Niobium Seeded Tantalum Film Stress Characterization on AJA-Q

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Primary CNF Tools Used: AJA-Q2, FleXus Film Stress Measurement, Filmetrics R50, and the P7 Profilometer

Abstract:

This research investigated how niobium (Nb) and tantalum (Ta) sputtering pressures affect the stress and electrical properties of Nb-seeded Ta thin films intended for superconducting devices. The tested film structure consisted of approximately 5 nm of Nb beneath 100 nm of Ta on a silicon substrate. Nb deposition pressures of 3, 7, 15, and 20 mTorr were combined with Ta pressures of 3, 7, and 20 mTorr, creating 12 deposition conditions. Before deposition, each wafer received a MOS clean within four hours of being loaded into the deposition system. Film stress, thickness, deposition rate, and resistivity were evaluated for each condition. The results showed that both Nb and Ta deposition pressures influenced film stress. The 7 mTorr Nb and 7 mTorr Ta combination produced the lowest stress magnitude among the tested Nb-seeded film.

Summary of Research:

Tantalum is a promising material for superconducting devices because of its electrical and superconducting properties. However, its performance depends strongly on its crystalline phase. Alpha-phase tantalum is preferred because it has a resistivity of approximately 15–20 μΩ·cm and a superconducting transition temperature near 4.3 K. Beta-phase tantalum has a much higher resistivity of approximately 150–200 μΩ·cm and a transition temperature below 1 K. A thin Nb seed layer can promote the formation of the preferred alpha-Ta phase.

In addition to having low resistivity, a deposited film must have acceptable stress properties. Excessive tensile or compressive stress can contribute to wafer bow, film cracking, delamination, and variations during later fabrication processes. These problems can reduce device uniformity and process repeatability. The objective of this research was therefore to determine how Nb and Ta sputtering pressures affected film stress and to identify conditions that produced a low-stress film while maintaining desirable electrical properties.

Wafer preparation was an important part of the experimental procedure. Before deposition, each silicon wafer underwent a MOS clean. The clean was performed within four hours of deposition to limit the accumulation of airborne particles, organic residue, and other surface contaminants. Maintaining a clean wafer surface supported consistent film adhesion and uniform growth of the Nb seed layer and Ta film. Applying the same cleaning requirement to each wafer also helped reduce sample-preparation differences between deposition conditions.

The film stack consisted of approximately 5 nm of Nb followed by 100 nm of Ta. Four argon pressures were tested during Nb deposition: 3, 7, 15, and 20 mTorr. Each Nb pressure was paired with Ta pressures of 3, 7, and 20 mTorr. This created a matrix of 12 Nb–Ta pressure combinations. Ta-only films deposited at 3, 7, and 20 mTorr were also evaluated as baseline samples.

Film stress was determined by measuring wafer curvature before and after deposition using the FleXus stress-measurement system. The change in curvature was used to calculate the stress produced by the deposited film. Stress values closer to zero represented films with lower overall stress magnitude. Film thickness was measured to confirm the deposited thickness and calculate deposition rates. Electrical measurements were used to calculate resistivity and determine whether the films had properties consistent with alpha-Ta. Heat maps were then created to compare stress and resistivity across the tested pressure combinations.

The results demonstrated that deposition pressure had a substantial effect on film stress. For the Ta-only baseline samples, the 3 mTorr Ta condition produced the greatest stress magnitude. Increasing the Ta pressure

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generally reduced the magnitude of the measured stress. A similar overall relationship was observed for the Nb-seeded films, although the Nb deposition pressure also influenced the final stress.

Among the Nb-seeded samples, the combination of Nb deposited at 7 mTorr and Ta deposited at 7 mTorr

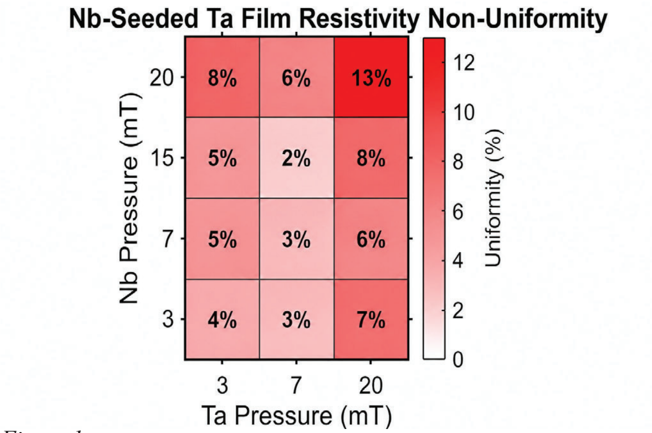

Figure 1.

