O 63: Topology and symmetry protected materials & Topological insulators (joint session O/HL/TT)

Time: Wednesday 15:00–17:45 Location: HSZ/0401

O 63.1 Wed 15:00 HSZ/0401

Majorana or Not? An Insight from Atomic-Scale Shot-Noise — •Abhishek Maiti[1], Genda Gu[2], and Freek Massee[1] — [1]Université Paris-Saclay, CNRS, Laboratoire de Physique des Solides, 91405, Orsay, France — [2]Condensed Matter Physics and Materials Science Department, Brookhaven National Laboratory, Upton, NY, USA

The search for non-abelian states of matter has become a central theme of modern quantum material research. Notably, Majorana zero modes are of special interest, as they can serve as the foundation for topological qubits. A robust zero-bias conductance peak, observed in scanning tunneling spectra, is often regarded as the primary signature of a Majorana zero mode. Yet similar features can also arise from trivial bound states, raising a long-standing challenge of how to distinguish a genuine Majorana from imposters. In my talk, I will address this problem with a new approach, atomic-scale shot-noise spectroscopy, that goes beyond conductance measurements. Through a detailed investigation on multiple defect- and vortex-bound zero-bias states in the widely studied (putative) topological superconductor Fe(Se,Te), I will show that while differential conductance measurements might sometimes fail to detect an imposter Majorana state locally, noise measurements consistently provide a conclusive diagnostic, offering a powerful complementary probe. Looking ahead, this technique can be applied to other reported platforms to verify whether their Majorana-like signature in tunneling conductance can pass the shot-noise test.

O 63.2 Wed 15:15 HSZ/0401

Intrinsic topological superconductivity revealed by surface-extended Andreev bound states in $PtBi_2$ — •Xiaochun Huang[1], Lingxiao Zhao[2], Sebastian Schimmel[3,4], Julia Besproswanny[3,4], Patrick Härtl[1], Christian Hess[3,4], Bernd Büchner[4,5], and Matthias Bode[1] — [1]Experimentelle Physik 2, Physikalisches Institut, Universität Würzburg, Germany — [2]Quantum Science Center of Guangdong, Shenzhen, China — [3]Fakultät für Mathematik und Naturwissenschaften, Bergische Universität Wuppertal, Germany — [4]Leibniz-Institute for Solid State and Materials Research, Dresden, Germany — [5]Technische Universität Dresden, Germany

Intrinsic topological superconductivity remains a central question in condensed-matter physics. The three-dimensional Weyl semimetal $PtBi_2$ was recently shown by angle-resolved photoemission spectroscopy to host a superconducting gap that opens exclusively on its Fermi-arc surface states with a nodal structure, establishing it as a prime candidate for intrinsic topological superconductivity [1]. Using scanning tunneling microscopy and spectroscopy, we directly visualize surface-extended Andreev bound states (ABSs) across atomically pristine terraces within a sizable superconducting gap ($\Delta > 10\,\text{meV}$) in $PtBi_2$. Quantitative analysis of the tunneling spectra within an anisotropic chiral pairing framework identifies these ABSs as signatures of an emergent Majorana-cone dispersion. Our findings provide a definitive real-space spectroscopic fingerprint of intrinsic topological superconductivity in $PtBi_2$.

[1] A. Kuibarov *et al.*, Nature **626**, 294 (2024)

O 63.3 Wed 15:30 HSZ/0401

Probing chiral symmetry with a topological domain wall sensor — •Artem Odobesko[1], Glenn Wagner[2], Titus Neupert[2], Ronny Thomale[1], and Matthias Bode[1] — [1]Physikalisches Institut, Universität Würzburg, Würzburg, Germany — [2]Department of Physics, University of Zurich, Zürich, Switzerland

