Fabrication of Nanoscale Josephson Junctions for Quantum Coherent Superconducting Circuits

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Abstract:
We fabricate nanoscale superconductor tunnel junctions for experiments involving quantum coherent superconducting circuits. Such circuits have shown great promise in recent years for explorations of quantum mechanics at the scale of circuits on a chip and for forming qubits, the elements of a quantum computer. The superconducting qubit, where the entire device has two fundamental basis states, can be manipulated with resonant radiation and placed in an arbitrary quantum superposition of the basis states. Success in this area requires a fabrication process for making nanoscale junctions reproducibly with an architecture that allows for the placement of many qubits on a chip.

Summary of Research:
The unique properties of nanoscale Josephson junctions enable a wide range of novel superconducting circuits for investigations in many diverse areas. One such circuit, the superconducting flux qubit, has emerged as a promising candidate for the element of a quantum computer, due to the low intrinsic dissipation from the superconducting electrodes and the possibility of scaling to many such qubits on a chip [1,2]. This circuit consists of a thin-film superconducting loop interrupted by several Josephson tunnel junctions. When the applied magnetic flux is adjusted within a certain range and the temperature is below ~ 50 mK, these circuits have two states—all of the screening supercurrent flowing clockwise around the loop or counterclockwise. Resonant microwave radiation drives transitions between the two states and microwave pulses of well-defined lengths can be used to generate arbitrary superpositions of the two states. To engineer the energy level spacings in a convenient range, the junctions must have capacitances of only a few femtofarads, thus driving the junction sizes to be of the order of 100 nm × 100 nm. The sense of the circulating supercurrent can be measured with another superconducting device involving more Josephson junctions, a dc Superconducting QUantum Interference Device (SQUID). In addition, the SQUID can provide a controllable interaction for entangling two qubits together [3], a necessary ingredient for a scalable quantum computer [4].

We pattern these circuits at the Cornell NanScale Facility with 100 nm scale structures defined with electron-beam lithography integrated with photolithographically defined large-scale features with the goal to lead to scalable qubit architectures. Our investigations of these circuits will allow us to work on improvements in the quantum coherence in these devices, evaluate approaches for generating entanglement between multiple qubits, and investigate other novel quantum coherent circuits.

The junctions are fabricated using the standard double-angle shadow evaporation technique [5], in which a resist bilayer of copolymer and PMMA is used to produce a narrow PMMA airbridge suspended above the substrate. Evaporation of aluminum from two different angles with an oxidation step in between forms
a small Al-AlO$_x$-Al tunnel junction from the deposition shadow of the airbridge. We have developed a process for defining these junctions on the JEOL9300FS and we perform the aluminum evaporations in a dedicated chamber at Syracuse. We pattern the large-scale features using the Autostep 200 and evaporation of Al and Pd films. Measurements of these circuits are performed in cryogenic systems at Syracuse University, including a custom dilution refrigerator for achieving a temperature of 20 mK.

References:


