TT 73: Superconductivity: Tunneling and Josephson Junctions

Time: Thursday 9:30–12:45 Location: CHE/0089

TT 73.1 Thu 9:30 CHE/0089

Transparency-controlled multiple charge transfer in superconducting tunnel junctions at atomic scale — •Jiasen Niu[1,2,3], Yudai Sato[1,2,3], Maialen Larrazabal[4], Jian-feng Ge[5], and Milan Allan[1,2,3] — [1]Leiden Institute of Physics, Leiden University, Niels Bohrweg 2, 2333 CA Leiden, The Netherlands — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, Schellingstrasse 4, München 80799, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [4]Debye Institute of Nanomaterials Science, Utrecht University, PO Box 80000, 3508 TA Utrecht, The Netherlands — [5]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany

Charge transport in superconducting junctions enable multi-charge transfer and can be identified through shot noise. Using shot noise STM with a newly developed amplifier, we measured Pb(111) junctions with tunable transparency. At low transparency, the effective charge is strongly suppressed (q < ne), while increasing transparency enhances AR/MAR, driving q toward 2e in SIN junctions and ne in SIS junctions. The measurements agree quantitatively with single-channel simulations. Our results track the continuous evolution from multi-electron to single-electron transport and demonstrate transparency as a key parameter in controlling superconducting quantum transport.

TT 73.2 Thu 9:45 CHE/0089

The Evolution of the Josephson Effect: From Dynamical Coulomb Blockade to Dissipationless Supercurrent — •Irena Padniuk[1], Xianzhe Zeng[1], Joachim Ankerhold[2], Juan Carlos Cuevas[3], Klaus Kern[1,4], and Christian R. Ast[1] — [1]MPI für Festkörperforschung, Heisenbergstraße 1, Stuttgart — [2]Institute for Complex Quantum Systems, University of Ulm, Albert-Einstein-Allee 11, Ulm — [3]Departamento de Física Teórica de la Materia Condensada and Condensed Matter Physics Center (IFIMAC), Universidad Autónoma de Madrid, Madrid, Spain — [4]Institut de Physique, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

The Josephson effect measured with scanning tunneling microscopy (STM) offers a unique platform to study superconducting transport at the atomic scale. The tunneling of Cooper pairs in ultra-low temperature STM is typically dissipative due to the dynamical Coulomb blockade, involving energy exchange with the electromagnetic environment related to the junction's capacitance. In contrast, the well-known macroscopic Josephson effect between superconductors in planar tunnel junctions is dissipationless, allowing supercurrent to flow without energy loss. Until now, a direct connection between these two regimes has remained elusive. In my talk, I will discuss how, using our ultra-high energy resolution mK-STM, we investigate the evolution of the Josephson current over a wide range of junction transmissions. Our results provide insight into the transition between dissipative quantum transport and dissipationless Cooper pair tunneling in atomic-scale junctions.

TT 73.3 Thu 10:00 CHE/0089

Voltage fluctuations in atomic-scale Josephson junctions — •Verena Caspari[1], Werner M. J. van Weerdenburg[1], Christian Lotze[1], Clemens B. Winkelmann[2], and Katharina J. Franke[1] — [1]Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany — [2]Univ. Grenoble Alpes, CEA, Grenoble INP, IRIG-Pheliqs, Grenoble, France

Phase diffusion in Josephson junctions and the switching from the superconducting to the quasiparticle branch can be explained by the dynamics of a fictitious phase particle in the tilted washboard potential. Usually, only the average voltage is measured[1].

Here, we measure the voltage fluctuations in single-atom Pb-Pb junctions with MHz-bandwidth using a scanning tunneling microscope. In the current-bias regime, the current-voltage V(I) curves show a hysteretic behavior that allows to set the junction into the phase-diffusion regime, where we observe multi-level transitions in time traces. These can be interpreted as phase-slips events leading to the finite average voltage in the superconducting state. In the voltage-bias regime, we observe bistabilities indicating the transition between the superconducting and the quasiparticle branch. Our experiments allow access to the phase-slip dynamics in the STM-based Josephson junction.

