# O 103: Topology and Symmetry Protected Materials I

Time: Thursday 10:30–13:15 Location: WIL A317

O 103.1 Thu 10:30 WIL A317

**Zero Energy Bound States in the Proximity Induced Topological Superconductor System Bi2Te3 on Nb(110)** — •Felix Kuester[1], Yunyi Zhang[1], Matthew Gilbert[2], Paolo Sessi[1], and Stuart Parkin[1] — [1]Max-Planck-Institute for Microstructure Physics, Halle (Saale), Germany — [2]University of Illinois, Urbana-Champaign, USA

Majorana bound states can be hosted by states on the surface of a strong topological insulator coupled to an ordinary s-wave superconductor and localized inside Abrikosov vortices (Fu and Kane 2008). This prediction provided the ingredients needed to find topologically protected, robust quantum states suited to form Qbits and motivated experimental research to investigate such structures thoroughly. We observed, by measuring differential conductance spectra and maps, zero-energy bound states inside vortices on 5 QL Bi2Te3 grown by MBE on Nb(110) to create a proximity induced topological superconductor system. Bi2Te3 is a strong topological insulator with a single Dirac cone at the gamma point which was confirmed by ARPES data on our sample. A comparison shows that neither the bare Nb(110) nor a proximity induced Pt film on the Nb(110) substrate exhibit a zero-energy peak in the vortex core or other anomalous features observed on the Bi2Te3 film. Therefore we suggest that the observed phenomena of unconventional superconductivity originate from the topological character of the Bi2Te3 surface.

O 103.2 Thu 10:45 WIL A317

**Electronic and magnetic structure of the intrinsic magnetic topological insulator system $(Bi_2Te_3)_n(MnBi_2Te_4)$ ($n = 0,1$)** — •Thiago R. F. Peixoto[1,5], Raphael C. Vidal[1,5], Alexander Zeugner[2,5], Simon Moser[3,5], Michael Ruck[2,5], Bernd Büchner[4,5], Anna Isaeva[4,5], Hendrik Bentmann[1,5], and Friedrich Reinert[1,5] — [1]Exp. Phys. VII, Universität Würzburg — [2]Faculty of Chemistry and Food Chemistry, TU Dresden — [3]Exp. Phys. IV, Universität Würzburg — [4]Leibniz IFW Dresden and Faculty of Physics, TU Dresden — [5]Würzburg-Dresden Cluster of Excellence *ct.qmat*

Recently, $MnBi_2Te_4$ has been established as the first antiferromagnetic (AFM) topological insulator [1,2], and represents the $n = 0$ member of the layered series $(Bi_2Te_3)_n(MnBi_2Te_4)$. For $n = 1$, we confirm a non-stoichiometric composition proximate to $MnBi_4Te_7$, and featuring an AFM state below 13 K, followed by a state with net out-of-plane magnetization below 5 K [3]. Here we present the spectroscopic signatures of these magnetic topological phases by means of angle-resolved photoemission (ARPES) and X-ray magnetic linear and circular dichroism (XMLD/XMCD) experiments on $MnBi_2Te_4$ and $MnBi_4Te_7$ single crystals. Both compounds reveal topologically non-trivial Dirac surface states on the (0001) surface, providing a versatile platform for the realization of magnetic topological states of matter.

[1] M. M. Otrokov *et al.*, ArXiv:1809.07389 (2019).
[2] R. C. Vidal *et al.*, Phys. Rev. B **100**, 121104(R) (2019).
[3] R. C. Vidal *et al.*, ArXiv:1906.08394 (2019).

O 103.3 Thu 11:00 WIL A317

**Room temperature in-situ measurement of the spin voltage of a $BiSbTe_3$ thin film** — •Arthur Leis[1,2,3], Michael Schleenvoigt[2,4], Abdur Rehman Jalil[2,4], Vasily Cherepanov[1,2], Gregor Mussler[2,4], Detlev Grützmacher[2,4], F. Stefan Tautz[1,2,3], and Bert Voigtländer[1,2,3] — [1]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Jülich Aachen Research Alliance (JARA), Fundamentals of Future Information Technology, 52425 Jülich, Germany — [3]Experimentalphysik IV A, RWTH Aachen University, 52074 Aachen, Germany — [4]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany

One of the hallmarks of topological insulators (TIs), the intrinsic spin polarisation in the topologically protected surface states, is investigated at room temperature in-situ by means of four-probe scanning tunnelling microscopy (STM) for a $BiSbTe_3$ thin film. To achieve the required precision of tip positions for measuring a spin signal, a precise positioning method employing STM scans of the local topography with each individual tip is demonstrated. From the transport measurements, the spin polarisation in the topological surface states (TSS) is estimated as p ∼ 0.3 - 0.6, which is close to the theoretical limit.

