TT 6: Superconductivity: Tunnelling & Josephson Junctions

Time: Monday 9:30–13:00 Location: H18

TT 6.1 Mon 9:30 H18

Strain Spectroscopy and Decoherence of Two-Level Systems — •Jürgen Lisenfeld, Grigorij Grabovskij, Georg Weiss, and Alexey V. Ustinov — Physikalisches Institut, Karlsruhe Institut für Technologie (KIT), Karlsruhe

Two-level systems (TLSs) are believed to originate in individual atoms which may tunnel between two metastable positions of a disordered-lattice. Recently, TLSs have been identified as a source of noise and decoherence in nanofabricated devices such as MOSFETs, electromagnetic and nanomechanical resonators, detectors, SQUIDs, and superconducting qubits. Despite this ubiquitous importance, the microscopic nature of TLSs has remained obscure until today and is subject of current debate.

We perform novel experiments which allow us to obtain high-resolution images of the TLS distribution in a Josephson junction's tunnel barrier by operating a superconducting phase qubit as a sensitive TLS detector. Using a piezo actuator, we are able to control the mechanical strain in the sample in-situ and find that it strongly affects the TLS frequency and asymmetry energy. We will present data on the characteristic strain dependence of individual TLS's coherence times. These results are relevant for verification of TLS theoretical models within the long-standing effort of revealing the nature of TLS in disordered solids.

TT 6.2 Mon 9:45 H18

Direct observation and characterization of two coherent and strongly coupled TLS using a superconducting phase qubit — •Grigorij J. Grabovskij[1], Jürgen Lisenfeld[1], Jared H. Cole[2], Clemens Müller[3], Georg Weiss[1], and Alexey V. Ustinov[1] — [1]Karlsruhe Institute of Technology, Physikalisches Institut, 76131 Karlsruhe, Germany — [2]Chemical and Quantum Physics, School of Applied Sciences, RMIT University, Melbourne, 3001, Australia — [3]Département de Physique, Université de Sherbrooke, Sherbrooke, Québec, Canada J1K 2R1

Atomic two-level tunneling systems (TLS) are known to be present in amorphous dielectrics. The use of a superconducting phase qubit allows one to study the quantum mechanical properties of individual and coherent TLS in detail. Recently, we demonstrated that controlled flexing of the substrate with a piezo actuator changes the TLS resonance frequency. Some TLS show a hyperbolic frequency dependence [1]. In further measurements, we found and investigated in detail two interacting TLS. The spectroscopically observed frequency-strain dependence exhibits a characteristic S-like shape with clearly visible avoided level crossings, both being clear signatures of the coherently coupled TLS. By measuring and analyzing this 4-level system we determine energies of the states, coupling constants and coherence times. From these data, we estimate the spatial separation between these two interacting TLS.

[1] G. J. Grabovskij *et al.*, Science **338**, 232 (2012)

TT 6.3 Mon 10:00 H18

Superconductivity induced by carrier injection into non-superconducting $Bi_2Sr_2CaCu_2O_8$ — •Yilmaz Simsek[1], Yuri Koval[1], Irina Lazareva[1], Christian Steiner[1], Xiaoyue Jin[2], and Paul Müller[1] — [1]Department of Physics, Universität Erlangen — [2]Department of Electrical Engineering and Computer Science, MIT, Cambridge, Massachusetts, USA

The doping-induced phase transition from the antiferromagnetic to the superconducting state is still one of the fascinating subjects of high-Tc superconductors. Unlike doping by oxygen excess, we are able to change the carrier concentration of $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi2212) single crystals by injecting large currents along the c-axis. The injected electrons are trapped in the BiO and SrO layers which is compensated by increasing the hole concentration in the CuO layers. The goal of our contribution is to induce superconductivity in non-superconducting Bi2212. To eliminate the contact resistance, we have fabricated double cross-bar crystal stacks of fully oxygen depleted Bi2212 single crystal which was not superconducting above 4.2 K. Therefore we were able to investigate the evolution of c-axis transport properties from the antiferromagnetic to the superconducting state exclusively by carrier injection. We have also investigated the doping mechanism by carrier injection depending on the number of intrinsic Josephson junction, ambient temperature and doping level of the sample.

TT 6.4 Mon 10:15 H18

Tunable qubit based on a molecule of two fractional Josephson vortices — •Dennis Manuel Heim[1], Karl Vogel[1], Wolfgang Peter Schleich[1], Dieter Koelle[2], Reinhold Kleiner[2], and Edward Goldobin[2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, D-89069 Ulm, Germany — [2]Physikalisches Institut and Center for Collective Quantum Phenomena in LISA$^+$, Universität Tübingen, D-72076 Tübingen, Germany

We propose a concept of a qubit based on two coupled fractional vortices pinned at two artificially created κ discontinuities of the Josephson phase in a long Josephson junction. Each discontinuity can be created by a pair of tiny current injectors with the current $I_{\rm inj}$ applied. We map the dynamics of the system to the dynamics of a single particle in a double-well potential and calculate the effective parameters of this potential. By tuning the discontinuities $\kappa \propto I_{\rm inj}$ during the experiment we are able to control the parameters of the effective double-well potential as well as to initialize the fractional vortex molecule to a desired state. The system can be used to study macroscopic quantum phenomena involving tailored vortex matter.

