Fabricating Oxygen Managed and Thermally Robust Nb-Based Josephson Junction

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Primary CNF Tools Used: PT770 etcher, AJA sputter deposition, Oxford 81 etcher, Primaxx vapor HF etcher, SC4500 Even-hour evaporator, GCA 6300 DSW 5X g-line wafer stepper, DISCO dicing saw, Heidelberg mask writer - DWL2000, Zeiss SEM

Abstract:

Superconducting Josephson junctions (JJs) are important building blocks of a quantum qubit for next-generation quantum communication and technology. Fabrication of JJs has been heavily relied on aluminum due to its long coherence time and high-quality native oxide. However, aluminum has a low critical temperature (Tc), which makes Al-based JJs susceptible to quasiparticle poisoning and have a limited operation frequency [1-3]. Niobium, on the other hand, has higher Tc and provide a wide range of operation frequency. We fabricate niobium-based JJs that can withstand high temperature with minimized oxygen diffusion, leading to qubits with long coherence times. To achieve this, we create JJs from a trilayer where AlOx is capped with an oxygen diffusion barrier and optimize the sidewall profile of JJs to mitigate loss.

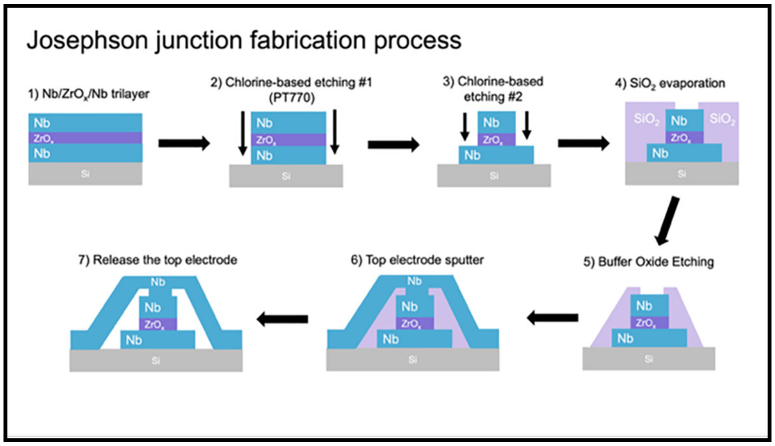

Figure 1: Fabrication process of a Nb/ZrOx/Nb Josephson junction.

Summary of Research:

AlOx tunnel barrier suffers from chemical and thermal instability due to oxygen diffusion between the AlOx and electrodes, which can cause qubit decoherence. To mitigate this diffusion, we are capping AlOx with diffusion barrier. Materials with low heat of enthalpy such that it reduces the chemical gradient between AlOx and electrodes are good candidates for diffusion barrier. We are still in process of finding an optimal material for this diffusion barrier in collaboration within Cornell, and among Syracuse University and NIST-Boulder.

In the meantime, we start the fabrication process of the JJs to optimize etching process for sidewall characterization. We make JJs from a Nb/ZrOx/Nb trilayer. ZrOx is known to have good oxygen conservation [4], and we are going to compare its performance with that of a Nb/AlOx/Nb junction. We make junction geometry circular to allow sidewall access from any angles. Figure 1 summarizes the fabrication process. We use the GCA 6300 DSW 5X g-line wafer stepper to make a pattern of the junction. The junction diameter ranges from 2 μm to 9 μm within a device. Then, we use the PT 770 etcher for chlorine-based inductively coupled plasma (ICP) etching of the electrode and tunneling barrier. We evaporate the SiO_2 spacer layer after defining the mesa feature of the tunneling barrier. Subsequently, we sputter the top electrodes, which is followed by HF vapor etching of SiO_2 to release the top electrodes.

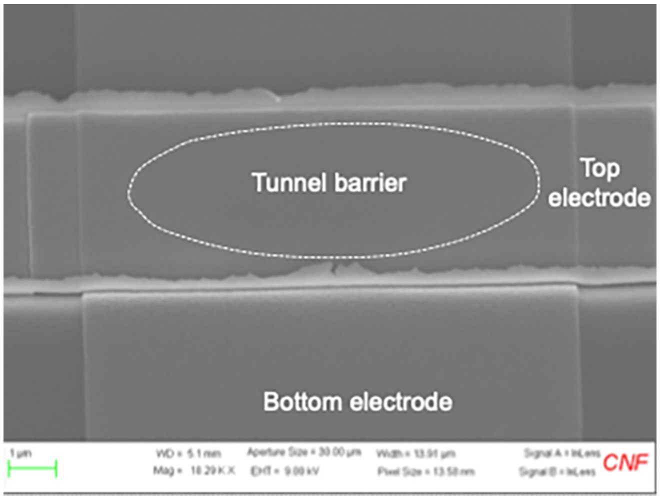

Figure 2: SEM image of the Josephson junction after releasing the top electrode.

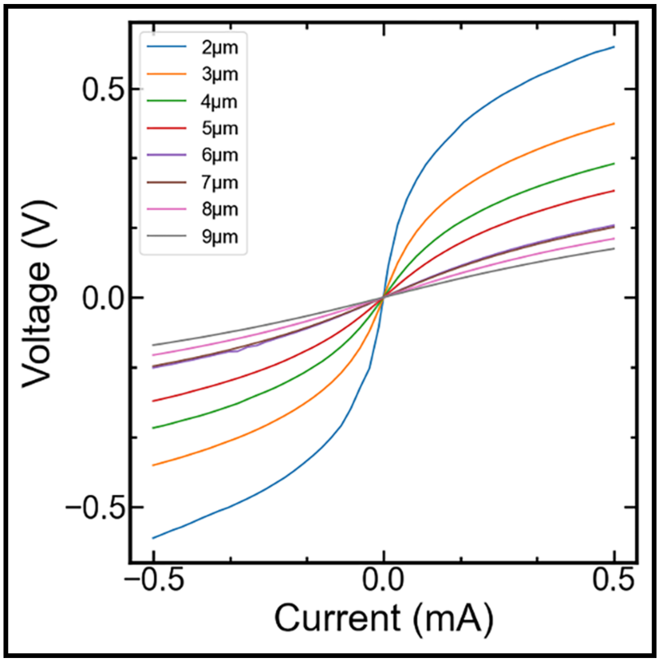

Figure 3: Current-voltage (I-V) curve from Josephson junctions of various diameter, ranging from 2 µm to 9 µm.

Figure 2 is an SEM image of the resultant Josephson junction. As shown in the image, lift-off residue persists despite multiple cycles of sonication. This is because sputtering is somewhat isotropic and not optimal for thick films. We can also see a gap between the top and bottom electrodes, indicating that the airbridge structure does not collapse after its release. We conduct four-wire voltage measurements by sourcing a current. Figure 3 is current-voltage (I-V) curves from the Nb/ZrOx/Nb JJs at room temperature. The I-V curves exhibit non-linear behavior, characteristic of tunnel junctions.

Conclusions and Future Steps:

We successfully fabricated a Nb/ZrOx/Nb JJ with non-linear I-V characteristics. Next, we will fabricate a Nb/AlOx/Nb JJ and compare its performance with that of the Nb/ZrOx/Nb JJs. Also, once the optimal material for diffusion barrier is determined, we will cap AlOx with that material and test its performance.

References:

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