TT 32: Focus Session: Topological Devices (joint session TT/KFM)

The properties of topological phases of matter give rise to unique phenomena, such as edge or surface transport, spin-momentum locking, or topological protection against perturbations. Many years after their conception, several topological platforms have reached maturity, and research interests have shifted towards mesoscopic devices unveiling rich and new topological physics, driven in part by the perspectives of novel topological quantum computation. Within this Focus Session, recent examples of devices exploring or exploiting the topological properties of various phases of matter shall be discussed.

Organizers: Erwann Bocquillon, Oliver Breunig, Yoichi Ando (all Universität zu Köln)

Time: Thursday 15:00–18:30 Location: H10

Invited Talk TT 32.1 Thu 15:00 H10
Supercurrents in HgTe-based topological nanowires — •Dieter Weiss — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg/Germany

Topological insulator (TI) nanowires in proximity to conventional superconductors constitute a tunable platform to realize topological superconductivity and Majorana zero modes [1]. Tuning is done by an axial magnetic flux ϕ transforming the system from trivial at $\phi = 0$ to topologically nontrivial when a magnetic flux quantum $\phi_0 = h/2e$ threads the wire's cross-section. Here, we investigate the evolution of the supercurrent in ballistic HgTe Josephson junctions as a function of axial magnetic flux ϕ and examine the periodicity of the supercurrent utilizing microwave irradiation and probing Shapiro steps. Suppressed odd Shapiro steps herald the existence of 4π-periodic supercurrents, a signature of topological superconductivity. Our data suggest that at small ϕ this 4π-periodic supercurrent is of trivial origin but that at magnetic fields above $\phi_0/2$, topological 4π-periodic supercurrents take over [2].

Work done in cooperation with Ralf Fischer, Wolfgang Himmler, Johannes Ziegler, Jordi Picó-Cortés , Gloria Platero, Milena Grifoni, Dmitriy A. Kozlov, N. N. Mikhailov, Sergey A. Dvoretsky , Michael Barth, Jakob Fuchs, Cosimo Gorini, Klaus Richter, and Christoph Strunk.

[1] A. Cook and M. Franz, PRB 84, 201105(R) (2011)
[2] R. Fischer et al., PRR 4, 013087 (2022)

Invited Talk TT 32.2 Thu 15:30 H10
Majorana bound states and non-reciprocal transport in topological insulator nanowire devices — •Henry Legg — Department of Physics, University of Basel

I consider devices consisting of a three-dimensional topological insulator (TI) nanowire placed in proximity to an s-wave superconductor.

First, I will show that a non-uniform chemical potential induced, for instance, by gating enables the device to be brought into a topological superconducting phase at relatively weak magnetic fields with Majorana bound states (MBSs) present for an exceptionally large region of parameter space in realistic systems. I also consider the experimental challenges posed by the metallization effect that occurs as a result of bringing a TI nanowire into proximity with a superconductor.

Second, I will discuss non-reciprocal transport evidence for the subband splitting that is central to the proposal to achieve MBSs in TI nanowires. I will show that a giant magnetochiral anisotropy observed in the normal state of the TI nanowire provides strong evidence for the artificial breaking of inversion symmetry due to gating effects. Furthermore, I will argue that the superconducting diode effect can be used as measure of inversion symmetry breaking in the presence of a superconductor and to determine when the TI nanowire is in the region of parameter space where topological superconductivity is expected.

Invited Talk TT 32.3 Thu 16:00 H10
Integration of topological insulator Josephson junctions in superconducting qubit circuits — •Tobias W. Schmitt[1], Malcolm R. Connolly[2,3], Michael Schleenvoigt[1], Chenlu Liu[2], Oscar Kennedy[3], José M. Chávez-Garcia[4], Anne Schmidt[1], Albert Hertel[1], Tobias Lindström[5], Sebastian E. de Graaf[5], Karl D. Petersson[4], Detlev Grützmacher[1], and Peter Schüffelgen[1] — [1]Peter Grünberg Institute & Jülich-Aachen Research Alliance, Forschungszentrum Jülich — [2]Blackett Laboratory, Imperial College London — [3]London Centre for Nanotechnology, University College London — [4]Center for Quantum Devices, University of Copenhagen — [5]National Physical Laboratory

