TT 10 Superconductivity - Tunneling, Josephson Junctions, SQUIDs

Zeit: Samstag 08:30–12:45 Raum: TU H104

TT 10.1 Sa 08:30 TU H104

High–T_c SQUIDs With an Unusual Current–Phase Relation — •Christof Schneider[1], German Hammerl[2], Gennadij Logvenov[1], Thilo Kopp[1], John Kirtley[3], Peter Hirschfeld[4], Helene Raffy[5] und Jochen Mannhart[1] — [1]Lehrstuhl für Experimentalphysik VI, Institut für Physik, Universität Augsburg, D-86135 Augsburg — [2]IBM Zurich Research Laboratory, CH 8803 Rueschlikon, Switzerland — [3]IBM Thomas J. Watson Research Center, P.O.Box 218, Yorktown Heights, New York 10598, USA — [4]Department of Physics, University of Florida, Gainesville, Florida 32611, USA — [5]Laboratoire de Physique des Solides, Université de Paris-Sud, 91405 Orsay, France

Current-voltage characteristics of SQUIDs show as a function of the applied magnetic field a periodic variation of the critical current. Usually, the periodicity corresponds to one flux quantum $\Phi_0 = h/2e$. In this contribution we present measurements of high–T_c SQUIDs showing a characteristic periodicity of the critical current of $1/2 \times \Phi_0$ in small magnetic fields. The interpretation of the phase–sensitive experiments is consistent with higher harmonics of the current–phase relation for the Josephson current. They are also consistent with a finite interaction between Cooper pairs, leading to a quartet formation of electrons as a possible admixture to the superconducting condensate.

TT 10.2 Sa 08:45 TU H104

Experimental observation of moving $4\pi-$kinks in Josephson-junction arrays — •Judith Pfeiffer, Marcus Schuster, Abdufarrukh A. Abdumalikov, and Alexey V. Ustinov — Physikalisches Institut III, Universität Erlangen-Nürnberg, 91058 Erlangen

We experimentally study the dynamics of kinks (magnetic vortices) in annular parallel arrays of underdamped Josephson junctions with different discreteness. Parallel arrays of Josephson junctions are described by the discrete sine-Gordon-model. For small discreteness parameters, we measured very precise phase locking resonances. For systems with higher discreteness, we observe bunched states of two moving kinks, which form either a $4\pi-$kink or various bound states of two phase locked $2\pi-$kinks with finite distance between them. To our knowledge, this is the first experimental observation of dynamically stable $4\pi-$kinks, which have been predicted for discrete sine-Gordon systems by Peyrard and Kruskal [1]. Our numerical results agree quantitativly with the experimental data.
[1] M. Peyrard, M. D. Kruskal *Phys. Ref. D **14** (1984), 88*

TT 10.3 Sa 09:00 TU H104

Thermally induced injection of vortices in narrow long Josephson junctions — •Abdufarrukh A. Abdumalikov[1], Mikhail V. Fistul[2], and Alexey. V. Ustinov[1] — [1]Physikalisches Institut III, Universität Erlangen-Nürnberg, D-91058 Erlangen — [2]Theoretische Physik III, Ruhr-Universität Bochum, D-44801 Bochum

We report an experimental and theoretical study of a novel resistive state in ultra-narrow long Josephson junctions induced by thermal fluctuations. In the presence of an externally applied magnetic field, the hysteretic current-voltage characteristics show a low-voltage branch emerging directly from the superconducting state. We explain this feature by random injection of vortices into the junction in the presence of a large high-frequency damping. We obtain the current-voltage characteristics by calculating the dc bias dependent activation rate of the vortex injection. This activation rate is determined by a surface barrier that is controlled by an external magnetic field. Our theoretical analysis, taking into account thermally induced injection of vortices, quantitatively agrees with experimental results.

TT 10.4 Sa 09:15 TU H104

Arbitrary fractional Josephson vortices — •Edward Goldobin, Dieter Koelle und Reinhold Kleiner — Physikalische Institut – Experimentalphysik II, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen

Recently we have suggested and demonstrated experimentally that one can create an arbitrary κ-discontinuity in a long Josephson junction (LJJ) made of conventional superconductors, such as Nb, using a pair of tiny current injectors[1]. In this way one can create and study arbitrary fractional vortices which carry the flux $0\ldots\Phi_0$ proportional to κ or to $2\pi-\kappa$. While for semifluxons ($\kappa=\pi$) a vortex and an antivortex are mirror symmetric, for arbitrary κ-vortices the symmetry is broken. We study several simplest ground states and investigate the boundaries of their stability.