[1] R. L. Kautz, J. M. Martinis, Phys. Rev. B 42, 9903 (1990)

TT 73.4 Thu 10:15 CHE/0089

Non-Linear Response Theory of the Josephson Effect — •Christian R. Ast[1] and Juan Carlos Cuevas[2] — [1]MPI for Solid State Research, Stuttgart — [2]Universidad Autónoma de Madrid, Spain

The dissipationless supercurrent in the Josephson effect depends linearly on the junction conductance in a planar superconductor-insulator-superconductor tunnel junction, if there is no interaction with the environment. In ultrasmall tunnel junctions, such as in a scanning tunneling microscope (STM), the interaction with the environment cannot be neglected, which leads to a dissipative supercurrent that depends quadratically on the junction conductance. This dissipative supercurrent has been very successfully modeled within the dynamical Coulomb blockade and $P(E)$-theory based on Fermi's golden rule. In this talk, I will present a derivation of the dissipative supercurrent based on non-linear response theory. The result is basically identical to the existing model, although there are some distinct differences, which will be discussed.

TT 73.5 Thu 10:30 CHE/0089

Microwave mediated Cooper pair currents in single and double Josephson junctions — •Stefano Trivini[1], Leonard Edens[1], Jon Ortuzar[2], and Jose Ignacio Pascual[1,3] — [1]CIC nanoGUNE-BRTA, San Sebastian, Spain — [2]Quantronics group SPEC, CEA-Saclay — [3]Ikerbasque, Basque Foundation for Science, Bilbao, Spain

Tunnelling of Cooper pairs in STM Josephson junctions (JJs) is usually described as an incoherent process mediated by the junction's electromagnetic environment. Under microwave irradiation, photons can assist the tunnelling of quasiparticles as captured by the Tien-Gordon theory. For a current-biased, phase-coherent junction, Shapiro steps at voltages multiple of hv/2e are expected. Here, we study Pb-Pb single JJs realized in bulk Pb and in double JJs systems, formed by small Pb islands, under microwave irradiation. The microwave power maps depend on the tip-sample distance and can be described either by the TG approach or the RCSJ model. In double JJs, we observe asymmetric microwave maps whose shape reflects Coulomb-blockade processes on the Pb island.

TT 73.6 Thu 10:45 CHE/0089

Supercurrent Transport and Shapiro response in phase-pure core/shell GaAs/InAs nanowire-based Josephson junctions — •Farah Basaric[1,2], Yurii Kutovy[2,3], Alexander Pawlis[2,3], Detlev Grützmacher[1,2], and Thomas Schäpers[1,2] — [1]Peter Grünberg Institut (PGI9), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, Germany — [3]Peter Grünberg Institut (PGI10), Forschungszentrum Jülich, 52425 Jülich, Germany

We investigate Josephson junctions based on epitaxially grown, phase-pure core/shell GaAs/InAs nanowires comprising closed-loop states in the InAs shell. The core/shell architecture, combined with superconducting Al, enables confined states in the InAs shell that are expected to enhance proximity coupling at the InAs/Al interface. Using shadow-wall evaporation for junction and contact definition, we are able to realize nanowire-based Josephson junctions in the short junction limit. Current-voltage characteristics measurements under radio-frequency irradiation reveal both integer as well as fractional Shapiro steps, the latter commonly associated with ballistic junctions. Additionally, magnetoconductance measurements on nanowires with normal contacts provide insight into the transport properties of the nanowire segment forming the weak link. Together, these results demonstrate that GaAs/InAs core/shell nanowires constitute a very promising platform for future quantum circuits based on hybrid devices.

