HL 54: Focus Session: Evolution of Topological Materials into Superconducting Nanodevices III (joint session HL/TT)

The focus session intends to span the arc between topological materials and superconducting nanodevices, both experimentally and theoretically. Such structures are interesting for applications in future topological quantum circuits. In recent years, the number of topological materials and the knowledge about them has rapidly increased. As part of the focus session, material properties of layered systems made of topological materials, especially in combination with superconductors, are discussed. On the other hand, the special challenges in the nanofabrication of these materials for use in future topological quantum processors are addressed. Another focus is the quantum transport in nanoscale hybrid structures.

Organized by Thomas Schäpers, Philipp Rüßmann, and Peter Schüffelgen

Time: Friday 9:30–12:45 Location: EW 202

Invited Talk HL 54.1 Fri 9:30 EW 202

Tunneling spectroscopy of a phase-tunable topological insulator Josephson junction — •Jakob Schluck[1], Ella N. Nikodem[1], Anton Montag[2], Alexander Ziesen[2], Mahasweta Bagchi[1], Zhiwei Wang[1], Fabian Hassler[2], and Yoichi Ando[1] — [1]Institute of Physics II, University of Cologne — [2]JARA-Institute for Quantum Information, RWTH Aachen University

Topological superconductivity is predicted to be realized in a topological insulator proximitized by an s-wave superconductor [1]. In such a system, vortices host Majorana zero modes - quasiparticle excitations obeying non-Abelian exchange statistics that could have important applications as topological qubits.

Here we present our experimental findings concerning the bound state spectrum of topological insulator Josephson junctions. We locally probe the density of states through tunnel contacts made on top of the junction, while tuning the phase difference across it by applying an external magnetic field.

We find a periodic filling of the induced gap, with states reaching zero energy for a local phase difference of π. Taking the phase gradient along the junction into account, we interpret those as signatures of Majorana zero modes bound to the π-phase boundary [2]. We will discuss their stability with respect to the chemical potential and possible trivial origins.

[1] Liang Fu and C. L. Kane, Phys. Rev. Lett. 100, 096407 (2008) [2] A. C. Potter and L. Fu, Phys. Rev. B 88, 121109 (2013).

Invited Talk HL 54.2 Fri 10:00 EW 202

Robust Majorana modes in topological material-based nanoelectronic hybrid devices — •Kristof Moors — Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, Germany — JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, Germany

Majorana modes have the potential to be used as robust carriers of quantum information for future fault-tolerant quantum information processing applications. While their realization in various condensed matter systems is well understood in principle, realistic conditions (with, e.g., disorder or imperfections) can complicate their formation as well as experimental verification in practice. I will present recent modeling and simulation results on two promising platforms for Majorana devices: magnetic and nonmagnetic topological insulator nanoribbons with proximity-induced superconductivity, respectively. These platforms have distinct advantages for a robust realization of Majorana modes by forming them out of their proximitized and topologically protected surface or edge states. In this way, a higher tolerance with respect to disorder and less finetuned conditions can be obtained as compared to alternative platforms. I will discuss the topological phase with well-separated Majorana modes in such systems under realistic conditions, the robustness against disorder, and distinct signatures in spectroscopy and transport experiments. I will also comment on the latest status regarding the experimental development.

Invited Talk HL 54.3 Fri 10:30 EW 202

Thermal and electric response of superconducting topological materials; are Majorana states more widespread than expected? — •Ewelina Hankiewicz — Institute for Theoretical Physics, Uni Würzburg, Germany

In this talk, we will discuss different Josephson junctions based on semimetals, metals and topological insulators proximitized with s-wave superconductors. We show that thermal response can be more sensitive to Majorana bound states than an electrical response [1,2]. Moreover, due to the 4pi periodicity of topological Josephson junctions, the thermal engines built on them are more efficient as the ones on the classical Josephson junctions [3].

Furthermore, we predict that the s-wave superconductivity proximitized j=3/2 particles in 2D Luttinger materials are able to host Majorana bound states even in the absence of Dresselhaus and Rashba spin-orbit couplings [4]. This originates from the hybridization of the light and heavy hole bands of the j=3/2 states in combination with the superconducting pairing. We predict that Majorana bound states should be seen in many classes of materials like p-doped GaAs and bulk HgTe [4].

