TT 55: Superconducting Electronics: SQUIDs, Qubits, Circuit QED III

Time: Friday 9:30–13:00 Location: H36

TT 55.1 Fri 9:30 H36

Superconducting devices based on the NbTiN Josephson junctions — •Vasilii Sevriuk[1], Azat Gubaydullin[1], Aki Ruhtinas[2], Michael Perelshtein[1], Alexey Mironov[1], Pertti Hakonen[3], Ilari Maasilta[2], and Valerii Vinokur[1] — [1]Terra Quantum AG, Kornhausstrasse 25, 9000 St. Gallen, Switzerland — [2]Nanoscience Center, Department of Physics, University of Jyväskylä, FI-40014 Jyväskylä, Finland — [3]QTF Centre of Excellence, Department of Applied Physics, Aalto University, P.O. Box 15100, FI-00076 AALTO, Finland

Quantum devices based on superconducting circuits are a promising technology that could have a significant impact on many aspects of human life. However, the production of high-coherence circuits remains one of the key challenges. Recent results on the fabrication of NbTiN Josephson junctions using a focused helium ion beam [1] suggest that this method is well-suited for a wide range of applications in superconducting electronics, due to the excellent mechanical, electrical, and microwave properties of NbTiN. Here we present our results on the characterization of the superconducting circuits based on this technology.

[1] A. Ruhtinas, I. Maasilta, arXiv:2303.17348v2.

TT 55.2 Fri 9:45 H36

Argon milling strategies for Tantalum Transmon qubits — •Philipp Lenhard[1], Mathieu Fechant[1], Ritika Dhundhwal[1], Thomas Reisinger[1], and Ioan M. Pop[1,2,3] — [1]IQMT, Karlsruhe Institute of Technology — [2]PHI, Karlsruhe Institute of Technology — [3]1. Physikalisches Institut, University of Stuttgart

Tantalum has emerged as a promising material for enhancing the coherence time of superconducting qubits [1,2]. This study focuses on the fabrication of qubits, emphasizing the necessity of establishing a coherent contact between Ta-based structures and $Al/AlO_x/Al$ Josephson junctions. The removal of native oxide layers via Argon milling is critical to this process. We present various approaches to achieve optimal contact through Argon milling, along with a discussion of the associated challenges and potential solutions.

[1] Place et al., Nat. Commun. 12:1779 (2021).
[2] Ganjam et al., Nat. Commun. 15:3687 (2024).

TT 55.3 Fri 10:00 H36

Simultaneous locking and operation of gradiometric fluxonium qubits — •Denis Bénâtre[1], Mathieu Féchant[1], Nicolas Gosling[1], Nicolas Zapata[1], Patrick Paluch[1], Martin Spiecker[1], and Ioan Pop[1,2,3] — [1]IQMT, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany — [2]PHI, Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]PI1, Stuttgart University, 70569 Stuttgart, Germany

Gradiometric fluxoniums, introduced by Gusenkova et al. (Appl. Phys. Lett. 120, 2022), have the ability to be flux-locked at the sweet spot of operation by trapping a persistent current in their most external loop. We demonstrate the reliability of the procedure by simultaneously locking several fluxoniums sitting in the same waveguide and show that the locking in stable in time. We engineer devices with varying asymmetries and exhibit samples with close-to-zero asymmetry, allowing them to be used with little additional flux-biasing. Such devices could thus help reduce cross-talk between flux lines addressing flux qubits.

TT 55.4 Fri 10:15 H36

Low cross-talk modular flip-chip architecture for coupled superconducting qubits — •Sören Ihssen[1], Simon Geisert[1], Gabriel Jauma[2,3], Patrick Winkel[1,4,5], Martin Spiecker[1], and Ioan M. Pop[1,6,7] — [1]IQMT, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Institute of Fundamental Physics IFF-CSIC, Calle Serrano 113b, 28006 Madrid, Spain — [3]Applied Physics Department, Salamanca University, Salamanca 37008, Spain — [4]Departments of Applied Physics and Physics, Yale University, New Haven, CT 06520, USA — [5]Yale Quantum Institute, Yale University, New Haven, CT 06520, USA — [6]PHI, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [7]Physics Institute 1, Stuttgart University, 70569 Stuttgart, Germany

