Quantum-Limited Measurement as a Tool for Entanglement in Superconducting Circuits

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Principal Investigator(s): Ivan Pechenezhskiy, Britton Plourde
User(s): Jadrien Paustian

Affiliation(s): Syracuse University

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Contact: ivpechen@syr.edu, jtpausti@syr.edu

Primary CNF Tools Used: Anatech Oxygen Descum, PlasmaTherm 770 Reactive Ion Etch, Photoresist Processing, DISCO Dicing Saw

Abstract:

As part of the Materials Characterization and Quantum Performance: Correlation and Causation project, we tuned up the niobium base layer recipes for fabrication of quantum superconducting devices while carefully documenting correlations between process changes and resonator internal quality factors. We find significant correlations between internal quality factors and the deposition conditions, the photoresist stripping chemistry, and the dose of post-fabrication hydrofluoric acid treatment.

Summary of Research:

We performed in-house photolithography before moving on to fabrication at the CNF, where we make use of the Anatech as an oxygen descum prior to a reactive ion etching with the PlasmaTherm 770 using a chlorine-based reactive ion etch. We then stripped off the photoresist in the hot strip baths in the photoresist section, before an additional descum with the Anatech tool and spinning protective resist on the sample for dicing. Dicing was performed using the DISCO dicing saw. Then, at Syracuse University, we performed additional HF treatments afterwards. The resonator devices are measured in an adiabatic demagnetization refrigerator. A packaged sample is shown in Figure 1. 20 minutes of buffered oxide etch provides the best quality factors for our samples, as shown in Figure 2. We solved significant issues created by the resist stripping process, demonstrating an optimal resist strip using AZ300T, shown in Figure 3. Additionally, after noticing anomalies in our temperature-dependent measurements, we began varying our sputter parameters. This altered our film stress by changing the deposition environment, and we found that film stress creates an anomalous increase in thermal losses, as shown in Figure 4.

Conclusions and Future Steps:

We observe that the interplay between treatments at different fabrication steps can have unintuitive effects on sample quality. We find distinct correlations between hydrofluoric acid treatment, resist stripping, and internal quality factors of superconducting resonators. We additionally find that sputter deposition parameters can alter the film stress, which can produce anomalous temperature dependence in loss.

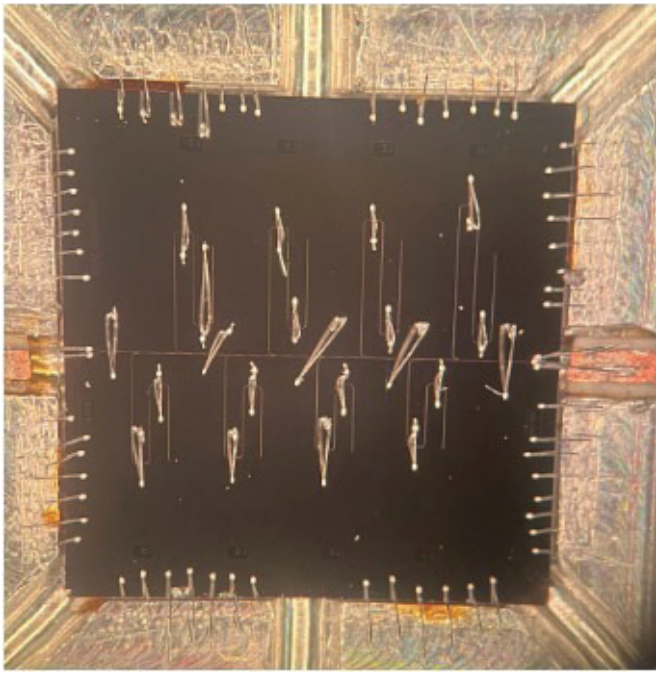

Figure 1: Fully packaged sample

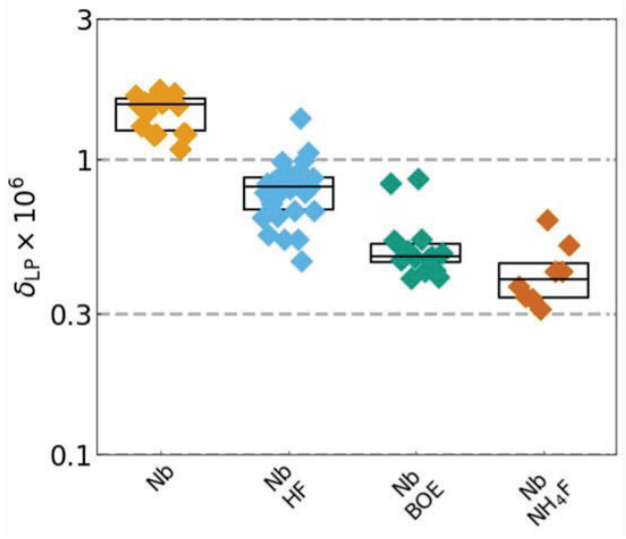

Figure 2: Loss tangents achieved with optimal HF treatment using buffered oxide etch, and a further improvement with ammonium fluoride.

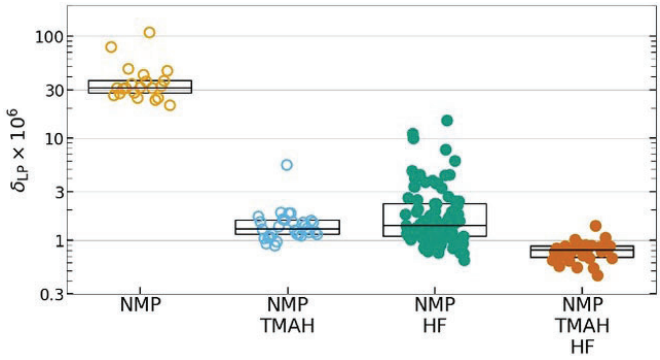

Figure 3: Loss tangents achieved with AZ300T resist stripping, a solution of n-methyl-2-pyrrolidone and tetramethyl-ammonium-hydroxide.

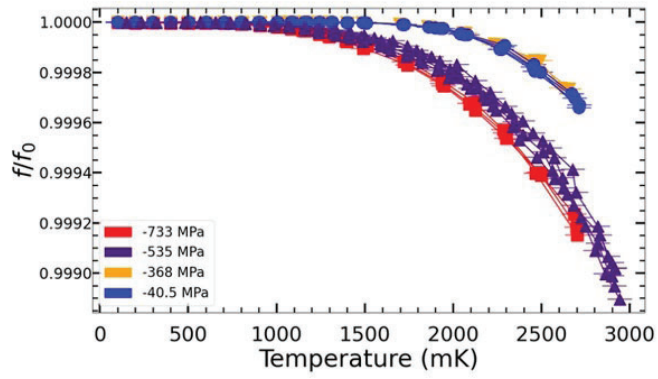

Figure 4: Relative resonator frequency shifts with anomalous temperature dependent frequency shifts for samples with average room temperature film stress beyond -500 MPa.

References:

[1] Maciej W. Olszewski et al. Low-loss Nb on Si superconducting resonators from a dual-use spin-tronics deposition chamber and with acid-free post-processing. 2025. arXiv: 2503.13285 [quant-ph]. url: https://arxiv.org/abs/2503.13285.