Improved Materials for High-Performance Superconducting Quantum Circuits

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Abstract:
Circuits based on nanoscale superconductor tunnel junctions and low-loss microwave resonators have emerged as some of the leading candidates for forming a quantum computer. The quantum coherence properties of such circuits are strongly linked to the materials properties of the various components that are used to form the devices. We are studying a variety of approaches to improving the coherence of these superconducting quantum circuits.

Summary of Research:
Superconducting circuits involving nanoscale superconductor tunnel junctions and low-loss microwave resonators are currently being investigated by many research groups worldwide for forming the elements of a quantum computer. The inherent nonlinearity of Josephson junctions allows for the possibility of forming two-state quantum systems, or qubits, and low-loss resonators provide a route for transmitting or storing single microwave quanta [1]. The ultimate performance of these circuits is tied to a variety of materials properties in the components used to form the qubits and resonators, including microwave loss and various types of noise processes [2].

We are working on a variety of approaches for probing some of the materials properties that limit the coherence of these superconducting quantum circuits. Microwave loss in the native oxide that forms on the surfaces of most superconducting thin films is one of the dominant loss channels that limits the quality factors of superconducting resonators at low temperatures [3]. We are exploring different superconducting films, including NbN, and surface treatments in an attempt to reduce the loss from surface oxides [4]. For the Josephson junctions that form the nonlinearity in most superconducting qubits, defects in the tunnel barrier and fluctuations in the critical current can limit the coherence properties of the qubit. To address the coherence problems arising from the junction barrier, we are developing a novel Josephson junction design where the junction is formed from a superconducting nanoscale constriction rather than a tunnel barrier [5].

We deposit our various superconducting films in dedicated vacuum systems, both sputtering and electron-beam evaporation, at Syracuse University. We pattern resonators from these films at the CNF with photolithography on the Autostep 200 followed by reactive ion etching. For defining the nanoscale constriction junctions, we use the JEOL 6300 to write narrow lines on a-MoGe films. We then transfer the nanowire pattern into the films by ion beam etching. We perform measurements of these circuits in cryogenic systems at Syracuse University.

References:
Figure 1: Optical micrograph of superconducting NbN coplanar waveguide microwave resonator.

Figure 2: Transmission measurement through feedline that is weakly coupled to NbN microwave resonator at 300 mK.

Figure 3: Scanning electron micrograph of 25 nm wide a-MoGe nanowire patterned by electron-beam lithography and ion beam etching.

Figure 4: Current-voltage characteristic of 25 nm wide a-MoGe nanowire measured at 1.7 K with three different frequencies of microwave irradiation.