TT 6.5 Mon 10:30 H18

Tripartite GHZ generation scheme in presence of bosonic baths — •Samuele Spilla[1], Rosanna Migliore[2], Matteo Scala[1], and Anna Napoli[1] — [1]Dipartimento di Fisica, Università di Palermo, via Archirafi 36, 90123 Palermo, Italy — [2]Institute of Biophysics, National Research Council, via U. La Malfa 153, 90146 Palermo, Italy

We analyse an entangling protocol to generate tripartite Greenberger-Horne-Zeilinger (GHZ) states in a system consisting of three superconducting qubits with pairwise coupling. The dynamics of the open quantum system is investigated by taking into account the interaction of each qubit with an independent bosonic bath with an ohmic spectral structure. To this end, a microscopic master equation is constructed and exactly solved. We find that the protocol discussed here is stable against decoherence and dissipation due to the presence of the external baths.

TT 6.6 Mon 10:45 H18

φ Josephson junctions with a tunable current-phase relation — •Hanna Sickinger[1], Adi Lipman[2], Roman Mints[2], Martin Weides[3], Hermann Kohlstedt[4], Dieter Koelle[1], Reinhold Kleiner[1], and Edward Goldobin[1] — [1]Universität Tübingen, Germany — [2]Tel Aviv University, Israel — [3]KIT Karlsruhe, Germany — [4]Universität zu Kiel, Germany

Josephson junctions (JJs) with a ferromagnetic interlayer can be used to fabricate π JJs, which have a phase drop of π in the ground state in comparison to conventional JJs having a phase drop of 0 (0 JJs). One can use these π JJs in superconducting circuits as a device that provides a constant phase shift, i.e. as a π phase battery. A generalization of a π JJ is a φ JJ, which has the phase $\pm\varphi$ in the ground state. The value of φ can be chosen by design and tuned in the interval $0 < \varphi < \pi$. The φ JJs we used in our experiment are fabricated as 0-π JJs with asymmetric current densities in the 0 and π facets [1]. This system can be described by an effective current phase relation [1], which is tunable by an externally applied magnetic field. We present the experimental evidence of such a φ JJ [2]. In particular we demonstrate that: (a) a φ JJ has two states $-\varphi$ and $+\varphi$, (b) the unknown state can be detected (read out) by measuring I_c (I_{c+} or I_{c-}), and (c) we can prepare a particular state by applying a magnetic field or a special bias sweep sequence. The experimental data are in good agreement with the theoretical predictions.

[1] E. Goldobin, et al., Phys. Rev. Lett. **107**, 227001 (2011)
[2] H. Sickinger, et al., Phys. Rev. Lett. **109**, 107002 (2012)

TT 6.7 Mon 11:00 H18

Towards π Josephson Junctions with Fe, Si based Barriers — •Nico Ruppelt[1], Ondrej Vavra[1], Hanna Sickinger[2], Edward Goldobin[2], Dieter Koelle[2], Reinhold Kleiner[2], and Hermann Kohlstedt[1] — [1]Nanoelektronik, Technische Fakultät, Christian-

Albrechts Universität zu Kiel, Germany — [2]Physikalisches Institut, Experimentalphysik II, Universität Tübingen, Germany

π Josephson junctions are promising elements for RSFQ logic [1] and flux qubits [2]. We fabricate and investigate Josephson junctions with barriers made of Si-Fe alloy aiming to achieve high critical current densities j_c in the π state. In order to vary parameters like composition and thickness independently in a single wafer run, a combinatorial sputtering technique for alloy and multi layer deposition of Fe and Si is presented. Our approach is based on a common planetary-type sputter system. Both materials were deposited with monotonic thickness gradients which were aligned perpendicular to each other. Alloys are formed by stacking of alternately deposited submonolayers of Fe and Si. Various Nb/Al based Josephson junctions with FeSi alloy interlayers and different combinations of Si|Fe multilayers were prepared. Electrical I–V characteristics and $I_c(B)$ look as expected (RSJ-like and Fraunhofer-like), while the critical current density j_c as a function of the Fe content demonstrates non-trivial behavior.

[1] T. Ortlepp, et al., Science **312**, 1495–1497 (2006)
[2] A. K. Feofanov, et. al., Nature Physics **6**, 593–597 (2010)

15 min. break

TT 6.8 Mon 11:30 H18

Fractional Flux Quantization in Loops of Unconventional Superconductors — •Florian Loder, Arno P. Kampf, and Thilo Kopp — Center for Electronic Correlations and Magnetism, University of Augsburg, Germany

The magnetic flux threading a conventional superconducting ring is typically quantized in units of $\Phi_0 = hc/2e$. The factor 2 in the denominator of Φ_0 originates from the existence of two different types of pairing states with minima of the free energy at even and odd multiples of Φ_0. Here we show that spatially modulated pairing states exist with energy minima at fractional flux values, in particular at multiples of $\Phi_0/2$. In such states condensates with different center-of-mass momenta of the Cooper pairs coexist. The proposed mechanism for fractional flux quantization is discussed in the context of cuprate superconductors, where $hc/4e$ flux periodicities as well as uniaxially modulated superconducting states were observed.

