

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:

Quasiparticles are a significant intrinsic decoherence channel in superconducting qubits. Although their characterization and mitigation have been extensively studied in transmon qubits, their impact on fluxonia remains comparatively unexplored. To investigate this, we generate excess quasiparticles in fluxonia by injecting pair-breaking phonons and photons via on-chip injectors. In this controlled injection, we observe the qubit population dynamics that warrant separate extraction of qubit excitation and relaxation rates.

Summary of Research:

Superconducting quantum systems are among the leading platforms for implementing quantum computing. Josephson tunnel junctions provide the necessary nonlinearity for the spectral isolation of qubit computational states. The fluxonium qubit specifically comprises a small Josephson junction shunted by a capacitor and a large inductance realized with an array of Josephson junctions. This qubit design exhibits long coherence times and large anharmonicity [1, 2].

Figure 1a shows an SEM image of our recent design of a fluxonium qubit fabricated at the CNF. The two niobium capacitor pads ($40\text{ }\mu\text{m} \times 100\text{ }\mu\text{m}$ each) define the capacitive energy scale $E_C/h \sim 1.1\text{ GHz}$. The Al/AlOx/Al small Josephson junction ($\sim 100\text{ nm} \times 100\text{ nm}$) between the pads sets the Josephson energy $E_J/h \sim 2.1\text{ GHz}$. The inductor formed by an array of ~ 200 Josephson junctions ($\sim 0.5\text{ }\mu\text{m} \times 1\text{ }\mu\text{m}$ each) is associated with the inductive energy $E_L/h \sim 90\text{ MHz}$.

Photolithography and electron-beam lithography were performed at the CNF, and electron-beam evaporation and sputtering were carried out at Syracuse University. The flux bias line can be seen on the right in Fig. 1a. Each qubit is capacitively coupled to a resonator for dispersive readout of the qubit state. Figure 1b displays the design of the injector Josephson junction, which is

voltage biased to produce pair-breaking phonons and photons that subsequently produce quasiparticles at the qubit junctions [3].

The qubits are measured in a dilution refrigerator at 10 mK. Under certain injection biases, we observed an apparent increase in energy relaxation time T_1 extracted from standard free decay measurements, as shown in Fig. 2a. This is because the excitation rate becomes comparable to or even exceeds the relaxation rate, causing the excited-state population to decay toward a steady state above the background. Fitting such dynamics to a simple exponential that neglects this offset can yield an apparent increase in the extracted T_1 , necessitating a direct extraction of the individual transition rates. In Fig. 2b, we show background and post-injection population dynamics after the qubit initialization to states $|0\rangle$ and $|1\rangle$. We use this protocol to investigate the increase in transition rates caused by quasiparticle poisoning, including the effects arising from the efficient coupling of pair-breaking photons from the injector to the qubit, mediated by spurious antenna modes of the injector and qubit geometries [4].

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] L. Nguyen et al. High-Coherence Fluxonium Qubit. *Phys. Rev. X* 9, 041041 (2019). <https://doi.org/10.1103/PhysRevX.9.041041>
- [3] V. Iaia et al. Phonon downconversion to suppress correlated errors in superconducting qubits. *Nature Communications*, 13, 6425 (2022). <https://doi.org/10.1038/s41467-023-35986-3>
- [4] C. Liu et al. Quasiparticle Poisoning of Superconducting Qubits from Resonant Absorption of Pair-Breaking Photons. *Phys. Rev. Lett.* 132, 1 (2024). <https://link.aps.org/doi/10.1103/PhysRevLett.132.017001>

