Interface-sensitive microwave loss in tantalum films grown on c-plane sapphire for quantum information applications

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Tantalum (Ta) has garnered much attention in the field of superconducting quantum computing recently because of multiple published reports showing a performance enhancement of Ta devices when compared to aluminum or niobium (Nb). Fabrication of high-performance Ta devices is thought to rely on the formation of the α-phase (body centered cubic) structure which typically requires heating the substrate during growth, while β-phase (tetragonal) Ta usually dominates the composition of films deposited at room temperature. Formation of two distinct elemental phases contrasts with niobium (Nb), which typically only forms α-phase thin films.

We systematically vary the growth temperature of sputtered Nb and Ta thin films deposited on c-plane sapphire (Al_2O_3(001)) resulting in thin films of β-Ta, mixed phase β- /α-Ta and α-Ta and Nb. The structural properties of the resulting thin films are measured with reflection high energy electron diffraction (RHEED), X-ray diffraction (XRD), atomic force microscopy (AFM), and transmission electron microscopy (TEM). Established lithography and dry etching processes are used to fabricate Hall bars for DC transport measurements and superconducting coplanar-waveguide resonators for microwave characterization in a dilution refrigerator.

Our measurements show that the structural and DC electrical properties of both Nb and Ta films are mostly consistent with prior reports, however, it was found that the microwave performance of superconducting resonators made from epitaxial Ta(111) films grown directly on Al_2O_3(001) was markedly poor. Considering these findings, the Ta/Al_2O_3(001) interface was tested by inserting either a thin, epitaxial Nb interlayer or by amorphizing the sapphire surface before Ta growth using an *in-situ* Ar plasma. Both of these approaches were found to enhance the internal quality factor (Q_i) of the superconducting resonators by nearly two orders of magnitude. This suggests that the epitaxial Ta(111)/Al_2O_3(001) interface is a significant source of microwave loss, which may be mitigated by modifying the sapphire surface before growth. Possible origins of this loss and methods to characterize and mitigate it will also be discussed.