. Rauch, H. Nguyen-Minh, J. Henk, and I. Mertig, Phys. Rev. B, submitted.

TT 8.2 Mon 9:45 A 151

Transport Spectroscopy of Induced Superconductivity in the three-dimensional Topological Insulator HgTe — •Jonas Wiedenmann — Experimentelle Physik III, Universität Würzburg, Am Hubland, 97074 Würzburg

Inducing superconducting pairing into the surface states of a topological insulator is predicted to lead to the emergence of mixed spin singlet/triplet superconducting correlations and Majorana bound state related physics. We studied the proximity-induced superconducting state into the topological surface states of strained bulk HgTe by Andreev reflection point-contact spectroscopy. By analyzing the conductance as a function of voltage for various temperatures, magnetic fields and gate-voltages, we find evidence, in equilibrium, for an induced order parameter in HgTe of 0.070 meV and an order parameter of the superconducting gap of niobium of 1.1 meV. To describe the full conductance curve we suggest that a charge imbalance suppresses the induced superconducting state. As a result the relevant scattering region changes depending on the applied bias voltage.

TT 8.3 Mon 10:00 A 151

Interplay between topology and disorder in a two-dimensional semi-Dirac material — P V Sriluckshmy, •Kush Saha, and Roderich Moessner — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We investigate the role of disorder in a two-dimensional semi-Dirac material characterized by a linear dispersion in one, and a parabolic dispersion in the orthogonal, direction. Using the self-consistent Born approximation, we show that disorder can drive a topological Lifshitz transition from an insulator to a semi-metal, as it generates a momentum independent off-diagonal contribution to the self-energy. Breaking time-reversal symmetry enriches the topological phase diagram with three distinct regimes– single-node trivial, two-node trivial and two-node Chern. We find that disorder can drive topological transitions from both the single- and two-node trivial to the two-node Chern regime. We further analyze these transitions in an appropriate tight-binding Hamiltonian of an anisotropic hexagonal lattice, by calculating the real-space Chern number. Additionally we compute the disorder-averaged entanglement entropy which signals both the topological Lifshitz and Chern transition as a function of the anisotropy of the hexagonal lattice. Finally, we discuss experimental aspects of our results.

TT 8.4 Mon 10:15 A 151

Optical properties of topological insulator nanoparticles — •Gleb Siroki, Derek Lee, Peter Haynes, and Vincenzo Giannini — Imperial College London, South Kensington, SW7 2AZ, London, UK

Topological insulators are materials that have metallic surface states protected by time-reversal symmetry. Such states are delocalised over the surface and are immune to non-magnetic defects and impurities.

Building on previous work [1] we have studied the interaction of light with topological insulator nanoparticles. Our main finding is that the occupied surface states can lead to charge density oscillations akin to plasmons in metallic nanoparticles. Furthermore, these oscillations can couple to phonons forming a previously unreported excitation [2]. Because the states occur at the surface a small number of them is enough to change the absorption spectrum of a particle containing many thousands of atoms. We are going to show how the effect can be adjusted by varying the particle's size and shape. Furthermore, we will discuss the robustness of the effect in the presence of disorder [3].

In conclusion, topological insulator nanoparticles can be used as a highly-tunable building block to create a metamaterial operating in THz range. This may be interesting for plasmonics and metamaterials communities as well as researchers working on cavity electrodynamics and quantum information.

[1] Imura et al, PRB 86, 235119 (2012)
[2] Siroki et al, Nat. Comm. 7, 12375 (2016)
[3] Siroki et al, PRMaterials, 1, 024201 (2017)

TT 8.5 Mon 10:30 A 151

Multi probe transport measurements on Bi_2Te_3 thin films — •Sebastian Bauer, Stephanie Hoepken, Mandana Soleimani, Christian A. Bobisch, and Rolf Möller — Faculty of Physics, Center for Nanointegration Duisburg-Essen, University of Duisburg-Essen, 47048 Duisburg, Germany

We present a detailed study of the electron transport properties of a thin Bi_2Te_3 film on Si(111). Bi_2Te_3 is a prototype system of so called three dimensional topological insulators. Such materials are insulating inside their bulk while they provide a metallic state on their surface which is protected by the materials topology [1]. The nanoscale transport field of the Bi_2Te_3 surface was studied by scanning tunneling potentiometry (STP), an extension of the scanning tunneling microscope (STM) which allows us to analyze the microscopic topography and the correlated microscopic electrochemical potential of the surface simultaneously [2]. The STP analysis shows that morphological features like step edges and grain boundaries are barriers for conduction electrons. The conductivity of step edges and grain boundaries were determined to 700 S/cm and 350 S/cm in the surface state, confirming former STP studies [3,4].