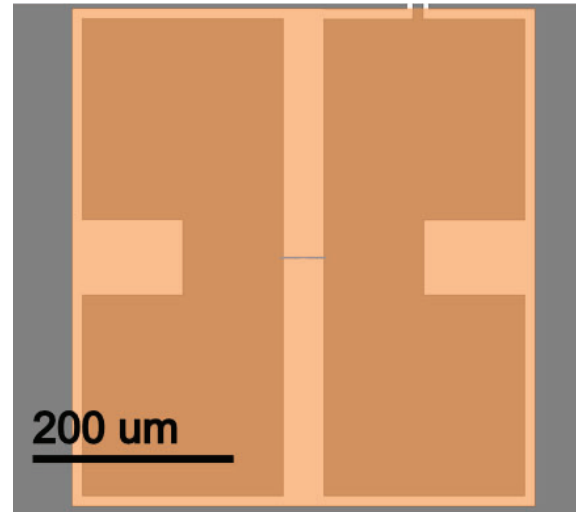
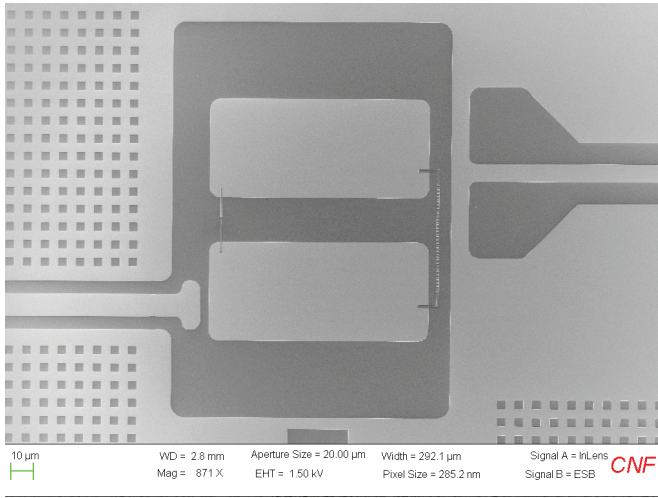


Figure 1: (a) Scanning electron micrograph of the fluxonium qubit showing the capacitor pads, single Josephson junction, and the chain of Josephson junctions. (b) Design of the Josephson junction injector.

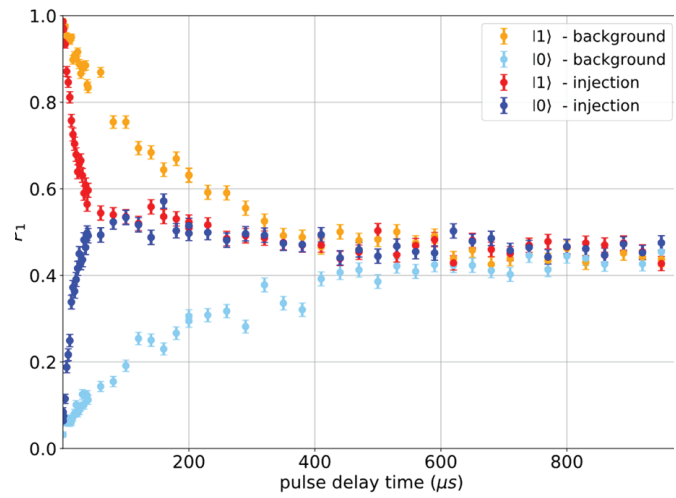
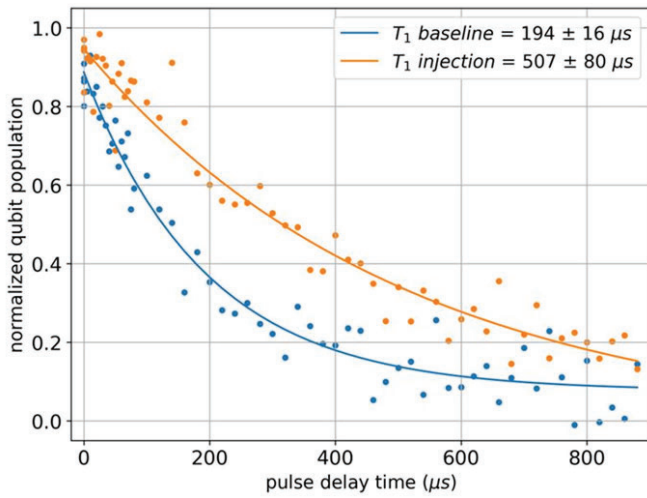


Figure 2: Two different measurement protocols for the baseline and injection cases. (a) Conventional free decay T_1 measurement. (b) Qubit populations measured after initialization in the $|0\rangle$ and $|1\rangle$ states.