TT 55: Superconductivity: Tunnelling and Josephson Junctions

Time: Thursday 9:30–12:45 Location: HSZ 204

Invited Talk TT 55.1 Thu 9:30 HSZ 204

Probing Triplet Superconductivity by Scanning Tunneling Spectroscopy — Simon Diesch[1], Peter Machon[1], Michael Wolz[1], Christoph Sürgers[2], Detlef Beckmann[3], Wolfgang Belzig[1], and •Elke Scheer[1] — [1]Physics Department, University of Konstanz, Konstanz, Germany — [2]Physical Institute, KIT, Karlsruhe, Germany — [3]Institute for Nanotechnology, KIT, Karlsruhe, Germany

In this talk we address the proximity effect between a superconductor (S) and a normal metal (N) linked by a spin-active interface. With the help of a low-temperature scanning tunneling microscope we study the local density of states of trilayer systems consisting of Al (S), the ferromagnetic insulator EuS, and the noble metal Ag (N). In several recent studies it has been shown that EuS acts as ferromagnetic insulator with well-defined magnetic properties down to very low thickness [1]. We observe pronounced subgap structures that either reveal a zero-bias peak (ZBP) or an additional zero-bias splitting (ZBS) and that can be tuned by a magnetic field. We interpret our findings in the light of recent theories of odd-triplet contributions created by the spin-active interface [2,3]. In particular, we discuss that the ZBS is a hallmark for spin-polarized triplet pairs, able to carry long-ranged supercurrents into F, while the ZBP is a signature for short-ranged, mixed-spin triplet pairs.

[1] S. Diesch et al., Nature Commun. **9**, 5248 (2018)
[2] B. Li et al., Phys. Rev. Lett. **110**, 09700 (2013)
[3] A. Cottet et al., Phys. Rev. B **80**, 184511 (2009)

TT 55.2 Thu 10:00 HSZ 204

Josephson Tunneling through Magnetic and Non-Magnetic Impurities — •Christian Ast[1], Haonan Huang[1], Jacob Senkpiel[1], Robert Drost[1], Juan Carlos Cuevas[2], Alfredo Levy Yeyati[2], Ciprian Padurariu[3], Björn Kubala[3], Joachim Ankerhold[3], and Klaus Kern[1,4] — [1]MPI für Festkörperforschung, Stuttgart — [2]Universidad Autónoma de Madrid, Spain — [3]Universität Ulm — [4]EPFL, Lausanne, Switzerland

The Josephson effect describes the tunneling of Cooper pairs between two coupled superconductors. The critical current, which is the characteristic coupling parameter of a Josephson junction, carries valuable information about the coupled superconductors as well as the properties of the tunnel junction itself, such as the symmetry of the order parameters or the presence of magnetic impurities in the tunnel junction. We employ scanning tunneling microscopy (STM) to study the local properties of Josephson junctions in the presence of magnetic and non-magnetic impurities. We find that the critical current is reduced, depending on the coupling strength of the magnetic impurity to the superconducting substrate, which is extracted from the energy of the induced Yu-Shiba-Rusinov state. We further discuss the impact of non-magnetic impurities on the critical current.

TT 55.3 Thu 10:15 HSZ 204

Phase-dependent spin polarization of Cooper pairs in magnetic Josephson junctions — •Samme M. Dahir, Anatoly F. Volkov, and Ilya M. Eremin — Institut für Theoretische Physik III, Ruhr-Universität Bochum, D-44780 Bochum, Germany

Superconductor-ferromagnet hybrid structures (SF) have attracted much interest in the past decades, due to a variety of interesting phenomena predicted and observed in these structures. One of them is the so-called inverse proximity effect. It is described by a spin polarization of Cooper pairs, which occurs not only in the ferromagnet (F), but also in the superconductor (S), yielding a finite magnetic moment M_{S} inside the superconductor. This effect has been predicted and experimentally studied. However, interpretation of the experimental data is mostly ambiguous. Here, we study theoretically the impact of the spin polarized Cooper pairs on the Josephson effect in an SFS junction. We show that the induced magnetic moment M_{S} does depend on the phase difference φ and, therefore, will oscillate in time with the Josephson frequency $2eV/\hbar$ if the current exceeds a critical value. Most importantly, the spin polarization in the superconductor causes a significant change in the Fraunhofer pattern, which can be easily accessed experimentally.

