# Epitaxial Niobium Titanium Nitride thin films for superconducting quantum circuits

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Engineered superconducting thin film heterostructures are needed to create future generations of high-fidelity superconducting qubits. Through a structure-first approach, Plasma Assisted Molecular Beam Epitaxy is used to grow a niobium titanium nitride alloy superconductor directly on c-plane sapphire with an abrupt metamorphic interface. The ternary thin film, $Nb_{0.85}Ti_{0.15}N$, has an engineered lattice constant that is designed and synthesized to match the in-plane atomic spacing of aluminum nitride.

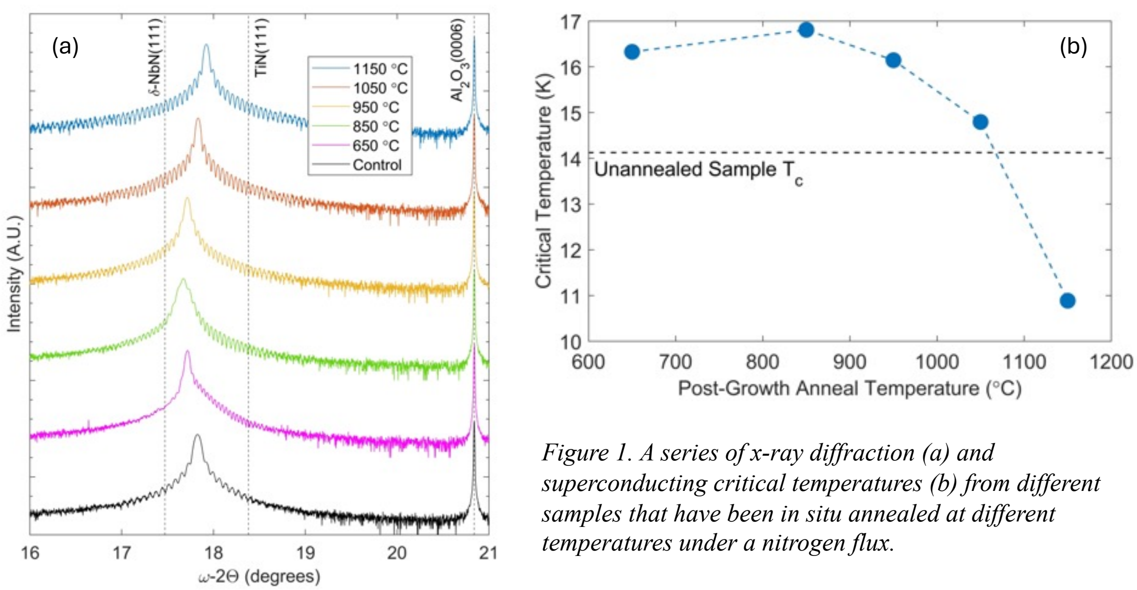


*Figure 1. A series of x-ray diffraction (a) and superconducting critical temperatures (b) from different samples that have been in situ annealed at different temperatures under a nitrogen flux.*

The best annealed films exhibit improved surface roughness to achieve a root-mean-square surface roughness less than 1 Å and improved superconducting critical temperature over 16 K. All films exhibit high quality factors at low powers, non-saturating superconducting microwave loss-behavior at high powers, and low kinetic inductance. These engineered superconducting thin films are ideal for the creation of an epitaxial Josephson junction and qubit devices that operate at higher temperatures.

In addition to exploring optimal growth parameters to produce thin ternary nitride superconductors, trilayers of NbTiN-AlN-NbTiN have been grown. Some of these samples have been measured using atomic probe tomography allowing crystallinity, homogeneity, and continuity of the AlN tunnel barrier to be quantitatively determined on the nanometer scale.[1]

[1] E. Supple, C. J. K. Richardson, & B. Gorman, *J. Vac. Sci. Tech. A* (2024).

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# Supplemental Material to Epitaxial Niobium Titanium Nitride thin films for superconducting quantum circuits

