

Fabrication of Tantalum Based Superconducting Qubits at CNF

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Primary CNF Tools Used: GCA 6300 DSW 5X g-line Wafer Stepper, Heidelberg DWL2000, Oxford 81 Etcher, Oxford 82 Etcher, PT770 Etcher - Left Side, JEOL 6300, Angstrom-Quantum, Zeiss Ultra SEM, AJA-Q2, Dicing Saw - DISCO, P7 Profilometer

Abstract:

We demonstrate fabrication of quantum devices based on tantalum on silicon films. Coplanar waveguide resonators fabricated from tantalum on silicon films show best in class performance. We fabricate transmon qubits from Ta/Si films and find that device performance is at the state of the art for superconducting qubits.

Summary of Research:

Superconducting qubits based on tantalum (Ta) thin films have demonstrated the highest-performing microwave resonators and qubits. This makes Ta an attractive material for superconducting quantum computing applications [1]. So far, deposition of the cubic (BCC) phase of tantalum has relied on high substrate temperatures exceeding 400 °C. Changing the sputter gas from argon to krypton we have recently demonstrated growth of BCC tantalum on silicon at growth temperatures as low as 200 °C [2]. This low temperature film growth enables compatibility with process standards used in the back-end-of-line semiconductor fabrication. The films grown using krypton show larger grain size and enhanced residual resistivity ratio, compared to films grown with argon.

Coplanar waveguide (CPW) resonators are fabricated from the Ta/Si films on 100 mm wafers using photolithography and an optimized recipe for dry-etching and resist stripping. Resonators made from Ta/Si films grown at low temperatures show best-in-class performance with a low power quality factor of 4.1 million for resonators with 3 μm gap. These resonators show higher performance than resonators built using niobium seeded growth of tantalum as well as resonators built from Ta/Si films grown at high temperature of 600 °C (Fig. 1)

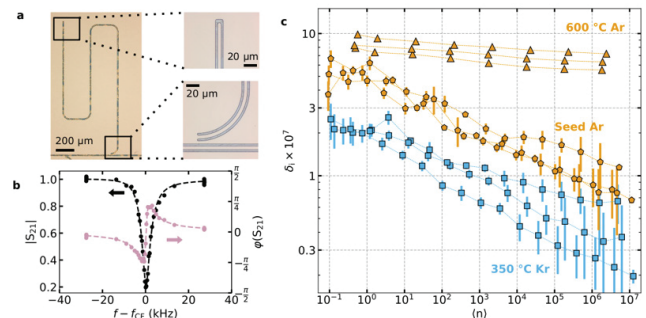


Figure 1: (a) Optical microscope image of a 100 nm thick Ta CPW resonator deposited with Kr at 350 °C. (b) Resonator quality factor measurement at single photon powers for 100 nm thick Ta CPW resonator deposited with Kr at 350 °C. Black indicates magnitude, while pink is the phase. (c) Power dependence of losses for three different types of resonators, from top to bottom: 600 °C Ar, RT Nb-seeded Ar, and 350 °C Kr.

We fabricate transmon qubits based on these high-performing Ta/Si baselayers. Josephson junctions of the Manhattan type are fabricated using shadow evaporation using MMA/PMMA masks. The masks are fabricated using electron beam lithography (JEOL 6300). For evaporation we use the newly installed Angstrom-Quantum tool, which provides in-situ Ar ion milling, thermal oxidation, and angled-evaporation of aluminum (Fig. 2, 3). Transmon devices are characterized in a dilution refrigerator at temperatures below 10 mK. We observe lifetimes and coherence times at the state of the art for superconducting qubits with T_1 times approaching 1ms and quality factors $Q_1 = 2\pi T_1$ fqubit clearly exceeding 10 million (Fig. 4).

Acknowledgements:

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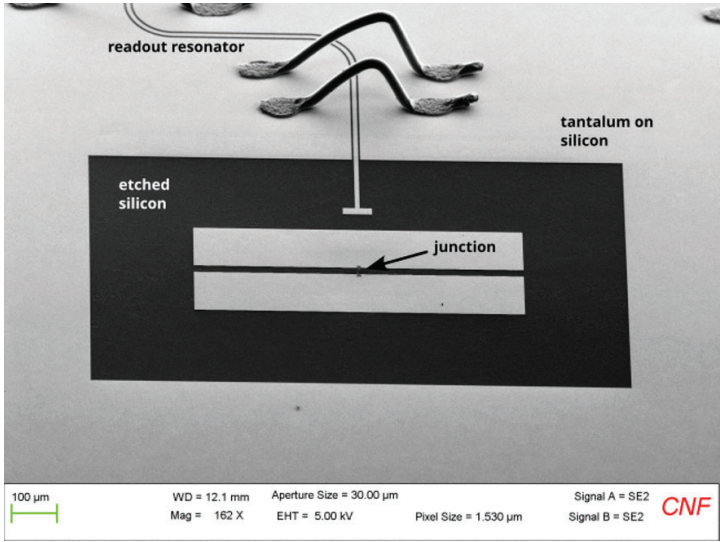


