TT 48: Superconductivity: Tunnelling, Josephson Junctions, SQUIDs 2

Time: Wednesday 15:00–17:45 Location: HSZ 201

TT 48.1 Wed 15:00 HSZ 201

Josephson parametric amplifier with mixing of three traveling waves — •Alexander B. Zorin, Judith Dietel, Ralf Dolata, and Marat Khabipov — Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany

Due to accessible quantum-limited performance Josephson parametric amplifiers are important tools in quantum information technology and the traveling-wave Josephson parametric amplifiers with inherently large bandwidth are especially desired for fast signal processing and frequency multiplexing. So far these devices have required the four-wave mixing condition to operate and special compensation of unavoidable phase mismatch [1,2]. We show, however, that there is an elegant way to realize efficient three-wave mixing at negligible phase mismatch without applying sophisticated dispersion engineering. Our Josephson traveling-wave parametric amplifier is based on a chain of rf-SQUIDs forming a metamaterial transmission line possessing quadratic nonlinearity [3]. It can have large (exponential) gain, wide bandwidth, and ultimately quantum-limited characteristics, outperforming its state-of-the-art four-wave counterparts. Recent experimental data obtained with first Nb circuits at temperature $T = 4.2$ K will also be reported.

[1] T. C. White *et al.*, Appl. Phys. Lett. **106**, 242601 (2015).
[2] C. Macklin *et al.*, Science **350**, 307 (2015).
[3] A. B. Zorin, Phys. Rev. Applied **6**, 034006 (2016).

TT 48.2 Wed 15:15 HSZ 201

Superconducting nanowire loop capacitively coupled to a microwave resonator — •Hannes Rotzinger[1], Sebastian T. Skacel[1], Jochen Braumüller[1], Andre Schneider[1], Hans Mooij[2], and Alexey V. Ustinov[1] — [1]Karlsruher Institut für Technologie, Karlsruhe, Deutschland — [2]Kavli Institute of NanoScience, Delft, the Netherlands

We present continuous and pulsed microwave measurements of a high-impedance superconducting loop with an embedded superconducting nanowire of 20 nm width and 250 nm length. In the experiment, we monitor the dispersive shift of a microwave resonator which couples capacitively to the loop. When applying weak magnetic fields, the system shows pronounced anti-crossings at the resonator frequency that occur at stable and reproducible fields. At larger fields, the anti-crossings are shifted hysteretically by magnetic flux values comparable to the magnetic flux quantum per loop area. We analyse the anti-crossings by two-tone measurements and find signatures of several specific two-level states at different magnetic fields. Rabi oscillations as well as T1 and T2 coherence times are measured by applying microwave pulses.

TT 48.3 Wed 15:30 HSZ 201

A niobium based three-axis vector nanoSQUID — •Katrin Meyer[1], Maria José Martínez-Pérez[1], Benedikt Müller[1], Diego Gella[1], Viacheslav Morosh[2], Thomas Weimann[2], Roman Wölbing[1], Javier Sesé[3], Oliver Kieler[2], Reinhold Kleiner[1], and Dieter Koelle[1] — [1]Physikalisches Institut and Center for Quantum Science (CQ) in LISA$^+$, Universität Tübingen, Germany — [2]Fachbereich Quantenelektronik, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Laboratorio de Microscopías Avanzadas (LMA), Instituto de Nanociencia de Aragón (INA), Universidad de Zaragoza, Spain

We present the design, realization, and performance of 3-axis vector nanoSQUIDs [1]. They consist of three mutually orthogonal SQUID nanoloops (two magnetometers, one gradiometer) that allow simultaneous and independent detection of the three components of the vector magnetic moment of individual magnetic nanoparticles (MNPs). All three nanoSQUIDs are realized within an area of a few μm^2 on a single chip. The devices are based on intrinsically shunted Nb/HfTi/Nb Josephson junctions and exhibit linewidths of $\sim 250\,$nm. Operation at 4.2 K in external magnetic fields up to $\sim 50\,$mT is demonstrated, with a flux noise below $\sim 250\,\mathrm{n}\Phi_0/\mathrm{Hz}^{1/2}$ in the white noise limit. Depending on device geometry and MNP position, spin sensitivities down to below $100\,\mu_\mathrm{B}/\mathrm{Hz}^{1/2}$ are achieved. We also present approaches to extend operation to larger external magnetic fields and to improve the spin sensitivity.

[1] M. J. Martínez-Pérez *et al.*, ACS Nano **10**, 8308–8315 (2016).

