

Aluminum Resonator and Josephson Junction Fabrication Process Development for Superconducting Qubits

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Primary CNF Tools Used: Electron-beam Lithography, Optical Lithography, AJA sputtering systems, ICP Etcher

Abstract:

This report summarizes process development for Al resonators and Josephson junctions for superconducting qubits. The work focused on fabricating aluminum thin-film device structures on sapphire substrates, with emphasis on resonator patterning, Josephson junction electrode definition, multilayer alignment, and process reproducibility. A major part of the effort involved troubleshooting fabrication steps such as resist coating, lithography exposure, pattern transfer, etching, resist removal, structural alignment and surface cleaning to obtain clean and well-defined Al patterns. Resonator structures were successfully patterned on Al-on-sapphire samples, providing a foundation for future microwave characterization. In parallel, Josephson junction electrode layouts were designed and developed to support controlled bottom-electrode definition, oxidation, and top-electrode integration. These efforts establish an initial fabrication framework for superconducting qubit components and provide guidance for future process optimization.

Summary of Research:

This project focused on developing fabrication processes for superconducting qubit components, specifically Al microwave resonators and Al Josephson junction structures on sapphire substrates. Aluminum is widely used in superconducting quantum circuits because it can form both superconducting electrodes and a native aluminum oxide tunnel barrier, while sapphire provides a low-loss insulating substrate suitable for microwave devices.

The first part of the work focused on Al resonator fabrication. Aluminum films on sapphire substrates were patterned into resonator structures using lithography and dry etching. The goal was to produce clean and continuous Al features with good pattern fidelity and minimal process-related defects. As shown

in Figure 1, resonator patterns were successfully defined on an Al-on-sapphire chip, demonstrating the feasibility of the fabrication workflow. A significant amount of troubleshooting was required to improve the final pattern quality, including optimization of resist processing, lithography conditions, etching parameters, and cleaning steps. Optical inspection was used throughout the process to evaluate pattern definition, identify defects, and guide process adjustments.

The second part of the work focused on Josephson junction process development. Josephson junctions are key nonlinear circuit elements for superconducting qubits, but their fabrication requires precise control of electrode geometry, tunnel barrier formation, and alignment between multiple lithography steps. The



Figure 1: Fabricated Al-on-sapphire resonator chip showing patterned resonator structures on the top surface.

junction process was developed around Al bottom and top electrodes, with controlled oxidation used to form the aluminum oxide barrier. Figure 2 shows the designed Josephson junction electrode feature from CAD, including the bottom and top electrode regions and the intended overlap area for junction formation.

A major challenge in the Josephson junction process was achieving reliable alignment between different

lithography layers. Since the final junction area depends on the overlap between electrodes, even small offsets can affect device yield and reproducibility. Process trials were therefore used to evaluate alignment strategies, mark visibility, resist thickness, exposure conditions, and overlay accuracy. Additional troubleshooting was

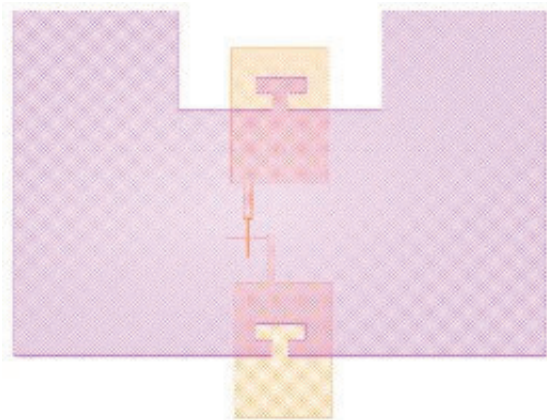


Figure 2: CAD layout of the Josephson junction electrode design.

also performed during etching, resist removal, and surface preparation steps to obtain cleaner electrode features and more reliable pattern transfer.

Conclusions and Future Steps:

This work established a preliminary fabrication process for Al resonators and Josephson junctions on sapphire substrates for superconducting qubit applications. Resonator patterns were successfully fabricated, and Josephson junction electrode designs and key process steps were developed. Troubleshooting across lithography, etching, resist removal, surface cleaning, and alignment helped improve pattern quality and process reproducibility.

Future work will focus on improving overlay accuracy, optimizing oxidation and etching conditions, and reducing fabrication variability. The next steps will also include device performance testing.