Chiral symmetry is a fundamental property with profound implications for the properties of elementary particles, that implies a spectral symmetry (i.e. E -> -E) in their dispersion relation. In condensed matter physics, chiral symmetry is frequently associated with superconductors or materials hosting Dirac fermions such as graphene or topological insulators. There, chiral symmetry is an emergent low-energy property, accompanied by an emergent spectral symmetry. While the chiral symmetry can be broken by crystal distortion or external perturbations, the spectral symmetry frequently survives. As the presence of spectral symmetry does not necessarily imply chiral symmetry, the question arises how these two properties can be experimentally differentiated. Here, we demonstrate how a system with preserved spectral symmetry can reveal underlying broken chiral symmetry using topological defects. Our study shows that these defects induce a spectral imbalance in the Landau level spectrum, providing direct evidence of symmetry alteration at topological domain walls. Using high-resolution STM/STS we demonstrate the intricate interplay between chiral and translational symmetry which is broken at step edges in topological crystalline insulator $Pb_{1-x}Sn_xSe$.

[1] G. Wagner et al., Newton **1**, 100009 (2025)

O 63.4 Wed 15:45 HSZ/0401

Quantifying quasiparticle chirality in a chiral topological semimetal — •Jiaju Wang[1], Amit Kumar[1], Markel Pardo-Almanza[1], Jaime Sanchez-Barriga[2], Jorge Cardenas-Gamboa[3], Maia Vergniory[3], Vladimir Strokov[4], Moritz Hoesch[5], Chandra Shekhar[6], Claudia Felser[6], Stuart Parkin[1], and Niels Schröter[1] — [1]Max Planck Institute of Microstructure Physics, Halle (Saale), Germany — [2]Helmholtz-Zentrum Berlin, Berlin, Germany — [3]Donostia International Physics Center, San Sebastián, Spain — [4]Paul Scherrer Institute, Villigen, Switzerland — [5]Deutsches Elektronen-Synchrotron, Hamburg, Germany — [6]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

Recently, electron chirality has been proposed as an order parameter to quantify chirality. In chiral topological semimetals with the B20 structure, electron chirality is linked to parallel spin-momentum locking (SML) and spin deviations from SML, which affects numerous physical properties. However, experimental quantification of spin deviation still remains a big challenge. To achieve this, we have used spin and angle-resolved photoemission spectroscopy to directly probe the spin texture of Weyl cones in RhSi, a chiral topological semimetal with strong spin-orbit coupling (SOC). The spin-resolved spectra at different azimuthal angles are intricately fitted to extract numerical values of spin deviation for Weyl cones, allowing us to calculate the normalized electron chirality density (NECD). It was found that deviations can decrease the NECD from 1 down to 0.8. This observation may help interpret physical phenomena in chiral topological semimetals.

O 63.5 Wed 16:00 HSZ/0401

Topology and Real-Space Obstruction: The Phase Diagram of the Triangular p-Orbital Lattice — •Jonas Erhardt[1,2], Sven Schemmelmann[3], Fabian Schöttke[3], Jörg Schäfer[1,2], Giorgio Sangiovanni[2,4], Markus Donath[3], and Ralph Claessen[1,2] — [1]Physikalisches Institut, Universität Würzburg — [2]Würzburg-Dresden Cluster of Excellence ctd.qmat — [3]Physikalisches Institut, Universität Münster — [4]Institut für Theoretische Physik und Astrophysik, Universität Würzburg

Triangular p-orbital monolayers (MLs) host a rich topological phase diagram governed by the competition between spin-orbit coupling (SOC) and substrate-induced inversion-symmetry breaking (ISB). The SOC-dominated quantum spin Hall insulator (QSHI) phase arises from a band inversion in the $p_\pm$ manifold and was first realized in indenene, a triangular ML of In atoms on SiC [1]. Real-space interference shifts the associated Wannier centers away from the atoms to interstitial sites A/B, which for the QSHI phase produces an alternating ABAB energy sequence in the charge localization, as demonstrated by scanning tunneling microscopy (STM) [1]. Using the same STM approach, we identify the complementary ISB-dominated regime in a Tl ML on Si(111), where strong adsorption-induced ISB exceeds Tl's SOC. The charge likewise shifts off the atoms but evidences a non-alternating AABB sequence, characterizing Tl/Si(111) as a trivial obstructed atomic insulator. These results complete the experimental validation of the topological phase diagram for triangular p-orbital MLs.

