TT 51: Superconductivity: Tunneling, Josephson Junctions, SQUIDs

Time: Wednesday 15:00–19:00 Location: H19

TT 51.1 Wed 15:00 H19

Investigation of niobium structures for micro-SQUIDs — •Sandra Gottwals[1], Frank Heyroth[2], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Germany — [2]Interdisziplinäres Zentrum für Materialwissenschaften, MLU Halle-Wittenberg, Germany

In the presence of the Spin-Nernst-Effect a temperature gradient generates spin accumulations in a metal film. The magnetic moment of these accumulations causes a magnetic field. We intend to measure these low magnetic fields using Nb-based micro-SQUIDs. Superconducting Niobium layers are deposited by e-beam evaporation and protected by capping layers either from Ru or Si. The Niobium layers are patterned by e-beam lithography. We have fabricated test stripes with different width varying from 1000 nm to 20 nm. We will present structural and electrical characterization of Nb stripes patterned by different etching processes. Most of the structures show Ohmic behavior at room temperature. At low temperature a transition to the superconducting state is observed with a transition temperature depending on layer thickness and structures size.

TT 51.2 Wed 15:15 H19

Microwave resonators with high kinetic inductance made from superconducting AlO_x — •Sebastian T. Skacel[1], Micha Wildermuth[1], Julian Münzberg[1], Jan N. Voss[1], Marco Pfirrmann[1], Lucas Radtke[1], Sebastian Probst[1], Martin Weides[1,2], Hannes Rotzinger[1], and Alexey V. Ustinov[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, D-76131 Karlsruhe, Germany — [2]Institute of Physics, Johannes Gutenberg University Mainz, D-55128 Mainz, Germany

We present superconducting resonators made out of AlO_x with a kinetic inductance fraction - the ratio between kinetic and total inductance of the resonator - close to unity and high quality factors. We show measurements of coplanar waveguide resonators with ultra high impedances and therefore allowing for compact design in the microwave regime. For instance, a coplanar $\lambda/4$ type resonator with resonance frequency of about 5 GHz can be reduced to a length of 180 μm. The resonator impedance depends on the geometry, i.e. length and the width of the central conductor, and its missmatch factor with the 50 Ω feedline changes from about 5 to 30. This also influences the resonator quality factor, due to the altered coupling.
The resonators are fabricated in a simple single layer process starting with the sputter deposited aluminium oxide (AlO_x) on a silicon substrate, followed by optical lithography and reactive ion etch process.

TT 51.3 Wed 15:30 H19

Development of Nb nanoSQUIDs based on SNS junctions for operation in high magnetic fields — •Viacheslav Morosh[1], Benedikt Müller[2], Maria Jose Martinez-Perez[2], Oliver Kieler[1], Thomas Weimann[1], Alexander Zorin[1], Reinhold Kleiner[2], and Dieter Kölle[2] — [1]Physikalisch - Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig — [2]Physikalisches Institut and Center for Quantum Science in LISA$^+$, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen

Investigation of the magnetization reversal of single magnetic nanoparticles requires SQUIDs with high spatial resolution, high spin sensitivity (a few Bohr magneton μ_B) and at the same time sufficient stability in high magnetic fields. We fabricated dc nanoSQUIDs comprising overdamped SNS sandwich-type (Nb/HfTi/Nb) Josephson junctions using optimized technology based on combination of electron beam lithography and chemical-mechanical polishing. Our nanoSQUIDs have Josephson junctions with lateral dimensions $\leq$ 150 nm $\times$ 150 nm, effective loop areas $<$ 0.05 μm^2 and the distance between the Josephson junctions $\leq$ 100 nm. The feeding strip lines of the width $\leq$ 200 nm have been realized. The nanoSQUIDs have shown stable operation in external magnetic fields at least up to 250 mT. Sufficiently low level of flux noise resulting in spin sensitivity of few tens $\mu_B/Hz^{1/2}$ has been demonstrated. A further reduction of the nanoSQUID size using our technology is possible.

