TT 31: Superconducting Electronics: SQUIDs, Qubits, Circuit QED, Quantum Coherence and Quantum Information Systems 1

Time: Wednesday 9:30–13:00 Location: HSZ 03

TT 31.1 Wed 9:30 HSZ 03

Shining new light on long standing questions: Recent insights into the understanding of low frequency excess flux noise — •Anna Ferring-Siebert, Fabian Kaap, Andreas Fleischmann, Christian Enss, and Sebastian Kempf — Kirchhoff-Institute for Physics, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

Low frequency excess flux noise (LFEFN), which scales as $1/f^{\alpha}$, strongly impairs the performance of superconducting quantum devices (SQDs) such as SQUIDs and Qubits. Although it was believed for quite a long time that its magnitude $\sqrt{S_{\Phi}}$ and exponent α are fairly independent of the device material and inductance, there meanwhile exist hints for the contrary. It is also known that LFEFN somehow depends on the equipment used for device fabrication, but the reason for that remained unknown up to now.
In this contribution, we first discuss the origin of fabrication induced LFEFN as well as means to minimize it. In particular, we show that commercial deposition equipment often yield material layers containing magnetic impurities causing LFEFN. Whithin this context, we further present how we modified commercial sputter sources to reduce LFEFN as well as indications for a correlation between the LFEFN amplitude and the dc-magnetization of deposited material layers. Finally, we discuss recent measurements investigating the dependence of LFEFN on device inductance suggesting that energy sensitivity rather than magnetic flux noise is the more appropriate figure of merit for describing LFEFN.

TT 31.2 Wed 9:45 HSZ 03

Post-production Tile-and-Trim Process for Superconducting Lumped Element Resonators and Transmission Line Resonators in Microwave SQUID Multiplexers — •Felix Ahrens, Patrick Paluch, Daniel Richter, Constantin Schuster, Mathias Wegner, Christian Enss, and Sebastian Kempf — Kirchhoff-Institute for Physics, Heidelberg University, Germany

Microwave SQUID multiplexing (μMUXing) is likely the most promising technique to read out large metallic magnetic calorimeter (MMC) detector arrays. Here, high-quality superconducting GHz resonators based either on transmission lines or lumped-element inductors and capacitors are used for frequency encoding. These resonators are typically designed to have a bandwidth of $\sim$1 MHz to maintain the very fast signal rise time of MMCs and the frequency spacing between two neighbouring channels is set to $\sim$10 MHz to yield a cross-talk level below 10^{-4}. However, due to fabrication inaccuracies, the resonance frequency of micro-fabricated resonators differs very often from the design value and the frequency spacings between neighbouring resonators severely scatter. In order to overcome the resulting μMUX performance degradation e.g. due to an enhanced cross-talk level a post-production fine-tuning of the resonance frequencies is essential. In this contribution we present our post-production tile-and-trim processes allowing to adjust the resonance frequency of both lumped element and transmission line resonators within a microwave SQUID multiplexer.

TT 31.3 Wed 10:00 HSZ 03

Superconducting qubit devices: fabrication suite — •Wei Liu, Kok Wai Chan, Tianyi Li, Johannes Heinsoo, Vasilii Sevriuk, Caspar Ockeloen-Korppi, Jani Tuorila, Juha Hassel, Juha Vartiainen, Kuan Yen Tan, Jan Goetz, and Mikko Mottonen — IQM Finland Oy, Vaisalantie 6, 02130 Espoo, Finland

Scalable quantum computing architecture and fabrication processes have been a hot research topic in the past decade. We focus on the realization of a quantum computer based on superconducting qubits with a fast qubit reset and initialization techniques, utilizing a quantum-circuit refrigerator. We present the fabricated devices and results achieved to date, which includes resonators with high quality factors, $> 10^6$, long qubit lifetime > 0.02 ms and 3D integration techniques such as airbridges.