Figure 2: SEM of transmon qubit fabricated from Ta/Si film. The capacitor pads of size $120\ \mu\text{m} \times 800\ \mu\text{m}$ are separated by a $20\ \mu\text{m}$ gap. Wirebonds are used to remove spurious electromagnetic modes.

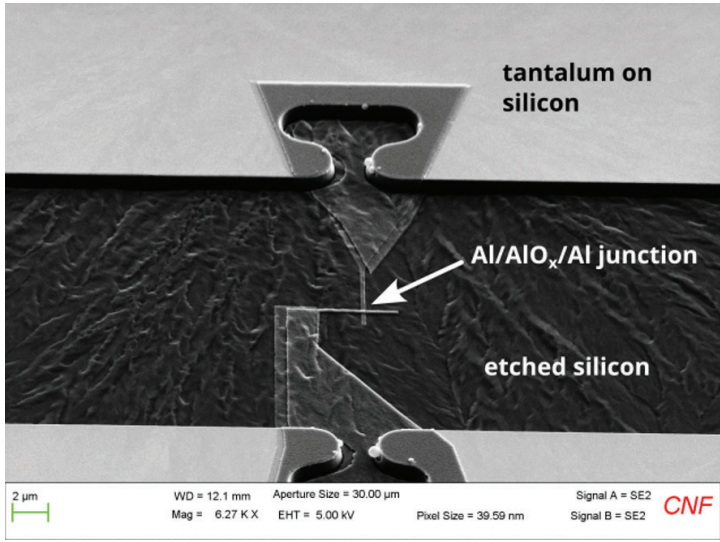


Figure 3: Zoom into Fig 2. shows the Manhattan-type Josephson junction. The Ta film is overetched by about $800\ \text{nm}$ into the silicon substrate. Etching the high-crystallinity Ta films results in high roughness of the etched silicon surface. Two electrodes are shadow-evaporated to form the Al/AIO_x/Al junction with an area of $\sim 200\ \text{nm} \times 200\ \text{nm}$.

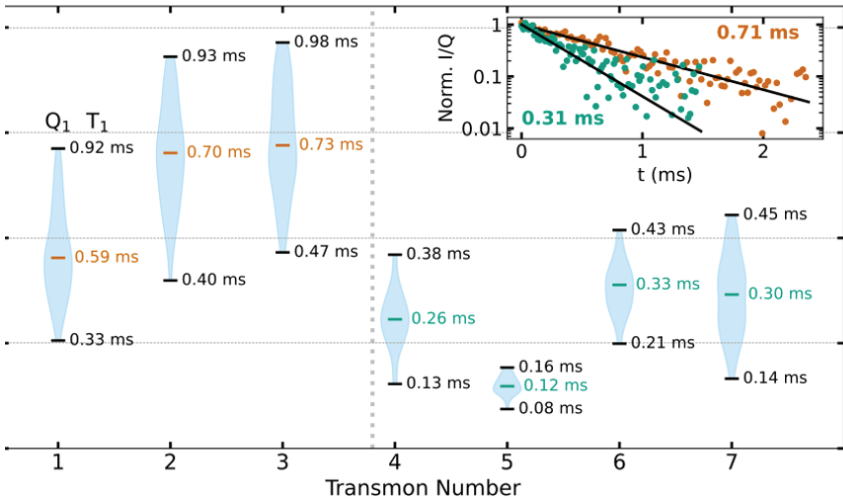


Figure 4: Violin plots of transmon quality factor for seven qubits measured; the distributions come from measuring T_1 repeatedly over about twelve hours. Values top to bottom represent maximum, median, and minimum lifetimes measured. Transmons 1-3 were fabricated without an oxygen descum, while transmons 4-7 had an additional oxygen descum. Insert has two example plots of lifetimes near the median value for both sets of devices.

References:

[1] M. P. Bland et al., Millisecond lifetimes and coherence times in 2D transmon qubits, *Nature* 647, 343–348 (2025).
 [2] M. W. Olszewski et al., Krypton-sputtered tantalum films for scalable high-performance quantum devices, arXiv:2601.20091 (2026).