15 min. break

TT 73.7 Thu 11:15 CHE/0089

Supercurrent Interference in Planar Josephson Junction Arrays Probed by Microwave Excitations — •Alexander Kirchner[1], Simon Feyrer[1], Vjeko Dimić[1], Sebastian Ramsauer[1], Johanna Berger[1], Narges Momeni[1], Francisco Jesus Matute-Cañadas[2], Davide Curcio[3], Matthias Kronseder[1], Michael Prager[1], Dieter Schuh[1], Dominique Bougeard[1], Giorgio Biasiol[3], Alfredo Levy Yeyati[2], Nicola Paradiso[1], Christoph Strunk[1], and Leandro Tosi[1,4] — [1]Institut für Experimentelle und Angewandte Physik, University of Regensburg, Regensburg, Germany — [2]Departamento de Física Teórica de la Materia Condensada, Condensed Matter Physics Center (IFIMAC) and Instituto Nicolás Cabrera, Universidad Autónoma de Madrid, Madrid, Spain — [3]CNR-IOM Istituto Officina dei Materiali, Trieste, Italy — [4]Centro Atómico Bariloche and Insitituto Balseiro, CNEA, CONICET, San Charlos de Bariloche, Río Negro, Argentina

We present measurements of one dimensional Josephson junction arrays based on a hybrid superconductor-semiconductor quantum well heterostructure probed at microwave frequencies. The behavior of their plasma modes as a function of an applied magnetic field reveals interference patterns: an out-of-plane field results in a Fraunhofer-like pattern, from which we extract the effective transparency of the junctions; furthermore, periodic oscillations of the inductance occur when applying an in-plane magnetic field. The periodicity of these oscillations scales with the length of the island, pointing towards an orbital origin.

TT 73.8 Thu 11:30 CHE/0089

Purely even harmonic Josephson current due to crossed pair transmission across strongly spin-polarized materials — •Danilo Nikolić, Niklas L. Schulz, and Matthias Eschrig — Institut für Physik, Universität Greifswald, Felix-Hausdorff-Straße 6, 17489 Greifswald, Germany

We revisit the problem of the second harmonic generation in the current-phase relation across ferromagnetic bilayers placed between BCS superconductors. In particular, we consider a strongly spin-polarized metallic ferromagnet coupled to two superconducting leads via thin spin-active (left) and non-spin-active (right) insulating layers. The system is examined in the framework of the quasiclassical Green's function formalism both in the ballistic (Eilenberger) and the diffusive (Usadel) limit. Strong spin polarization allows for neglecting short-range mixed-spin correlations, and the Josephson supercurrent across the ferromagnet is fully mediated by long-range equal-spin triplet correlations. Using a diagrammatic technique for ballistic propagators, we describe the relevant Andreev processes responsible for the effective conversion of two spin-singlet Cooper pairs in the superconductor into two ↑↑ and ↓↓ pairs in the ferromagnet. Contrary to the naive picture of direct conversion, we show that the lowest order process involves four Cooper pairs in the superconductor, among which three are incoming and one is outgoing giving rise to net charge transport of $4e$ across the non spin-active interface. The self-consistent numerical treatment of the diffusive junction, typically more relevant in experiments, confirms this picture quantitatively.

TT 73.9 Thu 11:45 CHE/0089

Signatures of triplet pairing in FSF hybrid junctions — •Andreas Costa[1], Pablo Tuero[2], Cesar Gonzalez-Ruano[2,3], Yuan Lu[4], Farkhad G. Aliev[2], and Jaroslav Fabian[1] — [1]University of Regensburg, Germany — [2]Universidad Autónoma de Madrid, Spain — [3]Universidad Pontificia Comillas, Spain — [4]Université de Lorraine, France

Interfaces between ferromagnets and conventional s-wave superconductors serve as prototype systems to explore the conversion of singlet into spin-polarized triplet Cooper pairs in superconducting spintronics.

Recent experimental studies found anomalous quasiparticle conductance modulations in ferromagnet/superconductor/ferromagnet (FSF) hybrids under a rotated in-plane magnetic field. In this talk, we will report on our theoretical conductance simulations performed to unravel the physical origin of these anomalies. We will demonstrate that the experimental data show strong signatures of nonuniform magnetization and complex interfacial spin-orbit fields present in these junctions. As both are expected to induce spin-triplet Cooper pairs by rotating the spin quantization axis, we propose the observed conductance anomalies to provide a possible experimental fingerprint of unconventional triplet superconductivity.

