Vortex Dynamics in Nanofabricated Superconducting Devices

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Abstract:

We fabricate superconducting microwave devices for studying the dynamics of vortices and quasiparticles at low temperatures. Vortices are quantized bundles of magnetic flux that thread many different superconductors over a particular range of applied magnetic field. Our experiments are aimed at investigating loss mechanisms that can limit the performance of superconducting circuits for quantum information processing. In addition to probing the loss in these circuits that arises from trapped magnetic flux, we are also studying techniques for coupling superconducting digital control circuitry to superconducting qubits for control of the quantum state.

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 and quasiparticles. Vortices can be trapped in the superconducting electrodes when background magnetic fields are present and contribute to dissipation when driven with microwave currents [1].

Quasiparticles are excitations above the superconducting ground state and also result in microwave losses in superconducting electrodes. Various mechanisms can lead to the generation of excess quasiparticles, including the operation of superconducting digital control circuitry in close proximity to qubits [2]. Thus, techniques for controlling the trapping of vortices and the mitigation of quasiparticles are critical to the development of large-scale quantum information processors with superconducting circuits.

We are fabricating a system of microwave resonators using a variety of superconducting thin films, including Nb and TiN, for studying the loss contributed by trapped flux in these materials over the frequency range from 1.5-11 GHz [3]. By cooling the resonators in different magnetic fields, we are able to probe the loss from vortices as a function of field at the resonance frequencies contained in our design.

We are also working on fabricating and testing devices containing superconducting quantum circuits as well as digital control circuitry for cryogenic control of the quantum state of superconducting qubits [2]. The qubits are fabricated at the CNF and Syracuse with Al-AlOx-Al junctions and the superconducting digital circuits are fabricated by collaborators at the University of Wisconsin, Madison with a Nb-based process [4,5]. We have demonstrated techniques for mitigating the effects on qubit coherence due to stray quasiparticles from the operation of the digital control circuitry [6]. The qubit junctions for these devices are currently patterned on the JEOL9500, but we are pursuing a parallel approach with an all-photolithography process on the ASML for defining the junction electrodes.

We fabricate our microwave resonators from various superconducting films, including aluminum, deposited onto silicon wafers in our electron-beam evaporator 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 wet-etch processing. We define the electrodes for our Josephson tunnel junctions with electron-beam lithography on the JEOL9500 and ASML. We measure these circuits at temperatures of 100 mK and below in our lab at Syracuse University.
References:

Figure 1: Optical micrograph of superconducting titanium nitride microwave resonator for low-temperature experiments probing the effects of magnetic flux vortices on microwave loss.

Figure 2: Zoomed-in optical micrograph of portion of superconducting titanium nitride microwave resonator. Square holes in ground plane ensure that magnetic flux vortices are trapped in the coplanar waveguide center conductor during field-cooling measurements.

Figure 3: Optical micrograph of Al-AlOx-Al superconducting tunnel junctions and Nb capacitor pads for a superconducting transmon qubit for investigations of qubit control with digital superconducting electronics.

Figure 4: Scanning electron micrograph of superconducting Al-AlOx-Al tunnel junction fabricated with photolithography on the ASML stepper.