TT 11: Superconductivity: Tunneling, Josephson Junctions, SQUIDs

Time: Monday 15:15–18:00 Location: H 3010

Invited Talk TT 11.1 Mon 15:15 H 3010

Superconducting Quantum Interference Filters — •Nils Schopohl — Institut für Theoretische Physik der Universität Tübingen

Basic principles of Josephson junction based interferometer arrays are reviewed. Key features of parallel and also serial Superconducting Quantum Interference Filters (SQIFs) are explained in detail. It is shown that SQIF interferometers can be engineered to have a specific voltage output pattern vs. magnetic field that is well suited for applications in magnetometry and also microwave sensorics.

TT 11.2 Mon 15:45 H 3010

Tailored Josephson phase: 0, π and 0–π SIFS Josephson junctions — •Martin Weides[1], Alexey Bannykh[1], Uthayasankaran Peralagu[1], Judith Pfeiffer[2], Matthias Kemmler[2], Dieter Koelle[2], Reinhold Kleiner[2], and Edward Goldobin[2] — [1]Institute for Solid State Research, Research Centre Jülich — [2]Physikalisches Institut - Experimentalphysik II,

In superconducting/ferromagnet (S/F) systems the superconducting wave function extends into the ferromagnet with a damped oscillatory behavior. This results in novel and interesting physics, such as the possibility to realize a π Josephson junction (JJ) — a JJ with the phase drop of π in the ground state. Recently, we fabricated Nb/Al_2O_3/NiCu/Nb JJs with uniform as well as step-like ferromagnetic layer to obtain 0, π and 0-π JJs[1,2].
Here we present our recent results on planar SIFS JJs with F-layer made of Ni, and compare them with the theory in the clean/dirty limit and with experiments by other groups. The critical current density in the π state is larger and the order parameter decay is weaker than for π JJs made using weak ferromagnetic alloys, e.g. NiCu.
The 0–π boundary in JJs with a step-like F-layer thickness may give rise to a pinned spontaneous vortex of supercurrent with magnetic flux $\leq |\Phi_0/2|$. Latest experiments on short and long stepped SIFS JJs (0–π, 0–π–0 etc.) will be discussed.

[1] M. Weides *et al.*, Phys. Rev. Lett. **97**, 247001 (2006)
[2] M. Weides *et al.*, Appl. Phys. A **89**, 613–617 (2007)

TT 11.3 Mon 16:00 H 3010

Magnetic flux dynamics in 0, π and 0-π SIFS Josephson junctions — •Judith Pfeiffer[1], Martin Weides[2], Matthias Kemmler[1], Alexey K. Feofanov[3], Jürgen Lisenfeld[3], Dieter Koelle[1], Alexey V. Ustinov[3], Reinhold Kleiner[1], and Edward Goldobin[1] — [1]Physikalisches Institut-Experimentalphysik II and Center for Collective Quantum Phenomena, Universität Tübingen, D-72076 Tübingen, Germany — [2]Center of Nanoelectronic Systems for Information Technology (CNI), Research Centre Jülich, D-52425 Jülich, Germany — [3]Physikalisches Institut III, Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We present experimental and numerical studies of high quality underdamped Superconductor-Insulator-Ferromagnet-Superconductor (SIFS) Josephson junctions fabricated as Nb/Al_2O_3/$Cu_{40}Ni_{60}$/Nb heterostructures. Varying the thickness of the ferromagnetic barrier one can fabricate 0, π and 0-π junctions. The dynamic and static properties of these junctions are studied by measuring the I-V characteristic and critical current I_c vs. magnetic field H. Using microwave spectroscopy we have investigated the eigenfrequencies of a 0, π and 0-π Josephson junction in the temperature range 4.2 K...300 mK. Harmonic, subharmonic and superharmonic pumping is observed in experiment and the experimental data are compared with numerical simulations. Perfoming thermal escape measurements at temperatures down to 300 mK we try to reach the quantum tunnelling regime.