The theory part of this work has been supported by Deutsche Forschungsgemeinschaft (DFG; German Research Foundation)—454646522; 314695032.

TT 73.10 Thu 12:00 CHE/0089

Critical current surfaces of multiterminal graphene Josephson junctions — •Paul Maier, Romain Danneau, and Detlef Beckmann — Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, D-76021 Karlsruhe, Germany

Topological states are predicted to exist in the Andreev bound state spectrum of multiterminal Josephson junction with four or more terminals [1]. Superconductor graphene hybrid structures are especially suitable to realize such devices due to the gate tunability of graphene and high contact transparencies which are necessary to form Andreev bound states. Understanding the distribution of supercurrent in graphene multiterminal Josephson junctions is one step in the search for these states. We report on the experimental investigation of transport in four-terminal graphene Josephson junctions with current control or phase control by up to two superconducting loops and flux lines. We observe magnetic interference patterns in two-terminal measurements and critical current surfaces by controlling a total of three currents or phases in multiterminal measurements, the results show excellent agreement with theoretical simulations.

[1] R.P. Riwar et al., Nat Commun 7, 11167 (2016).

TT 73.11 Thu 12:15 CHE/0089

Preserving the Josephson coupling of twisted cuprate junctions via tailored silicon nitride circuits boards — •Tommaso Confalone[1,2], Kornelius Nielsch[1,2], Golam Haider[1], and Nicola Poccia[1,3] — [1]IFW Dresden — [2]TU Dresden — [3]U. Naples

The fabrication of van der Waals (vdW) Josephson junctions (JJs) using the cuprate superconductor $Bi_2Sr_2CaCu_2O_{8+\delta}$ (BSCCO) remains limited by the material's extreme sensitivity to heat and chemical processing, which hinders the integration of high-quality junctions into functional device architectures. Although the cryogenic stacking technique (CST) has enabled atomically sharp BSCCO interfaces with preserved superconducting properties [1], conventional CST-based devices rely on post-assembly contacting strategies that degrade junction performance or restrict circuit complexity. Here, we present a CST-compatible contact scheme in which electrodes embedded in a silicon nitride membrane are directly transferred onto the BSCCO junction during assembly [2]. This membrane-based transfer eliminates high-temperature or chemically aggressive steps and preserves interface integrity. Using this approach, we realize twisted BSCCO JJs exhibiting the strongest Josephson coupling reported to date. The technique is fully compatible with ultra-high-vacuum (UHV) environments, enabling integration with emerging UHV-based vdW fabrication platforms. These results underscore the critical role of contact engineering and open the path for exploring the fundamental properties of these devices.

[1] Science 382,1422 (2023)
[2] Small e06520 (2025)

TT 73.12 Thu 12:30 CHE/0089

Cooper quartets in frustrated Josephson junction arrays — •Erik Lennart Weerda[1], Matteo Rizzi[1,2], Michele Burrello[3] und Olav Fredrik Syljuåsen[4] — [1]Forschungszentrum Jülich — [2]Universität zu Köln — [3]University of Pisa — [4]University of Oslo

Josephson junction arrays in the shape of the dice lattice are the main candidates for a mesoscopic realization of superconductivity mediated by Cooper quartets of charge 4e. Here, we analyze numerical signatures of this exotic phase emerging when these superconducting arrays are frustrated by the insertion of 1/3 of a flux quantum per rhombic plaquette. Through the simulation of relaxation dynamics and two-dimensional infinite tensor network techniques, we examine the related classical XY model at finite temperature. We evaluate the characteristic properties of the supercurrent in this system, its correlation functions, and entropy. We also consider the effects of Josephson energy and flux disorder typical of Josephson junction arrays, and we address the role of charging energies in the full two-dimensional quantum model. Our results indicate that the peak of critical currents and temperatures at frustration 1/3 corresponds to a Cooper quartet phase, and the related superconducting-insulating phase transition is caused by the deconfinement of half-vortices.