[1] Nat. Commun. **12**, 5396 (2021).

O 63.6 Wed 16:15 HSZ/0401

Majorana-metal transition in a disordered superconductor: percolation in a landscape of topological domain walls — Vladimir A Zakharov[1], Ion Cosma Fulga[2,3], •Gal Lemut[4], Jakub Tworzydło[5], and Carlo W. J. Beenakker[1] — [1]Instituut-Lorentz, Universiteit Leiden, PO Box 9506, 2300 RA Leiden, The Netherlands — [2]Institute for Theoretical Solid State Physics, IFW Dresden, Germany — [3]Würzburg-Dresden Cluster of Excellence ct.qmat, Dresden, Germany — [4]Dahlem Center for Complex Quantum Systems and Physics Department, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [5]Faculty of Physics, University of Warsaw, ul. Pasteura 5, 02-093 Warszawa, Poland

Most superconductors are thermal insulators. A disordered chiral p-wave superconductor, however, can make a transition to a thermal metal phase. Because heat is then transported by Majorana fermions, this phase is referred to as a Majorana metal. Here we present numerical evidence that the mechanism for the phase transition with increasing electrostatic disorder is the percolation of boundaries separating domains of different Chern number. We construct the network of domain walls using the spectral localizer as a "topological landscape function", and obtain the thermal metal-insulator phase diagram from the percolation transition.

O 63.7 Wed 16:30 HSZ/0401

fabrication and characterization of the Moiré surface state on a topological insulator — •yi zhang — Shanghai Jiao Tong University, Shanghai, China

A Moire* superlattice on the topological insulator surface is predicted to exhibit many novel properties but has not been experimentally realized. Here, we developed a two-step growth method to successfully fabricate a topological insulator Sb2Te3 thin film with a Moire* superlattice, which is generated by a twist of the topmost layer via molecular beam epitaxy. The established Moire* topological surface state is characterized by scanning tunneling microscopy and spectroscopy. By application of a magnetic field, new features in Landau levels arise on the Moire* region compared to the pristine surface of Sb2Te3, which makes the system a promising platform for pursuing next-generation electronics. Notably, the growth method, which circumvents contamination and the induced interface defects in the manual fabrication method, can be widely applied to other van der Waals materials for fabricating Moire* superlattices.

O 63.8 Wed 16:45 HSZ/0401

Backscattering in topological edge states despite time-reversal symmetry — Jonas Erhardt[1,2], •Mattia Iannetti[3,4], Fernando Dominguez[2,5], Ewelina M. Hankiewicz[2,5], Björn Trauzettel[2,5], Gianni Profeta[3,4], Domenico Di Sante[6], Giorgio Sangiovanni[2,5], Simon Moser[1,2], and Ralph Claessen[1,2] — [1]Physikalisches Institut, Universität Würzburg — [2]Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg — [3]Dipartimento di Scienze Fisiche e Chimiche, Università degli Studi dell'Aquila — [4]CNR-SPIN C/o Dipartimento di Scienze Fisiche e Chimiche, Università degli Studi dell'Aquila — [5]Institut für Theoretische Physik und Astrophysik, Universität Würzburg — [6]Department of Physics and Astronomy, University of Bologna

Quantum Spin Hall Insulators (QSHI) are promising materials for many applications based on Dirac fermions and topologically-protected edge states. Indium adatoms on a silicon carbide surface, the so-called Indenene, was the first material in which a topological classification solely based on an inspection of the bulk wave functions has been demonstrated. In this work, we present a combined experimental and theoretical study of finite-sized Indenene systems, using STM/STS measurements and a quantitative tight-binding model revealing the rich physics of edge states. We find that a strongly non-linear edge dispersion leads to inter-Kramers pair backscattering, thereby extending the conventional understanding of backscattering protection in topological edge states.

