Improving Quality Factors in Superconducting Resonators

CNF Project Number: 299822
Principal Investigator(s): Valla Fatemi
User(s): Maciej Olszewski (1), JT Paustian (2), Tathagata Banerjee (3), Haoran Lu (3)

Affiliation(s): (1) Cornell University Department of Physics, (2) Syracuse University Department of Physics, (3) Cornell University Applied and Engineering Physics

Primary Source of Research Funding: Air Force Research Laboratory, Laboratory for Physical Sciences

Contact: vf82@cornell.edu, mwo34@cornell.edu

Website: https://fatemilab.aep.cornell.edu/

Primary CNF Tools Used: G-Line Stepper, Oxford 81, PT 770, DISCO Dicing Saw, Heidelberg 2000 Mask WriterEven-Hour Evaporator

Abstract:

Superconducting microwave circuits are one of the leading candidate platforms for enabling quantum computing technology, and Nb on Si is a commonly implemented materials set. Currently one of the main bottlenecks for improving device performance and technological prospects is elimination of defects from the materials and interfaces within the superconducting circuits resulting from nanofabrication processing. In this report, we demonstrate compact (3 µm gap) coplanar waveguide resonators with low-power internal quality factors near one million. We achieve this using a resist strip bath with no post-fabrication acid treatment, which results in performance comparable to previous strip baths with acid treatments. Avoiding post-fabrication acid treatments reduces the aging in our devices by reducing oxide regrowth. We correlate improved performance with a reduction of post-etch contamination as shown by XPS. This work in based on our manuscript [1].

Summary of Research:

Superconducting transmon qubit fabrication involves many steps which have a profound impact on device performance. To better understand how each step impacts the final device quality we use superconducting coplanar resonators as a proxy for full qubit devices. Both devices share many fabrication steps including substrate preparation, superconductor growth, photolithography patterning, metal etching, photoresist removal, and device cleaning.

In this report, we focus on improving superconducting resonator performance by testing various solvents used for resist removal post dry reactive ion etching. To best isolate the impact of resist removal on resonator performance, we prepare devices with identical recipes, except we change the solvent used for resist removal. For this work we focus on comparing MICROPOSIT 1165 (1165) and Integrated Micro Materials AZ 300T (AZ 300T). Both solvents are N-methyl-2-pyrrolidinone based solvents while AZ 300T also contains propylene glycol and tetramethyl ammonium hydroxide (TMAH). Based on our discussions with the vendor, we believe that the addition of TMAH is the key difference in device performance.

After preparing devices with two different nanofabrication recipes, we test our resonators with cryogenic RF measurements at milli-Kelvin temperatures. We extract the internal loss tangents of resonators prepared with both methods. As shown in figure 1, we find a very significant difference in resonator performance between the samples prepared with 1165 and the ones with AZ 300T. This gap in performance is much larger than the fluctuations between devices and is statistically significant.

To better understand the reason behind this gap in performance, we look for physical differences between these devices. Using x-ray photoemission spectroscopy (XPS) we find that the two devices have significant differences in contaminants present on both niobium and silicon surfaces. As shown in figure 2, we find a significant difference in carbon contamination, as well as residue chlorine percentage. These indicate that AZ 300T is better at removing etch residue as compared to 1165, leading to better device performance.

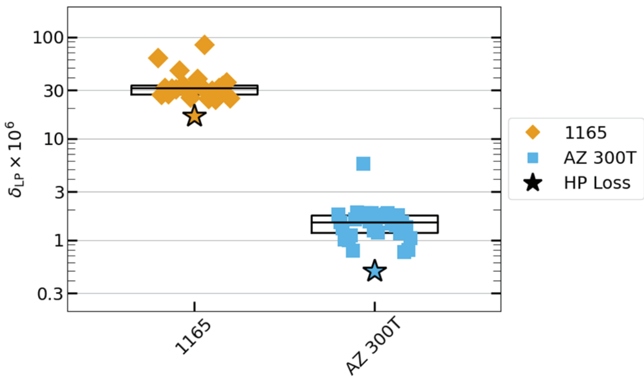

Figure 1 Caption: Boxplot comparing resonator performance with samples made with 1165 and samples made with AZ 300T, with otherwise identical fabrication.

Conclusions and Future Steps:

Our current fabrication procedure yields state of the art resonators as compared to other work in the literature. We plan to continue to further improve the quality of our devices by debugging other areas of our nanofabrication process, including using other materials, trying new etching recipes, and exploring new resist removers.

Further, we also plan on incorporating our improved devices into full transmon qubit devices by incorporating Josephson junctions into our recipe. The improvements in resonator performance should directly translate to better qubit performance, improving lifetimes. We plan to conduct a similar study on improving qubit performance through optimizing our nanofabrication procedure.

References:

[1] https://arxiv.org/abs/2503.13285

Surface	Si						Nb			
Element	C	Ca	Cl	N	Na	F	C	Na	Si	F
Pre-strip	10.3	-	1.4	0.8	-	-	/	/	/	/
AZ300T	6.5	-	-	-	-	-	11.5	0.2	-	-
NMP	8.9	-	1.1	0.9	-	-	18.0	-	1.0	-
PGMEA	6.8	0.4	1.0	-	0.3	-	33.9	-	-	-
1165	7.9	-	1.0	1.0	-	-	19.3	-	1.0	-

Figure 2 Caption: XPS data with contamination of various surfaces post-resist removal with various solvents