TT 55.4 Thu 10:30 HSZ 204

Coupling ferromagnetic insulators via quasiparticle states in a nodal superconductor — •Angelo Di Bernardo[1,2], Sachio Komori[2], Giorgio Livanas[3], Giorgio Divitini[2], Paola Gentile[3], Mario Cuoco[3], and Jason Robinson[2] — [1]Universität Konstanz, Department of Physics, Universitätsstraße 10, Konstanz, Germany — [2]Universitatstrasse 10 — [3]CNR-SPIN, c/o University of Salerno, I-84084 Fisciano, Salerno, Italy

The generation of parallel-aligned spin (spin-triplet) pairs of electrons at superconductor/ferromagnet (S/F) interfaces has triggered the field of superconducting spintronics –which aims at developing spintronic devices with high energy efficiency.

Even before the discovery of giant magneto resistance, which underlies spintronic spin valves, de Gennes predicted a FI/S/FI system (FI is a ferromagnetic insulator), where a variation in the critical temperature (ΔT_c) of S can be obtained by switching the FIs from parallel (P) to antiparallel (AP). In addition, if the S thickness (d_S) is smaller than its coherence length (ξ), S can favour an AP coupling of the FIs.

Recently, we have investigated a fully-oxide FI/S/FI system [1], where FI is the manganite $Pr_{0.8}Ca_{0.2}MnO_3$ and S is the nodal (d-wave) S $YBa_2Cu_3O_{7-\delta}$ (YBCO). Here, quasiparticle states at the Fermi surface of YBCO, induce a long-ranged exchange coupling between the FIs over a d_S up to 100 ξ, which is well-beyond de Gennes limit for a metallic FI/S/FI system. Such nodal exchange coupling reinforces an AP state at specific d_S and results in ΔT_c values up to 2 K.

[1] A. Di Bernardo et al., Nature Mater. **18**, 1194 (2019).

TT 55.5 Thu 10:45 HSZ 204

Skew Andreev reflection in superconducting junctions — •Andreas Costa[1], Alex Matos-Abiague[2], and Jaroslav Fabian[1] — [1]University of Regensburg, Germany — [2]Wayne State University Detroit, USA

Superconducting junctions offer unique possibilities to generate and control charge and spin supercurrents, particularly in combination with the antagonistic ferromagnetic phase. The interplay of superconductivity and ferromagnetism gets most fascinating in the presence of interfacial spin-orbit coupling (SOC), which invariably results from broken inversion symmetry. Our work [1] investigates the impact of SOC on the characteristic Andreev reflection (AR) processes at the interfaces of ferromagnet/superconductor junctions. We demonstrate that the resulting skew ARs spatially separate charge carriers and generate giant Hall currents in the ferromagnet, accompanied by sizable transverse supercurrent responses in the superconductor. Apart from that, the spin-active interface acts like a transverse electron spin filter and all predicted charge currents simultaneously come along with their spin current counterparts. We comment on various experimentally feasible ways to tune the currents, making them promising candidates for spintronics applications. In a next step, our results might become relevant for integrating Hall physics into Josephson junctions.

This work was supported by ENB IDK Topological Insulators, DFG SFB 1277 (B07), DARPA Grant DP18AP900007, and US ONR Grant N000141712793.

[1] Costa et al., Phys. Rev. B 100, 060507(R) (2019).