TT 48.4 Wed 15:45 HSZ 201

NanoSQUID magnetometry of individual cobalt nanoparticles — •Benedikt Müller[1], Maria José Martínez-Pérez[1], Dennis Schwebius[1], Dana Korinski[1], Jianxin Lin[1], Reinhold Kleiner[1], Javier Sesé[2], and Dieter Koelle[1] — [1]Physikalisches Institut and Center for Quantum Science (CQ) in LISA$^+$, Universität Tübingen, Germany — [2]Laboratorio de Microscopías Avanzadas (LMA), Instituto de Nanociencia de Aragón (INA), Universidad de Zaragoza, Spain

We demonstrate the operation of low-noise nanoSQUIDs based on the high critical field and high critical temperature superconductor $YBa_2Cu_3O_7$ (YBCO) as ultra-sensitive magnetometers for single magnetic nanoparticles (MNPs) [1]. The nanoSQUIDs contain grain boundary Josephson junctions and are patterned by focused ion beam milling. They can be operated over extremely broad ranges of applied magnetic field (up to $\sim 1\,$T) and temperature ($0.3\,\mathrm{K} < T < 80\,\mathrm{K}$). Cobalt MNPs with typical size of several tens of nm have been grown directly on top of the sensors by focused electron beam induced deposition. This allows us to investigate the magnetization reversal of individual MNPs with magnetic moments $(1-30)\times 10^6\mu_\mathrm{B}$. The magnetization reversal appears to be thermally activated over an energy barrier, which has been quantified for the (quasi) single-domain particles. These measurements demonstrate that YBCO nanoSQUIDs are exceptional magnetometers for the investigation of individual nanomagnets.

[1] M. J. Martínez-Pérez *et al.*, Supercond. Sci. Technol. **30**, 024003 (2016)

TT 48.5 Wed 16:00 HSZ 201

Charge QUantum Interference Device (CQUID) — Sebastian E. de Graaf[1], •Sebastian T. Skacel[2], Teresa Hoenigl-Decrinis[1,3], Rais Shaikhaidarov[3,4], Hannes Rotzinger[2], Sven Linzen[5], Mario Ziegler[5], Vladimir Antonov[3,4], Evgeni Il'ichev[5,6], Alexey V. Ustinov[2,6], Alexander Ya. Tzalenchuk[1,3], and Oleg A. Astafiev[1,3,4,6] — [1]National Physical Laboratory, Teddington, UK — [2]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Germany — [3]Department of Physics, Royal Holloway University of London, Egham, UK — [4]Moscow Institute of Physics and Technology, Moscow, Russia — [5]Leibniz Institute of Photonic Technology, Jena, Germany — [6]Russian Quantum Center, National University of Science and Technology MISIS, Moscow, Russia

Quantum mechanics postulate a duality between magnetic flux and electric charge in superconducting devices. We present the experimental realisation of the Charge QUantum Interference Device (CQUID), exactly dual to the conventional Superconducting QUantum Interference Device (SQUID). The CQUID is made out of 3.3 nm thin Atomic Layer Deposited superconducting NbN film. Two narrow constrictions connected in series via a small island act as barriers for flux tunnelling across the superconductor, carried by quantum phase slips. A gate electrode can tune the charge induced on the island, making the CQUID a charge sensitive interferometer based on the Aharonov-Casher effect. We demonstrate control of flux tunnelling interference across a continuous superconductor by an induced charge.

15 min. break.

TT 48.6 Wed 16:30 HSZ 201

Recent insights in low-frequency excess flux noise of superconducting quantum devices — •Sebastian Kempf, Anna Ferring, David Uhrig, Andreas Fleischmann, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

Low-frequency excess flux noise strongly diminishes the performance of flux-sensitive superconducting quantum devices. It limits, for example, the coherence time of flux and phase qubits and makes SQUID based measurements of low-frequency signals challenging. Recent experiments suggest that low-frequency excess flux noise in Josephson junction based devices originates from the random reorientation of interacting spins located in surface layer oxides or in the interface between the substrate and the device wiring. Though this explanation proves to be generally correct, the physical nature of these spins, i.e.

their origin as well as their interaction mechanisms, has not be been resolved so far and many questions remain.

In this contribution we present a comprehensive analysis of low-frequency excess flux noise. Our analysis include 373 individual noise spectra that were taken from 84 superconducting quantum devices at temperatures below 1 K. It revealed an evidence for a material and device type dependence of low-frequency excess flux noise and showed that SQUID arrays systematically feature higher noise exponents than single SQUIDs. This somehow facilitates to engineer the shape of magnetic flux noise spectra by choosing a proper device material and type.