TT 31.4 Wed 10:15 HSZ 03

Reaching the ultimate energy resolution of a quantum detector — •Bayan Karimi[1], Fredrik Brange[1,2], Danilo Nikolic[3], Joonas T. Peltonen[1], Peter Samuelsson[2], Wolfgang Belzig[3], and Jukka P. Pekola[1] — [1]QuESTech and QTF Centre of Excellence, Department of Applied Physics, Aalto University, 00076 Aalto, Finland — [2]Department of Physics and NanoLund, Lund University, Box 188, SE-221 00 Lund, Sweden — [3]QuESTech and Fachbereich Physik, Universität Konstanz, D-78467, Germany

We present a radio-frequency thermometer based on a zero-bias anomaly of a tunnel junction between a superconductor and proximitized normal metal [1,2]. It features noninvasive detection and essentially uncompromised sensitivity down to the lowest temperatures of below 20 mK in contrast to commonly used finite bias thermometers that dissipate orders of magnitude more power and lose their sensitivity at low temperatures. Using this thermometer we demonstrate detection of equilibrium fluctuations of temperature in a system of about 10^8 electrons exchanging energy with phonon bath at a fixed temperature [3].
[1] B. Karimi, J. P. Pekola, Phys. Rev. Appl. **10**, 054048 (2018).
[2] B. Karimi, D.anilo Nikolić, T. Tuukkanen, J. T. Peltonen, W. Belzig, J. P. Pekola, arXiv:1911.02844 (2019).
[3] B. Karimi, F. Brange, P. Samuelsson, J. P. Pekola, arXiv:1904.05041 (2019).

TT 31.5 Wed 10:30 HSZ 03

Development of RF-Power Dividers for the Josephson Arbitrary Waveform Synthesizer — •Hao Tian, Oliver Kieler, Ralf Behr, Rüdiger Wendisch, Rolf-Werner Gerdau, Karsten Kuhlmann, and Johannes Kohlmann — Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

The JAWS, based on pulse-driven series arrays of SNS Josephson Junctions (JJs) at 4 K, enables spectrally pure AC voltages to be synthesized from DC up to MHz. To simplify the experimental set-up and to increase the JJs operated by a single PPG channel, we designed two types of on-chip power dividers. One type is a two-stage serial-parallel power divider, the second type is a one-stage Wilkinson power divider. The outputs of the power dividers are equipped with DC-block capacitors and LCR filters. Different designs were simulated, integrated to JJs arrays and fabricated. The results showed that the test chips containing a 2-stage serial-parallel power divider and 2000 JJs are operational up to a maximum clock frequency of 13 GHz. Spectrally pure sinusoidal waveforms of 19 mV (RMS) could be synthesized with sigma-delta code amplitudes of 50%. The 1-stage Wilkinson power divider integrated with 1000 JJs and 3000 JJs can operate up to a clock frequency of 15 GHz. We successfully synthesized spectrally pure output voltages of 17.6 mV (RMS) and 33 mV (RMS). This work was partly supported by the EMPIR programme co-financed by the Participating States and from the EU H2020 programme (JRP 15SIB04 QuADC) and by the German BMWi (project ZF4104104AB7).

TT 31.6 Wed 10:45 HSZ 03

Fluxoid dynamics in high impedance long Josephson junctions — •Micha Wildermuth[1], Lukas Powalla[1], Konrad Dapper[1], Yannick Schön[1], Jan Nicolas Voss[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,3,4] — [1]Institute of Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Institute for Solid-State Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]National University of Science and Technology MISIS, Moscow, Russia — [4]Russian Quantum Center, Skolkovo, Moscow, Russia

The dynamics of Josephson vortices in long Josephson junctions is a well-known example of soliton physics and allows to study highly nonlinear effects on a mesoscopic scale. We experimentally study the characteristics of a Josephson junction with electrodes having a large kinetic inductance fraction which provides an additional degree of freedom. The London penetration depth exceeds the stack thickness which results in an incomplete screening of magnetic fields and in fluxoids with an altered shape. We present transport measurements of long Josephson junctions with electrodes made from disordered oxidized aluminum showing current steps with and without external magnetic fields and the IV-characteristics resemble the Fiske and zero-field steps. Magnetic field dependent measurements also show a very similar behavior to conventional long Josephson junctions.

TT 31.7 Wed 11:00 HSZ 03

Study of the relaxation and decoherence in 2D fluxoniums — •Farshad Foroughi, Karthik Bharadwaj, Luca Planat, Arpit Ranadive, Cecile Naud, Olivier Buisson, Nicolas Roch, and Wiebke Hasch-Guichard — univ. Grenoble Alpes, CNRS, Grenoble INP, Institut Néel, 38000 Grenoble, France

High anharmonicity and wide frequency tunability of the Fluxonium qubit make it an indispensable candidate for emerging quantum computers. Moreover fluxonium qubit in a 3D cavity or environment, when biased at sweet spot, shows very high relaxation time at the order of 10 ms[1]. However 2D and on-chip qubits are more favorable to scale up. The transition from 3D to 2D is not trivial as the coupling to the unwanted degrees of freedom increases a lot. In this work we coupled the fluxonium qubit to on-chip lumped element and distributed resonators. We have studied effect of different qubit parameters on the coherence times T1 and T2.

