HL 31: Focus Session: Evolution of Topological Materials into Superconducting Nanodevices II (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: Wednesday 11:45–13:00 Location: EW 202

HL 31.1 Wed 11:45 EW 202

Induced superconducting correlations in the quantum anomalous Hall insulator — •Anjana Uday[1], Gertjan Lippertz[1,2], Kristof Moors[3], Henry F. Legg[4], Rikkie Joris[2], Andrea Bliesener[1], Lino M. C. Pereira[2], Alexey Taskin[1], and Yoichi Ando[1] — [1]Physics Institute II, University of Cologne, Köln, Germany — [2]KU Leuven, Quantum Solid State Physics, Leuven, Belgium — [3]Peter Grünberg Institute 9, Forschungszentrum Jülich & JARA Jülich-Aachen Research Alliance, Jülich, Germany — [4]Department of Physics, University of Basel, Basel, Switzerland

Crossed Andreev reflection (CAR) has been reported in a hybrid quantum Hall (QH)/Superconductor (SC) system [1]. Similar experiments would be of great interest for quantum anomalous Hall (QAH) systems. It has been predicted that if Cooper pairing is induced in a QAH insulator, the system turns into a stereotypical spinless chiral p-wave superconductor associated with chiral Majorana edge states. In the QAH/SC system superconductivity can be suppressed by applying a magnetic field while keeping the 1D chiral edge state intact. Here we report the observation of crossed Andreev reflection (CAR) across a narrow superconducting Nb electrode contacting the chiral edge state of a QAHI, evinced by a negative nonlocal voltage measured downstream from the grounded Nb electrode. By changing the Nb width, the characteristic length of the CAR process is identified to be about 100 nm, which is three times longer than the superconducting correlation length in Nb.

[1] Lee et al., Nat. Phys., 13 (2017) 693-698

HL 31.2 Wed 12:00 EW 202

Work function engineering in superconducting Ir/Nb(110) films — •Adamantia Kosma[1], Stefan Blügel[1], and Philipp Rüssmann[1,2] — [1]Forschungszentrum Jülich — [2]University of Würzburg

The topological superconducting hybrid structures have been attracting considerable research interest in recent years, as they are promising candidates for topologically protected qubits. Because of this, a substantial demand for appropriate superconducting substrates has been created. In our study we explore the superconducting properties of Ir/Nb(110) films. Our focus is on the investigation of the change in the work function and the size of the proximity-induced superconducting gap of Ir overlayers deposited on Nb(110). The work function plays a crucial role in determining the behavior of electrons at the superconducting surface, thereby influencing the charge transport. In the specific context of superconductor hybrid structures for Majoranas, the target is to effectively manage the work function mismatch while maintaining a robust proximity effect through the overlayer. This approach will also provide valuable information for studying the proximity effect in a topological insulator/superconductor(TI/SC) system. Our findings are based on first-principles calculations using the full-potential Korringa-Kohn-Rostoker Green function method and its Kohn-Sham Bogoliubov-de Gennes (KS-BdG) extension to describe superconducting heterostructures [1].

We thank the ML4Q (EXC 2004/1 - 390534769) for funding.

[1] P. Rüßmann, and S. Blügel, Phys. Rev. B **105**, 125143 (2022).

HL 31.3 Wed 12:15 EW 202

Superconducting transition metal dichalcogenites for TI-based topological superconducting devices — •Philipp Rüssmann — Institute for Theoretical Physics and Astrophysics, University of Würzburg, Würzburg, Germany — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany

Proximitized topological insulators (TIs) are promising materials to build topological superconductors with the promise to realise Majorana-zero modes and topologically protected quantum devices. Here, we present an overview over our recent computational studies of heterostructures between superconducting transition-metal dichalcogenites (TMDCs) and TIs [1,2]. We compare different TMDC/TI interfaces and analyze the influence of the TMDCs on charge doping, band alignment and the superconducting proximity effect in the TI.

In our work we employ Kohn-Sham Bogoliubov-de Gennes simulations for the superconducting electronic structure based on density functional theory which is implemented in the full-potential relativistic Korringa-Kohn-Rostoker Green function method [3,4].

[1] Xian-Kui Wei *et al.*, arXiv 2311.16590 (2023)
[2] Abdur Rehman Jalil *et al.*, in preparation (2023)
[3] P Rüßmann and S Blügel, PRB **105**, 125143 (2022).
[4] JuDFTteam/JuKKR (2022). doi: 10.5281/zenodo.7284738

HL 31.4 Wed 12:30 EW 202

Superconducting diode effect in topological insulator nanowire Josephson junctions — •Ella N. Nikodem, Jakob Schluck, Mahasweta Bagchi, Zhiwei Wang, and Yoichi Ando — Physics Institute II, University of Cologne, Zülpicher Straße 77, 50937 Köln, Germany

Topological insulator nanowires coupled to conventional superconductors were predicted to host Majorana zero modes more than a decade ago [1]. An indication of the presence of such Majorana bound states in Josephson junction devices based on these nanowires is an enhanced superconducting diode effect in the topological regime, attributed to their 4π-periodic contribution to the current phase relation [2]. In this talk, we report our investigations of the superconducting diode effect in side-contacted etched nanowires made from exfoliated flakes of the bulk-insulating topological insulator BiSbTeSe2. We observed a strong dependence of the critical current on gate voltage and the magnetic field along the nanowire, as well as a significant superconducting diode effect. Its direction and magnitude can be switched by tuning the aforementioned parameters. Possible relevance of the Majorana bound states in the observed diode effect will be discussed.

[1] A. Cook and M. Franz, Phys. Rev. B 84, 201105(R) (2011).
[2] H. F. Legg et al., arXiv:2301.13740 (2023).

HL 31.5 Wed 12:45 EW 202

Nanoscale patterning of topological insulator thin film using a helium ion microscope — •Holger Mirkes[1,2], Filippo Romano[1,2], and Christoph Kastl[1,2] — [1]Walter Schottky Institute and Physik-Department, Technical University of Munich, Germany. — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany.

The helium ion microscope has evolved as a versatile tool for not only nanoscale imaging, but also nanoscale fabrication with a resolution well below 10 nm, limited only by substrate proximity effects for atomically thin films [1]. Here, we discuss the application of He-ion beam milling for nanofabrication of lateral superlattice structures in topological insulator thin films. We present results both on supported films grown by molecular beam epitaxy as well as on suspended films prepared by scotch tape exfoliation. The superior resolution of the He-ion microscope may be used to create lateral superlattice structures with topologically protected satellite Dirac cones [2]. The research is supported through the European Union*s Horizon Europe Research and Innovation Programme under Grant Agreement No 101076915 (2DTopS).

[1] E. Mitterreiter et al., Nano Lett. 2020, 20, 4437*4444.
[2] J. Cano et al., Phys. Rev. B 2021, 103, 155157.