

Nanofabricated Superconducting Devices for Vortex Dynamics and Qubits

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Primary CNF Tools Used: ASML Photostepper, JEOL 6300, 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 topologically protected against decoherence. With charge-sensitive superconducting qubits, we are able to probe sources of correlated errors in quantum processors.

mitigate this quasiparticle poisoning through the use of electroplated Cu metallic reservoirs for downconversion of high energy phonons [5].

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 6300 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.

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-AlO_x-Al Josephson tunnel junctions in novel arrays, it is possible to implement new qubit designs that are protected against decoherence [2-4]. We are also able to use such Al-AlO_x-Al tunnel junctions in superconducting qubits to probe poisoning effects from nonequilibrium quasiparticles, which are a source of correlated errors in quantum processors. We can

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] Liu, Y., Dodge, K., Cole, B., Shearrow, A., Brann, E., Snyder, M., Klots, A., Ioffe, L., McDermott, R., Plourde, B.; "Quantum stabilizers implemented with superconducting hardware"; *Bull. Am. Phys. Soc.* 2023, <https://meetings.aps.org/Meeting/MAR23/Session/M75.3>
- [4] Dodge, K., Liu, Y., Klots, A., Cole, B., Shearrow, A., Senatore, M., Zhu, S., Ioffe, L., McDermott, R., Plourde, B.; "Hardware implementation of quantum stabilizers in superconducting circuits"; arXiv:2303.00625.
- [5] Iai, V., Ku, J., Ballard, A., Larson, C.P., Yelton, E., Liu, C.H., Patel, S., McDermott, R., Plourde, B.L.T.; "Phonon downconversion to suppress correlated errors in superconducting qubits"; *Nature Communications* 13, 6425 (2022).

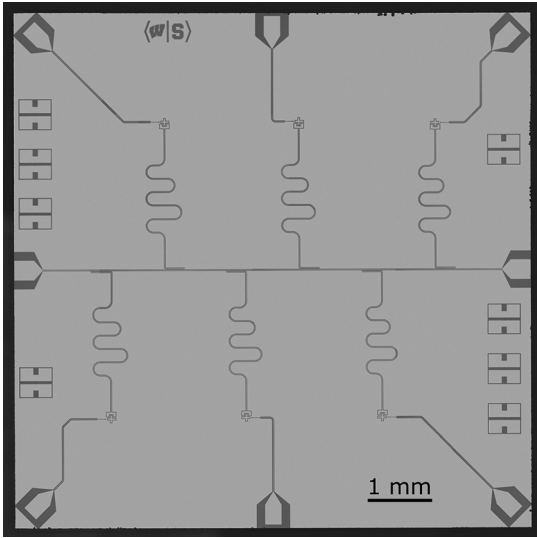


Figure 1: Optical micrograph of multi-qubit chip with Nb base layer and Al-AlO_x-Al tunnel junctions for probing phonon-mediated correlated errors.

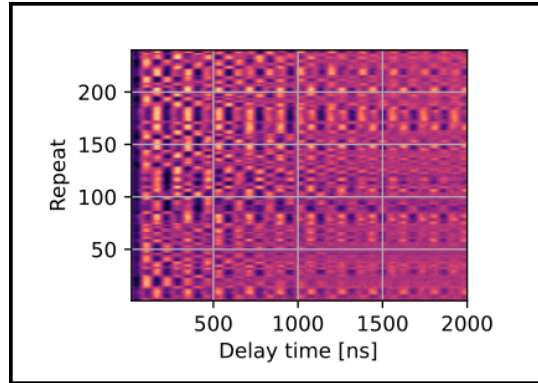


Figure 2: Repeated measurements of Ramsey fringe oscillations for charge-sensitive superconducting qubit subject to random offset charge jumps due to high energy particle impacts on device.

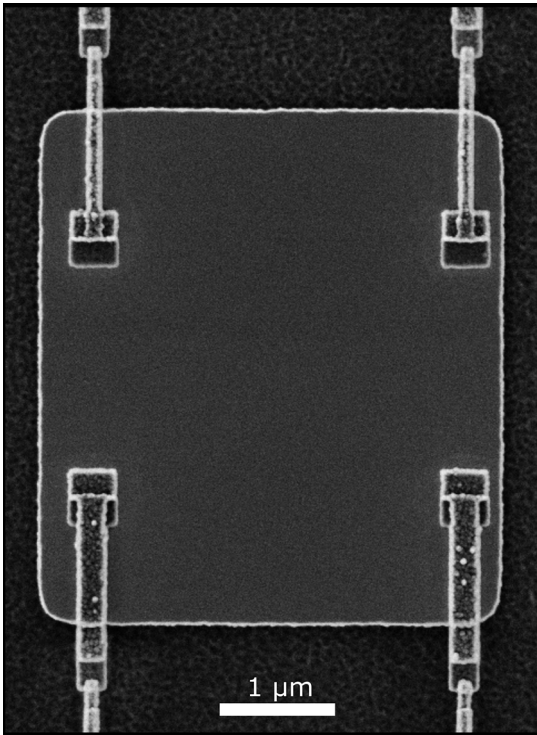


Figure 3: SEM image of central superconducting Nb island connected to four Al-AlO_x-Al tunnel junctions for topologically protected superconducting circuit.

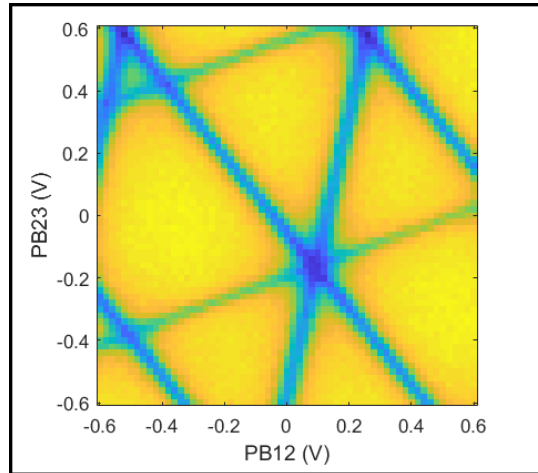


Figure 4: Measurement of microwave readout cavity modulation with magnetic flux using on-chip control lines coupled to topologically protected superconducting circuit.