TT 42: Superconductivity: Tunneling and Josephson Junctions

Time: Thursday 9:30–13:15 Location: H32

TT 42.1 Thu 9:30 H32

Extraction of the Density of States and the Gap Function on a Temperature Smearing Scale from the Tunneling Conductance Data — •Lucia Gelenekyová and František Herman — Comenius University in Bratislava

The aim of our work is to extract the density of states (DOS) and the gap function from the tunneling conductance data at higher temperatures. It is known that if the temperature approaches zero, the DOS function is proportional to the tunneling conductance, and therefore, it can be easily extracted. However, with increasing temperature, the temperature smearing causes that this approximation can no longer be used. Thus, we have developed an algorithm that was designed to extract the details of the DOS function and the gap function on a typical temperature scale, which can be used approximately up to 1/2 of T_c. Moreover, knowledge of the DOS in its normal state plays an important role. Hence, we present the results of the testing data sets and also the outcome from experimentally measured tunneling conductance data of the NbN superconductor.

This work has been supported by the Slovak Research and Development Agency under the Contract no. APVV-23-0515, by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Grant Agreement No. 945478.

TT 42.2 Thu 9:45 H32

Superconductivity of α-Gallium Probed on the Atomic Scale by Normal and Josephson Tunneling — Corinna Fohn[1], David Wander[1], Danilo Nikolic[2,3], Stéphanie Garaudée[1], Hervé Courtois[1], Wolfgang Belzig[3], Claude Chapelier[4], Vincent Renard[4], and •Clemens B. Winkelmann[1,4] — [1]Université Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, F-38000 Grenoble, France — [2]Institut für Physik, Universität Greifswald, Felix-Hausdorff-Strasse 6, D-17489 Greifswald, Germany — [3]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [4]Université Grenoble Alpes, CEA, Grenoble INP, IRIG/DEPHY/PHELIQS, F-38000 Grenoble, France

We investigate superconducting gallium in its α phase using scanning tunneling microscopy and spectroscopy at temperatures down to about 100 mK. High-resolution tunneling spectroscopies using both superconducting and normal tips show that superconducting α-Ga is accurately described by Bardeen-Cooper-Schrieffer theory, with a gap $\Delta_{\mathrm{Ga}} = 163$ μeV on the $\alpha-$Ga(112) facet, with highly homogeneous spectra over the surface, including atomic defects and step edges. Using a superconducting Pb tip, we furthermore study the low-bias conductance features of the Josephson junction formed between tip and sample. The features are accurately described by dynamical Coulomb blockade theory, highlighting $\alpha-$Ga as a possible platform for surface science studies of mesoscopic superconductivity.

TT 42.3 Thu 10:00 H32

Current Phase Relation of HgTe Nanowire Josephson Junctions in an Axial Magnetic Field — •Niklas Hüttner[1], Wolfgang Himmler[1], Ralf Fischer[1], Dmitriy Kozlov[1], Michael Barth[2], Jacob Fuchs[2], Andreas Costa[2], Klaus Richter[2], Leandro Tosi[1], Nicola Paradiso[1], Dieter Weiss[1], and Christoph Strunk[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg — [2]Institute for Theoretical Physics, University of Regensburg, 93053 Regensburg, Germany

Proximitized semiconductor nanowires are expected to show Anomalous Josephson effect by spin-orbit interaction and Zeeman effect in a magnetic field parallel to the wire direction [1]. The φ_0 shift is accompanied by a direction dependent critical current (Superconducting diode effect).[1] We directly probe the current phase relation (CPR) of HgTe nanowires proximitized by niobium leads via an asymmetric SQUID measurement. The topological surface states additionally pick up an Aharanov Bohm phase for $B_\parallel$ in wire direction [2]. We observe an highly tunable φ_0 shift, a 0-π transition, and a superconducting diode effect from the corresponding CPRs. Additionally a strong modulation of both the critical current and the content of higher harmonics is observed for magnetic flux between 0 and 1.5Φ_0.