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TT 51.4 Wed 15:45 H19

Ultra low field magnetic resonance imaging for the investigation of hyperpolarized contrast agents — •M. Rudolph[1], T. Misztal[2], P. Antkowiak[1], H. Meyer[2], R. Kleiner[1], D. Koelle[1], K. Scheffler[3], and K. Buckenmaier[3] — [1]Physikalisches Institut and Center for Quantum Science (CQ) in LISA$^+$, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Institut für Anorganische Chemie, Universität Tübingen, Auf der Morgenstelle 18, 72076 Tübingen, Germany — [3]High-Field Magnetic Resonance Center, Max Planck Institute for Biological Cybernetics, Spemannstraße 41, 72076 Tübingen, Germany

In NMR/MRI experiments at ultra low magnetic fields hyperpolarization techniques based on parahydrogen (pH_2) could offer a simple way to circumvent the lack of the low equilibrium polarization of the sample. A chemical exchange reaction, taking place at B_0 fields in the mT range, transfers polarized spins from pH_2 via a transfer catalyst to the sample. This transfer reaction can enhance the sample polarization in B_0 fields in the mT range by a factor of 10^5, offering sample polarizations comparable to polarization fields of 10^3-10^4 T. To investigate these newly developed techniques a SQUID based NMR/MRI system operating at a static magnetic field in the mT range is being developed. By using a SQUID for detecting the NMR Signal, the system can benefit from its very low intrinsic noise level. Additionally, SQUIDs are wide band detectors and can detect the signal of multiple kernels simultaneously. A design of an ultra low field MRI system and first results will be presented.

TT 51.5 Wed 16:00 H19

Sub-gap conductivity of disordered superconducting TaN and NbN thin films — •Marc Scheffler[1], M. Maximilian Felger[1], Moritz Scholze[1], Uwe S. Pracht[1], Martin Dressel[1], Konstantin S. Ilin[2], Michael Siegel[2], and Lara Benfatto[3] — [1]1. Physikalisches Institut, Universität Stuttgart — [2]Institut für Mikro- und Nanoelektronische Systeme, KIT — [3]ISC-CNR and Department of Physics, Sapienza University of Rome

Optical spectroscopy studies provide valuable insight into the characteristics of superconductors, such as the superconducting energy gap and the electrodynamical response of the superfluid condensate and the quasiparticles. Recently, the sub-gap optical conductivity of strongly disordered superconductors has gained substantial attention because of the possibility to observe collective modes that go beyond the classical, BCS-based predictions for the optical properties of superconductors.

We have performed broadband microwave spectroscopy on thin films of NbN (thickness between 3 nm and 20 nm; T_c between 5 K and 13 K) and TaN (thickness 5 nm; T_c around 9 K). The covered temperatures are down to 1.1 K and the frequency range goes up to 50 GHz (which is well below the energy gap). We analyze the real and imaginary parts of the frequency-dependent microwave conductivity and determine the contributions of quasiparticles and Cooper pairs, respectively. We compare these data to Mattis-Bardeen expectations and we discuss them in the light of the ongoing discussion of collective modes in superconductors.

TT 51.6 Wed 16:15 H19

Observation of thermoelectric currents in high-field superconductor-ferromagnet tunnel junctions — •Stefan Kolenda, Michael J. Wolf, and Detlef Beckmann — Institut für Nanotechnologie, Karlsruher Institut für Technologie

We report on the experimental observation of thermoelectric currents in superconductor-ferromagnet tunnel junctions in high magnetic fields [1]. The thermoelectric signals are due to a spin-dependent lifting of particle-hole symmetry, and are found to be in excellent agreement with recent theoretical predictions [2]. The maximum Seebeck coefficient inferred from the data is about -100 μV/K, much larger than commonly found in metalic structures. Our results directly give proof of the coupling of spin and heat transport in high-field superconductors.

[1] S.Kolenda *et al.*, arXiv:1509.05568
[2] A.Ozaeta *et al.*, PRL **112**, 057001 (2014)

TT 51.7 Wed 16:30 H19

"Isolation" of the proximity-induced triplet pairing channel in the superconductor/ferromagnet spin valve — •Pavel

Leksin[1,2], Nadir Garifyanov[2], Andrey Kamashev[2], Aidar Validov[2], Yakov Fominov[3,4], Joachim Schumann[1], Vladislav Kataev[1], Jürgen Thomas[1], Bernd Büchner[1,5], and Ilgiz Garifullin[2] — [1]Leibniz Institute for Solid State and Materials Research IFW Dresden, D-01171 Dresden, Germany — [2]Zavoisky Physical-Technical Institute, Russian Academy of Sciences, 420029 Kazan, Russia — [3]L. D. Landau Institute for Theoretical Physics, Russian Academy of Sciences, 142432 Chernogolovka, Russia — [4]Moscow Institute of Physics and Technology, 141700 Dolgoprudny, Russia — [5]Institute for Solid State Physics, Technical University Dresden, D-01062 Dresden, Germany

