Alpha-Tantalum Thin Film Deposition on Pure Silicon Wafers with the Angstrom-Q

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Primary CNF Tool Used: Angstrom-Q, Filmetrics R50, Zeiss Ultra SEM

Abstract:

Material choice in superconducting quantum circuits can greatly impact device coherence and losses. Recently, Tantalum thin films have shown great potential for transmon qubit fabrication, boasting high resonating times and high quality[1]. Tantalum's α crystal phase is especially important as it boasts a superconducting critical temperature of 4.2°K. Recent studies have shown that using a heated substrate can enable α-Tantalum thin film deposition [2,3,4]. The Cornell Nanoscale Facility recently introduced a new quantum-oriented electron beam evaporation tool witwh the capabilities to deposit these films, the Angstrom-Q. The project for this summer is to find the transition temperature where α-Tantalum can be deposited.

Summary of Research:

All samples for this project are deposited on 100mm undoped silicon wafers. All Tantalum depositions are completed at 1Å/s to a final thickness of 500Å.

Deposition Temperatures:

The temperature at which deposition takes place across different tools for α-Tantalum deposition can vary greatly based on the temperature measurement or deposition method. Sputtering an α-tantalum film may require a higher heat than evaporation as evaporation's particles carry heat onto the surface of the substrate. With studies showing α-Tantalum growth at 350°C [2], 400-500°C[3], and 600-650°C[4]. With this data, we chose to do a baseline run at room temperature, and then start at 350°C, moving at 50°C increments until the transition temperature is found, then move to 10°C increments.

Wafer cleaning:

One of the most important steps in creating a high quality α-Ta film is the cleaning. The wafers are RCA cleaned at the CNF MOS tanks, followed by a 60s bath in 20:1 HF to remove any surface oxides. This process remained until a water-streaked, highly non-uniform film began to appear at deposition temperatures above 425°C. We suspected that the HF bath in the MOS bath may be contaminated, or that the wafer was being oxidized by spending too long being rinsed in DI water. To correct this, we switched to removing the surface oxides by using 10:1 HF for 60s and 30s dip in DI water by hand. Additionally, it was found that the samples should spend less than one hour between the finish of the MOS clean and being processed.

Heated Deposition:

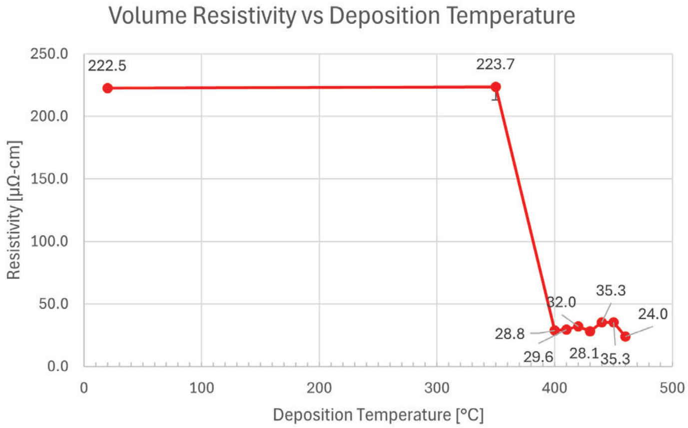
Once the wafer is fully cleaned and has its surface oxides stripped, it is placed in the Angstrom-Q load lock and put under vacuum. This is done in less than ten minutes to avoid the re-growth of surface oxides. Once in the machine, the wafer is heated to the desired deposition temperature, and then held at that temperature for 60 minutes to ensure even heating across the substrate. The wafer and carrier are allowed to cool and removed once reaching a temperature lower than 100°C.

Resistivity:

One convenient method to determine the crystallinity of a tantalum film is the film's resistivity. The room temperature resistivity of β-Ta is 150-200μΩ-cm and the resistivity of α-Ta is 15-20μΩ-cm [3]. We used the Filmetrics R50 four point probe to measure the sheet resistance of the film, then multiplied the sheet resistance by the thickness of the film to find the resistivity of the samples (Figure 1).

X-Ray Diffraction:

X-Ray Diffraction (XRD) scans were completed on all of the samples using the Rigaku SmartLab X-ray Diffractometer at the Cornell Center for Materials Research by Lingda Kong. Matching known scan peaks to our experimental runs shows what crystalline phase the sample is (Figure 2).



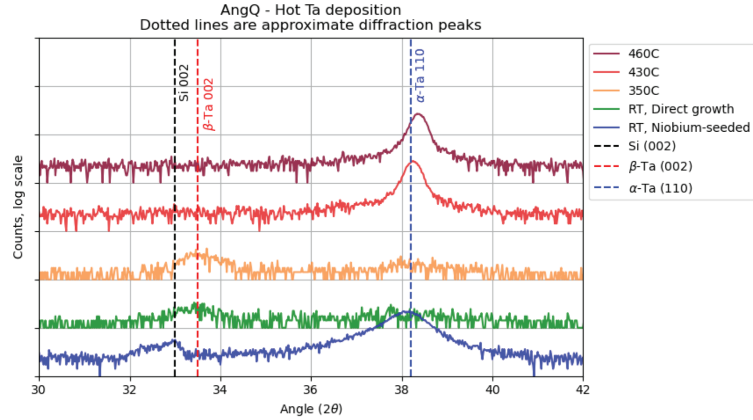


Figure 1 (Left): Volume Resistivity of Samples vs. their Deposition Temperature. Figure 2 (Right): X-Ray Diffraction Scans of Several Samples

Seed Layers:

A popular method for growing an α-Tantalum film is to use a thin layer of another material to avoid Tantalum-Silicon interactions and promote the correct crystalline phase. We did one Niobium seeded Tantalum deposition with 5Å of Niobium and 50Å of Tantalum, both deposited at 1Å/s at room temperature. The niobium seed layer sample had a RT resistivity of 60.8µΩ-cm. XRD scanning showed a peak around the α-Tantalum region without a peak in the α-Tantalum range (Figure 2).

Conclusions and Future Steps:

With this data, we can conclude that mostly pure α-Tantalum depositions on pristine silicon wafers at temperatures above 400°C, and that the transition temperature may lay in the 350-450°C range. Niobium seeded tantalum deposition shows α-Tantalum results at room temperature. Further depositions could be used to find the exact temperature range to form pure α-Tantalum. Additionally, films should be investigated to see if Tantalum Silicides (TaSi2) are being formed. Once completed, quantum computing components could be fabricated.

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