Since κ-vortices are pinned (for $\kappa \neq 2\pi n$) they cannot be moved by a Lorentz force which is induced by an applied bias current — the bias current only changes the shape of κ-vortex. If the bias current is removed, the vortex returns to its original shape performing decaying oscillations around its equilibrium shape. The frequency of these oscillations can be calculated and depends on κ. Using several coupled κ-vortices at some distance from each other one can design artificial "molecules" and 1D "crystals" with programmable eigen-frequencies (energy-bands) with typical frequencies somewhat below the Josephson plasma frequency.
[1] E. Goldobin et al., Phys. Rev. Lett. **92** 057005 (2004).

TT 10.5 Sa 09:30 TU H104

Discrete Breathers in Josephson Ladders — •Marcus Schuster and Alexey V. Ustinov — Physikalisches Institut III, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erwin-Rommel-Straße 1, 91058 Erlangen

We present an extensive study of intrinsic localized modes in ladder arrays of small underdamped Josephson junctions. These modes are time periodic localized dynamic states (named discrete breathers) which have recently been found in a large class of nonlinear lattices (see Ref. [1] for a review).

In experiments and numerical simulations, we investigate the spontaneous formation of intrinsic localized modes and their resonant interaction with linear oscillatory waves of the arrays. We furthermore study the propagation of the extended linear waves (Josephson plasmons) through the localized modes. Numerical simulations indicate the occurrence of a Fano resonance which arises from the time periodic scattering potential formed by the discrete breather. As a consequence, the resonant reflection of linear waves from the intrinsic localized mode is found.
[1] D. Campbell, S. Flach, and Y. S. Kivshar, Physics Today, January (2004), 43.

TT 10.6 Sa 09:45 TU H104

SIFS junctions for Semifluxon Qubits — •M. Weides[1], H. Kohlstedt[1], R. Waser[1], E. Goldobin[2], D. Koelle[2], R. Kleiner[2], and V. Ryazanov[3] — [1]Institut für Festkörperforschung,Forschungszentrum Jülich — [2]Physikalisches Institut –Experimentalphysik II, Universität Tübingen — [3]Institute for Solid State Physics,Chernogolovka, Russia

There are several approaches to realize qubits using π or 0-π Josephson junctions (JJs). Such JJs can be fabricated using a ferromagnetic barrier of thickness d_F between two superconductors, i.e. SFS or SIFS structures. Due to damped spatial oscillations of the order parameter in the F-layer, d_F determines the phase coupling (0 or π) and the critical current density j_c of such JJs. We fabricated SIFS multilayers $Nb/Al_2O_3/Cu_{40}Ni_{60}/Nb$ by magnetron sputtering. Similar JJs without an F-layer (SIS JJs) show $j_c \sim 2.5\,kA/cm^2$, low sub gap current and a large superconducting gap. In SIFS JJs the first side maximum of $j_c(d_F)$ corresponds to the π ground state and is clearly seen in our samples. For applications such as digital logic and qubits, a figure of merit is $V_c = I_c R_n$ in the π state, which for our SIFSs is about $10\,\mu V$ — the highest value obtained so far for SIFS JJs. The appearance of a degenerated semifluxon state at the boundary between 0- π parts[1] is interesting both for fundamental studies and applications. In the quantum limit, semifluxons could be used as quiet qubits or as a playground for testing quantum mechanics. We propose a way of designing 0-π SIFS junctions for the investigation of semifluxons.
[1] E. Goldobin *et al.*, Phys. Rev. B **66**, 100508 (2002).