[1] I. M. Pop et al., Nature 508, 369-372 (2014)

15 min. break.

TT 31.8 Wed 11:30 HSZ 03

Kinetic Inductance of thin Al Films using a Resonant Circuit — •Lorenz Fuchs, Christian Baumgartner, Dieter Schuh, Nicola Paradiso, Dominique Bougeard, and Christoph Strunk — Institute for Experimental and Applied Physics, University of Regensburg

Direct measurement of the magnetic penetration depth λ on thin films with a thickness $d \ll \lambda$ has been challenging ever since. We use a resonant circuit to determine the complex impedance of a superconducting thin film meander in the few MHz regime [1]. The meander is patterned into a 15nm thick aluminum film that is grown on a GaAs substrate. From the imaginary part of the impedance we determine the kinetic inductance of the superconducting condensate and from vortex motion in the pinning potential and from the real part a dissipative contribution caused by quasi-particle excitations and/or vortex motion. A small change of the total inductance of the system due to the kinetic inductance $L_{kin} = \mu_0\lambda^2/d$ of the superconductor below its critical temperature T_c leads to a significant decrease of the resonance frequency f_0. The system is sensitive to changes of inductance smaller than 50 pH, which can compete with the accuracy of more standard two-coil mutual inductance techniques [2]. Examination of the basic features of this technique will provide the basis for further investigation of proximity induced superconductivity in InAs 2DEGs with large spin-orbit coupling.

[1] R. Meservey and P.M. Tedrow, J. Appl. Phys. 40, 2028 (1969)
[2] T. Lemberger et al., Phys. Rev. B, 76, 094515 (2007)

TT 31.9 Wed 11:45 HSZ 03

Superconducting granular aluminum resonators resilient to magnetic fields up to 1 Tesla — •Alexandru Ionita, Kiril Borisov, Dennis Rieger, Patrick Winkel, Markus Wessbecher, Fabio Henriques, Francesco Valenti, Martin Spiecker, Daria Gusenkova, Wolfgang Wernsdorfer, and Ioan Pop — Physikalisches Institut, KIT, Karlsruhe, Germany

Superconducting granular aluminum (grAl) is an attractive high-kinetic inductance material with proven applicability in superconducting qubits [1, 2] and microwave detectors [3]. As the magnetic field is a double-edged sword, which provides an important control knob to superconducting circuits but could also lead to higher quasiparticle population and induced vortices, we investigate the field resilience of grAl superconducting resonators. We carried out reflection measurements in both in-plane and perpendicular external magnetic fields, which tune the resonance frequency by up to 70 MHz. The internal quality factor remains on the order of 10^5 in the single photon regime under in-plane magnetic field up to 1 T [4]. Moderate perpendicular field has a beneficial effect on the resonator properties and leads to a small increase of the internal quality factor by 15 %. We further discuss the field-dependence of self-Kerr coefficient [5], rate of quasiparticle relaxation [3] and coupling to spin-1/2 magnetic impurities.

[1] L. Grünhaupt, M. Spiecker, Nat. Mat. 18(8), 816 (2019).
[2] P. Winkel, arXiv: 1911.02333
[3] F. Valenti, Phys. Rev. Appl. 11, 054087 (2019
[4] K. Borisov (in preparation)
[5] N. Maleeva, Nat. Comm. 9(1), 3889 (2018)

TT 31.10 Wed 12:00 HSZ 03

Resistance tuning of disordered nanowires by current pulses and their electrical response at low temperatures — •Jan Nicolas Voss[1], Yannick Schön[1], Micha Wildermuth[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,3,4] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Institut für Festkörperphysik, Karlsruher Institut für Technologie, Karlsruhe, Germany — [3]Russian Quantum Center, Skolkovo, Moscow, Russia — [4]National University of Science and Technology MISIS, Moscow, Russia

Superconducting nanowires made from granular aluminium have unique electrical properties at low temperatures. They originate from the intrinsic network of Josephson junctions in the material and the spatial restrictions to dimensions that are of the order of the superconducting coherence length. We present a novel method, which allows changing the nanowire resistance by modifying the intrinsic junction network by electrical pulses. With this method, we test the quantum phase slip model for the wires at millikelvin temperatures.