O 103.4 Thu 11:15 WIL A317

**Mid-infrared-pump terahertz-probe spectroscopy on the topological insulator $(Bi_{1-x}Sb_x)_2Te_3$** — •Chris Reinhoffer[1], Andrea Bliesener[1], Gertjan Lippertz[1], Semyon Germanskiy[1], Yu Mukai[1,2], Yoichi Ando[1], Zhe Wang[1], and Paul H.M. van Loosdrecht[1] — [1]Institute of Physics II, University of Cologne, Cologne, Germany — [2]Department of Electronic Science and Engineering, Kyoto University, Kyoto, Japan

$(Bi_{1-x}Sb_x)_2Te_3$ is a series of topological insulators with the electronic properties tunable by varying the ratio between Bi and Sb. To get a better understanding of the inter-band scattering processes we performed mid-infrared-pump terahertz-probe spectroscopic measurements on three different $(Bi_{1-x}Sb_x)_2Te_3$ compounds, in which the Fermi energy was chemically tuned by varying x to be in the conduction-, valence-band, and bulk bandgap, respectively. The non-equilibrium response was studied systematically for pump energies above and below the bandgap of 200 meV and as a function of temperature down to 5 K. Our measurements show evident differences in the pump-probe response in the different compounds, which are compared with different theoretical scenarios.

O 103.5 Thu 11:30 WIL A317

**Photoelectron spectroscopy on the transition metal doped topological insulator $V{:}(Bi,Sb)_2Te_3$.** — •Philipp Kagerer[1], Thiago R. F. Peixoto[1], Raphael Crespo Vidal[1], Sonja Schatz[1], Martin Winnerlein[2], Steffen Schreyeck[2], Celso I. Fornari[1], Katharina Kissner[1], Charles Gould[2], Karl Brunner[2], Laurens W. Molenkamp[2], Hendrik Bentmann[1], and Friedrich Reinert[1] — [1]Experimental Physics VII, University of Würzburg — [2]Experimental Physics III, University of Würzburg

On the path towards combining topological surface states with ferromagnetism, transition-metal doped topological insulators have shown to be promising material systems. Here, we focus on V-doped $(Bi,Sb)_2Te_3$ thin films, which exhibit the quantum anomalous Hall effect (QAHE) at low temperatures and a ferromagnetic ground state with a comparably high $T_c$. Nevertheless, the electronic structure is still not comprehensively understood. We present a detailed study of the electronic structure of $V{:}(Bi,Sb)_2Te_3$ films based on angle-resolved photoemission spectroscopy (ARPES) in laboratory- and synchrotron-based experiments. Using systematic photon-energy dependent measurements, including resonant photoemission at the V L-edge, we study the electronic states close to the Fermi energy. Our results show that the topological surface state overlaps energetically with a dispersionless V impurity band. In our studies we will investigate the interplay between those states and search for possibilities of material engineering by tuning the position of the Fermi energy.

O 103.6 Thu 11:45 WIL A317

**Core level and valence band dynamics of $Bi_2Se_3$** — •Michael Heber[1], Kevin Kühlmann[2], Dmytro Kutnyakhov[1], Federico Pressacco[3], Nils Wind[3], Davide Curcio[4], Klara Volckaert[4], Yves Acremann[2], Philip Hofmann[4], Kai Rossnagel[1,5], and Wilfried Wurth[1,3] — [1]DESY Photon Science, Hamburg, Germany — [2]Department of Physics, ETH Zürich, Switzerland — [3]Physics Department, University of Hamburg, Germany — [4]Aarhus University, Denmark — [5]IEAP, CAU Kiel, Germany

$Bi_2Se_3$ is one of the text book examples of a topological insulator. We investigated the ultrafast dynamics in the electronic structure of $Bi_2Se_3$ with time- and angle-resolved photoelectron spectroscopy. A time-of-flight-based momentum microscope in a pump-probe setup allows simultaneous detection of the three-dimensional band structure, with both parallel momentum components and binding energy, as well as the delay time in a single scan. Using the monochromatized XUV radiation delivered by the XUV beamline PG2 of FLASH provides the possibility to study the temporal response of the valence band simultaneous with the Se 3*d* and Bi 5*d* core levels. The relaxation dynamics of the core levels and the valence band will be presented with a focus on the excited electrons in the surface state above $E_F$.

