QI 16: Superconducting Qubits (joint session QI/TT)

Time: Wednesday 9:30–13:15 Location: HFT-FT 131

QI 16.1 Wed 9:30 HFT-FT 131

Improving Fabrication Methods for High Coherence Superconducting Qubits — •Niklas Bruckmoser[1,2], Leon Koch[1,2], David Bunch[1,2], Ivan Tsitsilin[1,2], Kedar E. Honasoge[1,2], Thomas Luschmann[1,2], Lasse Södergren[1,2], Christian Schneider[1,2], Max Werninghaus[1,2], and Stefan Filipp[1,2] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany

The development of superconducting qubits and resonators with long coherence times and high quality factors is an essential milestone on the way towards useful quantum applications. While significant improvements in coherence time have been achieved over the last years, reaching qubit lifetimes well beyond 0.1 ms involves careful investigation of all fabrication processes. In this talk, we show that achieving such high-quality devices becomes possible through a combination of substrate cleaning, etching optimization, and post-process sample cleaning. By using resonator measurements as a figure of merit to minimize TLS loss, we achieve internal quality factors of more than $Q_{\mathrm{int}} = 1 \times 10^7$ for thin-film niobium coplanar waveguide resonators in the single-photon regime and observe transmon qubits with single-shot lifetimes as high as $T_1 = 0.7$ ms. Additionally, we exploit the high quality of the niobium resonators as sensors to investigate losses arising from different types of silicon substrates.

QI 16.2 Wed 9:45 HFT-FT 131

Enhanced parameter targeting in flip-chip geometry for large-scale superconducting quantum computing — •Léa Richard[1,2], Agata Skoczylas[1,2], Franziska Wilfinger[1], Niklas Bruckmoser[1,2], Leon Koch[1,2], David Bunch[1,2], Lasse Södergren[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany

In order to use quantum computing to tackle classically intractable problems, quantum processors must grow to larger scales. However, routing multiple control lines to an increasing number of qubits is not feasible in current superconducting planar architectures.

Using 3D-integration techniques, such as flip-chip bonding, plays a crucial role in mitigating this problem. A challenge arising from this new technology is the precise control of the vertical placement of the chips. In quantum circuits, capacitances and inductances are determined by the geometry of the electrodes. Hence, in a flip-chip assembly, it depends on the gap separating the two bonded chips. During the bonding process, variations may occur, preventing an accurate parameter targeting.

In this talk, we discuss the fabrication of thermally evaporated indium bumps and review the development of an optimized flip-chip bonding process. Moreover, we present a method for improved interchip spacing control and parameter targeting through the use of polymer spacers.

QI 16.3 Wed 10:00 HFT-FT 131

Frequency tuning of superconducting qubits by junction annealing — •Julius Feigl[1,2], Leon Koch[1,2], Florian Wallner[1,2], Niklas Bruckmoser[1,2], David Bunch[1,2], Lasse Södergren[1,2], Christian Schneider[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany

When scaling superconducting quantum processors beyond a couple of qubits, frequency collisions can become a limiting factor for gate fidelities. These collisions arise from parameter variations in the fabrication process, resulting in imprecise frequency targeting. A solution to enhance frequency targeting of individual superconducting qubits is the controlled annealing of the Josephson junction. In fact, Josephson junction resistance can be increased by local heating via a tightly focused laser beam. This leads to a modified Josephson inductance. In our work, we investigate wafer-scale laser annealing of fixed-frequency transmons with Al/AlOx/Al junctions. We explore the influence of annealing parameters on the resistance change for various junction sizes. The observed variations of the junction resistance after the annealing step reveal different temperature regimes for annealing. Temperatures exceeding 200 °C induce a reduction of up to 35 % in resistance, while temperatures below lead to an increase of up to 5 % in resistance. Consequently, we present a prospective approach to bi-directional annealing.

QI 16.4 Wed 10:15 HFT-FT 131

All-nitride superconducting devices for quantum computing — •Thomas Smart, Roudy Hanna, Michael Schleenvoigt, Albert Hertel, Abdur Rehman Jalil, Detlev Grützmacher, and Peter Schüffelgen — Forschungszentrum Jülich GmbH, Wilhelm-Johnen-Strasse, Jülich, 52425, Germany

The ongoing search for better superconducting devices for quantum computing has led to many proposals on how these devices can be improved to yield longer coherence times. Nitride based superconducting devices have been proposed as a potential platform for the next generation of quantum computing due to their stability and desirable superconducting properties. Here, we present the fabrication of all-nitride superconducting devices via molecular beam epitaxy on c-plane sapphire. These devices exhibit high crystalline quality and desirable superconducting properties. We explore the advantages of these devices compared to commonly used alternatives and how the use of reconstructed sapphire yields ideal growth qualities.

