Revealing Possible Coherence Limiting Sources in Superconducting Qubit with Advanced Electron Microscopy

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Superconducting materials hold great potential for solid-state quantum computing. Their fabrication relies on established semiconductor fabrication techniques, such as thin film deposition and lithography, but the complex processing steps can result in defects at the qubits' interfaces and surfaces that can negatively impact coherence time. To improve superconducting qubit performance, it is essential to understand the structural features, at the atomic scale, that may act as sources of decoherence limiting factor in both the Josephson junction (JJ) and resonators, which are key components of superconducting qubit. [1,2] This talk will present our recent studies on the microstructures in a 2D-transmon, with an emphasis on the JJ. A combination of advanced microscopy techniques, including high-resolution (S)TEM imaging, and spectroscopy (EDS and EELS) are used to identify possible coherence-limiting defects or structural features.

Figure 1 shows a detailed structural characterization of the JJ and JJ-lead region. The JJ is fabricated by Rigetti Computing using two angled Al evaporation on the silicon substrate with an oxidation step in between. Figure 1 (a) is an SEM image showing that the evaporated Al layer has a polycrystalline structure with an uneven surface. Two FIB lift-out samples were prepared along (red rectangle) and perpendicular (yellow rectangle) to the JJ-lead from similar JJs. Corresponding STEM images and EDS mappings are shown in Fig. 1b and 1c, respectively. A notch is observed between the upper Al and JJ-lead (as indicated by red lines in Fig. 1b), while a gap partially filled with aluminum oxide is observed between the lower and upper Al lead (Fig. 1c). The gap appears to have formed due to the nucleation of upper Al at the lower Al edge (with a step) during the evaporation process. The observed gap and notch structures are potential noise sources for the nearby JJ. We will also discuss the impact of Al deposition condition on JJ structure and possible grain structure that cause JJ failure.

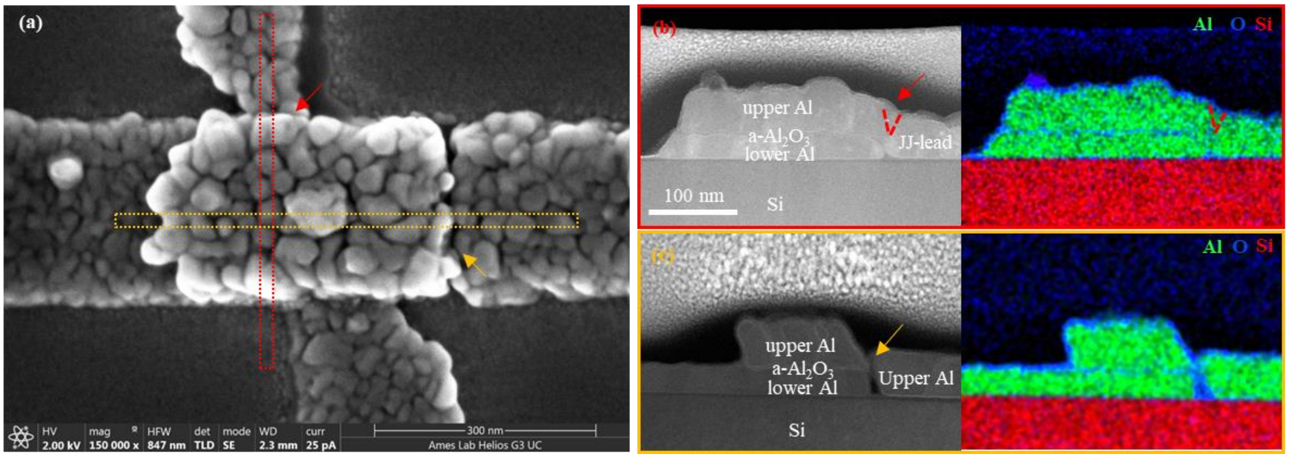

Figure 1. (a) SEM image of a typical JJ prepared by two-angle Al evaporation. Two FIB lift-out TEM samples were prepared from the red and yellow rectangle indicated area in similar JJs. (b) STEM image and corresponding EDS elemental mapping of a JJ and upper-lead. (c) STEM image and corresponding EDS elemental mapping of a JJ image along the direction without JJ lead.

References:

[1] W. D. Oliver, P. B. Welander, MRS Bull., **38** (2013), p816. https://doi.org/10.1557/mrs.2013.229k
[2] Xiaotian Fang, Jin-Su Oh, Matt Kramer, A. Romanenko, A. Grassellino, John Zasadzinski, Lin Zhou, Materials Research Letter, **11**(2023), p108. https://doi.org/10.1080/21663831.2022.2126737
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