O 103.7 Thu 12:00 WIL A317

**Electronic structure of antimonene layers on Bi2Se3: insight from ab-initio calculations** — •Kris Holtgrewe[1,2], Conor Hogan[3], and Simone Sanna[1,2] — [1]Justus Liebig University, Giessen, Germany — [2]Center for Materials Research, Giessen, Germany — [3]CNR-ISM, Rome, Italy

Topological insulators exhibit unconventional physical effects that have attracted the interest of the scientific community, especially when coupled to trivial insulators. A topologically insulating $Bi_2Se_3$ substrate covered by the trivial insulator antimonene is an ideal testbed to study the interfacial phenomena [1], and is furthermore interesting for applications such as topological pn-junctions [2].

Much research effort has been dedicated to the preparation of antimony layers on $Bi_2Se_3$ surfaces [3] and recently, the phase transition between two phases of the system has successfully been explained by *ab-initio* thermodynamics [4]. However, the Sb-coverage dependent spin texture is still not fully understood. Our work concentrates on the theoretical investigation of the relationships between structural motifs, band structures and STM patterns. Thereby, we show how an approach beyond local density functional theory, including both spin-orbit coupling and dispersion, is crucial for the correct modelling of the system.

[1] Jin et al, Phys Rev B **93**, 075308 (2016)
[2] Kim et al, ACS Nano **11**, 9671 (2017)
[3] Flammini et al, Nanotechnology **29**, 065704 (2018)
[4] Hogan et al, ACS Nano **13**, 10481 (2019)

O 103.8 Thu 12:15 WIL A317

**Surface and bulk electronic structure of the 3D topological insulator HgTe(001)** — •Raphael Crespo Vidal[1], Julia Issing[1], Lukas Lunczer[2], Giovanni Marini[3], Lena Fürst[2], Simon Moser[4], Giorgio Sangiovanni[5], Domenico Di Sante[5], Hartmut Buhmann[2], Gianni Profeta[3], Laurens W. Molenkamp[2], Hendrik Bentmann[1], and Friedrich Reinert[1] — [1]Experimental Physics VII, University of Würzburg, Germany — [2]Experimental Physics III, University of Würzburg, Germany — [3]Department of Physical and Chemical Sciences & SPIN-CNR, University of L'Aquila, Italy — [4]Experimental Physics IV, University of Würzburg, Germany — [5]Theoretical Physics I, University of Würzburg, Germany

Since the discovery of topological insulators HgTe proved itself to be a versatile material system, exhibiting a variety of topologically nontrivial states depending on adjustable structural parameters. Despite its persistent relevance in the field of topological materials a comprehensive understanding of its electronic band structure is still lacking. Here we will present an extensive angle-resolved photoemission (ARPES) study of epitaxially grown HgTe on CdTe(001). The lattice mismatch induces a strain of 0.3% which drives the system in its 3D TI phase. The surface preparation for ARPES was done by cleavage of a Te capping layer as well as *in situ* transfer. Structural and chemical characterisation by LEED and core-level spectroscopy ensure a pristine surface quality. We find good agreement of our ARPES data with *ab initio* DFT calculations regarding band positions and dispersions as well as the orbital symmetry of the bands.