TT 55.6 Thu 11:00 HSZ 204

Photon-assisted resonant Andreev tunneling through Yu-Shiba-Rusinov states — •Olof Peters[1], Nils Bogdanoff[1], Sergio Acero Gonzalez[2], Larissa Melischek[2], Rika Simon[1], Gaël Reecht[1], Clemens B. Winkelmann[3], Felix von Oppen[2], and Katharina J. Franke[1] — [1]Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany — [3]Univ. Grenoble Alpes, Institut Néel, 25 Avenue des Martyrs, 38042 Grenoble, France

The incoherent coupling of a photon field to the electrodes in a tunnel junction leads to photon-assisted tunneling expressed as symmetric sidebands. These bands can be very well described by the ac modulation of the energy levels in both electrodes [1].

We use scanning tunneling spectroscopy to investigate the Yu-Shiba-Rusinov (YSR) states of Mn adatoms inside the superconducting energy gap of Pb(111). At large tunneling resistance these YSR states show symmetric sidebands in an RF field of up to 40 GHz. At low resistance the tunneling process through the YSR state changes from single electron to resonant Andreev tunneling, which in contrast has asymmetric sidebands. By extending the theory of Tien and Gordon, we are able to explain and simulate this asymmetric splitting.

[1] P. K. Tien and J. P. Gordon, Phys. Rev. **129**, 647 (1963)

15 min. break.

TT 55.7 Thu 11:30 HSZ 204

Josephson and Andreev transport in a superconducting single electron transistor with a normal lead (SSN SET) — •Laura Sobral Rey[1,2], Susanne Sprenger[1], and Elke Scheer[1,2] — [1]Physics department, University of Konstanz, 78464, Konstanz, Germany — [2]QuESTech consortium

An island coupled via a tunnel barrier to two leads and a gate forms a single electron transistor (SET) that shows Coulomb blockade. All-superconducting SETs (SSS-SETs) have shown to enable multitude of possible charge transport processes which are not well understood, in particular in the strong-coupling regime [1]. To disentangle these processes, we study here the conceptually simpler SSN-SET, which has never been investigated experimentally before.

The SSN-SETs studied here consist of an S island coupled to an N lead via an oxide tunnel barrier, and to an S lead with a mechanically controlled break junction (MCBJ). Via the MCBJ, different coupling regimes can be tuned: from a tunnel contact when the MCBJ is broken to a point contact when it is closed. In that limit the MCBJ accommodates a small number of highly transmissive transport channels.

For weak coupling our experimental findings can be understood in terms of the orthodox theory [2]. For stronger couplings, we observe Andreev and Josephson transport, as well as a renormalization for the charging energy and dynamical coulomb blockade, which are also observed in the N state.

[1] T. Lorenz, J. Low Temp. Phys. 191, 301 (2017).
[2] R. J. Fitzgerald, Phys. Rev. B 57, R11073(R) (1997)

TT 55.8 Thu 11:45 HSZ 204

Microwave-assisted tunnelling and interference effects in superconducting junctions under fast driving signals — •Robert Drost[1], Peter Kot[1], Maximilian Uhl[1], Juan Carlos Cuevas[2], Joachim Ankerhold[3], and Christian Ast[1] — [1]Max-Planck-Institut für Festkörperforschung, Heisenbergstraße 1, 70569 Stuttgart, Germany — [2]Departamento de Física Teórica de la Materia Condensada and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, 28049 Madrid, Spain — [3]Institut für Komplexe Quantensysteme and IQST, Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany

As scanning tunnelling microscopy is pushed towards fast local dynamics, a quantitative understanding of tunnel junctions under the influence of a fast AC driving signal is required, especially at the ultra-low temperatures relevant to spin dynamics and correlated electron states. We subject a superconductor-insulator-superconductor junction to a microwave signal from an antenna mounted in situ and examine the DC response of the contact to this driving signal. Basic quasi-particle tunnelling can be interpreted using a modified density of states in the electrodes. The situation is more complex when it comes to higher order effects such as multiple Andreev reflections. Microwave assisted tunnelling unravel these complex processes, providing deeper insights into tunnelling than are available in a pure DC measurement.

