TT 108: Topological Superconductors

Time: Friday 9:30–12:00 Location: H 2053

TT 108.1 Fri 9:30 H 2053

Two dimensional topological superconductivity with antiferromagnetic insulators — •Jose Lado and Manfred Sigrist — Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland

Two dimensional topological superconductivity has attracted great interest due to the emergence of Majorana modes bound to vortexes and propagating Majorana modes at the edges [1]. However, due to its rare appearance in natural compounds, its experimental replication relies on delicate artificial engineering by combination of helical states, magnetic fields and conventional superconductors [2]. Here we introduce a platform alternative to those mechanisms, by showing that a class of three dimensional antiferromagnets can be used to engineer a two dimensional topological superconductor. Our proposal relies on the appearance of solitonic states at the interface between an antiferromagnet and a superconductor, that become topologically gapped by intrinsic spin-orbit coupling. We show that those interfacial states do not require fine tuning between the superconducting and the antiferromagnetic exchange fields, as its existence is protected by asymptotic boundary conditions. Our findings open the venue of using three dimensional antiferromagnetic insulators as a solid state platform to engineer topological superconductivity.

[1] S. R. Elliott, M. Franz, Rev. Mod. Phys. 87, 137
[2] C. W. J. Beenakker, Annual Review of Condensed Matter Physics 2013 4:1, 113-136

TT 108.2 Fri 9:45 H 2053

Tunabale hybridization of Majorana bound states at the quantum spin Hall edge — •Felix Keidel[1], Pablo Burset[2], and Björn Trauzettel[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, D-97074 Würzburg, Germany — [2]Department of Applied Physics, Aalto University, FIN-00076 Aalto, Finland

We study the helical edge of a quantum spin Hall insulator in proximity to an s-wave superconductor (S) and ferromagnetic insulators (F). Hybrid structures of this kind are known to give rise to topological superconductivity and allow for Majorana bound states in regions where both the ferromagnetic and the superconducting gap close. This can be used to localize and couple Majorana modes.

In our work, we consider junctions with alternating S and F barriers and a system with three S barriers. The cavities between them can be understood as quantum dots hosting overlapping Majorana (MBS) and Andreev quasi-bound states (ABS). We demonstrate how the resulting hybridization and splitting depend on distinct parameters of the systems. Remarkably, we can make a close connection between the localized bound states and the induced nonlocal pairing amplitudes. The anomalous correlations provide a way to distinguish MBS and ABS and exhibit odd-frequency dominated triplet pairing for resonances associated with hybridized MBS.

TT 108.3 Fri 10:00 H 2053

The Electronic Structure and Transport Properties of Niobium Doped Bismuth Selenide — •Henriette Elisabeth Lund[1], Marco Bianchi[1], Simone Munkholm Kevy[2], Laura Wollesen[2], Martin Bremholm[2], Mark Jonas Haastrup[1], Elze Jantien Knol[3], Alexander Ako Khajetoorians[3], Steffen Wiedmann[4], and Philip Hofmann[1] — [1]Department of Physics and Astronomy, Interdisciplinary Nanoscience Center (iNano), Aarhus University, 8000 Aarhus C, Denmark — [2]Center for Materials Crystallography, Department of Chemistry and iNano, Aarhus University, 8000 Aarhus C, Denmark — [3]Institute for Molecules and Materials, Radboud University, 6525 AJ Nijmegen, The Netherlands — [4]High Field Magnet Laboratory, Institute for Molecules and Materials, Radboud University, 6525 ED Nijmegen, The Netherlands

It is believed that topological superconductivity can be realized in bismuth selenide, Bi_2Se_3, doped with Cu, Sr, and Nb. Little is known about the properties of Nb doped Bi_2Se_3. In the present study, the electronic structure and transport properties of $Nb_xBi_2Se_3$ have been investigated. Angle-resolved photoemission spectroscopy, scanning tunneling microscopy and atomic force microscopy measurements point towards an inhomogeneous surface structure. Transport measurements show that samples become partly superconducting with the critical temperature ranging between 2.3 K and 3.2 K. The results indicate that the $Nb_xBi_2Se_3$ system crystallizes in an inhomogeneous manner which makes it challenging to understand the origin of the superconductivity and motivates further work on this project.

TT 108.4 Fri 10:15 H 2053

Nematic superconductivity in $Cu_xBi_2Se_3$ — •Matthias Hecker and Jörg Schmalian — KIT, Karlsruhe, Germany

$Cu_xBi_2Se_3$ is a doped topological insulator that becomes superconducting at a temperature $T_c \approx 3.8K$. Recent NMR Knight-shift measurements in the superconducting phase have revealed the spontaneous symmetry breaking of the threefold rotational symmetry of the underlying lattice, in addition to the global U(1)-symmetry. This fact is most consistent with an odd-parity two-component superconducting order parameter, as proposed by [1]. We study the role of order parameter fluctuations, and show that the system can realize a nematic phase with $T_{nem} > T_c$, where actual superconductivity is not yet present. Besides, we find that the nematic phase transition is always a first order transition. Inside this new phase, we calculate the anisotropy in the resistivity in order to provide a tool for experimental verification.

