Characterization of Fluxonium Qubits

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

Abstract:

We fabricate and characterize superconducting fluxonium qubits, which are among the leading qubit candidates for scalable quantum computing processors. They possess very high (millisecond-long) characteristic times and large anharmonicity [1]. A comprehensive characterization of the different noise channels that affect fluxonia is required to devise appropriate mitigation strategies to enhance qubit performance for fault-tolerant operation. We aim to study the different extrinsic and intrinsic decoherence mechanisms that affect this qubit. In particular, we perform experiments to understand the quasiparticle effects in fluxonia.

Summary of Research:

Superconducting quantum systems have emerged as one of the leading platforms for quantum computing. Josephson tunnel junctions are the backbone of these superconducting qubits, providing the required anharmonicity. A fluxonium qubit consists of a small Josephson junction connected to two large capacitor pads and a chain of Josephson junctions acting as a large inductor [2].

An external magnetic flux is applied to tune the properties of this qubit. At the sweet spot, when a half-integer superconducting flux quantum threads the loop, the qubit exhibits a very high coherence, large anharmonicity, and is protected from flux noise decoherence.

The SEM image of our fluxonium qubit fabricated at CNF is shown in Figure 1a. The two niobium capacitor pads (40 μm × 80 μm each) set the capacitive energy scale $E_C/h \sim 1.31$ GHz. The Al/AlOx/Al small Josephson junction (90 nm × 100 nm) between the pads determines the Josephson energy $E_J/h \sim 1.29$ GHz. The array of 130 Josephson junctions (1.3 μm × 0.1 μm each) to the immediate right of the pads is associated with the inductive energy $E_L/h \sim 0.21$ GHz. In the multistep fabrication process, we utilized photolithography and electron-beam lithography tools at CNF, and an electron-beam evaporator and sputtering system at Syracuse University. The flux bias line can be seen in the right part of Figure 1a. Each qubit is capacitively coupled to a coplanar waveguide resonator, shown in the left part of Figure 1a, for dispersive readout of the qubit state. Figure 1b displays the injector Josephson junction, which can be brought to its resistive state to inject pair-breaking phonons and create quasiparticles at the qubit junctions [3].

The fabricated qubit is housed inside a sample box that sits on the 10 mK plate of a dilution refrigerator. Using the injector junction, we control the quasiparticle environment of the qubit to distinguish quasiparticle-induced effects from other decoherence channels. Figure 2 shows the exponential decay curves of the qubit T_1 measurement with (orange) and without (blue) a quasiparticle injection pulse. Compared to the baseline, we observe degradation in qubit energy relaxation time when the quasiparticle density at the qubit is elevated. Figure 3 shows the qubit T_1 as a function of external flux in three different situations: without injection, 2 μs injection, and 4 μs injection, illustrating a reduction in T_1 with injection. In the near future, we plan to study the effect of design variations in device geometry on inferred quasiparticle densities in the small and array junctions of fluxonia.

References:

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

[2] L. Nguyen, et al. Phys. Rev. X 9, 041041 (2019). https://doi.org/10.1103/PhysRevX.9.041041.

[3] V. Iaia, et al. Nature Communications, 13, 6425 (2022). https://doi.org10.1038/s41467-022-33997-0.

PHYSICS & NANO-STRUCTURE PHYSICS

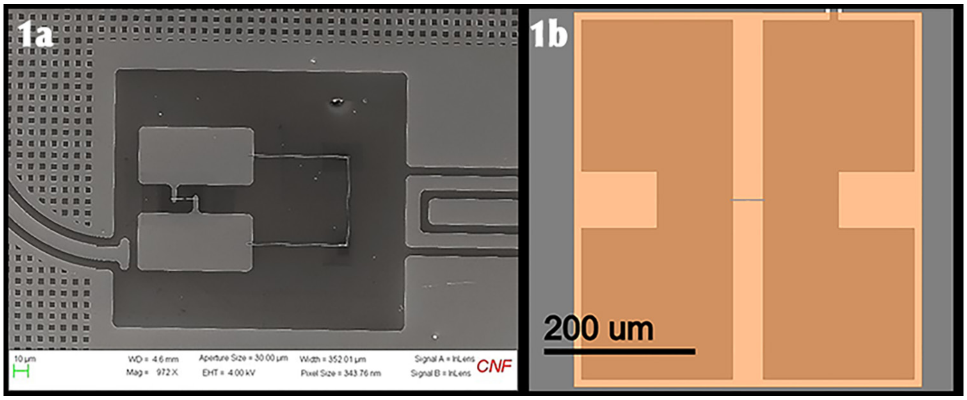

Figure 1: (a) SEM image of the fluxonium qubit showing the capacitor pads, single Josephson junction, and the chain of Josephson junctions. (b) Injector Josephson junction.

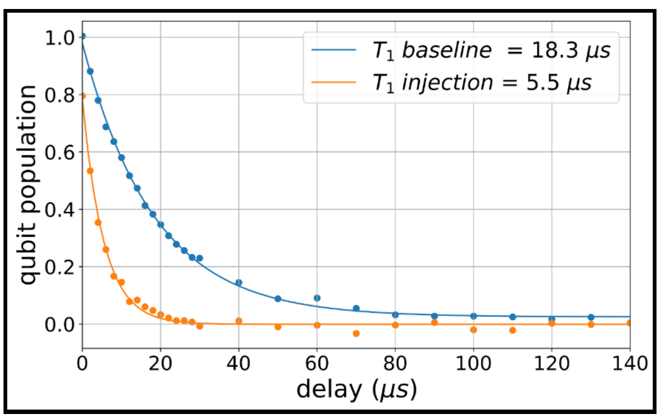

Figure 2: T$_1$ *traces measured at* $\Phi_{ext} = 0.0\ \Phi_0$ *for the baseline and injection cases.*

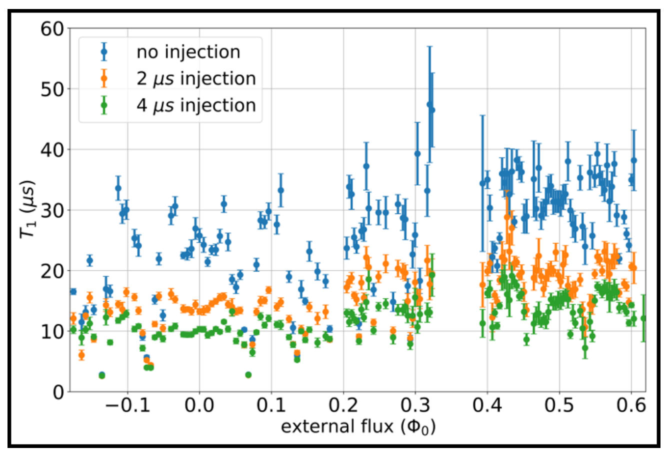

Figure 3: T$_1$ *versus external flux for a fluxonium qubit measured in three cases: baseline, with 2 µs injection pulse length, and with 4 µs injection pulse length.*