[1] T. Yokoyama et al., Phys. Rev. B 89, 195407 (2014).
[2] W. Himmler et al., Phys. Rev. Res. 5, 043021 (2023).

TT 42.4 Thu 10:15 H32

Theory of Josephson Scanning Tunneling Microscopy with s-Wave Tip on a Cuprate Surface — •Peayush Kumar Choubey[1] and Peter Hirschfeld[2] — [1]Indian Institute of Technology Roorkee, Roorkee 247667, Uttarakhand, India — [2]University of Florida, Gainesville, Florida 32611, USA

The Josephson scanning tunneling microscopy (JSTM) is a direct local probe of superconducting gap order parameter (SCOP). JSTM studies have been largely limited to the cases where superconducting sample and superconducting tip, both, have the same gap symmetry- either s-wave or d-wave. It has been generally assumed that in an s-to-d SJTS study of cuprates the critical current would vanish everywhere owing to the orthogonality of tip and sample SCOPs. We show here that this is not the case. Using first-principles Wannier functions for $Bi_2Sr_2CaCu_2O_8$, we develop a scheme to compute Josephson critical current (I_c) measured by a JSTM setup employing an s-wave tip with sub-angstrom resolution. We show that I_c remains finite everywhere in the unit cell except along Cu-Cu directions, changes sign under four-fold rotation, and attains largest magnitude above O sites, which can be regarded as a hallmark of the d-wave gap symmetry. Further, we find that I_c is suppressed near a strong scatterer like Zn and modulations in I_c around an impurity occur at wavevectors distinct from quasi-particle interference (QPI). Our work provides a theoretical foundation for probing unconventional superconductivity using JSTM set-up with s-wave tip.

TT 42.5 Thu 10:30 H32

Optimal Parametric Control of Transport Across a Josephson Junction — •Hannah Victoria Kleine-Pollmann, Guido Homann, and Ludwig Mathey — Zentrum für Optische Quantentechnologien and Institut für Quantenphysik, *Universität Hamburg, 22761 Hamburg, Germany

We present optimal control strategies for the DC transport across a Josephson junction. Specifically, we consider a junction in which the Josephson coupling is driven parametrically, with either a bichromatic or a trichromatic driving protocol, and optimize the prefactor of the $1/\omega$ divergence of the imaginary part of the conductivity. We demonstrate that for an optimal bichromatic protocol an enhancement of 70 can be reached, and for an optimal trichromatic protocol an enhancement of 135. This is motivated by pump-probe experiments that have demonstrated light-enhanced superconductivity along the c-axis of underdoped YBCO, where the junction serves as a minimal model for the c-axis coupling of superconducting layers. Therefore, the significant enhancement of superconductivity that we show for multi-frequency protocols demonstrates that the advancement of pump-probe technology towards these strategies is highly desirable.

TT 42.6 Thu 10:45 H32

Gate-Controlled Superconductivity: Mechanisms, Parameters and Technological Potential — Leon Ruf, Jennifer Koch, Elke Scheer, and •Angelo Di Bernardo — University of Konstanz, Universitätsstraße 10, 78464 Konstanz

Over the past few years, several research groups have demonstrated the reversible control of the superconducting current flowing through a nanoscale-size constriction under the application of a gate voltage (V_G) - currently known as gate-controlled supercurrent (GCS) [1].

The numerous differences between fabrication protocols, device parameters and measurement setups adopted by these groups, however, have made it difficult to find universal features of the GCS effect.

In this talk, I will discuss the results of systematic studies carried by our group [2-4] that have allowed us to identify parameters that are key for the GCS observation and to achieve high reproducibility in the functioning of GCS devices [4]. In addition, I will review the progress that we have made towards the optimization of performance parameters that are important for the future development of technological applications based on the GCS.

