Quantum-Limited Measurement and Entanglement in Superconducting Circuits

CNF Project # 1577-07
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Abstract:
An outstanding goal in condensed-matter physics is the generation, manipulation, and high-fidelity readout of coherent quantum states in micro- and nanofabricated circuits, such as superconducting circuits based on Josephson junctions. These systems can be viewed as artificial atoms, with energy levels that are tunable over a broad range on nanosecond timescales. These artificial atoms can be made to couple strongly and controllably both to one another and to microwave photons. Thus, they form an ideal test bed for the exploration of fundamental quantum mechanics concepts. We are investigating the fundamental physics that governs decoherence in superconducting quantum circuits, and developing tools for measurement approaching the quantum limit.

Summary of Research:
Superconducting quantum circuits incorporating Josephson junctions are a leading candidate for scalable quantum information processing in the solid state. Despite recent advances including controllable coupling of superconducting qubits [1] and quantum state tomography [2], the microscopic physics that governs decoherence of the quantum state is poorly understood.

In the case of the Josephson phase and flux qubits, dephasing is due to a low frequency magnetic flux noise with $1/f$ spectrum and magnitude at 1 Hz around $1 \mu \Phi_0 / \text{Hz}^{1/2}$, where $\Phi_0 = h/2e$ is the magnetic flux quantum. Our recent experiments suggest that this noise is due to a high density of unpaired electron spins on the surfaces of the superconducting films that are used to realize the qubit [3]. We are conducting additional experiments to understand the physics that drives spin fluctuations, and we are exploring novel fabrication techniques to realize superconducting detectors and qubits with reduced noise.

At the same time, accurate characterization of entanglement in solid-state quantum circuits demands measurement capabilities approaching the quantum limit in the microwave regime. We are investigating novel nanofabrication and device techniques to realize superconducting amplifiers with noise performance approaching this goal. These devices will be used in the full tomographic characterization of solid-state qubit circuits.

We are using the CNF to make reticles for the preparation of thin-film superconducting devices at the Wisconsin Center for Applied Microelectronics (WCAM). Superconducting Al and Nb thin films are grown by sputter deposition, while dielectric films are grown by plasma-enhanced chemical vapor deposition. The films are patterned photolithographically and etched with chlorine- and fluorine-based reactive ion etching. Device characterization is performed at millikelvin temperatures in our laboratories at the University of Wisconsin.
References:


Figure 1: Interdigitated capacitor structure formed from 100 nm Al thin film.

Figure 2: Al-AlOx-Al Josephson junction.