We have observed a transition from an insulating over a metallic to a superconducting response in about a two hundred individual resistance steps. The measurement results are compared with theoretical predictions.

TT 31.11 Wed 12:15 HSZ 03

Rabi Oscillations in a Superconducting Nanowire Circuit — •Yannick Schön[1], Jan Nicolas Voss[1], Micha Wildermuth[1], Andre Schneider[1], Sebastian T. Skacel[1], Martin P. Weides[1,3], Jared H. Cole[4], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,5,6] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Institut für Festkörperphysik, Karlsruher Institut für Technologie, Karlsruhe, Germany — [3]University of Glasgow, Glasgow, United Kingdom — [4]RMIT University, Melbourne, Australia — [5]National University of Science and Technology MISIS, Moscow, Russia — [6]Russian Quantum Center, Skolkovo, Moscow, Russia

Disordered oxidized (granular) aluminum is a new material for superconducting quantum circuits, featuring not only a very high kinetic inductance but also microwave resonators with high quality factors. Applied to wires of nanometer scale it allows for a pronounced nonlinear microwave response.

We investigate the circuit quantum electrodynamics of superconducting nanowire oscillators. The sample circuit consists of a capacitively shunted nanowire with a width of about 20 nm and a varying length up to 350 nm, capacitively coupled to an on-chip resonator. By applying microwave pulses we observe Rabi oscillations, measure coherence times and the anharmonicity of the circuit. Despite the very compact design, simple top-down fabrication and high degree of disorder in the granular aluminum material, we observe lifetimes in the microsecond range.

TT 31.12 Wed 12:30 HSZ 03

Implementation of a transmon qubit using superconducting granular aluminum — •Patrick Winkel[1], Kiril Borisov[2], Lukas Grünhaupt[1], Dennis Rieger[1], Martin Spiecker[1], Francesco Valenti[1,3], Alexey V. Ustinov[1,4], Wolfgang Wernsdorfer[1,2,5], and Ioan M. Pop[1,2] — [1]Physikalisches Institut, KIT, Karlsruhe, Germany — [2]Institute of Nanotechnology, KIT, Karlsruhe, Germany — [3]Institut für Prozessdatenverarbeitung und Elektronik, KIT, Karlsruhe, Germany — [4]Russian Quantum Center, MISIS, Moscow, Russia — [5]Institut Néel, CNRS, Grenoble, France

The high kinetic inductance offered by granular aluminum (grAl) has recently been employed for linear inductors in superconducting high-impedance qubits and kinetic inductance detectors. Due to its large critical current density compared to typical Josephson junctions, its resilience to external magnetic fields, and its low dissipation, grAl may also provide a robust source of non-linearity for strongly driven quantum circuits, topological superconductivity, and hybrid systems. Having said that, can the grAl non-linearity be sufficient to build a qubit? Here we show that a small grAl volume shunted by a thin film aluminum capacitor results in a microwave oscillator with an anharmonicity of 4.48 MHz, two orders of magnitude larger than its spectral linewidth, effectively forming a transmon qubit. Resonance fluorescence measurements of the fundamental transition yield an intrinsic qubit linewidth corresponding to a lifetime of 16 μs. This linewidth remains below 150 kHz for in-plane magnetic fields up to 70 mT.

TT 31.13 Wed 12:45 HSZ 03

Amplitude and frequency sensing of microwave fields with

a superconducting transmon qubit — •Maximilian Kristen[1], Andre Schneider[1], Alexander Stehli[1], Tim Wolz[1], Sergey Danilin[2], Hannes Rotzinger[1], Alexey V. Ustinov[1,3,4], and Martin Weides[1,2] — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]University of Glasgow, Glasgow, UK — [3]National University of Science and Technology MISIS, Moscow, Russia — [4]Russian Quantum Center, Moscow, Russia

Experiments with quantum circuits require careful calibration of the applied pulses and fields over a large frequency range. Here, we demonstrate how frequency and local amplitude of a microwave signal can be inferred from the ac Stark shifts of higher transmon levels. In time-resolved measurements we employ Ramsey fringes, allowing us to detect the amplitude of the system's transfer function over a range of several hundreds of MHz with an energy sensitivity on the order of 1e-4. The presented sensing method can facilitate pulse correction for high fidelity quantum gates in superconducting circuits and allows for the characterization of arbitrary microwave fields for experiments with hybrid microwave systems.