TT 74: Topological Insulators

Time: Thursday 9:30–12:45 Location: CHE/0091

TT 74.1 Thu 9:30 CHE/0091

Probing the Quantized Berry Phases of an Obstructed Atomic Band in 1H-NbSe$_2$ Using Scanning Tunneling Microscopy — Dumitru Călugăru[1,2], Yi Jiang[3], Haojie Guo[3], Sandra Sajan[3], •Yongsong Wang[3], Haoyu Hu[1,3], Jiabin Yu[1], B. Andrei Bernevig[1,3], Fernando de Juan[3], and Miguel M. Ugeda[3] — [1]Princeton University, Princeton, USA — [2]University of Oxford, Oxford, United Kingdom — [3]Donostia International Physics Center, San Sebastián, Spain

Topologically trivial insulators can host obstructed atomic phases, where the electronic charge is localized at symmetry positions that do not coincide with atomic sites. Despite intense theoretical interest, such phases have lacked quantitative experimental confirmation. Here we provide direct experimental evidence that the narrow band at the Fermi level of monolayer 1H-NbSe$_2$ and TaSe$_2$ realizes an optimally compact obstructed atomic phase by means of STM/STS (1). Bias-dependent constant-height conductance maps reveal a strong redistribution of spectral weight between inequivalent high-symmetry positions within the unit cell. We identify these positions experimentally by using substitutional transition-metal alloys and chalcogen vacancies as local markers. By deconvolving the STM images with orbital-resolved wave functions from ab-initio calculations, we reconstruct the short-range inter-orbital correlations and real-space charge distribution associated with the band. The resulting pattern is centered at non-atomic positions and is uniquely consistent with an obstructed atomic insulator.

[1] Calugaru et al., Nature Physics, in press(2025).

TT 74.2 Thu 9:45 CHE/0091

Characterization of TI nanowire junctions using resonator circuits — •Lucas Marten Janssen, Jorge Esteban Bolio, Christian Dickel, and Yoichi Ando — Physics Institute II, University of Cologne, Zülpicher Str. 77, 50937 Köln, Germany

Topological insulators (TIs) are being investigated for their potential to host Majorana Zero Modes (MZMs). Specifically, TI nanowires proximitized by a conventional superconductor have shown signatures of potential topological phase transitions [1]. Microwave measurements can be used to investigate the hardness of the gap [2] and to reconstruct the current-phase relationship [3]. Additionally, high-frequency operation could be necessary to eventually realize topological qubits. To assess the quality of our TI nanowire junctions, we design co-planar waveguide resonator circuits of NbTiN with a parallel plate capacitor to ground on one side and a connection to ground through the nanowire junction on the other side. This allows us to measure the sub-gap resistance and the current-phase relationship of the junction. In order to investigate the TI nanowire in the topological regime, an in-plane magnetic field of about 1 T needs to be applied. The resonators are engineered to be compatible with such fields.

[1] Nikodem et al., arXiv:2412.07993 (2024)
[2] Schmidt et al., Nat. Commun. 9, 4069 (2018)
[3] Uhl et al., Phys. Rev. Applied 22, 064052 (2024)

TT 74.3 Thu 10:00 CHE/0091

Growth and quantum transport analysis of high mobility Bi$_2$Te$_3$ thin films — •Jonas Buchhorn[1,2], Abdur Rehman Jalil[1,3], Detlev Grützmacher[1,2], and Thomas Schäpers[1,2] — [1]Peter-Grünberg-Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, 52425 Jülich, Germany — [3]Institute of Experimental Physics III, Würzburg University, 97070 Würzburg, Germany

To improve future hybrid devices, underlying material properties and conduction mechanisms must be understood and controlled. In this work, we use quantum mechanical and classical models to describe the measured conductivity tensor of Bi$_2$Te$_3$ thin films. The crystals have been prepared by molecular beam epitaxy on sapphire substrates and were shaped into Hall bar structures by optical lithography and Ar-etching. At cryogenic temperatures non-linear Hall resistance and Shubnikov-de Haas oscillations were observed. A multi-channel model motivated from band structure calculations is used to extract classical carrier properties. Model residues are quantitatively analyzed to include electron-electron interaction, spin-orbit-effects and quantum oscillations of surface states. Considering these insights, we attempt to disentangle the complex conduction mechanisms of bulk and surface states of topological insulators. The proposed methods should also be applicable to the state-of-the-art ternary or quaternary compounds to identify remaining bulk-contributions.

TT 74.4 Thu 10:15 CHE/0091

Dual-gated hBN/BiSbTeSe/hBN heterostructures: fabrication and low-temperature magnetotransport — •Kirill Teslenko, Holger Mirkes, Alexandre Bernard, and Christoph Kastl — Walter Schottky Institute, School of Natural Sciences, Technical University of Munich

Topological insulators with tunable surface states provide a platform for exploring quantum transport phenomena. We present the fabrication and characterization of dual-gated hBN/BiSbTeSe/hBN (BSTS) heterostructures designed to allow controlled access to the topological surface states. The devices are fabricated via optimized optical lithography, and the heterostacks are assembled using a dry-transfer stacker operated both under nitrogen atmosphere and under ambient conditions. Two approaches are used: transferring BSTS onto prepatterned metal contacts, and assembling the full heterostack before metal evaporation. Photocurrent measurements on non-encapsulated BSTS, BTS, and SbTe flakes were carried out to assess their optoelectronic response. Furthermore, low-temperature magnetotransport measurements on the encapsulated devices are carried out to resolve characteristic signatures of topological surface states.