[1] L. Ruf et al., Appl. Phys. Rev. **11**, 041314 (2024).
[2] L. Ruf et al., APL Mater. **11**, 091113 (2023).
[3] J. Koch et al., Nano Res. **17**, 6575 (2024).
[4] L. Ruf et al., ACS Nano **18**, 20600 (2024).

TT 42.7 Thu 11:00 H32

Gate-Controlled Supercurrents in Three-Terminal Devices Made on Industrial Grade SiO_2 and Al_2O_3 — •Leon Ruf, Jennifer Koch, Elke Scheer, and Angelo Di Bernardo — University of Konstanz, Universitätsstraße 10, 78457 Konstanz

Gate-controlled supercurrent (GCS) is a growing, highly debated field of research. It was found that in gated three-terminal devices made of Ti and Al the supercurrent could be modulated by the application of a gate voltage [1]. The authors attribute their observation to a direct electric field effect, which would pave the way for future CMOS compatible transistors. Contrary, other works reported about a leakage related effect: high-energy quasiparticle emission through vacuum [2], phonon-induced heating of the electronic system [3], out-of-equilibrium state induced by phonons and/or high energy electrons without sizeable heating [4]. Here we are studying the GCS in Nb and NbRe Dayem bridges on industrial grade SiO_2 and Al_2O_3. Our results reveal a strong correlation between the substrate material and the GCS parameters, such as suppression voltage and stability. Herby, SiO_2 and Al_2O_3 show major differences. Further, our results suggest that for both SiO_2 and Al_2O_3 the leakage current is mediated via defects giving rise to trap-assisted tunneling. We discuss our results in the light of the above-mentioned mechanism [1-4].
[1] De Simoni et al., Nat. Nanotechnol. **13**, 802 (2018);
[2] Alegria et al., Nat. Nanotechnol. **16**, 404 (2021);
[3] Ritter et al., Nat. Electron. **5**, 71 (2022);
[4] Basset et al., Phys. Rev. Rese. **3**, 043169 (2021).

15 min. break

TT 42.8 Thu 11:30 H32

Transport Measurements on Arrays of Four-Terminal Nb-Pt-Nb Josephson Junctions — •Justus Teller[1,2], Christian Schäfer[1,2], Benjamin Bennemann[1], Matvey Lyatti[1,2], Kristof Moors[1,2], Detlev Grützmacher[1,2], Roman-Pascal Riwar[1], and Thomas Schäpers[1,2] — [1]Peter Grünberg Institut (PGI-9, PGI-10, PGI-2), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, Germany

Arrays of interconnected two-terminal Josephson junctions have been investigated since the 1980's. Usually, the array is realized as a square lattice with four two-terminal Josephson junctions connected in a square unit cell. Recently, Graziano et al. [1] showed that a multi-terminal Josephson junction can be described as a network of interconnected two-terminal Josephson junctions. Based on that concept, we present an array made of 30×30 four-terminal Nb-Pt-Nb Josephson junctions. The in-situ fabrication of large networks of Josephson junctions, using molecular beam epitaxy, is described. For this process, a periodically patterned shadow mask of Si_3N_4 has been developed. The physical concept of a multi-terminal Josephson junction array is introduced. Its theoretical explanation is based on a lattice of interconnected two-terminal Josephson junctions, each described as a resistively-capacitively-shunted junction. Critical current and resistance of the array show oscillations connected to its unit cell.
[1] G. V. Graziano et al., Phys. Rev. B 101, 054510 (2020).

TT 42.9 Thu 11:45 H32

Superconducting Atomic Contacts under Microwave Irradiation, Photon-Assisted Tunneling and Fractional Shapiro Steps — •Oliver Irtenkauf[1], Patrick Raif[1,2], Carlos Cuevas[1,3], and Elke Scheer[1] — [1]University of Konstanz, Germany — [2]University of Basel, Switzerland — [3]Universidad Autónoma de Madrid, Spain

