Fabrication of Superconducting Devices for Quantum Information Science

CNF Project Number: 1873-10
Principal Investigator: Britton L. T. Plourde
Users: Joel Strand, Matthew Ware, Bo Xiao

Affiliation: Department of Physics, Syracuse University
Primary Source of Research Funding: Intelligence Advanced Research Projects Agency (IARPA)
Contact: bplourde@phy.syr.edu, joel.strand@gmail.com, mware87@gmail.com, bxiao@nsu.edu
Web Site: http://www.phy.syr.edu/~bplourde

Abstract:
We are fabricating nanoscale superconductor tunnel junctions and microwave resonators for investigations in quantum information science. Such circuits have shown great promise in recent years for forming qubits, the elements of a quantum computer. We are developing architectures involving multiple superconducting qubits and microwave resonators. This involves a combination of photolithographic processing of large-scale features and electron-beam lithography for the tunnel junctions.

Summary of Research:
In recent years, circuits composed of nanoscale Josephson junctions have emerged as promising candidates 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]. The quantum coherent properties of the circuits are measured at temperatures below 50 mK with manipulation of the qubit state through microwave excitation.

We are working to develop architectures involving multiple superconducting qubits coupled to multiple low-loss microwave resonators [2]. We probe the coupling between each qubit and resonator either by measuring a vacuum Rabi splitting in the microwave transmission through the resonator when the qubit energy level difference is tuned to the characteristic frequency of the resonator, or by measuring the dispersive shift of the resonator frequency with the qubit detuned from the resonator [3].

We pattern these circuits at the CNF with nanoscale structures defined with electron-beam lithography integrated with photolithographically defined large-scale features on Si and sapphire substrates. The junctions are fabricated using the standard double-angle shadow evaporation technique, 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-AlOx-Al tunnel junction from the deposition shadow of the airbridge. We have developed a process for defining these junctions on the JEOL9300 and we perform the aluminum evaporations in a dedicated chamber at Syracuse. We pattern large-scale features using the Autostep 200, with sputter deposition of Nb and NbN films in dedicated systems at Syracuse University. Measurements of these circuits are performed in cryogenic systems at Syracuse University, including a custom dilution refrigerator for achieving temperatures of 30 mK.

References:
Figure 1: Optical micrograph of superconducting qubit incorporating two Josephson junctions with interdigitated shunting capacitors coupled to Nb microwave resonator.

Figure 2: Qubit energy levels measured with low-temperature microwave spectroscopy as a function of magnetic flux through superconducting qubit loop.

Figure 3: Optical micrograph of superconducting qubit with Al paddle capacitor plates and Al-AlOx-Al tunnel junction in center.

Figure 4: Scanning electron micrograph of Al-AlOx-Al tunnel junction at center of superconducting qubit.