[1] A. G. Bauer et al. Phys. Rev. B 104, L201410 (2021). [2] R. L. Klees, D. Gresta, J. Sturm, L. W. Molenkamp, and E. M. Hankiewicz arXiv:2306.17845 (2023). [3] B. Scharf, A. Braggio, E. Strambini, F. Giazotto, E. M. Hankiewicz, Communications Physics 3, 198 (2020). [4] J.-B. Mayer, M. A. Sierra, and E. M. Hankiewicz, Phys. Rev. B 105, 224513 (2022).

15 min. break

Invited Talk HL 54.4 Fri 11:15 EW 202

Tunable Josephson coupling in HgTe nanodevices — •Martin P. Stehno — Physikalisches Institut EP3 und Institut für Topologische Isolatoren, Julius-Maximilians-Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Mercury telluride offers access to a variety of topological phases in a single material system. This opens up opportunities for disentangling the complex interplay of band structure effects, interface preparation, and phase dynamics that characterize the Josephson effect in topological insulator nanodevices. We study a new generation of gate-tunable Josephson junctions with weak links fabricated from 2D and 3D topological insulator HgTe. These devices feature ballistic transport over a wide range of carrier densities and allow us to map out the Josephson coupling of topological states and bulk modes using a combination of quantum transport methods, supercurrent interference, and microwave spectroscopy. By adding a gated constriction into a 2D topological insulator weak link, we create a quantum point contact (QPC) that allows us to study the ac Josephson effect as a function of the number of open channels. As we deplete the constriction further, we explore proximity-induced superconductivity in the quantum spin Hall edge channels and in the regime of the recently discovered 0.5-anomaly in HgTe QPC devices.

Invited Talk HL 54.5 Fri 11:45 EW 202

Superconducting proximity effect in topological Dirac materials — •Chuan Li[1], Anqi Wang[2], Caizhen Li[2], Chhunguang Chu[2], Zhimin Liao[2], and Alexander Brinkman[1] — [1]MESA+ Institute for Nanotechnology, University of Twente, 7500 AE Enschede, The Netherlands. — [2]State Key Laboratory for Mesoscopic Physics and Frontiers Science Center for Nano-optoelectronics, Peking University, 100871 Beijing, China

Inducing superconductivity in topological materials stimulates the formation of novel quantum states of matter. Besides the original prediction in 3D topological insulators, the notion of topological phases has been generalized to different dimensions and extended to the higher-order states.

In the last few years, our research has demonstrated the possibility of realizing the topological superconductivity in engineered 3D topological insulators, 3D Dirac semimetals [1,2], and their 1D hinge states. Particularly, Cd3As2 is predicted to be a higher-order topological semimetal, possessing three-dimensional bulk Dirac fermions, two-dimensional Fermi arcs [3], and one-dimensional hinge states [4] or non-Hermitian states [5]. These topological states have different characteristic length scales in electronic transport. We show that the superconducting proximity effect can be a sensitive probe for distinguishing these states.

[1] Li, C. et al. Nat. Mater. 17, 875 (2018). [2] Wang, A. Q. et al. PRL (2018). [3] Li, C.-Z. et al. Nat. Commun.(2020). [4] Li, C.-Z. et al. PRL (2020). [5] C. G. Chu, et al., Nat. Commun. (2023).

Invited Talk HL 54.6 Fri 12:15 EW 202

Exploring Josephson Junctions made of Topological Insulator Wires and Superconductors — •Dieter Weiss — Experimentelle und Angewandte Physik, Universität Regensburg, 93040 Regensburg

Topological insulator (TI) nanowires in proximity to conventional superconductors provide a tunable platform to realize topological superconductivity and Majorana bound states (MBS) [1]. Tuning is achieved by an axial magnetic flux ϕ which transforms the system from trivial at $\phi = 0$ to topologically non-trivial when a magnetic flux quantum $\phi_0 = h/2e$ threads the wire cross section. Here we study the supercurrent I_C and its periodicity on the superconducting phase as a function of the axial magnetic field using Josephson junctions made of strained HgTe wires (the TI) with Nb contacts. Depending on the transparency of the contacts we observe either a monotonically decreasing I_C with increasing B for high transparency or $h/2e$, $h/4e$, and even $h/8$e periodic oscillations of the supercurrent for samples with lower transparency [2]. Samples with high transparency exhibit 4π periodic supercurrents, a signature of MBS [3]. I will discuss the significance of these signatures and the origin of the flux-periodic oscillations.

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

[1] A. Cook and M. Franz, Phys. Rev. B 84, 201105(R) (2011)
[2] W. Himmler et al., Phys. Rev. Res. 5, 043021 (2023)
[3] R. Fischer et al., Phys. Rev. Res. 4, 013087 (2022)