We introduce a novel flip-chip architecture designed for an array of coupled superconducting qubits, where each circuit component is housed within its own microwave enclosure. Unlike traditional flip-chip designs, our approach features electrically floating qubit chips, enabling a straightforward and fully modular assembly of capacitively coupled components, including qubits, control systems, and coupling structures. This design minimizes crosstalk among components. We validate our concept using a chain of three nearest-neighbor coupled generalized flux qubits, with the central qubit functioning as a frequency-tunable coupler. Through this coupler, we achieve a transverse coupling on/off ratio of approximately 50, zz-crosstalk below 1.4 kHz between resonant qubits, and over 70 dB of isolation between the qubit enclosures.

TT 55.5 Fri 10:30 H36

Optically mediated control for superconducting qubits — •Kevin Kiener[1,2], Gleb Krylov[1,2], Florian Wallner[1,2], Max Werninghaus[1,2], Nadeem Akhlaq[2,3], Frederik Pfeiffer[1,2], Johannes Schirk[1,2], and Stefan Filipp[1,2] — [1]Walther-Meißner-Instiut, Bayerische Akademie der Wissenschaften — [2]Technical University of Munich, TUM School of Natural Sciences, Department of Physics — [3]Walter Schottky Institut

In superconducting quantum computers, scaling control and readout wiring infrastructure presents significant challenges. Optical fibers offer a promising alternative to microwave cables by providing lower passive heat load, reduced footprint per channel, reduced crosstalk and the potential for multiplexing control channels. Here, we explore the conversion of microwave- to optical signals via amplitude modulation and the subsequent reconversion to microwave signals at millikelvin (mK) temperatures. Two fiber coupling strategies are experimentally evaluated in a cryogenic environment, focusing on their practicality for qubit control. We theoretically investigate methods to reduce the power dissipation of the photodiode at mK temperatures, focusing on two approaches: utilizing an impedance converter and employing high-impedance transmission lines. We investigate the validity of the signal generation for different frequencies and identify suitable frequency ranges to control different qubit architectures and coupling elements.

We acknowledge financial support from GeQCoS, MUNIQC-SC, MCQST, OpenSuperQPlus100, the Munich Quantum Valley and the Deutsche Forschungsgemeinschaft.

TT 55.6 Fri 10:45 H36

Spectroscopic characterization of noise and decoherence mechanisms in superconducting qubits — •Julian Englhardt[1,2], Emily Wright[1,2], Niklas Glaser[1,2], Leon Koch[1,2], Ivan Tsitsilin[1,2], Christian Schneider[1,2], Max Werninghaus[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Department of Physics — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften

Dynamical decoupling sequences during free evolution time have proven effective in suppressing the impact of environmental noise in superconducting qubits, thereby increasing coherence times towards the theoretical 2T1 limit. While primarily used for error suppression during quantum computation, these sequences can also serve as a diagnostic tool for noise characterization by revealing the qubit's response across specific frequency ranges. Beyond standard dynamical decoupling sequences, here we employ additional methods such as time resolved single-shot Ramsey measurements to probe low-frequency noise sources and the signature noise spectra of specific decoherence events. Specifically, we investigate charge parity jumps in superconducting Transmon qubits induced by quasiparticle tunneling across the Josephson junction. We believe that the combined toolkit for noise spectroscopy can contribute to the understanding of decoherence mechanisms in superconducting qubits.

We acknowledge financial support from GeQCoS, MUNIQC-SC, MCQST, OpenSuperQPlus100, the Munich Quantum Valley and the Deutsche Forschungsgemeinschaft.