Since the prediction of topological superconductivity in hybrid devices of topological insulators (TIs) and conventional s-wave superconductors (S), S-TI-S Josephson junctions have been studied intensively in electrical transport experiments. The integration of these Josephson junctions in superconducting qubit circuits allows to investigate them via circuit quantum electrodynamic techniques, which promises novel insights into their exotic characteristics. In this talk, I will present the implementation of transmon qubits with *in situ* fabricated S-TI-S Josephson junctions and outline fabricational challenges. I will further show results on coherent qubit control as well as temporal quantum coherence and discuss possible limitations on qubit coherence for the first generation of TI transmon devices [1]. An outlook on qubit improvements and developements towards the detection of topological superconductivity will be given.

[1] Nano Lett. 22, 7, 2595 (2022)

15 min. break

Invited Talk TT 32.4 Thu 16:45 H10
Universal fluctuations of the induced superconducting gap in an elemental nanowire — Lauriane Contamin, Lucas Jarjat, William Legrand, Audrey Cottet, Takis Kontos, and •Matthieu Delbecq — Laboratoire de Physique de l'Ecole Normale Supérieure, ENS, Université PSL, CNRS, Sorbonne Université, Université Paris-Diderot, Sorbonne Paris Cité, Paris, France.

Proximity induced superconductivity in a normal conductor is a rich field of experimental and theoretical investigations. Lately it has been at the heart of the quest for realizing topological modes in hybrid superconductor-nanowire nanodevices. Yet it turns out that there was a lack of investigations in elemental systems. In this work we therefore investigate an ultra-clean carbon nanotube coupled to a superconducting lead. We observe for the first time a long standing prediction of random matrix theory (RMT) that mesoscopic fluctuations of the mini-gap in a conductor follow a universal distribution with a clear transition when time reversal symmetry is broken, as predicted by RMT. Interestingly, mesoscopic fluctuations of the minigap were precisely predicted to lead to ubiquitous nontopological edge states clustering towards zero energy. We do indeed observe ubiquitous and robust zero bias conductance peaks under magnetic field in our device that cannot host topological modes by design. The RMT predictions that are compatible with our observations are very general and should be present in any system showing disorder. It therefore calls for alternatives to transport measurement to identify Majorana modes in 1D systems with microwave photons in a cavity as a promising platform.

Invited Talk TT 32.5 Thu 17:15 H10
Exploring the full potential of edge channel transport in HgTe based two-dimensional topological insulators — •Saquib Shamim[1,2], Wouter Beugeling[1,2], Pragya Shekhar[1,2], Jan Böttcher[3], Andreas Budewitz[1,2], Julian-Benedikt Mayer[3], Lukas Lunczer[1,2], Jonas Strunz[1,2], Johannes Kleinlein[1,2], Ewelina Hankiewicz[3], Björn Trauzettel[3], Hartmut Buhmann[1,2], and Laurens Molenkamp[1,2] — [1]Experimentelle Physik III, Physikalisches Institut, Universität Würzburg, Am Hubland, Würzburg, Germany — [2]Institute for Topological Insulators, Universität Würzburg, Am Hubland, Würzburg, Germany — [3]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany.

In this talk, I will discuss some of our recent results on HgTe-based two-dimensional topological insulators. Over the past few years, we have developed a chemical wet-etch technique to fabricate high-quality microstructures in HgTe quantum wells. Firstly, I will discuss some important achievements due to the wet-etch fabrication process: We fabricated quantum point contacts in topological HgTe quantum wells and investigated the interactions among helical edge channels. We also fabricated microstructures from (Hg,Mn)Te quantum wells and observed quantized conductance in these devices. Secondly, I will introduce a gate training method that allows us to approach conductance quantization in macroscopic devices. Finally, I will present recent magnetotransport results on (Hg,Mn)Te quantum wells and the emergence of quantum Hall plateaus at extremely low magnetic fields (~ 50 mT).

