Quantum-Limited Measurement and Entanglement in Superconducting Circuits

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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. The circuits can be made to couple strongly both to one another and to microwave photons. Thus, they form an ideal test bed for the exploration of fundamental quantum concepts. We are investigating the physics that governs decoherence in these circuits and developing techniques 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, the microscopic physics that governs decoherence of the quantum state is incompletely 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 $1 \mu \Phi_0/Hz^{1/2}$. 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. We are conducting additional experiments to understand the physics that drives spin fluctuations, and we are exploring novel surface treatments 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 quantum-limited performance in the microwave regime. We are investigating novel nanofabrication and device techniques to realize superconducting amplifiers with noise performance approaching the quantum limit. These devices will be used in the full tomographic characterization of solid-state qubit circuits. In addition, we are developing a Josephson photon counter, a microwave frequency analog of the avalanche photodiode: absorption of a single microwave photon causes the junction to switch to the voltage state, producing a large, readily measured classical signal.

We are using the CNF to fabricate reticles that are needed for the preparation of thin-film superconducting devices at the Wisconsin Center for Applied Microelectronics. Superconducting aluminum and niobium 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. In addition, graduate student Guilhem Ribeill spent one week at the CNF working with collaborators in the Plourde group (Syracuse University) to develop superconducting qubits and amplifiers based on submicron Josephson junctions.
Figure 1: Multiplexed Josephson junction photon counter.

Figure 2: Ultralow noise microwave amplifier based on the superconducting low-inductance undulatory galvanometer (SLUG).

Figure 3: High fidelity Josephson phase qubit incorporating a crystalline silicon shunt capacitor.