TT 55.7 Fri 11:00 H36

Suppressing chaos with mixed superconducting qubit devices — •Ben Blain[1,2], Giampiero Marchegiani[1], Luigi Amico[1,3,4], and Gianluigi Catelani[5,1] — [1]Quantum Research Center, Technology Innovation Institute, Abu Dhabi 9639, UAE — [2]School of Physics and Astronomy, University of Kent, Canterbury CT2 7NH, United

Kingdom — [3]Dipartimento di Fisica e Astronomia, Via S. Sofia 64, 95123 Catania, Italy — [4]INFN-Sezione di Catania, Via S. Sofia 64, 95127 Catania, Italy — [5]JARA Institute for Quantum Information (PGI-11),Forschungszentrum Jülich, 52425 Jülich, Germany

In quantum information processing, a tension between two different tasks occurs: while qubits' states can be preserved by isolating them, quantum gates can be realized only through qubit-qubit interactions. In arrays of qubits, weak coupling leads to states being spatially localized and strong coupling to delocalized states. Here, we study the average energy level spacing and the relative entropy of the distribution of the level spacings to analyze the crossover between localized and delocalized (chaotic) regimes in linear arrays of superconducting qubits. We consider both transmons as well as capacitively shunted flux qubits, which enables us to tune the qubit anharmonicity. Arrays with uniform anharmonicity display remarkably similar dependencies of level statistics on the coupling strength. In systems with alternating anharmonicity, the localized regime is found to be more resilient to the increase in qubit-qubit coupling strength in comparison to arrays with a single qubit type. This result supports designing devices that incorporate different qubit types to achieve higher performances.

15 min. break

TT 55.8 Fri 11:30 H36

Higher Josephson harmonics in superconducting qubits — •Abbas H. Hirkani[1,2], Giampiero Marchegiani[1], Luigi Amico[1,3,4], and Gianluigi Catelani[1,5] — [1]QRC, TII, Abu Dhabi, UAE — [2]SISSA, Trieste, Italy — [3]Dipartimento di Fisica e Astronomia, Catania, Italy — [4]INFN-Catania, Catania, Italy — [5]Forschungszentrum Jülich, Jülich, Germany

Measurements of higher-level spectra of transmon cannot be explained using the standard $I = I_0 \sin\phi$ current-phase relation, and a more accurate description of the Josephson element, with non-negligible contributions from higher harmonics, is needed [1]. Stray inductances can also lead to similar corrections to the spectrum; here we investigate the Fraunhofer effect in transmons comprising thin-film $Al/AlO_x/Al$ junctions under parallel magnetic field [2] as a tool to discriminate between contributions from inductances and from intrinsic higher harmonics of the junctions. The magnetic field modulates each harmonic on a different field scale; this results in a field dependence of the qubit spectrum measurably different from the one due to a stray inductance alone. We also examine how the presence of a few percent higher harmonic contributions affects various qubit designs, and comment on the implications for accurate targeting of qubit parameters.

[1] D. Willsch et al., Nat. Phys. 20, 815 (2024);
[2] J. Krause et al., Phys. Rev. App. 22, 044063 (2024).

TT 55.9 Fri 11:45 H36

Impact of infrared photons on superconducting qubits — •Markus Griedel[1,2], Jonathan Huschle[2], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Institut for Quanten Materials and Technologies (IQMT), Karlsruhe Institut for Technology (KIT), Karlsruhe, Germany — [2]hysikalisches Institut (PHI), Karlsruhe Institut for Technology (KIT), Karlsruhe, Germany

Low-noise superconducting quantum circuits are manipulated by microwave photons with energies below the superconducting energy gap. However, the impact of photons with much higher energies may break Cooper pairs and result in an increase in the noise level. Stray infrared (IR) radiation, e.g. transmitted through the dielectrics of coaxial cables, must be blocked by a low-pass filter to avoid this additional noise. The coherence of superconducting qubits is particularly sensitive to this influence and can be used as a detector. In the qBriqs project, we focus on studying the impact of far-infrared photons and present the results of a detailed experimental study. We propose materials to suppress the IR radiation, e.g. with an in-line filter, while maintaining good microwave properties.

