# Nanofabricated Superconducting Devices for Vortex Dynamics and Qubits

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*Primary CNF Tools Used: ASML stepper, JEOL 9500, Plasma-Therm 770*

## Abstract:

**We fabricate superconducting microwave devices for studying the dynamics of vortices at low temperatures and for forming novel qubits. Vortices are quantized bundles of magnetic flux that thread many different superconductors over a particular range of applied magnetic field. By using disordered superconducting thin films to form high kinetic inductance wires combined with novel arrays of Josephson junctions, we are able to build structures that can lead to qubits that are protected against decoherence.**

## Summary of Research:

Superconducting microwave circuits play an important role in quantum information processing. Circuits composed of Josephson junctions and capacitors with superconducting electrodes can serve as qubits, the fundamental element of a quantum computing architecture. Various loss mechanisms limit the ultimate performance of these devices, including trapped magnetic flux vortices. Vortices can be trapped in the superconducting electrodes when background magnetic fields are present and contribute dissipation when driven with microwave currents [1]. Thus, techniques for controlling the trapping of vortices are critical to the development of large-scale quantum information processors with superconducting circuits.

By arranging nanoscale Al-AlOx-Al Josephson tunnel junctions in novel arrays, it is possible to implement new qubit designs that are protected against decoherence [2,3].

We fabricate our microwave resonators from various superconducting films, including aluminum and niobium, deposited onto silicon wafers in vacuum systems at Syracuse University. We define the patterns on the ASML stepper and transfer them into the films with a combination of reactive ion etching and liftoff processing. For defining Josephson junctions, we use the JEOL 9500 along with a dedicated deposition system at Syracuse University. We measure these circuits at temperatures of 100 mK and below in our lab at Syracuse University.

## References:

[1] Song, C., Heitmann, T.W., DeFeo, M.P., Yu, K., McDermott, R., Neeley, M., Martinis, John M., Plourde, B.L.T.; "Microwave response of vortices in superconducting thin films of Re and Al"; Physical Review B 79, 174512 (2009).

[2] Doucot, B., Ioffe, L.; "Physical implementation of protected qubits"; Reports on Progress in Physics 75, 072001 (2012).

[3] Dodge, K., Liu, Y., Cole, B., Ku, J., Senatore, M., Shearrow, A., Zhu, S., Abdullah, S., Klots, A., Faoro, L., Ioffe, L., McDermott, R., Plourde, B.; "Protected C-Parity Qubits Part 1: Characterization and Protection"; Bull. Am. Phys. Soc. 2021, http://meetings.aps.org/Meeting/MAR21/Session/X31.3.

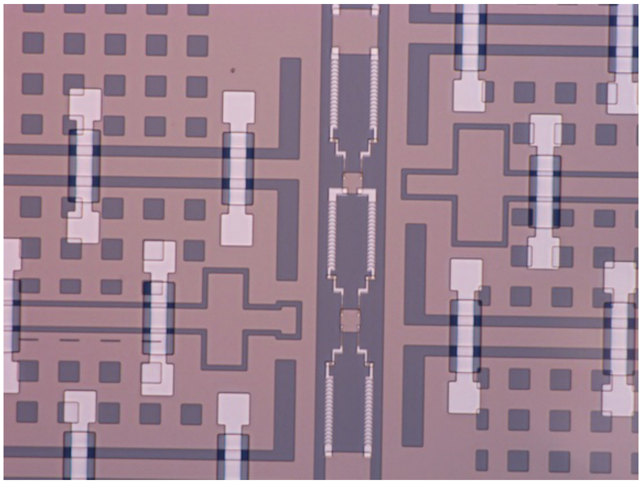

Figure 1: *Optical micrograph of plaquette structures formed from arrays of Al-AlOx-Al Josephson junctions for protected qubit design with Nb ground plane and Al/SiOx ground straps.*

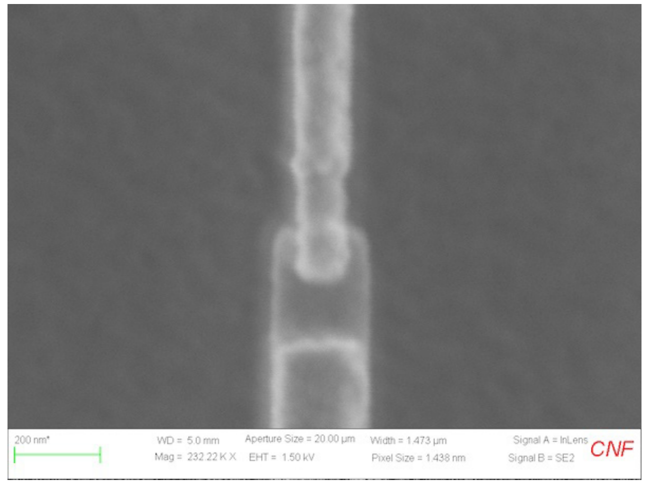


*Figure 2: Scanning electron micrograph image of small-area Al-AlOx-Al Josephson junction on protected qubit element.*

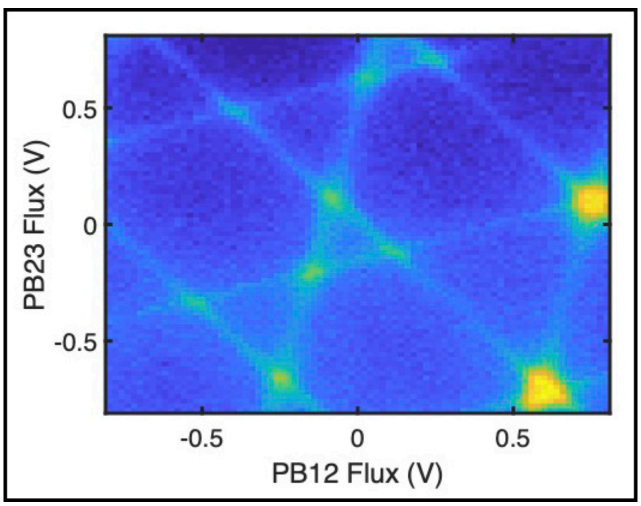


*Figure 3: Two-dimensional flux bias voltage modulation of resonant frequency for readout microwave resonator coupled to qubit.*

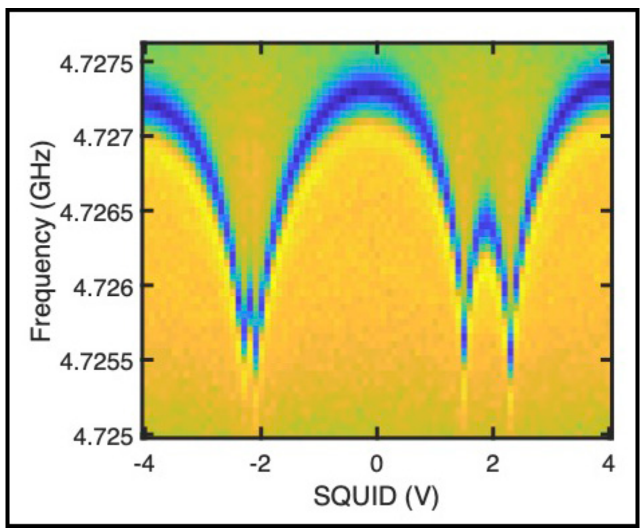


*Figure 4: Modulation of qubit transition frequency with flux bias voltage of SQUID tuning loop.*