[1] M. Z. Hasan, C. L. Kane, Rev. Mod. Phys. 82, 3045 (2010). [2] A. Bannani, C. A. Bobisch, R. Möller, Rev. Sci. Instrum. 79, 083704 (2008). [3] S. Bauer und C. A. Bobisch, Nat. Com. 7, 11381 (2016). [4] F. Lüpke et al., Nat. Com. 8, 15704 (2017).

TT 8.6 Mon 10:45 A 151

Mixed topological semimetals in two-dimensional spin-orbit ferromagnets — •Chengwang Niu[1], Jan-Philipp Hanke[1], Patrick M. Buhl[1], Hongbin Zhang[2], Gustav Bihlmayer[1], Daniel Wortmann[1], Stefan Blügel[1], and Yuriy Mokrousov[1] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Institute of Materials Science, Technische Universität Darmstadt, 64287 Darmstadt, Germany

Topological states of matter and ferromagnetism in two dimensions are nowadays two of the most intriguing and intensively researched fields in solid state physics. Here, we predict that diverse topological semimetallic phases can be obtained in 2D ferromagnets as a consequence of the spin-orbit driven changes in the electronic structure as the magnetization direction is varied. We show that the most natural way to classify these phases lies in analyzing either points or lines of degeneracies which occur in an extended phase space of Bloch vector and the magnetization direction. The emergence of the corresponding topological states, which we refer to as mixed Weyl semimetal and mixed nodal line semimetal, respectively, can be thereby confirmed by accessing corresponding topological invariants and edge states. We demonstrate the possible complexity of the topological phase diagram of 2D ferromagnets based on several model systems, and, using density functional theory, we identify two realistic examples exhibiting mixed Weyl semimetal and mixed nodal line semimetal phases.

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TT 8.7 Mon 11:00 A 151

Microscopic theory of the surface anomalous Hall conductivity — •Tomáš Rauch[1], Thomas Olsen[2], David Vanderbilt[3], and

Ivo Souza[1,4] — [1]Centro de Física de Materiales, San Sebastián, Spain — [2]Technical University of Denmark, Kongens Lyngby, Denmark — [3]Rutgers University, Piscataway, New Jersey, USA — [4]Ikerbasque Foundation, Bilbao, Spain

The dimensionless axion coupling θ describes the isotropic part of the linear magnetoelectric tensor. In a bulk crystal θ is only defined modulo 2π, and only its space-time gradients enter Maxwell's equations. At surfaces, the spatial gradient of θ gives rise to a surface anomalous Hall conductivity (AHC). In this work, we derive a microscopic expression for the AHC of an insulating surface. We find that in general it comprises not only a geometric contribution that is a property of the occupied states, but also a non-geometric "cross-gap" term that is absent from the expression for the intrinsic AHC of a free-standing film or slab. By constructing tight-binding models in a slab geometry, we numerically test our analytical results and explore the connection between the surface AHC and the bulk axion coupling. In particular, we illustrate how different insulating surfaces of the same bulk crystal can have AHCs that differ by an integer multiple of e^2/h, and that this difference resides in the geometric term alone.

15 min. break.

TT 8.8 Mon 11:30 A 151

A room-temperature and switchable Kane-Mele quantum spin Hall insulator — •Antimo Marrazzo, Marco Gibertini, Davide Campi, Nicolas Mounet, and Nicola Marzari — Theory and Simulation of Materials (THEOS) and National Centre for Computational Design and Discovery of Novel Materials (MARVEL), Ecole Polytechnique Federale de Lausanne, 1015, Switzerland

Fundamental research and technological applications of topological insulators are hindered by the rarity of materials exhibiting a robust topologically non-trivial phase, especially in two dimensions (2D). Here, by means of extensive first-principles calculations, we propose a novel quantum spin Hall insulator (QSHI) with a sizeable band gap of ∼0.5 eV at the G_0W_0 level, that is a monolayer of a naturally occurring layered mineral. This system realises the paradigmatic Kane-Mele model for QSHIs in a potentially exfoliable 2D monolayer with helical edge states that are robust even beyond room temperature and that can be manipulated exploiting a unique strong interplay between spin-orbit coupling, crystal-symmetry breaking, and dielectric response.