TT 32.6 Thu 17:45 H10

Quantum non-Hermitian topological sensors — •Florian Koch and Jan Carl Budich — Institute of Theoretical Physics, Technische Universität Dresden

Recent discoveries regarding the exceptional spectral and topological properties of non-Hermitian (NH) tight-binding models, e.g. their striking boundary-sensitivity, have triggered the quest for constructing novel sensors [1,2]. Here, using quantum master equations we promote the architecture of such sensing devices to a fully quantum-mechanical framework. Specifically, we study a setting of weakly-coupled bosonic modes arranged in an array with broken ring geometry that would realize a NH topological phase in the classical limit. Employing methods from quantum-information theory of Gaussian states, we show that a small coupling induced between the ends of the broken ring may be detected with a precision that increases exponentially in the number of coupled modes. Our findings pave the way towards designing quantum NH topological sensors (QUANTOS) that may observe with high precision any physical observable that couples to the boundary conditions of the device [3].

[1] J.C. Budich and E.J. Bergholtz, Phys. Rev. Lett. **125**, 180403 (2020).
[2] E.J. Bergholtz, J.C. Budich, and F.K. Kunst, Rev. Mod. Phys. **93**, 015005 (2021).
[3] F. Koch and J.C. Budich, Phys. Rev. Res. **4**, 013113 (2022).

TT 32.7 Thu 18:00 H10

First magnetic field measurements of a topological insulator based Transmon Qubit — •Anne Schmidt[1], Tobias W. Schmitt[1], Chenlu Liu[2], Albert Hertel[1], Christian Dickel[3], Michael Schleenvoigt[1], Malcolm R. Connolly[2,4], Yoichi Ando[3], Detlev Grützmacher[1], and Peter Schüffelgen[1] — [1]Peter Grünberg Institute & Jülich-Aachen Research Alliance, Forschungszentrum Jülich — [2]Blackett Laboratory, Imperial College London — [3]Institute of Physics II, University of Cologne — [4]London Centre for Nanotechnology, University College London

Hybrid topological insulator (TI) – superconductor (S) heterostructures are a promising platform for the realization of topologically protected quantum computation based on Majorana zero modes. This promises fewer physical qubits for creating a logical qubit compared to conventional superconducting qubits. Our full *in situ* device fabrication, which combines selective area growth of thin $(Bi,Sb)_2Te_3$ films and stencil deposition of superconductive Nb has already shown to create highly transparent S-TI interfaces. Recently, we have demonstrated that this fabrication process can readily be integrated into cQED structures as building block for a transmon qubit and performed coherence measurements at zero magnetic field. Here, we will expand these measurements to finite magnetic fields, as in-plane magnetic fields are a requirement for restoring the topological phase in confined $(Bi,Sb)_2Te_3$ nanostructures. We present initial results on the magnetic field dependence of the T_1 lifetime and the qubit's anharmonicity.

TT 32.8 Thu 18:15 H10

Kondo interactions of quantum spin Hall edge channels with charge puddles — •Christopher Fuchs[1,2], Pragya Shekhar[1,2], Saquib Shamim[1,2], Lena Fürst[1,2], Johannes Kleinlein[1,2], Jukka I. Väyrynen[3], Hartmut Buhmann[1,2], and Laurens W. Molenkamp[1,2] — [1]Physikalisches Institut, Universität Würzburg, Würzburg, Germany — [2]Institute for Topological Insulators, Universität Würzburg, Würzburg, Germany — [3]Department of Physics and Astronomy, Purdue University, West Lafayette, USA

Quantum spin Hall edge channels are protected against backscattering by time-reversal symmetry. However, since the first observation of the quantum spin Hall effect in HgTe in 2007 it is known that reproducible fluctuations shape the quantization plateau when the chemical potential is tuned through the bulk gap. Here, those fluctuations are examined in high-quality micron-sized quantum well structures of HgTe at millikelvin temperatures. By performing temperature and gate-dependent measurements, we conclude that the observed conductance fluctuations indicate interactions of the edge channel electrons with individual charge puddles – microscopic fluctuations in the potential landscape commonly observed in narrow gap semiconductors – that act like Kondo correlated quantum dots. The resulting spin-flip backscattering gives rise to a distinct Kondo-like temperature dependence of the conductance fluctuations, which is backed up by theoretical modelling. Our results provide insight into the leading mechanism of decoherence of quantum spin Hall edge channels.