We have studied the proximity induced superconducting triplet pairing in CoO_x/Py1/Cu/Py2/Cu/Pb spin-valve structure. By optimizing the parameters of structures we found a full switching between the normal and superconducting states. To observe an "isolated" triplet spin-valve effect we exploited the oscillatory feature of the magnitude of the ordinary spin-valve effect ΔT_c in the dependence of the Py2-layer thickness d_{Py2}. We determined the value of d_{Py2} at which ΔT_c caused by the ordinary spin-valve effect (the difference in T_c between antiparallel and parallel mutual orientation of magnetizations of the Py1 and Py2 layers) is suppressed. For such a sample a "pure" triplet spin-valve effect which causes the minimum in T_c at the orthogonal configuration of magnetizations has been observed.

15 min. break

TT 51.8 Wed 17:00 H19

Coherent emission of terahertz radiation from intrinsic Josephson junctions in $Bi_2Sr_2CaCu_2O_8$ — •Fabian Rudau[1], Raphael Wieland[1], Xianjing Zhou[2,3], Min Ji[2,3], Nickolay Kinev[4], Luyao Hao[2,3], Ya Huang[2,3], Jun Li[2], Peiheng Wu[2], Takeshi Hatano[3], Valery Koshelets[4], Huabing Wang[2,3], Dieter Koelle[1], and Reinhold Kleiner[1] — [1]Physikalisches Institut and Center for Quantum Science (CQ) in LISA$^+$, Universität Tübingen, Germany — [2]Research Institute of Superconductor Electronics, Nanjing University, China — [3]National Institute for Materials Science, Tsukuba, Japan — [4]Kotel'nikov Institute of Radio Engineering and Electronics, Moscow, Russia

Stacks of intrinsic Josephson junctions, made of the high-T_c superconductor $Bi_2Sr_2CaCu_2O_8$, can be used as emitters of electromagnetic waves at terahertz frequencies. Coherent emission from 0.3 to 2.4 THz was detected from large, rectangular or disc-shaped mesa structures. Having a linewidth of only a few MHz, emission powers of several tens of microwatt can be produced for single stacks and up to 0.61 mW for an array of mesas.

Since the mechanisms of synchronizing all the junctions in the stack is still not fully understood, we investigated the temperature distribution and electromagnetic standing waves in such stacks, as well as the generation of terahertz radiation, using a combination of electric transport measurements, direct radiation detection and low temperature scanning laser microscopy. Recent experimental results from our collaboration will be presented and compared to numerical simulations.

TT 51.9 Wed 17:15 H19

Stabilized superconductivity in periodically driven Josephson junction chains — •Junichi Okamoto[1,2,3], Andrea Cavalleri[4,5], and Ludwig Mathey[1,2,3] — [1]Center for Optical Quantum Technologies, University of Hamburg, Hamburg, Germany — [2]Institute of Laser Physics, University of Hamburg, Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [4]Max Planck Institute for the Structure and Dynamics of Matter — [5]University of Oxford

Motivated by recent pump-probe experiments indicating enhanced coherent *c*-axis transport in an underdoped YBCO, a typical high-T_c superconductor, we study a system of capacitively coupled alternating Josephson junctions periodically driven by laser pulses. Using Langevin simulations, we show that the reduction of current fluctuations is realized through the Kapitza effect for high-frequency driving. In this regime superfluid density calculated from the imaginary part of conductivity is indeed enhanced compared to the thermal value. Calculations based on effective models with renormalized parameters explain this enhancement of superfluid density and other features of driven states.

TT 51.10 Wed 17:30 H19

Self-heating in Josephson junction chains: new insight from old circuits — •Jared Cole[1], Michael Marthaler[2], and Timothy Duty[3] — [1]Chemical and Quantum Physics, School of Applied Sciences, RMIT University, Melbourne, Victoria 3001, Australia — [2]Institute für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [3]Centre for Engineered Quantum Systems (EQuS), School of Physics, University of New South Wales, Sydney, New South Wales 2052, Australia

The conduction properties of arrays of Josephson junctions are been studied for decades, yet the experimental results never really match the predictions of the idealised theoretical models. Many reasons have been given for this, including imperfections in the measurement, in the fabrication process or in the theoretical models used. Recently, using a combination of systematic numerical and experimental studies, the gap between theory and experiment is closing. As an example of this, we discuss the role of self-heating in the transport properties of one-dimensional Josephson junction chains. We show tantalising experimental measurements and how these can be compared to various theoretical models for the self-heating processes within the chains.