[1] Fu and Berg, PRL 105,4 097001 (2010)

TT 108.5 Fri 10:30 H 2053

Millikelvin scanning tunneling spectroscopy: electronic features of semimetals and putative topological superconductors at very low energies — •Hermann Suderow — Universidad Autonoma de Madrid, Madrid, Spain

Scanning tunneling microscopy and spectroscopy (STM/S) down to 100 mK is an efficient tool to study superconductors and semimetals. The local electronic density of states is obtained at atomic level with a resolution in energy of a few tens of micro eV. Friedel like oscillations are observed close to defects like vacancies or interstitials. Real space maps of the electronic density of states close to defects provide thus a visual account from which we can measure the wavelength of the electronic wavefunctions at the energy corresponding to the applied bias voltage. The Fourier transform of the real space maps provides the constant energy contour of the electronic dispersion relation. By making maps at different energies, below and above the Fermi level, we can in principle trace the full bandstructure. In this talk, I will discuss recent visualization experiments of scattering effects in superconductors and semimetals. I will focus on the typeII Weyl semimetal WTe_2, where we directly observe the signature of edge states associated to the Weyl points and recent efforts in the putative chiral d-wave superconductor URu_2Si_2.

15 min. break.

TT 108.6 Fri 11:00 H 2053

Hybrid structures of topological insulators and superconductors - a possible realization of Cooper pair splitting? — •Jacob Fuchs[1], Michael Barth[1], Raphael Kozlovsky[1], Cosimo Gorini[1], Inanc Adagideli[2], and Klaus Richter[1] — [1]Institut für Theoretische Physik, Universität Regensburg — [2]Faculty of Engineering and Natural Sciences, Sabanci University, Istanbul

Transport in hybrid structures of topological insulator (TI) nanowires and superconductors (SCs) is investigated. The main focus is on TI-SC-TI-like structures and the question how such devices can be used to split Cooper pairs into two spatially separated electrons. On the one hand, the utilization of the spin-momentum locking in combination with the spin-singlet nature of the Cooper pairs is discussed. On the other hand, magnetic fields parallel to the TI nanowire can cause vortices in the SC leading to Majorana modes at the TI-SC boundary. These enable the splitting of Cooper pairs. Using a T-shaped junction, the splitting can be observed via a negative differential resistance.

TT 108.7 Fri 11:15 H 2053

Creation of spin-triplet Cooper pairs in the absence of magnetic ordering — •Daniel Breunig[1], Pablo Burset[2], and Björn Trauzettel[1] — [1]Institute for Theoretical Physics and Astrophysics, *University of Würzburg, D-97074 Würzburg, Germany — [2]Department of Applied Physics, Aalto University, FIN-00076 Aalto, Finland

In superconducting spintronics, it is essential to generate spin-triplet Cooper pairs on demand. Up to now, proposals to do so concentrate on hybrid structures in which a superconductor (SC) is combined with a magnetically ordered material (or an external magnetic field). We, instead, identify a novel way to create and isolate spin-triplet Cooper pairs in the absence of any magnetic ordering. This achievement is only possible because we drive a system with strong spin-orbit interaction–the Dirac surface states of a strong topological insulator (TI)–out of equilibrium. In particular, we consider a bipolar TI-SC-TI junction, where the electrochemical potentials in the outer leads differ in their overall sign. As a result, we find that nonlocal singlet pairing across the junction is completely suppressed for any excitation energy. Hence, this junction acts as a perfect spin triplet filter across the SC generating equal-spin Cooper pairs via crossed Andreev reflection.

TT 108.8 Fri 11:30 H 2053

Nonequilibrium Andreev bound states population in short superconducting junctions coupled to a resonator — •Raffael L. Klees[1], Gianluca Rastelli[1,2], and Wolfgang Belzig[1] — [1]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [2]Zukunftskolleg, Universität Konstanz, D-78457 Konstanz, Germany

Inspired by recent experiments [1], we study a short superconducting junction of length $L \ll \xi$ (coherence length) inserted in a dc-SQUID containing an ancillary Josephson tunnel junction. We evaluate the nonequilibrium occupation of the Andreev bound states (ABS) for the case of a conventional junction and a topological junction [2], with the latter case of ABS corresponding to a Majorana mode. We take into account small phase fluctuations of the Josephson tunnel junction, acting as a damped LC resonator, and analyze the role of the distribution of the quasiparticles of the continuum assuming that these quasiparticles are in thermal distribution with an effective temperature different from the environmental temperature. We also discuss the effect of strong photon irradiation in the junction leading to a nonequilibrium occupation of the ABS. We systematically compare the occupations of the bound states and the supercurrents carried by these states for conventional and topological junctions.

[1] L. Bretheau *et al.*, Nature **499**, 312 (2013);
C. Janvier *et al.*, Science **349**, 1199 (2015);
D. J. van Woerkom *et al.*, Nat. Phys. **13**, 876 (2017);
A. Murani *et al.*, Nat. Commun. **8**, 15941 (2017).
[2] R. L. Klees *et al.*, Phys. Rev. B **96**, 144510 (2017).

TT 108.9 Fri 11:45 H 2053

Waiting time distributions for hybrid junctions with topological superconductors — •Pablo Burset, Shuo Mi, and Christian Flindt — Department of Applied Physics, Aalto University, Finland

Electron waiting times are an important tool for analyzing the internal dynamics of nano-scale conductors. Here we investigate the waiting time distributions (WTDs) of superconducting hybrid junctions. We consider both conventional and topologically nontrivial superconductors, with the latter hosting Majorana bound states (MBS) at their edges. We develop a scattering matrix formalism for the WTD in multi-channel, multi-terminal scatterers. The multi-channel WTDs allow us to characterize Andreev processes that entangle electrons and holes. Using our multi-terminal approach, we analyze (i) normal-superconductor (NS) junctions featuring Andreev bound states at the NS interface, and (ii) NSN junctions where Cooper pairs can be spatially split into different leads. In both cases, we include a resonant cavity at the NS interfaces that acts as a non-interacting quantum dot. The presence of Andreev bound states in the cavities leads to oscillations of the WTD and a finite probability of a simultaneous detection of electrons and holes, which always appears for topological superconductors due to the presence of the MBS.