TT 8.9 Mon 11:45 A 151

Testing Topological Protection of Edge States in Bismuthene on SiC — •Fernando Dominguez[1], Benedikt Scharf[1], Gang Li[2], Werner Hanke[3], Ronny Thomale[3], and Ewelina Hankiewicz[1] — [1]Institute for Theoretical Physics and Astrophysics, TP4, University of Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]School of Physical Science and Technology, ShanghaiTech University, Shanghai 201210, China — [3]Institute for Theoretical Physics and Astrophysics, TP1, University of Würzburg, Am Hubland, 97074 Würzburg, Germany

Due to its large bulk band gap, bismuthene on SiC offers intriguing new opportunities for room-temperature quantum spin Hall (QSH) applications. Although edge states have been observed in the local density of states (LDOS), there has been no experimental evidence until now that they are spin polarized and topologically protected. Here, we predict experimentally testable fingerprints of these properties originating from magnetic fields, such as changes in the LDOS and in ballistic magnetotransport due to a gap of a few meV opened at the crossing point between the QSH states. For armchair edges in particular, we find a distinct difference of behavior under out-of-plane (gap opening between the QSH states) and in-plane (no or tiny gap) fields. This unexpected robustness of armchair QSH edge states against in-plane fields can be understood from an effective low-energy model, where a helicity operator provides an additional protection of the QSH states. While we focus here on bismuthene on SiC, our main findings should also be applicable to other honeycomb-lattice-based QSH systems.

TT 8.10 Mon 12:00 A 151

High-temperature quantum oscillations of the Hall resistance in bulk Bi_2Se_3 — •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, 12489 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

Protected topological surface states (TSS) with helically spin-polarized Dirac fermions (HSDF) are of high interest as a new state of quantum matter. Electronic bulk states in three-dimensional (3D) materials with TSS often mask the transport properties of HSDF. In recent work, the high-field Hall resistance and low-field magnetoresistance indicate that the TSS may coexist with a layered two-dimensional electronic system (2DES) [1]. Here, we demonstrate quantum oscillations of the Hall resistance for temperatures up to 50 K, in nominally undoped bulk Bi_2Se_3 with a high electron density n of about $2{\cdot}10^{19}$ cm^{-3}. From the angular and temperature dependence of the Hall resistance and the Shubnikov-de Haas oscillations we identify 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 that the coexistence of TSS and 2D layered transport stabilizes the quantum oscillations of the Hall resistance.

[1] Chiatti *et al.*, Sci. Rep. **6**, 27483 (2016)

TT 8.11 Mon 12:15 A 151

Exploiting Topological Insulators for Majorana Devices — •Peter Schüffelgen[1], Daniel Rosenbach[1], Chuan Li[2], Michael Schleenvoigt[1], Tobias Schmitt[1], Sarah Schmitt[1], Abdur Jalil[1], Jonas Kölzer[1], Lidia Kibkalo[1], Benjamin Bennemann[1], Umut Parlak[1], Martina Luysberg[1], Gregor Mussler[1], Alexander Golubov[2], Alexander Brinkman[2], Thomas Schäpers[1], and Detlev Grützmacher[1] — [1]Peter Grünberg Institut, Forschungszentrum Jülich, D-52425 Jülich, Germany — [2]MESA+ Institute for Nanotechnology, University of Twente, 7500AE Enschede, The Netherlands

At the interface of s-wave superconductors (SC) and topological insulators (TI) exotic Majorana modes are predicted to occur. In this work, a novel fabrication technique is presented, which allows to construct TI-SC hybrid devices of high quality under ultra-high vacuum conditions. A stencil mask is applied to the substrate before growth of Bi-based TI thin films by means of molecular beam epitaxy. The shadow mask is used for stencil lithography of superconductive electrodes on top of the topological thin film in a second growth step. Measurements on such in-situ fabricated Josephson junctions indicate a high interface transparency. Furthermore, a missing first Shapiro step was detected in radio frequency experiments, indicating signatures of gapless Andreev bound states, so-called Majorana bound states. The presented process is applicable to a variety of new geometries, allowing fabrication of elaborated TI-SC hybrid devices, for further research on Majorana signatures.

TT 8.12 Mon 12:30 A 151

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

We report on the realization of one-dimensional topological states of matter within electrical circuits. At the example of the Su-Schrieffer-Heeger circuit, we elaborate how topological edge states and domain walls manifest themselves in the impedance read-out of a periodic electrical circuit. We further outline prospective generalizations and applications.

TT 8.13 Mon 12:45 A 151

Topolectrical Band Structures — •Tobias Hofmann[1], Tobias Helbig[1], Ching Hua Lee[2,3], and Ronny Thomale[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Am Hubland, D-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 constitute a new avenue of topological states realized in a classical environment. With them, it is possible to reproduce band structures seen in models for topological insulators (TI) where the bands correspond to impedance (or admittance) eigenvalues. Because electrical circuits are more easily accessible than TIs, they are particularly suitable for studying topological states, reaching from the simplest models to non-hermitian and other types of rather "exotic" physics. In our talk, we illustrate the explicit measurement of topological band structures in the context of topolectrical circuits.