# Fabrication of Superconducting Devices for Quantum Information Science

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*Primary CNF Tools Used: ASML 300C DUV stepper, JEOL 9500, Plasma-Therm PT740*

## Abstract:

**We are fabricating nanoscale superconductor tunnel junctions and microwave resonators for investigations in quantum information science. Such circuits have shown great promise in recent years for forming qubits, the elements of a quantum computer. We are developing architectures involving multiple superconducting qubits and microwave resonators. This involves a combination of photolithographic processing and etching of large-scale features and electron-beam lithography for the tunnel junctions.**

## Summary of Research:

In recent years, circuits composed of nanoscale Josephson junctions have emerged as promising candidates for the foundational element of a quantum computer, due to the low intrinsic dissipation from the superconducting electrodes and the possibility of scaling to many such qubits on a chip [1]. The quantum coherent properties of the circuits are measured at temperatures below 50 mK with manipulation of the qubit state through microwave excitation.

We are working to develop architectures involving multiple superconducting qubits coupled to multiple low-loss microwave resonators [2-4]. We probe the coupling between each qubit and resonator by measuring the dispersive shift of the resonator frequency with the qubit detuned from the resonator. Some of our experiments are aimed at developing qubit designs that have reduced sensitivity to low-frequency magnetic flux noise that can lead to decoherence [2]. We are also investigating alternative qubit designs [3] that may lead to more efficient two-qubit gates for generating entanglement between circuits [4].

We pattern these circuits at the CNF with nanoscale structures defined with electron-beam lithography integrated with photolithographically defined large-scale features on Si and sapphire substrates. The junctions are fabricated using the standard double-angle shadow evaporation technique, in which a resist bilayer of copolymer and PMMA is used to produce a narrow PMMA airbridge suspended above the substrate.

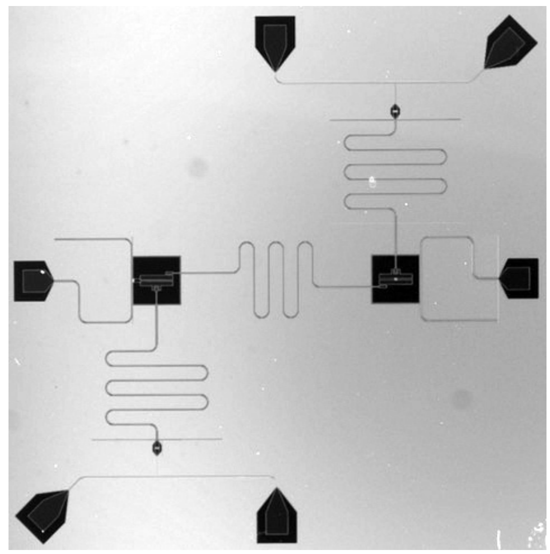

*Figure 1: Optical micrograph of device with two superconducting qubits coupled by common microwave bus resonator with separate readout resonators for each qubit.*

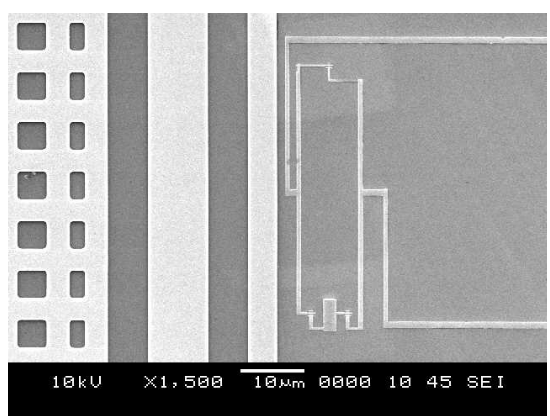


*Figure 2: Scanning electron micrograph of superconducting loop with Josephson junctions for a capacitively shunted flux qubit.*

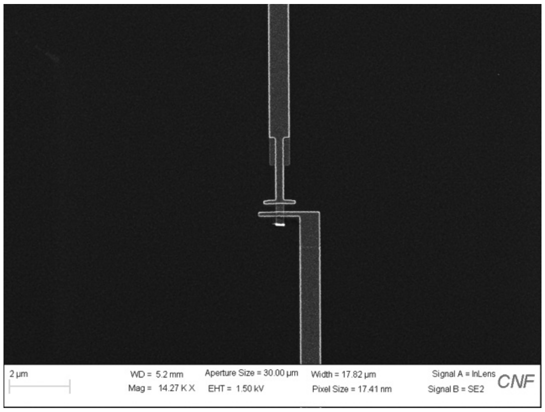


*Figure 3: Scanning electron micrograph of cross-style Al-AlOx-Al Josephson junction for superconducting qubit patterned on the JEOL 9500.*

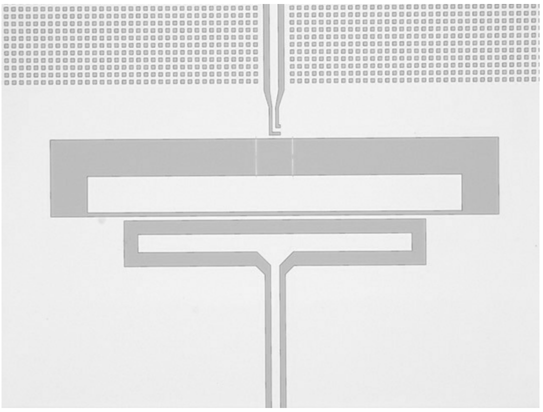

*Figure 4: Optical micrograph of superconducting qubit for experiments probing the effects of magnetic flux noise on qubit decoherence.*

Evaporation of aluminum from two different angles with an oxidation step in between forms a small Al-$AlO_x$-Al tunnel junction from the deposition shadow of the airbridge. We have developed a process for defining these junctions with electron-beam lithography on the JEOL 9500 and we perform the aluminum evaporations in a dedicated vacuum chamber at Syracuse. We pattern large-scale features using the ASML, with sputter deposition of superconducting Nb films in a dedicated vacuum system at Syracuse University. Microwave measurements of these circuits are performed in cryogenic systems at Syracuse University, including dilution refrigerators for achieving temperatures below 30 mK.

## References:

[1] Clarke, J. and Wilhelm, F.K.; "Superconducting quantum bits"; Nature, 453, 1031 (2008).

[2] Hutchings, M. D. Hertzberg, Jared B., Liu, Y., Bronn, Nicholas T., Keefe, George A., Chow, Jerry M., Plourde, B.L.T.; "Tunable Superconducting Qubits with Flux-Independent Coherence"; Physical Review Applied 8, 044003 (2017).

[3] Ku, Jaseung, Liu, Yebin, Plourde, Britton, Hertzberg, Jared, Brink, Markus, Magesan, Chow, Jerry; "Capacitively Shunted Flux Qubits and Asymmetric Transmons for Multi-qubit Operations"; Bull. Am. Phys. Soc. 2018, http://meetings.aps.org/Meeting/MAR18/Session/L33.8.

[4] Corcoles, A. D., Gambetta, Jay M., Chow, Jerry M., Smolin, John A., Ware, Matthew, Strand, J. D., Plourde, B. L. T., Steffen, M.; "Process verification of two-qubit quantum gates by randomized benchmarking"; Physical Review A 87, 030301(R) (2013).