TT 6.9 Mon 11:45 H18

Quantum critical temperature of a modulated oscillator — Lingzhem Guo[1,2], Vittorio Peano[3], •Michael Marthaler[1], Gerd Schön[1], and Mark Dykman[3] — [1]Institut für Theoretische Festkörperphysik — [2]Department of Physics, Beijing Normal University, Beijing 100875, China — [3]Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA

We show that the rate of switching between the vibrational states of a modulated nonlinear oscillator is characterized by a quantum critical temperature $T_c \propto \hbar^2$. The rate is independent of T for $T < T_c$. Above T_c there emerges a quantum crossover region where the slope of the logarithm of the distribution over the oscillator states displays a kink and the change of the switching rate with T is independent of the modulation. The results demonstrate the limitations of the conventional instanton theory of switching in systems lacking detailed balance.

TT 6.10 Mon 12:00 H18

Quantum phase fluctuations in Josephson junction systems — •Gianluca Rastelli — Universität Konstanz

Coherent Quantum Phase-Slip (CQPS) processes in superconducting systems are an active research topic. They have been studied theoretically [1-3] and experimentally, in 1D Josephson junction chains [4] and in superconducting nanowires [5]. CQPSs are of main interest for the realization of qubits topologically protected against decoherence and for the achievement of a fundamental current standard in quantum metrology [1]. I will discuss CQPSs in Josephson junction rings biased with an external magnetic flux and with an arbitrary (long) range for the electrostatic interaction between the N superconducting islands.I will also present a comparison between the theory and the experimental observations reported by the group of Grenoble.

[1] J. E. Mooij and Y. V. Nazarov, Nat. Physics (2006)
[2] K. A. Matveev et al., PRL (2002)
[3] G. Rastelli et al., arXiv:1201.0539
[4] I. M. Pop et al., Nat. Phys. Lett. (2010)
[5] O. V. Astafiev et al., Nat. Lett. (2012)

TT 6.11 Mon 12:15 H18

Spin-precession-assisted tunneling in hybrid superconducting point contacts — •Cecilia Holmqvist[1], Wolfgang Belzig[1], and Mikael Fogelström[2] — [1]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [2]Department of Microtechnology and Nanoscience - MC2, Chalmers University of Technology, SE-412 96 Göteborg, Sweden

The charge and spin transport properties of a quantum point contact coupled to a nanomagnet depend strongly on the dynamics of the nanomagnet's spin. We analyze the current-voltage characteristics of a junction coupled to a spin whose dynamics is modeled as Larmor precession brought about by an external magnetic field. The interaction between the spin dynamics and the Josephson effect leads to a rich subgap structure due to spin-precession-assisted multiple Andreev reflections. Additionally, the spin current displays Shapiro-like resonances due to the interplay between the ac Josephson current and the Larmor precession.

TT 6.12 Mon 12:30 H18

Josephson supercurrent in a graphene-superconductor junction — •Esmaeel Sarvestani[1] and Seyed Akbar Jafari[2] — [1]Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Department of Physics, Sharif University of Technology, Tehran 11155-9161, Iran

Within the tunneling Hamiltonian formulation for the eight-component spinors, the Josephson critical supercurrent has been calculated in a planar superconductor-normal graphene-superconductor junction. Coupling between superconductor regions and graphene is taken into account by a tunneling Hamiltonian which contains two types of tunneling, intravalley and intervalley tunneling. Within the present tunneling approach, we find that the contributions of two kinds of tunneling to the critical supercurrent are completely separable. Therefore, it is possible to consider the effect of the intervalley tunnelings in the critical supercurrent. The incorporation of these type of processes into the tunneling Hamiltonian exposes a special feature of the graphene Josephson junctions. The effect of intervalley tunneling appears in the length dependence plot of critical current in the form of oscillations. We also present the results for temperature dependence of critical supercurrent and compare with experimental results and other theoretical calculations.

TT 6.13 Mon 12:45 H18

Optical Josephson radiation from a Majorana Josephson junction — •Christoph Ohm and Fabian Hassler — Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany

We consider a voltage-biased Josephson junction between two nanowires hosting Majorana fermions which occur as topological protected zero-energy excitations at the junction. We show that two Majorana fermions localized at the junction, though being neutral excitations, interact with the electromagnetic field and generate coherent radiation similar to the conventional Josephson radiation in a voltage biased Josephson junction. Within a semi-classical analysis of the light field, we find that the optical phase gets locked to the superconducting phase difference and that the radiation is emitted at half of the Josephson frequency. In order to confirm the coherence of the radiation, we study correlations of the light emitted by two spatially-separated junctions in a SQUID geometry taking into account decoherence by spontaneous phase-switchings due to quasi-particle poisoning as well as by thermal effects.