Cryogenic growth and *in-situ* fabrication of superconducting Tantalum devices

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Superconducting devices are crucial in various fields of quantum information technology, including superconducting qubits and topological quantum computing. The vast majority of either of these qubit technologies use Aluminum as the superconducting component. Al is generally grown at low temperatures to achieve smooth thin films. This allows for easy integration of Al-based devices with material systems such as sapphire, Si, Ge, or III-V materials due to minimal interfacial reactions. Also, Al is often used for Josephson Junctions (JJ) that require *in-situ* oxidation to form AlO_x barriers. While Al is the most common superconductor, other superconductors show promising results as well. In particular, Tantalum-based superconducting qubits on sapphire show low loss and long coherence times.[1,2] One of the contributing factors to the enhancement of qubit performance is their higher chemical resistance during device fabrication. However, only a few substrates can be used to stabilize the required α-Ta phase with a BCC lattice structure. Due to its resilience to high temperatures, low-loss sapphire can withstand the growth of Ta at elevated temperatures necessary for the realization of desirable superconducting properties. Growth of Ta on Silicon or III-V substrates remains a challenge.

In this work, we explore the MBE growth and *in-situ* fabrication of superconducting tantalum films. The growth at ultralow temperatures below 10K shows the stabilization of the required superconducting phase of Tantalum (α-Ta). Moreover, Figure 1 shows that α-Ta can be stabilized at low temperatures regardless of the substrate choice. In each case, a superconducting transition temperature of above 4K is observed. Furthermore, this deposition technique can be combined with *in-situ* shadow masks, which allows for patterns with at least 1 μm precision. This can be used to realize $Ta/Ta_2O_5/Ta$ JJ's by using the native oxide, which is something that has never been shown before, or by depositing other dielectrics *in-situ* such as Silicon or Germanium. Our work demonstrates the growth of high-quality superconducting devices, which enables the exploration of different superconductors and dielectric combinations for use in quantum information technology.

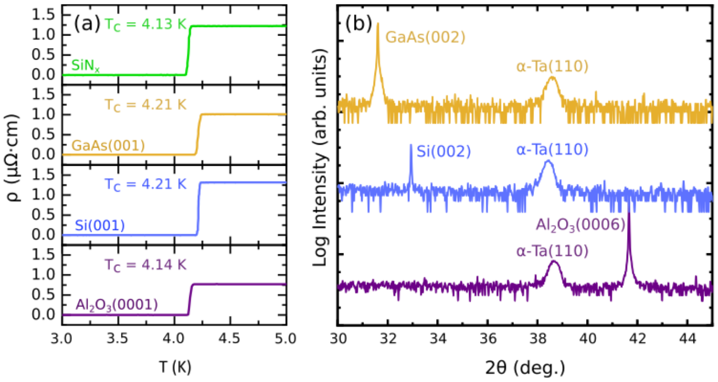

Figure 1. Electrical and structural characterization of Tantalum grown at different substrates. (a) Resistivity as a function of temperature measured in 4-probe in a line geometry for the substrates SiN_x, GaAs(001), Si(001), and Al_2O_3(0001). (b) XRD Spectra for crystalline substrates, in which α-Ta(110) peak is visible regardless of substrate.

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