Fabrication of Fluxonium-Like Qubits

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Principal Investigator(s): Ivan Pechenezhskiy
User(s): Benjamin Byrd, Kesavan Manivannan

Affiliation(s): Department of Physics, Syracuse University

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Contact: ivpechen@syr.edu, babyrd@syr.edu, kmanivan@syr.edu

Primary CNF Tools Used: ASML DUV Stepper, JEOL 6300, PT770 Plasma Etcher, Oxford81 Etcher, Heidelberg DWL2000 Mask Writer

Abstract:

We fabricate fluxonium and fluxonium-like qubits to study their potential for quantum computations, with our most recent study being focused on the behavior of broken Cooper pairs (quasiparticles) in superconducting coherent quantum devices. Quasiparticles are injected directly into our samples by driving a current through a Josephson junction larger than its critical current. Fluxonium qubits are intrinsically protected against charge noise and also against flux noise at the two flux sweet spots, making it easier to produce longer-lived devices. Some of these qubits have lifetimes exceeding a millisecond [1].

This project's fluxonium-like qubits are fabricated following a previously reported recipe [2].

PHYSICS & NANO-STRUCTURE PHYSICS

Summary of Research:

A fluxonium qubit (Figure 1) is composed of a capacitor, with a Josephson junction shunting the capacitive element. The key difference between a fluxonium and the more commonly studied transmon qubit is the inclusion of an inductor made of a chain of Josephson junctions, which shunts the two capacitor pads (Figure 2). This forms a closed loop through which we can apply a magnetic field. At certain values of flux threading through this loop, the qubit is protected from some crucial loss channels. The qubit is capacitively coupled to a resonator, whose frequency is shifted based on the state of the fluxonium qubit, allowing us to determine the state of the qubit by measuring the shift in the resonator frequency.

Our devices are fabricated on Si wafers, first by sputtering a ~ 70 nm layer of niobium to act as a superconducting ground plane from which we pattern microwave resonators, capacitors and co-planar waveguides. After patterning large features using the ASML DUV stepper for photolithography, the pattern is etched into the niobium using the PT770. After this, the devices are cleaned in the CNF hot strip bath, the Glen1000, then in a bath of 10:1 DI:HF. To form Josephson junctions, which are of the order of ~ 100 nm × 100 nm, e-beam lithography using the JEOL 6300 is required. After the junction is patterned in the JEOL 6300, the junctions are formed via e-beam evaporation using the Dolan bridge technique at Syracuse University.

By fabricating samples with a wide range of different geometries, we have been able to tune our fabrication process to improve coherence times in our devices by an order of magnitude. Additionally, adjusting the geometry of our Al/AlOx/Al Josephson junctions in the array enables us to tune the phase-slip rate across each junction, improving dephasing times for these devices as well [3]. In the near future we expect that these changes will improve our qubit dephasing times by an order of magnitude as well.

Extending our fabrication repertoire further, we have also begun to work on the Xactix XeF_2 etcher. With this, we will be able to suspend all Josephson junctions similar to the junctions in the blochnium qubit [4], giving us a wider range of accessible qubit parameters and new avenues to probe qubit dynamics.

References:

[1] A. Somoroff, et al. Millisecond Coherence in a Superconducting Qubit. Phys. Rev. Lett. 130, 267001 (2023). https://doi.org/10.1103/PhysRevLett.130.267001.

[2] V. Iaia, et al. Phonon downconversion to suppress correlated errors in superconducting qubits. Nature Communications 13, 6425 (2022). https://doi.org/10.1038/s41467-022-33997-0.

[3] M. Randeria, et al. Dephasing in Fluxonium qubits from Coherent Quantum Phase Slips. arXiv:2404.02989.

[4] I. V. Pechenezhskiy, et al. The superconducting quasicharge qubit. Nature 585, 368 (2020). https://doi.org/10.1038/s41586-020-2687-9.