TT 51.11 Wed 17:45 H19

Quasicharge depinning in bilinear Josephson juncton arrays — •Samuel Wilkinson, Nicolas Vogt, and Jared Cole — Chemical and Quantum Physics, School of Applied Sciences, RMIT University, Melbourne 3001, Australia

Bilinear Josephson junction arrays have been the subject of experimental studies, where interesting threshold, Coulomb drag and current mirror behaviour have been observed. Theoretically, the precise mechanisms are not currently well understood. We have applied the theory of quasicharge depinning, which has previously been successfully in describing linear arrays. Here we present the results of numerical simulations which offer insight into some of the experimentally observed phenomena, and suggests possible new effects which may be observed at high voltages.

15 min. break

TT 51.12 Wed 18:15 H19

Antibunched photons from inelastic Cooper-pair tunneling — •Juha Leppäkangas[1,2], Mikael Fogelström[1], Alexander Grimm[3], Max Hofheinz[3], Michael Marthaler[2], and Göran Johansson[1] — [1]Microtechnology and Nanoscience, MC2, Chalmers University of Technology, Göteborg, Sweden — [2]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]Université Grenoble Alpes, INAC-SPSMS, Grenoble, France

We demonstrate theoretically that charge transport across a Josephson junction, voltage-biased through a resistive environment, produces antibunched photons. We develop a continuous-mode description of the emitted radiation field in a semi-infinite transmission line terminated by the Josephson junction. Within a perturbative treatment in powers of the tunneling coupling across the Josephson junction, we capture effects originating in charging dynamics of consecutively tunneling Cooper pairs. We find that within a feasible experimental setup the Coulomb blockade provided by high zero-frequency impedance can be used to create antibunched photons at a very high rate and in a very versatile frequency window ranging from a few GHz to a THz.

TT 51.13 Wed 18:30 H19

Josephson switching current investigated in a scanning tunneling microscope junction — •Jacob Senkpiel[1], Berthold Jäck[1], Matthias Eltschka[1], Markus Etzkorn[1], Christian R. Ast[1], and Klaus Kern[1,2] — [1]Max-Planck-Institut für Festkörperforschung, 70569 Stuttgart — [2]École Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

Employing the $I(V)$-characteristics of a scanning tunneling microscope (STM) Josephson junction to directly determine the local order parameter of a superconductor would give a powerful tool to understand superconductivity on the atomic scale. Recent research in this field led to some valuable insights to this technique [1,2]. Being able to perform not only voltage but also current biased measurements of the same junction gives us a new approach to study the physics involved in the Josephson effect. Interestingly a comparison of the current and the voltage biased measurements shows that the Josephson switching current corresponds to the current value of the maximum in the voltage biased measurement. In contrast to conventional planar tunneling geometries, an STM allows for precise control of the tunneling resistance and makes it possible to tune the Josephson coupling energy. Using this ability we find, that the switching current is proportional to the square of the Josephson coupling energy.

[1] B. Jäck et al., APL **106**, 062904 (2015)
[2] C.R. Ast et al., arXiv:1510.08449

TT 51.14 Wed 18:45 H19

Cooper pair splitters beyond the Coulomb blockade regime
— •Ehud Amitai[1], Rakesh P. Tiwari[1], Stefan Walter[2], Thomas L. Schmidt[3], and Simon E. Nigg[1] — [1]Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland — [2]Institute for Theoretical Physics, University Erlangen Nuernberg, Staudtstrasse 7, 91058 Erlangen, Germany — [3]Physics and Materials Science Research Unit, University of Luxembourg, L-1511 Luxembourg

We consider the setup of a conventional s-wave Cooper pair splitter. However, we consider the charging energies in the quantum dots to be finite and smaller than the superconducting gap. We find analytically that at low energies the superconductor mediates an inter-dot tunneling term, the spin symmetry of which is influenced by a finite Zeeman field. This effect, together with an electrical tuning scheme of the quantum dot levels, can be used to engineer a non local triplet state on the two quantum dots, thereby extending the non-local state engineering capabilities of the Cooper pair splitter system.