TT 11.4 Mon 16:15 H 3010

Self resonances in Josephson π-junctions — •Georg Wild, Achim Marx, and Rudolf Gross — Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany

Due to their potential application as π-phase shift elements Josephson junctions with ferromagnetic interlayer have attracted much interest. We have developed a self-aligned multilayer process for the fabrication of superconductor/insulator/ferromagnetic metal/superconductor (SIFS) Josephson junctions (S=Nb, I=Al_2O_3, F=NiPd). Our junctions show RCSJ-like current-voltage characteristics (IVCs) and a Fraunhofer diffraction pattern for the magnetic field dependence of the critical current I_c. The dependence of the I_cR_n-product on the ferromagnet thickness shows a clear crossover between the zero- and the π-state. The π-coupled multilayers show critical current densities of about 50 A/cm^2 and I_cR_n-products of about 20 μV at $T = 1.5$ K. The IVCs of these junctions show both Fiske resonances and zero field steps. The height of the Fiske steps can be fitted by Kulik's theory. Fitting the measured height of the Fiske steps of different order we derived quality factors varying between 20 and 40.
This work was supported by the DFG via SFB 631 and the Excellence Initiative via NIM.

15 min. break

TT 11.5 Mon 16:45 H 3010

Advanced models of Josephson junction arrays (exchanged with TT 11.9) — •Carsten Hutter[1], Kai Stannigel[1,2], Eric Tholén[3], Jack Lidmar[4], and David Haviland[3] — [1]Department of Physics, Stockholm University, Sweden — [2]Institut für theoretische Festkörperphysik, Universität Karlsruhe, Germany — [3]Nanostructure Physics, Royal Institute of Technology, Stockholm, Sweden — [4]Department of Physics, Royal Institute of Technology, Stockholm, Sweden

One-dimensional Josephson junction arrays are interesting in many contexts. For instance, they can undergo quantum phase transitions [1], but they can also be used as a tunable environment in the study of other tunnel junctions or SQUIDs [2]. Here we investigate a model for the array, which besides the Josephson junction and capacitance to ground additionally includes a stray inductance for each array element. For certain parameters, the dynamics of the system change drastically: In the phase regime, the impedance becomes purely imaginary in a parameter-dependent frequency range. We further find a gap in the dispersion relation for the same frequency range. We suggest a modified array with two different junctions per array element, in which this behaviour can be observed more easily.

[1] S.L. Sondhi et al., RMP 69, 315 (1997)
[2] S. Corlevi et al., PRL 97, 096802 (2006)

TT 11.6 Mon 17:00 H 3010

Fabrication and performance of Niobium-microsquids — •Martin Batzer[1], Georg Schmidt[1], Charles Gould[1], Laurens Molenkamp[1], and Wolfgang Wernsdorfer[2] — [1]Julius-Maximilians-Universität Würzburg — [2]Institut Néel, CNRS Grenoble

Microsquids are useful instruments to detect and measure strongly localized ultrasmall magnetic moments. Here we present the fabrication and characterization of Niobium-based microsquids with diameters equal to or less than 1 μm by dry-etching. In order to avoid degradation during processing, the Nb-layer needs to be covered by a protective layer directly after the Nb-deposition. This protective layer mainly determines the further processing steps. The layers used for our experiments either consist of 15 nm of Nb covered by 2 nm of Si or of 30 nm of Nb covered by a bi-layer of 10 nm of Al and 10 nm of Ru. For the patterning process, a metal mask is patterned on top of the multilayer by electron beam lithography and lift-off. RIE-etching in a mixture of CHF_3 and O_2 is used to transfer the pattern into the niobium. For the tri-layer an additional Ar^+-etch is necessary to remove the Ru and Al layer. For both layer systems working microsquids have successfully been fabricated. The best resolution that we obtain in preliminary measurements is $\Phi_0/200$. We anticipate that additional shielding and optimization of the read out electronics will allow for a lower noise level and thus higher resolution.