TT 55.9 Thu 12:00 HSZ 204

Supercurrent in topological insulator nanowire - superconductor Josephson junctions — •Michael Barth, Jacob Fuchs, Cosimo Gorini, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg

Helical surface states of 3d topological insulator (TI) nanowires are expected to have very promising physical properties like forbidden backscattering [1]. Moreover it is predicted that a topological superconducting state which could possibly host Majorana fermions can be realized by bringing a normal s-wave superconductor in close proximity to a TI [2]. In our theoretical work we are studying such hybrid systems in a Josephson junction setup [3]. We numerically calculate the supercurrent in the system as a function of an applied external magnetic field parallel to the wire axis. Already in the normal state such a magnetic flux leads to Aharonov-Bohm oscillations of the conductance [4] but also in the superconducting state signatures of such oscillations can be observed as a consequence of spin-splitting in the superconducting TI.

[1] X.-L. Qi and S.-C. Zhang, Rev. Mod. Phys. **83**, 1057 (2011)
[2] A. Cook and M. Franz, Phys. Rev. B **84**, 201105(R) (2011)
[3] B.D. Josephson, Phys. Lett. **1**, 251 (1962)
[[4] J. Ziegler et al., Phys. Rev. B **97**, 035157 (2018)

TT 55.10 Thu 12:15 HSZ 204

Transport signatures of the Higgs mode in a normal-superconductor junction — •Gaomin Tang[1], Wolfgang Belzig[2], Ulrich Zülicke[3], and Christoph Bruder[1] — [1]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — [2]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [3]School of Chemical and Physical Sciences and MacDiarmid Institute for Advanced Materials and Nanotechnology, Victoria University of Wellington, P.O. Box 600, Wellington 6140, New Zealand

The magnitude of the superconducting order parameter can be excited to oscillate under certain resonant conditions. We study the fingerprints of this so-called amplitude, or Higgs, mode in the transport properties of a voltage biased normal-superconductor tunnel junction when the superconducting contact is exposed to microwave radiation. As a key signature, the AC charge current at fixed voltage bias shows pronounced resonant behaviour when the microwave frequency coincides with the static part of the superconducting-gap amplitude. We also find an interesting nonmonotonic behavior of the AC charge current with increasing DC voltage bias.

TT 55.11 Thu 12:30 HSZ 204

Optimized proximity thermometer for ultra-sensitive detection — Bayan Karimi[1], •Danilo Nikolic[2], Tuomas Tuukkanen[1], Joonas T. Peltonen[1], Wolfgang Belzig[2], and Jukka P. Pekola[1] — [1]QuESTech and QTF Centre of Excellence, Department of Applied Physics, Aalto University School of Science, P.O. Box 13500, 00076 Aalto, Finland — [2]QuESTech and Fachbereich Physik, Universität Konstanz, D-78467, Germany

Due to its importance for understanding the quantum principles of nature as well as technological development, the possibility of measuring low temperatures has drawn attention over decades. We present a set of experiments to optimize the performance of the noninvasive thermometer based on proximity superconductivity. Current through a standard tunnel junction between an aluminum superconductor and a copper electrode is controlled by the strength of the proximity induced to this normal metal, which in turn is determined by the position of direct superconducting contact from the tunnel junction. Several devices with different distances were tested. We develop a theoretical model based on the Usadel equations and dynamic Coulomb blockade which reproduces the measured results and yields a tool to calibrate the thermometer and to optimize it further in future experiments. This project has received funding from the EU Horizon 2020 program (Marie Sklodowska-Curie action QuesTech 766025).

[1] B.Karimi, D.Nikolic, T.Tuukkanen, J.T.Peltonen, W.Belzig, and J.P.Pekola, arXiv:1911.02844 [cond-mat.mes-hall] (2019).