QI 16.5 Wed 10:30 HFT-FT 131

Magnetic field dependence of a Josephson travelling wave parametric amplifier — •Lucas Janssen[1], Christian Dickel[1], Guilliam Butseraen[2], Jonas Krause[1], Alexis Coissard[3], Luca Planat[3], Gianluigi Catelani[4], Nicolas Roch[2], and Yoichi Ando[1] — [1]University of Cologne, Cologne, Germany — [2]Institut Néel, Grenoble, France — [3]Silent Waves, Grenoble, France — [4]Technology Innovation Institute, Abu Dhabi, United Arab Emirates

We investigate the magnetic field dependence of a Josephson travelling-wave parametric amplifier (TWPA) that is designed as a version of photonic crystal. We show that the change in photonic bandgap and plasma frequency of the TWPA can be modelled by considering the suppression of the critical current in the Josephson junctions (JJs) of the TWPA due to the Fraunhofer effect and closing of the superconducting gap in magnetic fields. These dependencies allow us to tune the operation of the TWPA by magnetic fields in a wide range of frequencies without using SQUIDs. The JJ geometry is found to be crucial for the magnetic-field dependences: for example, the TWPA bandgap can be widely shifted without losing gain or bandwidth by an in-plane magnetic field in one direction, while in the other in-plane direction the TWPA performance is severely compromised already at 2mT. With out-of-plane field, the TWPA's response is hysteretic, and it is severely compromised at 5mT. We also show that we can use magnetic shielding to use the TWPA in experiments where high fields are required.

QI 16.6 Wed 10:45 HFT-FT 131

Embedded Amplifier for Efficient Superconducting Qubit Readout — •Lindsay Orr[1,2], Benton Miller[3,4], Florent Lecocq[3,5], and Anja Metelmann[1] — [1]Institute for Theory of Condensed Matter, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany — [3]National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA — [4]Department of Physics, University of Colorado, Boulder, Colorado 80309, USA — [5]Department of Electrical, Computer, and Energy Engineering, University of Colorado, Boulder, Colorado 80309, USA

High fidelity qubit readout is a cornerstone of quantum computing. In superconducting architecture, this is typically achieved by routing signals from a readout cavity to a parametric amplifier via microwave circulators. The use of these off-chip components enables the independent design and optimization of the readout cavity and parametric amplifier. However, the intrinsic losses and large magnetic fields of these circulators reduces measurement efficiency and inhibits scalability. Our strategy to circumvent this is to perform the amplification and signal routing directly on-chip, by coupling a transmon qubit to a nonreciprocal multimode parametric system. As a consequence of this, the qubit and amplifier become a single open quantum system with a large Hilbert space. In this talk, we will discuss the theoretical challenges in understanding the quantum dynamics, focusing on extracting qubit measurement and dephasing rates.

QI 16.7 Wed 11:00 HFT-FT 131

Three wave mixing with a dimer Josephson junction array amplifier — •Mitchell Field[1], Nicolas Zapata[1], and Ioan M. Pop[1,2,3] — [1]Institute of Quantum Materials and Technology, Karlsruhe Institute of Technology — [2]Physikalisches Institut, Karlsruhe Institute of Technology — [3]1. Physikalisches Institut, University of Stuttgart

Superconducting Josephson junction parametric amplifiers are robust, low noise amplifiers used to improve the signal to noise ratio of microwave quantum measurements. A common way to generate amplification is with the intrinsic non-linearity of superconducting quantum interference devices (SQUIDs), which sustain four wave mixing processes. In this work we re-engineer an established optical lithography design for dimer Josephson junction array amplifiers [1] by replacing SQUIDs with superconducting non-linear asymmetric inductive elements (SNAILs) [2] which we use to introduce a three wave mixing process. The asymmetric Josephson potential of SNAILs induces a so-called Kerr-free point [3], which we use to improve the dynamic range [4] and increase the signal-pump detuning to several gigahertz.

1. Winkel, P. et al. Phys. Rev. Applied 13, 024015 (2020).
2. Frattini, N. E. et al. Applied Physics Letters 110, 222603 (2017).
3. Sivak, V. V., Shankar, S., Liu, G., Aumentado, J. & Devoret, Phys. Rev. Appl. 13, 024014 (2020).
4. Eichler, C. & Wallraff, A. EPJ Quantum Technol. 1, 119 (2014).