We form an atomic contact from a mechanically controlled aluminum break junction and irradiate it with microwaves in its superconducting state [1]. In the dI/dV spectra, we observe the well-known structures caused by photon-assisted tunneling, which, in the case of tunnel contacts, are fully explained by the Tien-Gordon (TG) model [2]. However, for higher-order transport processes, the model requires extensions, as shown in simulations based on the TG model [3,4]. Shapiro steps, i.e., replicas of the supercurrent, reveal deviations from the theoretical predictions described in references [5,6]. Fractional Shapiro steps, which we observe in atomic contacts with high-transmission channels at high frequencies, differ from traditional Shapiro steps and represent a new phenomenon.
[1] P. Raif, Master Thesis, *Uni. Konstanz* (2024);
[2] P. K. Tien & J. P. Gordon, *PR* **129**, 647 (1963);
[3] P. E. Gregers-Hansen et al., *PRL* **31**, 524 (1973);
[4] J.C. Cuevas et al., *PRL* **88**, 157001 (2002);
[5] G. Falci, V. Bubanja & G. Schön, *Z. Phys.* **85**, 451 (1991);
[6] P. Kot et al., *PRB* **101**, 134507 (2020).

TT 42.10 Thu 12:00 H32

High-Frequency Irradiation of Single-Atom Josephson Junctions — •Martina Trahms[1,2], Bharti Mahendru[2], Clemens B. Winkelmann[1], and Katharina J. Franke[2] — [1]University Grenoble Alpes, LATEQS, 38042 Grenoble, France — [2]Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany

Understanding superconducting junctions on the atomic scale yields significant insights for the prospect of using superconducting circuits in future technological applications. Here, we investigate the influence of single magnetic adatoms (Mn) on the phase dynamics of current-biased Pb-Pb Josephson junctions in a scanning tunneling microscope (STM) in the presence of high-frequency (HF) irradiation that is applied via an antenna close to the junction. We observe Shapiro steps that indicate coherent absorption of the irradiation while at the same time phase diffusion is enhanced due to incoherent absorption. In the presence of a magnetic adatom, phase diffusion is more prominently enhanced compared to the pristine junction which indicates that the quantum spin of the magnetic impurity influences the coherence of the tunneling processes in the junction.

TT 42.11 Thu 12:15 H32

Amplification Schemes for Single Microwave Photons — •Lukas Danner[1,2], Hanna Zeller[2], Ciprian Padurariu[2], Joachim Ankerhold[2], and Björn Kubala[1,2] — [1]Institute for Quantum Technologies, German Aerospace Center (DLR), Ulm (Germany) — [2]Institute for Complex Quantum Systems and IQST, University of Ulm, Ulm (Germany)

The detection of single microwave photons plays a crucial role in a wide range of envisioned technological applications of quantum microwaves. However, this is challenging because of the large thermal background and the low energy of a single photon. Here, we investigate schemes to amplify single itinerant mircowave photons using Josephson photonics devices [1, 2]. These devices consist of a dc-voltage biased Josephson junction, connected in series with two microwave cavities. By tuning the dc voltage, various resonances can easily be accessed, such that e.g. a Cooper pair tunneling through the junction enables a coherent transfer between one excitation in the first cavity and n excitations in the second cavity. We show that a single photon pulse absorbed by the device effectively triggers the emission of multiple photons from the second cavity that can subsequently be detected. To study such processes theoretically, we use a recently developed formalism [3] to describe arbitrary traveling photon pulses interacting with a quantum system in a cascaded manner.
[1] Leppäkangas et al., Phys. Rev. A 97, 013855 (2018)
[2] Albert et al., Phys. Rev. X, 14, 011011 (2024)
[3] Kiilerich and Mølmer, Phys. Rev. Lett. 123, 123604 (2019)

TT 42.12 Thu 12:30 H32

Tunneling in Altermagnet/Superconductor/Altermagnet Junctions — •Marcel Polák[1], František Herman[1], Andreas Costa[2], and Jaroslav Fabian[2] — [1]Comenius University Bratislava, Slovakia — [2]University of Regensburg, Germany

Their unprecedented spectral characteristics—particularly their large local magnetic exchange splittings in momentum space without rising an overall net spin polarization—make altermagnets promising candidates for engineering strongly spin-polarized currents in superconducting heterostructures.