TT 10.7 Sa 10:00 TU H104

Josephson junctions with nonlinear damping for qubit-RSFQ circuit applications — •A. B. Zorin, M. I. Khabipov, D. V. Balashov, R. Dolata, F.-I. Buchholz, and J. Niemeyer — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

The overdamped Josephson tunnel junctions with resistive shunts are the key elements of the Rapid Single-Flux-Quantum (RSFQ) circuits enabling processing of information presented in quantized leaps of the Josephson phase. The normal metal shunts generate significant current noise even in the quiescent (zero-voltage) state of the Josephson junctions, so an application of such circuits for readout of a Josephson qubit is problematic because of dramatic dephasing. We demonstrate that shunting of tunnel junctions by Superconductor-Insulator-Normal metal (S-I-N) structures having pronounced nonlinear *I-V* characteristics can ensure both sufficient damping for proper functioning of the circuit and negligibly small noise in the quiescent state. Superconducting Nb/AlO_x/Nb junctions shunted by Nb/AlO_x/AuPd junctions of S-I-N type were fabricated and, in agreement with our model, exhibited non-hysteretic *I-V* characteristics at temperatures down to at least 1.4 K.

TT 10.8 Sa 10:15 TU H104

Epitaxial growth of Al/AlOx/Al trilayers for Josephson junction fabrication — •J. Eroms, A.H. Verbruggen, C.J.P.M. Harmans, A.v.d. Enden, P.F.A. Alkemade, A.R.H.F. Ettema, H.W. Zandbergen, and J.E. Mooij — Kavli Institute of Nanoscience Delft, Delft University of Technology, Delft, The Netherlands

Superconducting qubit circuits are mainly built from aluminum based Josephson junctions fabricated by shadow evaporation or in a trilayer process. The aluminum films are polycrystalline in both cases. Charge noise and critical current fluctuations limit the performance of present qubits made from those devices. To achieve a defect free barrier, we explore epitaxial aluminum films as a base material for Josephson junctions. We grow Al/AlOx/Al trilayers on Si (111) wafers in a molecular beam epitaxy system. The films are characterized *in situ* with RHEED and after growth with high-resolution TEM, Kikuchi backscattering and X-ray reflectivity measurements. The bottom Al layer grows epitaxially on the Si subtrate, the oxide barrier appears amorphous, but very smooth, and the top Al layer is polycrystalline, but with Al (111) planes still parallel to the Si (111) planes.

TT 10.9 Sa 10:30 TU H104

$1/f$ noise measurements on sub-micron Josephson junctions — •J. Eroms, J.H. Plantenberg, R.N. Schouten, A.H. Verbruggen, C.J.P.M. Harmans, and J.E. Mooij — Kavli Institute of Nanoscience Delft, Delft University of Technology, Delft, The Netherlands

Superconducting qubits belong to the most promising systems in solid state quantum information processing. They are explored by a number of groups in different configurations, and control of single and two-qubit systems is progressing rapidly. However, decoherence is still a serious issue. Low-frequency fluctuations in the critical current are believed to be an important source of decoherence, as was pointed out e.g. in Ref. 1. This article also gives a universal noise figure based on noise measurements published over the last two decades. Tocharacterize and improve our junction fabrication we have therefore measured $1/f$ noise in the tunnel resistance of sub-micron Josephson junctions at temperatures down to 300 mK. We used a bridge configuration of two identical junctions and measured the voltage noise with a cross-correlation technique. The noise in our devices was significantly lower than the value expected from the data in Ref. 1.

[1] D.J. Van Harlingen *et al.*, Phys. Rev. **B 70**, 064517 (2004).

TT 10.10 Sa 10:45 TU H104

Experiments with Josephson vortex ratchets — •Edward Goldobin[1], Markus Beck[1], Dieter Koelle[1], Reinhold Kleiner[1] und Michael Siegel[2] — [1]Physikalische Institut – Experimentalphysik II, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen — [2]Institut für Mikro- und Nanoelektronische Systeme, Universität Karlsruhe, Hertzstr. 16, 76187 Karlsruhe

We investigate experimentally a Josephson vortex ratchet — a fluxon in an asymmetric periodic potential driven by a force with zero time average. The highly asymmetric periodic potential is created in underdamped annular long Josephson junction by means of a current injector[1]. Experimental characterization shows good asymmetry of the constructed potential. We have measured the ratchet effect for driving forces with different spectral content. At low frequencies ($\sim$ 100 Hz) we obtained smooth rectification curves $V_{dc}(I_{ac})$ for different amplitudes of the potential and driving shapes. For monochromatic high frequency drive the rectified voltage becomes quantized. At very high frequencies we also observe half-period dynamics, current reversal and chaotic behavior. Such effects can be reproduced in simulation and associated with the inertial mass of a fluxon.

