

Resist-free Josephson Junction Fabrication for Superconducting Qubits

CNF Project Number: 3306-25

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Primary CNF Tools Used: JEOL 6300, Oxford 100, Oxford Cobra Silicon, Angstrom-Q, Heidelberg MLA150, Oxford 81, Primaxx vapor HF, Zeiss Ultra SEM

Abstract:

State-of-the-art Josephson junction fabrication depends on lift-off processes to define the superconductor-insulator-superconductor trilayer, which introduces organic contaminants and limits materials choices. In this project, we have developed a completely resist-free approach to the Josephson junction evaporation step, which eliminates the issues arising from the lift-off approach. We fabricated superconducting qubits using the design and have found performance better than other novel qubit designs and lower performance variation than comparable qubits in literature.

Summary of Research:

We fabricated novel resist-free Josephson junctions, which do not have any resist on the surface at the time of the evaporation [1]. We leverage the shadowing effect of the sidewalls of silicon trenches during e-beam evaporation. By changing the width of the trench, we control the presence or absence of an overlap of the films from either direction, creating a junction in the middle (Fig. 1).

We use these junctions to fabricate qubits in the CNF and conduct post-fabrication cleaning with oxygen descum and vapor HF to reduce surface residues (Fig. 2). We find that the qubit relaxation times (T_1) and pure dephasing times (T_2) scale as a function of the gap between the capacitor pads of the qubit (Fig. 3). The best performing qubit has a performance better than any other proposed novel qubit design.

We also characterize the qubit over longer time periods to examine the fluctuations of the parameters (Fig. 4). We find that the best qubit shows a relatively gaussian distribution of coherence time over 36 hours, which is indicative of high stability. Allan deviation analysis shows deviations lower than any comparable qubit in

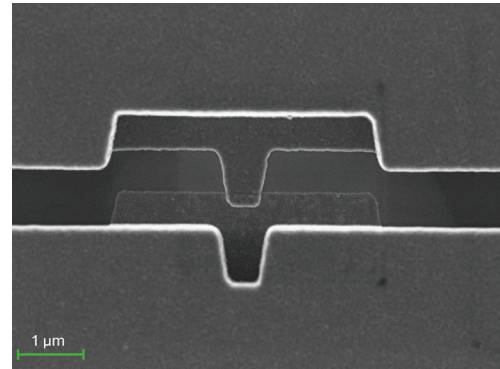


Figure 1: Top-down SEM image of the trench-based Josephson junction. No resist was used at the time of the junction evaporation, and thus there is no lift-off step necessary. Adapted from [1].

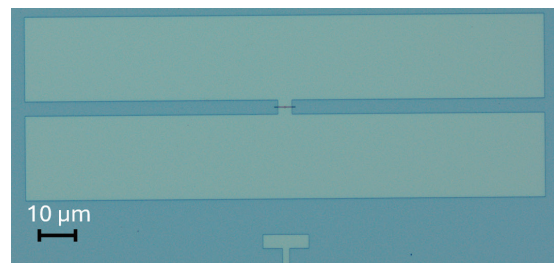


Figure 2: Fabricated qubit. The trench junction is in the middle, with rectangular capacitor pads to define the qubit capacitance. The qubit is coupled to a readout resonator to measure and characterize the qubit.

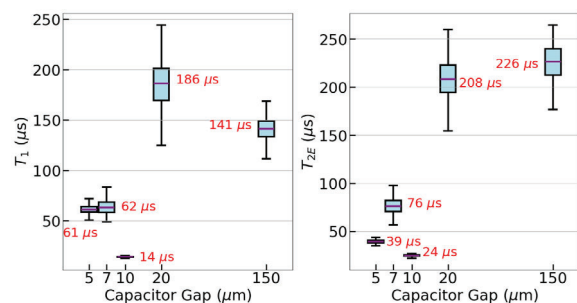


Figure 3: Qubit performance measurement. We measure qubit relaxation time T_1 and pure dephasing time T_{2E} over different capacitor gap distances and report. The performance increases as gap size increases. Data is reported in [1].

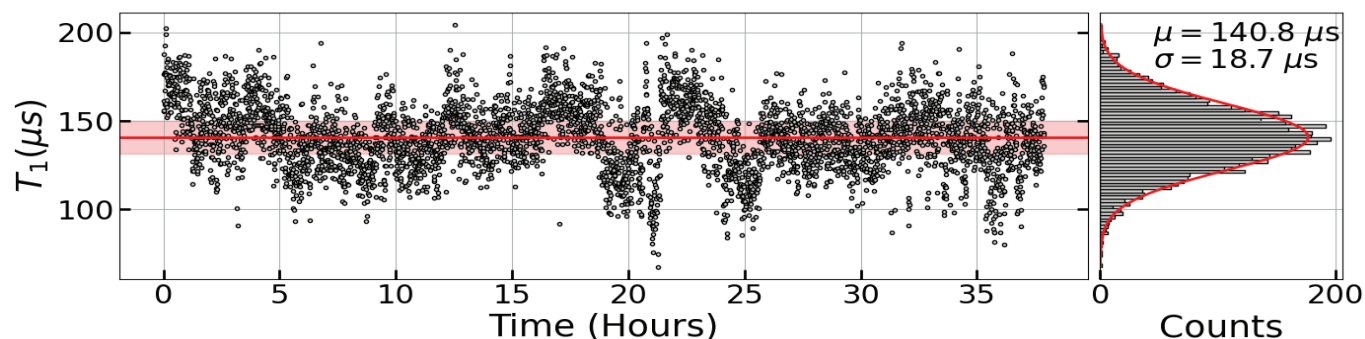


Figure 4: Coherence time fluctuations over 36 hours for one qubit, measured every 30s. We see a gaussian distribution, with standard deviation lower than equivalent qubits made with traditional fabrication processes. Adapted from [1].

the field, indicating that the elimination of the residues is likely causing a significant increase in the stability of the device.

Conclusions and Future Steps:

The ability to create such junctions creates several advantages, such as the elimination of organic residue between the junction and the substrate via aggressive HF cleaning, as well as the use of novel materials which can usually damage the resist if evaporated in the lift-off configuration.

The two primary insights from this work are the ability to try new materials and the reduction in qubit performance variation. Future work involves exploring further surface and interface preparation towards reducing the performance variation, and the use of materials such as Nb and Ta in conjunction with Al to leverage their properties to fabricate Josephson junctions.

References:

- [1] T. Banerjee, S.D. Funni, S. Roy, J.J. Cha, & V. Fatemi. Resist-free shadow deposition using silicon trenches for Josephson junctions in superconducting qubits, arXiv:2604.09796 (2026).