In this talk, we will focus on lateral altermagnet/superconductor/altermagnet junctions in the ballistic limit to theoretically explore the ramifications of their d-wave-like spin-split Fermi surfaces on superconducting transport. We will demonstrate that the subgap interplay of Andreev and quasiparticle tunnelings, and thereby the experimentally accessible tunneling conductance, is tunable through the absolute and relative orientations of the altermagnets' Fermi surfaces, recovering the two important limiting cases in which the altermagnets behave either rather like normal metals or ferromagnets. Finally, we will also investigate geometrical conductance oscillations at supergap voltages in the presence of resonant scattering and compare our results against the ferromagnetic junction counterpart.

This work has been supported by Contract no. APVV-23-0515, by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Grant Agreement No. 945478 and by DFG Grants 314695032 (SFB 1277) and 454646522.

TT 42.13 Thu 12:45 H32

Chiral Interference Pattern in Tunneling Junctions and SQUIDs Made of Time-Reversal Invariant Weyl Superconductors — •Anastasiia Chyzhykova[1,2], Vira Shyta[1], Jeroen van den Brink[1], and Flavio Nogueira[1] — [1]Leibniz Institute for Solid State and Materials Research, IFW Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [2]Technische Universität Dresden

In recent years a number of experiments have reported superconductivity in various Weyl semimetals. The low-energy electromagnetic response of Weyl semimetals is governed by the axion term in the action arising due to the chiral anomaly. A recent publication [1] demonstrated that the time-reversal invariant Weyl superconductors (SCs) exhibit a chiral Meissner state. In our work we explore the influence of the chiral Meissner state on the tunnel junctions and squids made of time-reversal invariant Weyl SCs. We derive a modified Fraunhofer interference pattern in such a junction and demonstrate how the presence of the axion term affects Josephson energy in asymmetric squids and Berry phase in charge qubits. The effect of the chiral Meissner state manifests as a temperature-dependent deficit flux, which provides a new tuning parameter compared to ordinary squids.

[1] V.Shyta, J.van den Brink, F.S.Nogueira, Phys.Rev.Res. 6, 013240 (2024).

TT 42.14 Thu 13:00 H32

Superconductor-Altermagnet Proximity Effect with Nonmagnetic Impurities — •Christian Wiedemann[1], Danilo Nikolić[2], Matthias Eschrig[2], and Wolfgang Belzig[1] — [1]Universität Konstanz, Konstanz, Germany — [2]Universität Greifswald, Greifswald, Germany

Altermagnetism is a novel magnetic phase with zero net magnetization and momentum-dependent (e.g. d-wave) spin-split Fermi surface which has been recently discovered [1]. Similarly to ferromagnets [2,3], when brought to the proximity of a superconductor (S) an altermagnet (AM) modifies the spectral properties of the former [4,5]. However, most works in the field of superconducting spintronics involving altermagnets have assumed the absence of impurities that are, however, typically unavoidable in experiments. In this talk, we address this question explicitly presenting a systematic analysis of the inverse proximity effect in an S/AM bilayer in the presence of nonmagnetic impurities. Utilizing the quasiclassical Green's function theory, we investigate the effect of impurities on observables, e.g., the self-consistently calculated order parameter and the density of states. We observe interesting phenomena such as the gapless superconductivity and an impurity-enhanced critical temperature.

[1] L. Šmejkal *et al.*, Phys. Rev. X **12**, 040501 (2022).
[2] A. I. Buzidn, Rev. Mod. Phys. **77**, 935 (2005).
[3] M. Eschrig, Rep. Prog. Phys. **78**, 104501 (2015).
[4] S. Chourasia *et al.*, arXiv:2403.10456.
[5] M. Wei *et al.*, Phys. Rev. B **109**, L201404 (2024).