

Digital Etching of Single-Crystalline Silicon Fin Barriers Down to Sub-10 nm

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A superconducting transmon qubit consists of a shunt capacitor in parallel with a nonlinear inductor, a Josephson Junction (JJ) [1]. The conventional JJ is composed of two superconducting aluminum contacts separated by thin amorphous aluminum oxide (AlO_x) [2]. It is believed that the high density of two-level system defects in or near the barrier limits the qubit performance. One promising route towards low-loss JJs is utilizing single-crystalline dielectric materials, which lack the structural disorder believed to be responsible for TLS in amorphous oxides [3]. High-resistivity undoped float-zone Si is one of the lowest loss dielectric materials at cryogenic temperature and microwave frequencies [4]. Based on first-principles calculations of Schottky barrier heights indicate that to achieve sufficient Josephson critical current density requires a Si barrier thickness in the 5~10 nm regime for Al contacts [5].

This work presents a fabrication process to realize sub-10 nm thick, high-aspect-ratio single-crystalline Si fins. Fins are defined on float-zone Si (110) by electron-beam lithography and anisotropic KOH etching through an LPCVD SiN_x hard mask, which also serves as the shadow mask for the subsequent superconductor angle deposition. Following the anisotropic wet etching, a digital etching process based on repeated oxidation and hydrofluoric acid etching of the resulting oxide was developed until the desired thickness is achieved. Fin thickness as thin as 6 nm have been achieved. We have investigated oxidation methods ranging from room-temperature ozone oxidation to rapid thermal annealing (RTA) oxidation at various temperatures and ambients, with liquid and vapor HF for oxide removal, using cross-sectional transmission electron microscopy to determine the thickness and roughness of the barriers. RTA oxidation provides better oxide thickness tunability and the ramp ambient governs the thickness uniformity along the fin. In this presentation, we will discuss how the choice of oxidation and etching method affects the fin thickness and the uniformity of the barrier.

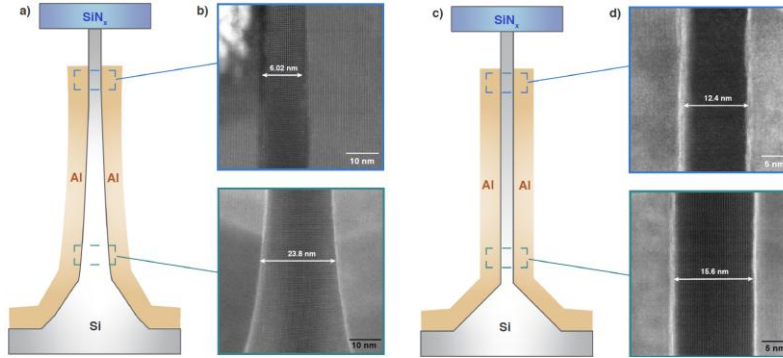


Figure 1 Si fin thickness at the top and near the substrate for two RTA ramp conditions. A pure O_2 ramp (a, b) leaves a ~17 nm top-to-base difference with 6 nm on the top, while an N_2/O_2 (5:1) ramp (c, d) reduces it to ~3 nm. Both fins received the same oxidation sequence. (a, c) schematics; (b, d) cross-sectional STEM.

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