TT 55.10 Fri 12:00 H36

Investigation of parasitic two-level systems in merged-element Transmon qubits — •Etienne Daum[1], Benedikt Berlitz[1], Alexey V. Ustinov[1,2], and Jürgen Lisenfeld[1] — [1]PHI, Karlsruher Institut für Technologie, 76131 Karlsruhe, Deutschland — [2]IQMT, Karlsruher Institut für Technologie, 76131 Karlsruhe, Deutschland

In conventional transmon qubits, decoherence is dominated by large numbers of parasitic two-level systems (TLS) residing at the edges of its large area coplanar shunt capacitor. Avoiding these defects by improvements in design, fabrication and materials proved to be a significant challenge that so far led to limited progress. The merged-element transmon qubit, a recently proposed paradigm shift in transmon design, attempts to address these issues by engineering the Josephson junction to act as its own parallel shunt capacitor. Incorporating an additional aluminium deposition and oxidation into the *in-situ* bandaged Niemeyer-Dolan technique, we were able to fabricate flux-tunable mergemon qubits in the low transmon regime ($E_J/E_C \approx 34$). A mean T_1 relaxation time of about $20\mu s$ ($Q \approx 5.4 \times 10^5$) has been observed over a six hour time period. TLS spectroscopy under applied strain and electric fields revealed that the majority of coherence limiting TLS ($\sim 60\%$) still reside on the interfaces of exposed qubit electrodes, despite their drastically reduced surface area. This indicates that material and fabrication improvements, in combination with optimized electrode geometries, are still necessary before the advantages of the "mergemon" approach can be exploited.

TT 55.11 Fri 12:15 H36

Demonstration of a Solid-State Random Defect Maser — •Christian Ständer, Jan Blickberndt, Andreas Fleischmann, Andreas Reiser, and Christian Enss — Kirchhoff Institute for Physics, Heidelberg University

The low temperature properties of amorphous solids are governed by atomic tunneling systems, which can be described as two-level systems (TLS) with a distribution of their energy splitting E, as assumed by the phenomenological standard tunnelling model. Recent interest in these systems due to their deteriorative effects on the performance of superconducting quantum devices lead to experimental investigations of atomic tunnelling systems.
We designed and microfabricated a superconducting LC-resonator to study the dielectric rf-response of an amorphous sample in the presence of a slowly varying electric bias field and two symetrically detuned pump tones. A novel method of applying this electrical bias field was introduced to the resonators. By shifting the energy splitting of the inverted TLS with the external bias, to match the resonators frequency we found a paramterspace of negative dielectric loss, hence gain. In this way we demonstrate that a media containing random TLS could be transformed from an inertially lossy system to a system that features no significant dielectric loss, up to a point of coherent gain.

TT 55.12 Fri 12:30 H36

Two-qubit entangling quantum gates in a 2D ring resonator architecture — •Anirban Bhattacharjee[1,2], Panya Jain[1], Jay Deshmukh[1], Srijita Das[1], Madhavi Chand[1], Meghan Patankar[1], and Rajamani Vijayaraghavan[1] — [1]Tata Institute of Fundamental Research, Mumbai, India — [2]Walther Meissner Institute, Garching b Muenchen, Germany

A novel ring resonator [1] design allows interqubit connectivity beyond nearest neighbours, which has always been a topological constraint in present state-of-art quantum architectures. In this work, we demonstrate connectivity between three fixed-frequency transmon qubits coupled to a ring resonator in a planar 2D architecture. We have also demonstrated two-qubit entangling gates between two fixed-frequency qubits in this geometry. Our results show the ability to demonstrate quantum entanglement using the ring resonator and opens up the possibility of exploring various gate implementations in this architecture.

[1] Phys. Rev. Appl. 16, 024018 (2021).

TT 55.13 Fri 12:45 H36

Study of the quarton-quarton qubits interaction — •Hossam Tohamy[1], Alex Kreuzer[1], Andras Di Giovanni[1], Thilo Krumrey[1], Hannes Rotzinger[1,2], and Alexey V. Ustinov[1,2] — [1]Physikalisches Institut (PHI), Karlsruhe Institute of Technology (KIT) — [2]Institute for Quantum Materials and Technologies (IQMT), Karlsruhe Institute of Technology (KIT)

Tunable qubits are a useful resource in superconducting quantum processors to enable high-performance quantum gates. While much of the recent focus has been on the exploration of transmon multiqubit architectures, the quarton qubit [1] offers a three- to five-times higher and, in addition, positive anharmonicity. In this work, we experimentally study the interaction between two quarton qubits. We have performed spectroscopy and time-domain measurements on these qubits system, and compared the experimental results with theoretical model.

[1] F. Yan et al., arXiv:2006.04130 (2020).