15 min. break

QI 16.8 Wed 11:30 HFT-FT 131

Single-qubit gates on Fluxonium qubits with a sub-harmonic drive — •Johannes Schirk[1,2], Florian Wallner[1,2], Niklas Bruckmoser[1,2], Leon Koch[1,2], Ivan Tsitsilin[1,2], Niklas Glaser[1,2], Vincent Koch[1,2], Longxiang Huang[1,2], Klaus Liegener[1,2], Max Werninghaus[1,2], Etienne Denois[3], Dominique Sugny[3], Christian Schneider[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [3]Laboratoire Interdisciplinaire Carnot de Bourgogne, CNRS-Université de Bourgogne, Dijon, France

Current implementations of superconducting quantum processors rely on microwave drive lines and flux bias lines to control qubits. To ensure fast and high-fidelity operations, the coupling between the qubit and the control lines must be sufficiently large, which in turn increases energy relaxation of the qubits. In this talk, we present a new approach to control Fluxonium qubits. We experimentally realize high-fidelity single-qubit gates by applying a parametric drive to the qubit's flux line, eliminating the need for an additional charge line. Moreover, we demonstrate the ability to drive the qubit with a sub-harmonic drive frequency at a fraction of its resonance frequency, using a multi-photon process to excite the qubit. This allows us to place a low-pass filter on the flux line below the qubit's resonance frequency, thereby suppressing energy relaxation into this single remaining control line.

QI 16.9 Wed 11:45 HFT-FT 131

High-Fidelity Readout of Fluxonium Qubits — •Florian Wallner[1,2], Johannes Schirk[1,2], Niklas Bruckmoser[1,2], Leon Koch[1,2], Ivan Tsitsilin[1,2], Niklas Glaser[1,2], Vincent Koch[1,2], Longxiang Huang[1,2], Klaus Liegener[1,2], Max Werninghaus[1,2], Christian Schneider[1,2], and Stefan Filipp[1,2] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany

Fast and high-fidelity qubit readout is one of the fundamental operations for quantum computation. A higher readout fidelity significantly reduces the number of experiments needed to reach the specified accuracy. Recently, the use of measurements in a mid-circuit fashion with classical feedback became an important resource for efficient quantum circuits. Here the performance of the readout is even more critical for the resulting circuit fidelity. In this talk we report on our recent advances to improve the readout of superconducting Fluxonium qubits. We demonstrate dispersive readout within $1.2\,\mu$s with assiment fidelities higher than 98.3 % and a QNDness of up to 98.0 %. These high numbers enable us to use an active feedback based reset that outperforms passive methods to initialize the qubit. Due to our high readout photon number of $\bar{n} > 50$ we can mitigate the use of a parametric amplifier. Moreover, through dedicated flux pulses we can utilize the dispersive shift landscape of the qubits. With this, we can protect the qubit during idling times and significantly enhance the resonator shift during readout improving the readout fidelity even further.

QI 16.10 Wed 12:00 HFT-FT 131

Improving Transmon Qudit Measurement on IBM Quantum Hardware — •Tobias Kehrer, Tobias Nadolny, and Christoph Bruder — Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

The Hilbert space of a physical qubit typically features more than two energy levels. Using states outside the qubit subspace can provide advantages in quantum computation. To benefit from these advantages, individual states of the d-dimensional qudit Hilbert space have to be discriminated properly during readout. In this contribution (arXiv:2307.13504), we propose and analyze two measurement strategies that improve the distinguishability of transmon qudit states. Both strategies aim to minimize drive-frequency dependent assignment errors of qudit states. Based on a model describing the readout of IBM Quantum devices, these strategies are compared to the default measurement. In addition, we employ higher-order X-gates that make use of two-photon transitions for qudit state preparation.

QI 16.11 Wed 12:15 HFT-FT 131

Automated Characterization of Superconducting Quantum Processors — •Konstantin Lehmann, Adam Lawrence, Timo van Abswoude, Thorsten Last, and Adriaan Rol — Orange Quantum Systems B.V., Elektronicaweg 10, 2628 XG Delft, NL

The qubit count of transmon-based quantum processors is steadily increasing. Some processors are already beyond the 100-qubit scale [1]. In order to keep the development cadence of those quantum processors high, the test time per qubit need to be strongly reduced from days to hours. Therefore, we developed the library SCQT and its accompanied automation framework GRACE.