TT 74.5 Thu 10:30 CHE/0091

Field-induced band modification and large magnetoresistance in topological-insulator Bi$_{1-x}$Sb$_x$ thin films — •E. Osmic[1,2], P. Bercoff[3], F. Commeto[3], Y. Skourski[1], F. Ganss[4], J. Wosnitza[1,2], and J. Barzola Quiquia[5] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL), HZDR, Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]Universidad Nacional de Córdoba, Córdoba, Argentina — [4]Institut für Ionenstrahlphysik und Materialforschung, HZDR, Dresden, Germany — [5]Felix-Bloch Institute for Solid-State Physics, Universität Leipzig, Germany

We studied the magnetic-field and temperature dependence of the electrical transport in topological-insulator Bi$_{1-x}$Sb$_x$ ($x = 0.1, 0.15, 0.2$) thin films. The resistivity $\rho(T)$ shows a clear crossover between metallic surface transport at low temperatures and semiconducting bulk behavior at higher temperatures. Below 10 K, $\rho(T)$ exhibits a characteristic two-dimensional electron–electron interaction contribution. Magnetoresistance measurements in pulsed magnetic fields up to 69 T reveal large, nonsaturating MR values reaching 2250 % over a broad temperature range. The full MR response can be consistently described using a modified two-band bulk model with field-dependent charge-carrier concentrations, complemented by a weak-antilocalization description of the surface states. These results highlight the possible field-induced band modification and the interplay between bulk and surface transport in Bi–Sb thin films.

TT 74.6 Thu 10:45 CHE/0091

THz Signatures of Boundary-Dominated Transport in Bi$_2$TeI — •shuhan wang[1], Anjan N M[1], Mohammad Mehmandous[2], Michael Ruck[2], and Stefan Kaiser[1] — [1]Institute of Solid State and Materials Physic, TUD Dresden University of Technology — [2]Inorganic Chemistry II,TUD Dresden University of Technology

Bi$_2$TeI is a weak topological insulator made of stacked topologically nontrivial (QSH) layers separated by trivial insulating layers. Despite its weak topological indices, it still hosts symmetry-protected boundary states on specific crystal surfaces. Using terahertz time-domain spectroscopy (THz-TDS), we resolve its low-energy electrodynamics in thin films. The THz conductivity shows a low frequency Drude response dip at 15K-20 K. This behavior is consistent with dc transport measurements. Notably, these features are only seen in thin films which are absent in bulk crystals. The suppression of Drude weight points to a crossover toward boundary-dominated transport in Bi-TeI thin films.

15 min. break

TT 74.7 Thu 11:15 CHE/0091

Topological fragility and bilinear magneto-resistance in spin-momentum locked edge states — •Cosimo Gorini[1], Matthieu Bard[2], and Giovanni Vignale[3] — [1]SPEC, CEA, CNRS, Université Paris-Saclay, CEA Saclay, Gif sur Yvette, France — [2]Université Paris-Saclay, CNRS, Laboratoire de Physique des Solides, 91405 Orsay, France — [3]Institute for Functional Intelligent Materials, National University of Singapore

Time-reversal symmetric and topologically non-trivial electronic systems generally host one-dimensional (1D) spin-momentum locked states at their edges/hinges. Such 1D states are in principle fully protected against backscattering, and thus referred to as perfectly conducting: disorder cannot induce backscattering – not even via spin-orbit coupling – unless time-reversal is broken. We show however that such protection hides a remarkable fragility, yielding a bilinear magneto-resistance much stronger than in standard 2D systems. The mechanism we propose is fundamental and general, being based on spin-orbit interaction with the ever-present disordered background. It should thus be relevant in any system hosting 1D Dirac-like states with linear dispersion. Our theory compares favourably with transport measurements in high-order topological hinge states in Bi.

TT 74.8 Thu 11:30 CHE/0091

Procrustean symmetrization formalism for statistical topological matter — •Johanna Zijderveld[1], Adam Yanis Chaou[2], Isidora Araya Day[1,2,3], and Anton Akhmerov[1] — [1]Kavli Institute of Nanoscience, Delft University of Technology, Delft, The Netherlands — [2]Donostia International Physics Center, San Sebastian, Spain — [3]QuTech, Delft University of Technology, Delft, The Netherlands

The standard approach to characterizing topological matter, computing topological invariants, is known to be problematic when the symmetry protecting the topological phase only holds on average in a disordered system. Because of reliance on making the symmetry exact, the topological invariants identify more topological phases than are present in the system. Alternatively, in the recently discovered intrinsic statistical topological insulators [1], making the symmetry exact is guaranteed to destroy the topological phase. We define a procedure of symmetry embedding that solves both problems and provides a unified framework for describing disordered topological matter.