O 63.9 Wed 17:00 HSZ/0401

Quantized Subband Tunneling from Topological Insulator Nanowire Scanning Probe Tips — •Abhisek Kole[1,2], Felix Münning[3,4], Xiaosheng Yang[1,5], Jia G. Lu[6], Oliver Breunig[4], F. Stefan Tautz[1,2], Yoichi Ando[4], and Felix Lüpke[1,4] — [1]Peter Grünberg Institute (PGI-3), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Institute for Experimental Physics IV A, RWTH Aachen University, Otto-Blumenthal-Straße, 52074 Aachen, Germany — [3]Institute of Physics I, Universität zu Köln, Zülpicher Straße 77, 50937 Köln, Germany — [4]Institute of Physics II, Universität zu Köln, Zülpicher Straße 77, 50937 Köln, Germany — [5]School of Optical and Electronic Information, Huazhong University of Science and Technology, Wuhan 430074, China — [6]Department of Physics/Electrophysics, University of Southern California, Los Angeles, CA 90089, USA

In topological insulator nanowires, the interplay between size quantization and the surface states wrapping the nanowire circumference gives rise to a magnetic-flux-tunable band structure. We demonstrate the controlled fabrication of (Bi_(1-x) Sb_x)_2 Te_3 (BST) topological insulator nanowires into scanning tunneling microscopy tips. Tunneling spectroscopy reveals a series of distinct peak-like features that exhibit a characteristic 1D DOS, indicating tunneling into the quantized 1D subbands of the BST nanowire tips. Furthermore, a magnetic-field-induced gap-closing and reopening transition is observed, consistent with the Dirac-like gap-closing transition expected for such wires. Moreover, we find indications of spin-selective helical tunneling between the nanowire tip and the Rashba surface states of Au(111).

O 63.10 Wed 17:15 HSZ/0401

Simultaneous Characterization of Dispersion and Orbital Character of the Topological Surface State on the Topological Insulator Bi_2Te_3 — •Christoph Stephen Setescak, Adrian Weindl, and Franz Josef Giessibl — Universität Regensburg, D-93053 Regensburg

Scanning probe microscopy (STM and AFM) allows one to locally probe properties of topological insulators (TIs). On the compound Bi_2Te_3, atomic-scale electronic standing waves can be observed at crystalline step edges, which are associated with the hexagonal warping of the Dirac cone. These real-space oscillations provide a direct means to study the dispersion relation of the topological boundary mode. The interpretation relies on comparing the experimental data to calculations including not only the properties of the TI but also of the tip. In this framework, the tunneling current and differential conductance is modelled using Chen's derivative rule. Bending of the CO molecule at the tip apex due to lateral tip-sample forces is also included in the model. The relevant Bloch functions of the sample are obtained from Wannier-interpolated tight-binding Hamiltonians using maximally localized Wannier functions derived from first-principles DFT + *GW* computations. In combination with the high spatial resolution obtained with CO-terminated tips, not only the dispersion, but also the orbital character of the band structure can be probed.

O 63.11 Wed 17:30 HSZ/0401

Defect-induced displacement of topological surface state in magnetic topological insulator $MnBi_2Te_4$ — •Felix Lüpke[1,2], Marek Kolmer[3,4], Hengxin Tan[5], Adam Kaminski[3,4], and Binghai Yan[5,6] — [1]Peter Grünberg Institute (PGI-3) and JARA-FIT, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Universität zu Köln, Zülpicher Straße 77, 50937 Köln, Germany — [3]Ames National Laboratory, Ames, Iowa 50011, USA — [4]Iowa State University, Ames, Iowa 50011, USA — [5]Weizmann Institute of Science, Rehovot 7610001, Israel — [6]The Pennsylvania State University, University Park, Pennsylvania 16802, USA

The gapped topological surface states of $MnBi_2Te_4$ (MBT) are an attractive platform for the realization of quantum anomalous Hall and Axion insulator states. However, experimentally observed surface state gaps fail to meet theoretical predictions, with the exact mechanism behind the gap suppression still being debated. We report on the effect of intrinsic anti-site defects on the MBT surface states, which we study using scanning tunneling microscopy (STM), angle-resolved photoemission (ARPES), and density functional theory (DFT). Our results show that high defect concentrations lead to a displacement of the surface states into the interior of the MBT crystal, consistent with theoretical predicitons [PRL 130, 126702 (2023)].