O 103.9 Thu 12:30 WIL A317

**Unveiling the complex band structure of the potential non-symmorphic topological insulator $TaNiTe_2$** — •Tim Figgemeier[1], Jennifer Neu[2], Simon Moser[3], Johannes Hessdörfer[1], David J. Singh[4], Theo M. Siegrist[2,5], Hendrik Bentmann[1], and Friedrich Reinert[1] — [1]Experimentelle Physik VII, Universität Würzburg — [2]National High Magnetic Field Laboratory, Tallahassee, Florida — [3]Experimentelle Physik IV, Universität Würzburg — [4]University of Missouri, Columbia, Missouri — [5]College of Engineering, FAMU-FSU, Tallahassee, Florida

$NbNiTe_2$ and $TaNiTe_2$ are layered van-der-Waals systems. While $NbNiTe_2$ was discussed as a Weyl-semimetal candidate lately [1,2], $TaNiTe_2$ (space group #53, *Pmna*) is predicted to be a topological insulator with non-symmorphic crystal structure, characterized by a topological inavriant of $Z_4 = 1$ , that have rarely been studied experimentally up to now [3]. In this study we investigated the electronic structure of $TaNiTe_2$ by means of angle-resolved photoemission (ARPES) experiments and first-principle calculations. Systematic photon-energy- and polarization-dependent measurements allow us to disentangle the highly complex band structure. More than that, we discuss indications for the presence of a topological surface state.

[1] Wang et al., PRB 95, 165114 (2017)
[2] Neu et al., PRB 100, 144102 (2019)
[3] Vergniory et al, Nature 544, 480-450 (2019)

O 103.10 Thu 12:45 WIL A317

**Drumhead surface state in ZrSiTe probed by scanning tunneling microscopy** — •Brandon Stuart[1], Seokhwan Choi[1], Jisun Kim[1], Mohamed Oudah[1], Raquel Queiroz[2], Lukas Muechler[3], Leslie Schoop[4], Douglas Bonn[1], and Sarah Burke[1] — [1]Stewart Blusson Quantum Matter Institute, University of British Columbia,Vancouver, British Columbia, Canada V6T 1Z4 — [2]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel — [3]Center for Computational Quantum Physics, The Flatiron Institute, New York, New York, 10010, USA — [4]Department of Chemistry, Princeton University, Princeton, New Jersey 08544, USA

The family of materials ZrSiX (X = S, Se, Te) are topological nodal-line semimetals characterized by linear band crossings in 1-dimensional lines or loops in momentum space, rather than discrete points as in Dirac or Weyl semimetals. ZrSiTe is host to four nodal lines, two of which form loops in the BZ, one encircling the gamma point and the other encircling the Z point, and the other two forming lines that extend through the BZ. It was theoretically predicted that in the surface projection of ZrSiTe, the area between the nodal loops would contain a drumhead state, a topologically protected 2-dimensional surface state that links the nodal loops together [1]. Here, we show the first observed signature of electronic scattering within the drumhead state using low-temperature STM and QPI measurements.

[1] Muechler et al., arXiv:1909.02154

O 103.11 Thu 13:00 WIL A317

**Fully radial spin texture in the chiral crystal of Te** — Gianmarco Gatti[1], Daniel Gosálbez-Martinez[1], Michele Puppin[1], Serhii Polishchuk[1], Philippe Bugnon[1], Ivana Vobornik[2], Oleg Yazyev[1], Marco Grioni[1], and •Alberto Crepaldi[1] — [1]École polytechnique fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland — [2]C.N.R. - I.O.M., Strada Statale 14, km 163.5, Trieste 34149, Italy

Chiral crystals are the new frontier in the field of topological materials. The absence of mirror-symmetry protects special fermions that have no counterparts in high-energy Physics [1], such as the Kramers-Weyl fermions [2]. These special nodes manifest unique magneto-electrical and optical properties, as consequence of their unique fully radial spin texture.

Trigonal tellurium (Te) is among the simplest realization of a gyrotropic chiral crystal, and our high-resolution ARPES data, supported by ab initio calculations, reveal the existence of multiple Kramers-Weyl points [3]. By using spin-resolved ARPES, we have resolved the monopole-like spin texture of the Fermi surface, whose experimental determination represent a fundamental piece to clarify the complex puzzle of the magneto-transport properties of Te [4]. Our results indicate that this material might constitute a major breakthrough in the field of topological materials.

References: [1] B. Bradlyn et al., Science 353, aaf5037 (2016). [2] G. Chang et al., Nat. Materials 17, 978 (2018). [3] G. Gatti in preparation. [4] S. S. Tsirkin et al., Phys. Rev. B 97, 035158 (2018).