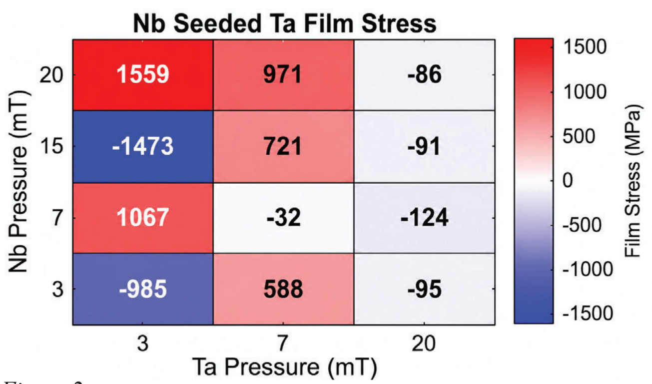

Figure 2.

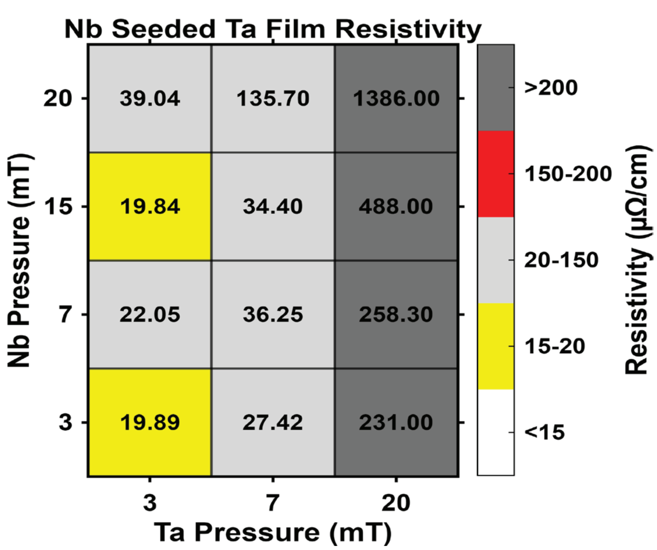

Figure 3.

produced a stress value closest to zero. It was therefore identified as the lowest-stress Nb-seeded condition tested. Several films deposited at a Ta pressure of 20 mTorr also demonstrated relatively low stress. However, changing the Ta pressure did not produce the same response for every Nb pressure. This indicates that the conditions used to deposit the seed layer affected how the Ta film grew and how stress developed within the completed stack.

Stress could not be used as the only factor when selecting an optimized process. A film with low stress would still be unsuitable for superconducting-device fabrication if it had the high resistivity associated with beta-Ta. The preferred process must balance low stress, low resistivity, wafer-scale uniformity, and repeatability. The pressure matrix narrowed the range of promising deposition conditions and identified the region near 7 mTorr Nb and 7 mTorr Ta as a candidate for further study.

Conclusions and Future Steps:

This research showed that both Nb and Ta sputtering pressures influenced the stress of Nb-seeded Ta thin films. Increasing the Ta pressure generally reduced the magnitude of film stress, but the Nb seed-layer pressure also affected the completed film. Of the 12 combinations evaluated, the 7 mTorr Nb and 7 mTorr Ta condition produced the lowest measured stress magnitude.

Consistent wafer preparation was also necessary for comparing the samples. Performing a MOS clean within four hours of deposition helped maintain a clean surface and supported uniform film adhesion and growth. This cleaning requirement should be maintained in future experiments so that differences between samples are primarily caused by deposition conditions rather than surface contamination.

Future work should repeat the most promising conditions to determine whether the results are reproducible. Additional pressures near 7 mTorr Nb and 7 mTorr Ta should be tested to define the optimum process more precisely. Stress, thickness, and resistivity uniformity should also be measured across the wafer. Structural characterization can be used to confirm alpha-Ta formation, while low-temperature measurements can determine the superconducting transition temperature. Finally, superconducting test devices should be fabricated using the optimized film to determine whether lower stress improves device uniformity, performance, and reliability.