[1] E. Goldobin et al., Phys. Rev. E **63**, 031111 (2001).

Pause

TT 10.11 Sa 11:15 TU H104

Elektrische Untersuchung serieller intrinsischer Josephsonkontaktarrays an dünnen $Tl_2Ba_2CaCu_2O_{8+x}$ Schichten auf r-cut Saphir und 20° vicinalem $LaAlO_3$ — •Michael Mans[1], Alexander Grib[2], Matthias Büenfeld[1], Ralf Bechstein[1], Frank Schmidl[1], Henrik Schneidewind[3] und Paul Seidel[1] — [1]Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Helmholtzweg 5, 07743-Jena, Deutschland — [2]Physics Department, Kharkov National University, 61077 Kharkov, Ukraine — [3]IPHT Jena, Albert - Einstein - Str. 9, 07745-Jena, Deutschland

Zur Messung intrinsischer Josephsoneffekte wurden TBCCO Schichten zum einen auf Saphir hergestellt und zu Mesas strukturiert, zum anderen auf 20° vicinalem $LaAlO_3$ hergestellt und zu brückenartigen Strukturen strukturiert. Für eine Anwendung dieser Kontaktarrays ist es wichtig eine Synchronisation der Kontakte zu erreichen. Aus diesem Grund haben wir die Arrays in Resonatoren platziert. Die Mesas zeigen sehr große Widerstände an der TBCCO-Gold Grenzflächen der Topelektrode, die jedoch durch Anlegen einer geeigneten Spannung gezielt verändert werden können. So sind die zuvor nicht messbaren Äste der U-I-Kennlinie sichtbar zu machen. Für die brückenartigen Kontaktarrays wird gezeigt, wie sich ein zusätzlicher normalleitender Shunt auf die Möglichkeit der Synchronisation auswirkt. Sie wurden hierzu mit Goldschichten versehen und in einem Resonator platziert. Numerische Simulationen an einem geshunteten Array aus 5 Kontakten zeigen deren erfolgreiche Synchronisation. Diese Arbeit wurde gefördert durch die DFG (Nr. Se 664/10-3)

TT 10.12 Sa 11:30 TU H104

Novel Josephson Effect in Triplet Superconductor - Ferromagnet - Triplet Superconductor Junctions — •Boris Kastening[1], Dirk K. Morr[1,2], Dirk Manske[3], and Karl Bennemann[1] — [1]Institut fuer Theoretische Physik, Freie Universitaet Berlin, 14195 Berlin, Germany — [2]Department of Physics, University of Illinois at Chicago, Chicago, IL, U.S.A. — [3]Max-Planck-Institut fuer Festkoerperforschung, Heisenbergstrasse 1, 70569 Stuttgart, Germany

We predict a new type of Josephson effect to occur in Triplet Superconductor - Ferromagnet - Triplet Superconductor Josephson junctions. In addition to the dependence of I_J on the phase difference between the superconductors, we show that a novel dependence on the relative orientation between the ferromagnetic moment and the **d**-vectors describing the superconducting pairing symmetry exists. This dependence can be used to build Josephson switches, in which the Josephson current can either be turned on or off or can be made to exhibit a square-wave oscillation.

TT 10.13 Sa 11:45 TU H104

Intrinsic tunneling in perovskite derivatives: From superconductivity to ferroelectricity — •Y. Koval[1], F. Chowdhury[1], P. Müller[1], F. Lichtenberg[2], and J. Manhart[2] — [1]Physikalisches Institut III der Universität Erlangen-Nürnberg, Erwin-Rommel Str. 1, 91058 Erlangen, Germany — [2]Experimentalphysik VI der Universität Augsburg, D-86135 Augsburg, Germany

There is a variety of extensions of the basic perovskite crystalline structure. Intercalating the perovskite octahedra with additional layers can result in superconductivity in the high-T_c materials, or in ferromagnetism in some Ruddlesden-Popper phases. In many cases the crystalline sheets of the layered structure alternate between conducting and insulating regions. As a consequence, electrical transport perpendicular to the layers is provided by tunneling. This can range from intrinsic Josephson effects in the high-T_c superconductors to interesting permanent memory effects in titanate based layered perovskites. We present a summary of our recent results.