TT 48.7 Wed 16:45 HSZ 201

Transmission-Line Resonators for the Study of Individual Two-Level-Systems — •Jan Brehm, Alexander Bilmes, Alexey V. Ustinov, and Jürgen Lisenfeld — Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Parasitic Two-Level-Systems (TLS) arise from microscopic material defects and are one of the main sources of decoherence in superconducting devices such as SQUIDs, resonators and quantum bits (qubits). The high sensitivity of quantum circuits motivates one to build a universal detector for single TLS, which can be applied to various materials. Josephson junction based superconducting qubits, e.g., offer the possibility to resonantly drive individual TLS' and to observe their quantum dynamics using the qubit for TLS readout. Yet, those experiments have been restricted to TLSs hosted in the dielectric tunnel barrier of the qubit's Josephson junctions, which reduces the choice of explorable materials to few dielectrics. Here we show how TLS in thin films can be studied using a superconducting coplanar notch-type resonator whose end is terminated by a capacitor containing TLS in its insulating layer. By tuning TLS via mechanical strain, we observe the signatures of individual strongly coupled TLS in the resonator's reflection spectrum and noise characteristics.

TT 48.8 Wed 17:00 HSZ 201

Finding the Location of Two-Level-Systems within the Josephson Junction of a Superconducting Qubit — •Alexander Bilmes[1], Sebastian Zanker[2], Andreas Heimes[2], Michael Marthaler[2], Gerd Schön[2], Georg Weiss[1], Alexey V. Ustinov[1,3], and Jürgen Lisenfeld[1] — [1]Physikalisches Institut, KIT, 76131 Karlsruhe, Germany — [2]Institut für Theoretische Festkörperphysik, KIT, 76131 Karlsruhe, Germany — [3]Russian Quantum Center, MISIS, Moscow 119049, Russia

Superconducting quantum circuits represent the first solid state quantum bits that are close to fulfilling all criteria to realize a quantum processor. However, a severe coherence-limiting factor have been Two-Level-Systems (TLS) that reside in dielectric layers such as surface-oxides and the tunnel barrier of the junction. The strong coupling of junction-hosted TLS by their electrical dipole moment to the qubit enables us to apply resonant microwave pulses to the circuit and to observe the quantum state evolution of individual TLSs, while the qubit serves for TLS-readout. Such experiments reveal microscopic properties of single TLS and offer possible clues to reduce their impact on the qubit's quality. In a recent experiment we showed that TLS couple to evanescent electronic wave-functions leaking from the junction electrodes into the dielectric: Once the superconducting system is brought out of equilibrium, the TLS' energy relaxation is enhanced by inelastic scattering of BCS-quasiparticles. We exploit this interaction scheme to estimate the TLS' position across the tunnel barrier, providing valuable information at which fabrication step TLS preferably emerge.

TT 48.9 Wed 17:15 HSZ 201

Dielectric properties of disordered thin-film $\mathbf{AlO}_x$ — •Arnold Seiler[1], Saskia Meissner[1], Hannes Rotzinger[1], Stefan Fritz[2], and Georg Weiss[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie — [2]Laboratorium für Elektronenmikroskopie, Karlsruher Institut für Technologie

The nature of atomic tunneling systems (TS) in disordered thin-film dielectric aluminium oxide layers is of great interest. Combined investigation of a variety of fabrication techniques, microstructure analysis of the resulting material, particularly HR-TEM, and measurements of the bulk dielectric properties may give a hint on the nature of the defects.

In this report dielectric measurements in a wide frequency range are presented in order to shed light on the distribution of tunneling systems in AlO_x thin-films and their relaxation to phonons.

Resonant absorption for selected frequencies in the range of 1-6GHz yield the TS density in narrow bands whereas the temperature dependence of the dielectric function gives information on a broad energy range of TS. In the kHz frequency range the application of a magnetic field has a large impact on the dielectric properties which may be a hint that the TS are preferrably located close to the electrodes and interact with quasiparticles.

TT 48.10 Wed 17:30 HSZ 201

Quasiclassical Green's Function Approach to Normal-Metal Quasiparticle Traps — •Raphael Schmit and Frank Wilhelm-Mauch — Saarland University, Theoretical Physics Department

Superconducting qubits, such as the charge or the flux qubit, are thought to store the information needed for quantum information processing. However, unwanted interactions with the qubit's environment lead to decoherence of the qubit and thus information loss. In addition to these extrinsic sources for decoherence, there is also an intrinsic one: the coupling between the qubit and the non-equilibrium quasiparticle excitations in the superconductor the qubit is made of. Decoherence is due to quasiparticle tunneling through a Josephson junction, but there is also an inhomogeneous broadening caused by changes in the occupations of Andreev states in the junction. Both mechanisms are highly depending on the location of the quasiparticles: quasiparticles far away from junctions have much less contribution to decoherence than the ones close to it. While it is difficult to prevent the generation of quasiparticles, trapping them in less active regions of the device seems to provide a practicable way to improve the device performance.

We are aiming to establish a quantitative theory of normal-metal traps simply consisting of an island of normal metal which is in contact with the superconductor. To do so, we are applying a Green's function formalism - the Keldysh technique in the dirty limit with a quasiclassical approximation - to investigate the properties of non-equilibrium quasiparticles in mesoscopic devices.