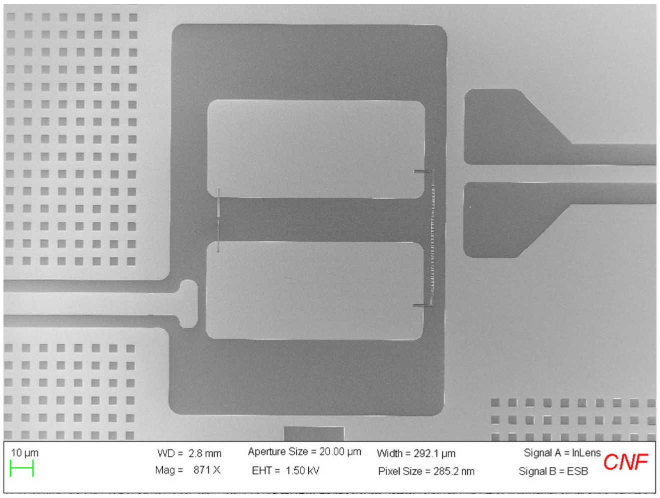

Figure 1: Scanning electron microscopy (SEM) image of one of the fluxonium qubits taken at CNF.

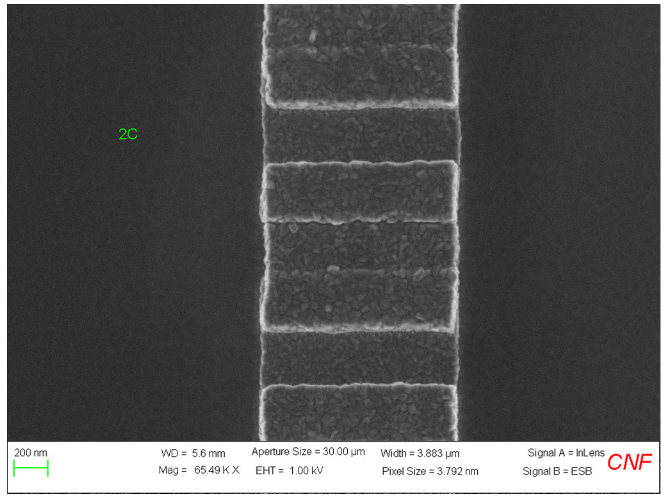

Figure 2: SEM image of a Josephson junction chain, taken at CNF.

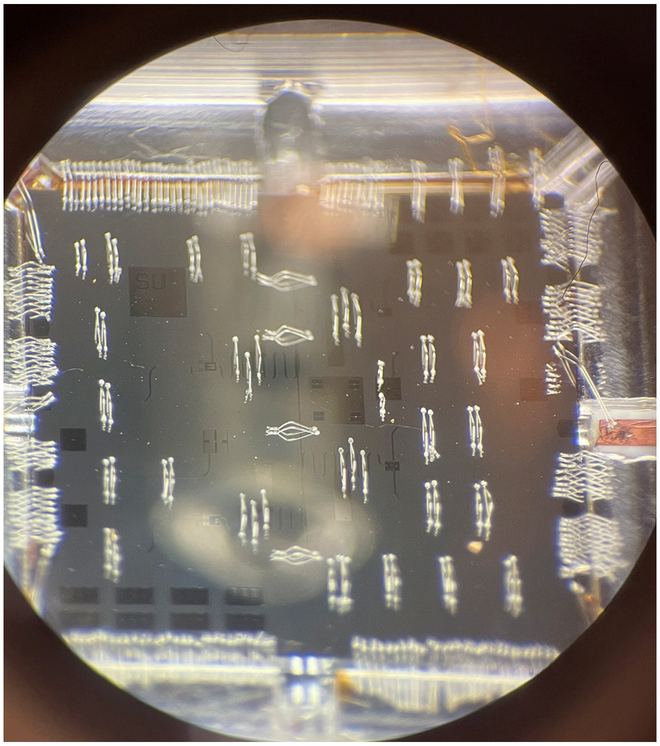

Figure 3: Photograph of a sample set into the holder wire-bonded for low-temperature measurements.