TT 11.7 Mon 17:15 H 3010

Josephson spin currents in triplet superconductor junctions — •Philip Brydon and Dirk Manske — Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany

The interplay of triplet superconductivity and magnetism leads to unconventional Josephson behaviour in junctions combining these two phases. This is shown, for example, by the dependence of the Josephson current on the alignment of the barrier magnetic moment with the bulk superconductor **d**-vectors in the triplet-superconductor–ferromagnet–triplet-superconductor (TFT) junction studied by P. M.

R. Brydon *et al.* (cond-mat/0709.2918). In general, the Josephson effect between triplet superconductors allows not only for a spontaneous charge current, but also a spontaneous spin current. Using a quasiclassical Green's function theory, we investigate the spin current through the TFT junction in the ballistic regime. Results for the dependence of the spin current vs phase relations upon the orientation of the two **d**-vectors and the ferromagnetic moment are presented.

TT 11.8 Mon 17:30 H 3010

Josephson current through a single Anderson impurity coupled to BCS leads — •Christoph Karrasch[1], Akira Oguri[2], and Volker Meden[3] — [1]Institut für Theoretische Physik, Universität Göttingen, D-37077 Göttingen, Germany — [2]Department of Material Science, Osaka City University, Sumiyoshi-ku, Osaka 558-8585, Japan — [3]Institut für Theoretische Physik A, RWTH Aachen, D-52056 Aachen, Germany

We investigate the Josephson current $\langle J(\phi)\rangle$ through a quantum dot embedded between two superconductors showing a phase difference ϕ. The system is modeled as a single Anderson impurity coupled to BCS leads, and the functional and the numerical renormalization group frameworks are employed to treat the local Coulomb interaction U. We reestablish the picture of a quantum phase transition occurring if the ratio between the Kondo temperature T_K and the superconducting energy gap Δ or, at appropriate T_K/Δ, the phase difference ϕ or the impurity energy is varied. We present accurate zero- as well as finite-temperature T data for the current itself, thereby settling a dispute raised about its magnitude.

TT 11.9 Mon 17:45 H 3010

Controllable manupulation and SQUID readout of two coupled semifluxons (exchanged with TT 11.5) — •Edward Goldobin, Andreas Dewes, Florian Jessen, Dieter Koelle, and Reinhold Kleiner — Physikalisches Institut–Experimentalphysik II and Center for Collective Quantum Phenomena, University of Tübingen, Auf der Morgenstelle 14, 72076, Tübingen, Germany

Josephson vortices carrying half of the magnetic flux quantum Φ_0 naturally appear in 0-π long Josephson junctions (LJJs) that can be fabricated using various technologies[1–3]. Such semifluxons are pinned at the 0-π boundary, but may have two polarities that can be used for information processing, i.e. the state $\uparrow$, corresponding to the flux $+\Phi_0/2$, and the state $\downarrow$, corresponding to the flux $-\Phi_0/2$. The first proposed prototype of a semifluxon based qubit employs two degenerate ground states $\uparrow\downarrow$ and $\downarrow\uparrow$ of a two semifluxon molecule in 0-π-0 LJJ[4]. It was predicted that such a molecule may be switched between the states $\uparrow\downarrow$ and $\downarrow\uparrow$ by applying a small bias current[5].

Using two SQUIDs placed in front of each semifluxon to readout their magnetic flux (polarity), we experimentally demonstrate the $\uparrow\downarrow\longleftrightarrow\downarrow\uparrow$ transition controlled by uniform dc bias current. We also observe $\uparrow\uparrow$ and $\downarrow\downarrow$ states and controllably changed them to the $\uparrow\downarrow$ and $\downarrow\uparrow$ states.

[1] H. Hilgenkamp et al. Nature **422**, 50 (2003)
[2] M. Weides et al., Phys. Rev. Lett. **97**, 247001 (2006)
[3] E. Goldobin et al., Phys. Rev. B. **72**, 054527 (2005)
[4] E. Goldobin et al., Phys. Rev. B **67**, 224515 (2003)
[5] E. Goldobin et al., Phys. Rev. B.**72**, 054527 (2005).