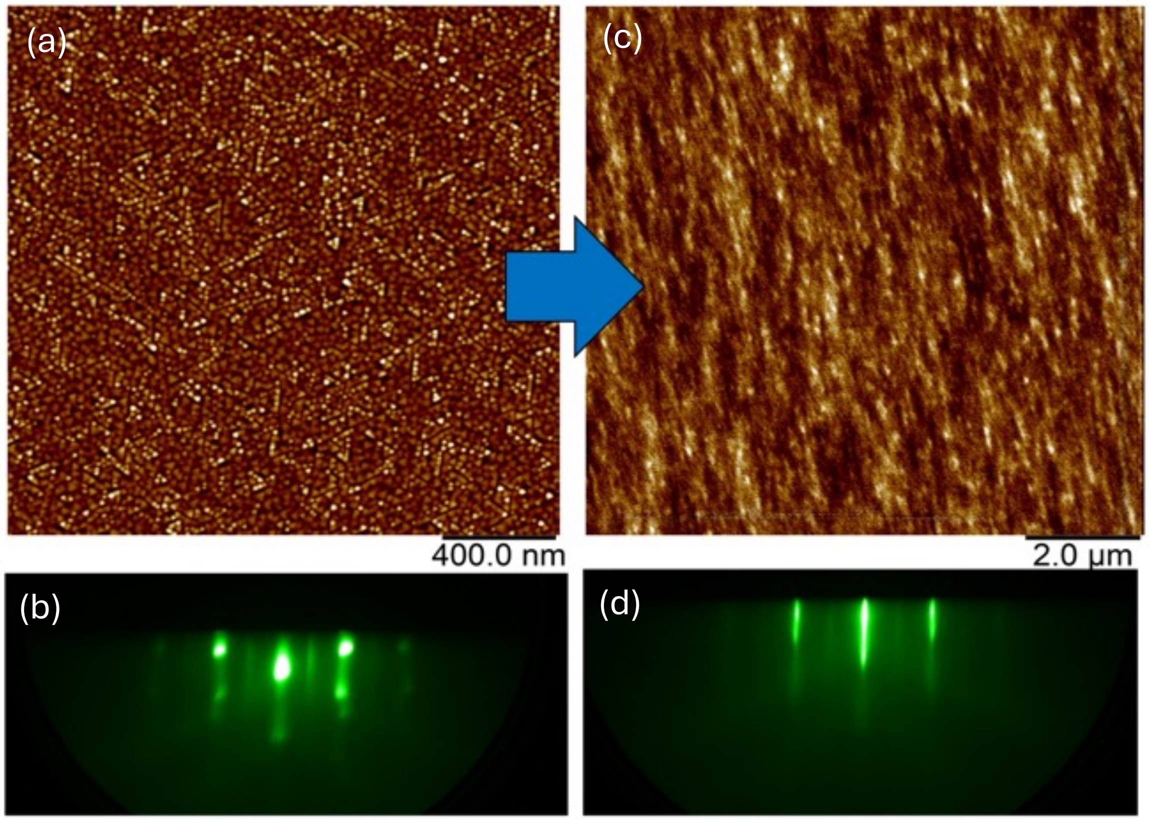


Figure S1. Atomic Force Micrograph (AFM) (a) and reflection high energy electron diffraction (RHEED) pattern of the as-deposited NbTiN surface. The AFM (b) and RHEED pattern (d) following in situ annealing at 800 ºC for 2 hours. The reduction in RMS roughness from 1.14 nm to 0.087 nm are consistent with improvements to other film characteristics.

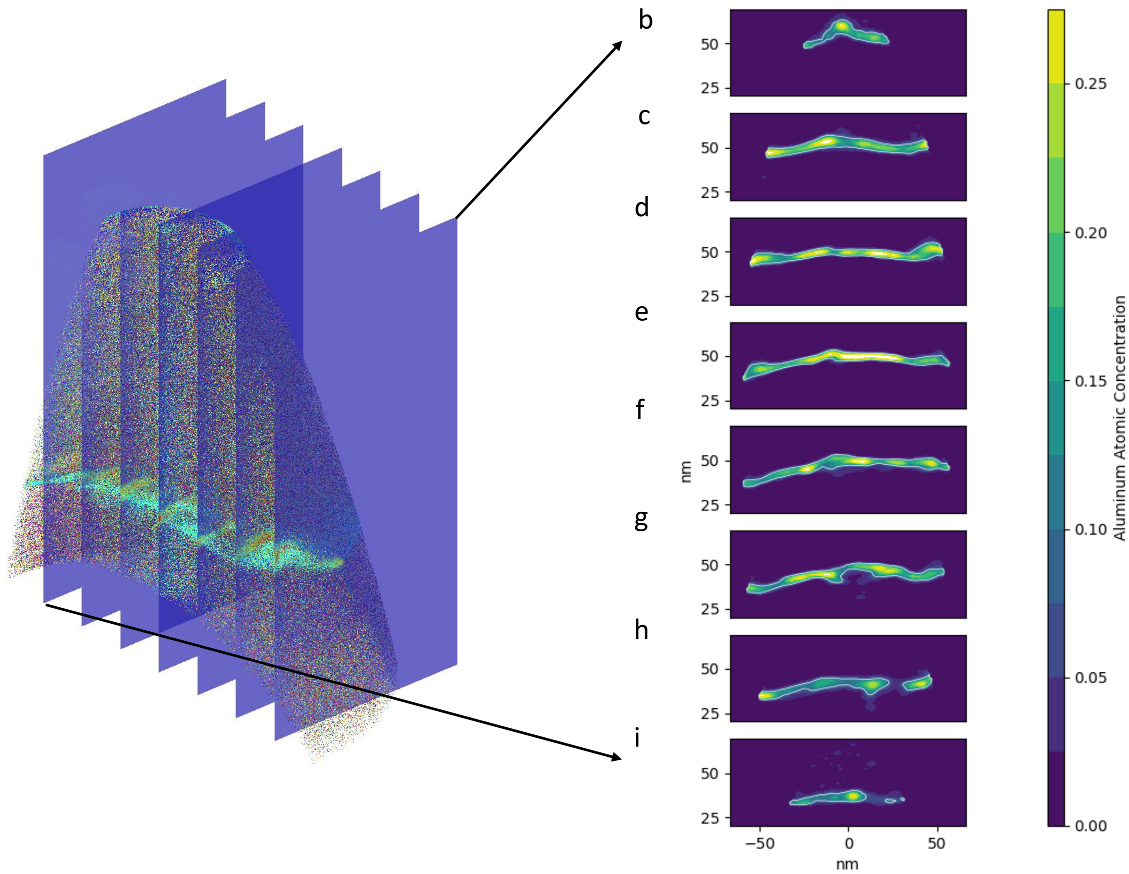


Figure S2. Atomic Probe Tomography reconstruction of a NbTiN-AlN-NbTiN trilayer heterostructure showing pinholes and variable thickness of the AlN layer.