[1] Phys. Rev. Lett. 134, 226601

TT 74.9 Thu 11:45 CHE/0091

Topological invariants for the SSH model coupled to a single mode cavity — •Anna Ritz-Zwilling and Olesia Dmytruk — CPHT, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris, 91120 Palaiseau, France

Coupling electronic systems to cavity photons offers a promising route to probe and control material properties through light-matter interactions. In particular, coupling to light might enable manipulation of topological phases of matter, which have gained significant attention due to their potential applications in quantum technologies. Yet, while the topological classification of non-interacting fermionic systems is well understood within the tenfold way, much less is known about how to identify topological protection when photonic operators enter the problem. In this work, we consider the Su-Schrieffer-Heeger (SSH) model as a paradigmatic one-dimensional topological insulator. In its topological phase, the SSH model exhibits zero-energy edge states protected by chiral symmetry. When the system is coupled to a cavity, however, it remains unclear whether chiral symmetry and topological protection survive. To address this question, we use a recently developed high-frequency expansion of the light-matter Hamiltonian, which traces out photonic degrees of freedom and yields an effective fermionic model. Light-matter coupling then manifests as additional interaction terms, allowing us to apply known results for interacting topological insulators. We discuss the symmetries of this effective model, compute observables such as the electronic polarization as potential topological invariants and analyze the fate of edge states.

TT 74.10 Thu 12:00 CHE/0091

Z_2 topological invariants from the Green's function diagonal zeros — Florian Simon[1] and •Corentin Morice[2] — [1]Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden — [2]Laboratoire de Physique des Solides, Université Paris Saclay, CNRS, Orsay, France

We investigate the relationship between the analytical properties of the Green's function and Z_2 topological insulators, focusing on three-dimensional inversion-symmetric systems. We show that the diagonal zeros of the Green's function in the orbital basis provide a direct and visual way to calculate the strong and weak Z_2 topological invariants. We introduce the surface of crossings of diagonal zeros in the Brillouin zone, and show that it separates TRIMs of opposite parity in two-band models, enabling the visual computation of the Z_2 invariants by counting the relevant TRIMs on either side.

TT 74.11 Thu 12:15 CHE/0091

Volkov-Pankratov states in shaped topological insulator nanowires — •Lilian Seyve and Cosimo Gorini — SPEC, CEA, Gif-Sur-Yvette, France

Topological insulators (TIs) host robust electronic states at interfaces where the bulk topological invariant changes, giving rise to protected Dirac surface modes. Beyond these gapless states, Volkov and Pankratov showed that smooth band inversions can also generate massive interface modes, now known as Volkov-Pankratov (VP) states. These states coexist with the topological zero mode and interpolate continuously between topological and bulk physics. While VP states have been studied in planar structures, how they behave in curved systems, such as nanowires, is still very much unknown.

In this work, we explore analytically and numerically how VP states appear in nanowires with cylindrical symmetry, where geometry and confinement strongly influence the electronic structure. Using a Dirac-model description with a smoothly varying mass at the wire's edge, we show how curvature, angular momentum, and longitudinal motion combine to create a set of quantized interface states. We obtain analytical expressions for their energies and spatial profiles and describe how interface curvature affects the physical properties of our system.

TT 74.12 Thu 12:30 CHE/0091

Accessing buried topological states: Revealing Dirac cones with ferromagnetic resonance — Laura Pietanesi[1], •Magdalena Marganska[2,3], Thomas Mayer[2], Michael Barth[3], Lin Chen[1], Ji Zou[4], Adrian Weindl[2], Alexander Liebig[2], Rebeca Diaz-Pardo[1], Dhavala Suri[1,5], Florian Schmid[2], Franz Giessibl[2], Klaus Richter[2], Yaroslav Tserkovnyak[4], Matthias Kronseder[2], and Christian Back[1] — [1]Technical University of Munich, Germany — [2]University of Regensburg, Germany — [3]Wrocław University of Science and Technology, Poland — [4]University of California, Los Angeles, USA — [5]Indian Institute of Science, Bengaluru, India

Ferromagnetic resonance is used to reveal features of the buried electronic band structure at interfaces between ferromagnetic metals and topological insulators [1]. The evolution of magnetic damping in a hybrid ferromagnet/3D topological insulator structure reveals a clear fingerprint of the Dirac point with additional features. The high energy resolution of this method allows us to resolve the energetic shift of the local Dirac points due to local variations of the electrostatic potential. The underlying spin-pumping mechanism relies on the dissipation of angular momentum by topological surface states (TSSs). Tuning of the Fermi level within the TSS was verified both by varying the stoichiometry of the 3DTI layer and by electrostatic backgating with a remarkable agreement. Calculations based on the chiral tunneling process naturally occurring in TSSs agree well with the experimental results.

[1] PRB 109, 064424 (2024)