SCQT is based on the open-source measurement framework Quantify [2]. It supports adaptive measurements to reduce the size and duration of large experiments. SCQT is designed with processor-scaling in mind and is equipped for features like tuneable couplers, leakage correction and cross-talk correction.

GRACE extracts the quantities of interest from the calibration protocols and transitions smoothly to the next protocol. This level of automation allows to take longer measurements without supervision, thereby reducing significantly the effort to characterize transmon-based quantum processors.

[1] https://www.ibm.com/quantum/roadmap
[2] https://quantify-os.org/

QI 16.12 Wed 12:30 HFT-FT 131

Suppression of coherent errors in Cross-Resonance gates via recursive DRAG — •Boxi Li[1,2], Tommaso Calarco[1,2,3], and Felix Motzoi[1] — [1]Forschungszentrum Jülich, Institute of Quantum Control (PGI-8), D-52425 Jülich, Germany — [2]Institute for Theoretical Physics, University of Cologne, D-50937 Cologne, Germany — [3]Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy

The high-precision control of quantum logical operations is a prerequisite to increasing circuit depths in quantum processors, implementing useful quantum algorithms, and reaching fault-tolerant scalable architectures. A ubiquitous approach used for entangling gates has been all-microwave control of superconducting qubits, primarily using the Cross-Resonance two-qubit gate; however, fidelities are still limited by control imperfections. Here, we derive a universal analytical pulse shape that significantly improves fidelities in Cross-Resonance gates, suppressing both the three off-resonant transitions on the control qubit and unwanted two-qubit rotation operators. Experimentally tested on the IBM Quantum Platform, our proposed drive pulse demonstrates successful suppression of coherent errors, allowing for much faster gates than the current state-of-the-art. Despite limited remote access, across multiple qubit pairs, we achieve a notable two to threefold reduction in error for the CNOT gate, resulting in coherence-limited gates with fidelities in the 99.7% range, higher than any publicly accessible CNOT gate on the IBM Quantum Platform.

QI 16.13 Wed 12:45 HFT-FT 131

Superconducting Qubit reset using Demolition Measurement — •Ashutosh Mishra[1], Frank Wilhelm-Mauch[1], and Shai Machnes[1,2] — [1]Peter Grünberg Institute - Quantum computing Analytics (PGI-12) Forschungszentrum Jülich, Jülich, Germany — [2]Qruise GmbH, Saarbrücken, Germany

Superconducting qubits have been a popular choice for quantum computing, but still are noisy and have been plagued with errors. The error budget of surface code as presented by Google Quantum AI [1] had almost half the errors due to measurement, leakage and qubit idle during measurement and reset. Measurement and reset of the qubits also constitute a large fraction of the time between two experiments. Since algorithms like VQE, QEC rely on multiple measurements to either estimate better parameters for the anstaz or to detect errors, reducing the time taken to measure and reset the qubit can significantly increase the data taking rate and at the same time reduce qubit idling errors. In this project we look for a scheme for combining the measurement and reset processes of the qubit and the readout resonator using optimal control tools. We demonstrate that one can perform a qubit readout, clear leakage population of the qubit and then empty the resonator and reset the qubit to the ground state within $1\mu s$.

[1] "Suppressing quantum errors by scaling a surface code logical qubit." Nature 614, no. 7949 (2023): 676-681.

QI 16.14 Wed 13:00 HFT-FT 131

Renormalization effects in driven quantum phase slip junctions — •Christina Koliofoti and Roman-Pascal Riwar — Forschungszentrum Jülich, Peter Grünberg Institut (PGI-2), 52425 Jülich, Deutschland

Quantum circuit theory is a powerful tool to describe superconducting circuits. In its language, quantum phase slips (QPSs) are considered to be the exact dual to the Josephson effect. This duality renders the integration of QPS junctions into a unified theoretical framework challenging. As we argue, different existing formalisms may be inconsistent, and the correct inclusion of time-dependent flux driving requires introducing a large number of auxiliary, nonphysical degrees of freedom. We resolve these issues by describing QPS junctions as inductive rather than capacitive elements, and reducing the Hilbert space to account for a compact superconducting phase. Our treatment provides an approach to circuit quantization exclusively in terms of node-flux-node variables, and eliminates spurious degrees of freedom. In this talk we present in particular the possibility of a voltage-dependent renormalization of the QPS amplitude, by accounting for spatial variations of the electric field built up across the junction.