Nanofabricated Superconducting Devices for Vortex Dynamics and Qubits

CNF Project Number: 1314-05

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Primary CNF Tools Used: ASML Autostepper, 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. In addition, highly disordered superconducting films, including granular Al, can be used to form wires with a compact high kinetic inductance. When combined with novel arrays of Al-AlO_x-Al Josephson junctions, 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, deposited onto silicon wafers in vacuum systems at Syracuse University. We define the patterns at CNF 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.

PHYSICS & NANO-STRUCTURE PHYSICS

References:

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

[3] Liu, Y., Dodge, K., Senatore, M., Zhu, S., Naveen, Shearrow, A., Schlenker, F., Klots, A., Faoro, L., Ioffe, L., McDermott, R., Plourde, B.; "Implementation of pi-periodic Josephson Elements for Topologically Protected Charge-Parity Qubits"; Bull. Am. Phys. Soc. 2019, http://meetings.aps.org/Meeting/MAR19/Session/S26.11.

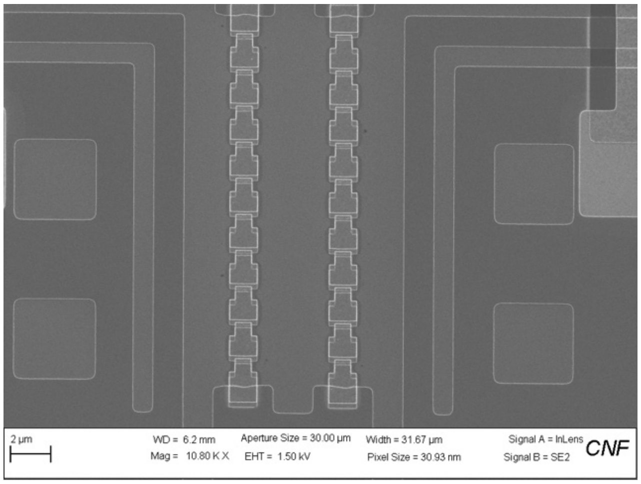

Figure 1: Scanning electron micrograph of inductors formed from arrays of Al-AlO$_x$-Al Josephson junctions for protected qubit design.

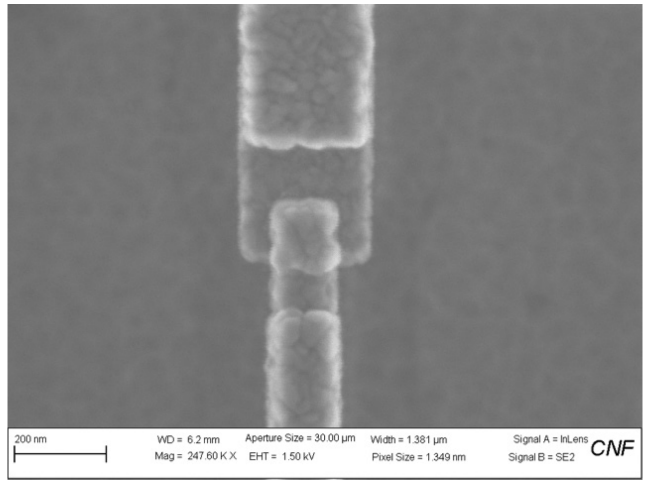

Figure 2: Scanning electron micrograph image of small-area Al-AlO$_x$-Al Josephson junction on protected qubit element.

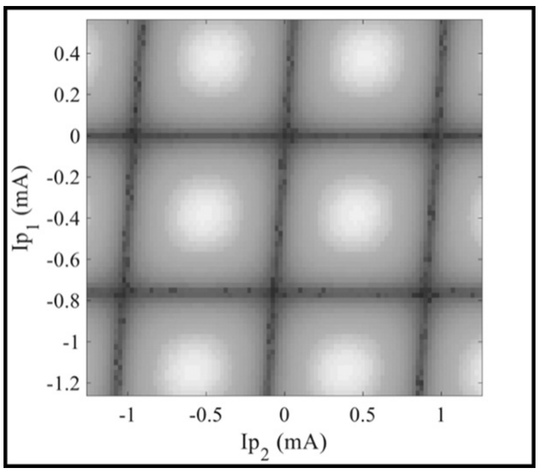

Figure 3: Two-dimensional flux bias current modulation of resonant frequency for readout microwave resonator coupled to qubit.

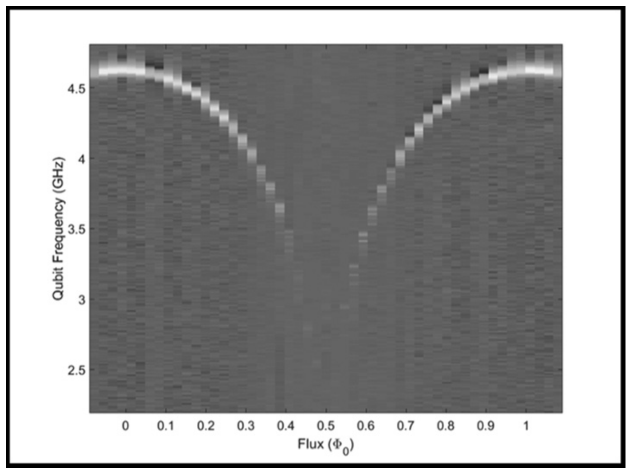

Figure 4: Flux modulation of qubit transition frequency.