TT 10.14 Sa 12:00 TU H104

Magnetoresistance of a mesoscopic DC SQUID — •Paul Goldbart, David Pekker, David Hopkins, and Alexey Bezryadin — Department of Physics, University of Illinois at Urbana-Champaign, 1110 West Green Street, Urbana, Illinois 61801-3080, U.S.A.

We analyze an all-superconducting mesoscopic DC SQUID, comprising a pair of thin-film strips connected by a pair of parallel ultra-narrow wires. We focus on the magnetoresistance of the device in the size range in which the strips are narrower than the penetration depth (i.e. the mesoscopic regime), and especially on the low-magnetic-field regime, in which no vortices are present in the strips. The resistance originates in dissipative order-parameter fluctuations in the wires, and its magnetic-field dependence comes from the phase-gradient of the order parameter in the strips, associated with screening currents. We present a theory of the magnetoresistance of this mesoscopic DC SQUID, based on the Langer-Ambegaokar-McCumber-Halperin theory of intrinsic resistance. We compare this theory with recent experimental data, and discuss why the device can be regarded as a superconducting phase gradiometer.

TT 10.15 Sa 12:15 TU H104

Supraleitende dünne Scheiben und SQUIDs mit und ohne Vortizes. — •Ernst Helmut Brandt — Max-Planck-Institut für Metallforschung, Stuttgart

Für supraleitende dünne Filme in Form runder oder rechteckiger Scheiben mit und ohne zentralem Loch und radialem Schlitz wird die Verteilung von Suprastrom und lokalem Magnetfeld berechnet aus der Maxwell-London-Theorie mit beliebiger magnetischer Eindringtiefe $\Lambda = \lambda^2/d$. Die Ströme können hervorgerufen werden a) durch ein senkrecht angelegtes Magnetfeld, b) durch im Loch eingefangenen Magnetfluss, c) durch Vortizes. Die Anwendung auf SQUIDs (Superconducting Quantum Interference Devices) wird diskutiert. Außerdem wird eine sehr effektive numerische Methode vorgestellt zur Berechnung des idealen periodischen Vortexgitters in Filmen beliebiger Dicke aus der Ginzburg-Landau-Theorie.

TT 10.16 Sa 12:30 TU H104

Sheet current density distribution in a SQUID washer probed by vortices — •Dietmar Doenitz[1], Matthias Ruoff[1], Rainer Straub[1], Ernst Helmut Brandt[2], John R. Clem[3], Reinhold Kleiner[1] und Dieter Koelle[1] — [1]Universität Tübingen, Physikalisches Institut - Experimentalphysik II, Auf der Morgenstelle 14, D-72076 Tübingen — [2]Max-Planck-Institut für Metallforschung, D-70506 Stuttgart — [3]Ames Laboratory - DOE and Department of Physics and Astronomy, Iowa State University, Ames Iowa 50011, USA

We use Low Temperature Scanning Electron Microscopy (LTSEM) to image vortices in YBCO washer SQUIDs. The imaging is based on the electron-beam-induced local displacement of vortices, which is detected as a flux change $\Delta\Phi$ in the SQUID. The function $\Phi(\vec{r})$ describing the amount of flux a single vortex couples into the SQUID hole is directly measured by the SQUID. The scalar stream function $G(\vec{r}) = \frac{1}{\Phi_0} \cdot \Phi(\vec{r})$ determines contrast C ($\propto |\vec{\nabla} G|$) and direction $\hat{d}$ ($\parallel \vec{\nabla} G$) of the vortex signals. When there is a ring current I flowing around the SQUID loop, the vortex-free sheet current density distribution is $\vec{J} = I \cdot (\hat{z} \times \vec{\nabla} G)$, leading to $|\vec{J}(\vec{r})| \propto C$ and $\hat{J} \perp \hat{d}$. This allows to extract full information on the sheet current density distribution at every position a vortex has been imaged, thus using the vortices as local detectors for $\vec{J}$. Our experimental results from vortex imaging are in very good agreement with numerical calculations of $\vec{J}(\vec{r})$.