Impact of Interfacial Defects and Lattice Strain on NbN_x Films for Integration with Wide Bandgap Semiconductors

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Niobium nitride (NbN) films have garnered significant attention due to their high critical temperature (T_c) and their usage in infrared-sensitive superconducting nanowire single photon detectors (SNSPDs). Devices fabricated from NbN have demonstrated single photon detection to mid-wave infrared wavelengths, which unlocks possibilities for novel applications such as long-range laser detection and ranging (LiDAR), interferometry of planetary emissions, quantum key decryption, and optical communications. To expand beyond a laboratory, however, these devices must be fabricated into focal plane arrays (FPAs), requiring integration with semiconducting device materials. In this work, we report progress on achieving a device structure comprised of a NbN SNSPD monolithically integrated with a wide bandgap semiconductor-based amplifier. This investigation is motivated by recent reports of monolithic integration of NbN with aluminum nitride (AlN) to provide a superconducting load for an amplifier [1].

NbN films for SNSPDs must be thin, typically <<100 nanometers. As a result, the film quality and defectivity, and ultimately SNSPD performance, are highly correlated to the interface between the NbN film and underlying lattice, lattice-mismatch strain, and deposition parameters of the NbN processing. In this talk, we investigate the impacts of the semiconducting interface on the NbN films utilized for SNSPD fabrication through XRD of grown films, AFM surface studies, cathodo-luminesce (CL), and TEM analysis. To optimize this interface, similar materials 6H-SiC (3.57% lattice mismatch) and wurtzite GaN (6.6% lattice mismatch) chosen to minimize intrinsic defect sources. XRD analysis of grown films indicates that growth on these substrates is possible with long range crystallinity, suggesting the presence of epitaxial growth for high quality films. Optimization of the stress of the film due to the lattice mismatch with the substrate is also investigated by modifying the growth temperature, pressure, and power to reduce lattice strain-induced defects. The presence of threading and other dislocations stemming from interface defects analyzed through CL and TEM will also be discussed.

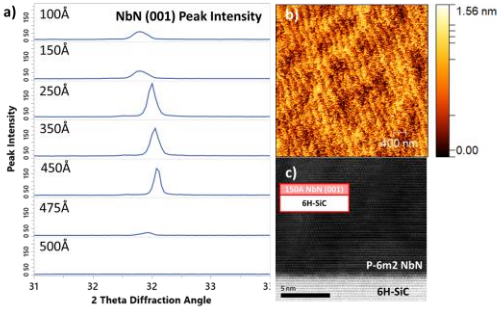

Figure 1: (001) NbN peak intensity measured in XRD, (b) AFM analysis of ultra-thin NbN films after growth, c) TEM of NbN/6H-SiC interface.

[1] R. Yan, G. Khalsa, S. Vishwanath, Y. Han, J. Wright, S. Rouvimov, D.S. Katzer, N. Nepal, B.P. Downey, D. Muller, H.G. Xing, D.J. Meyer, and D. Jena, Nature. **555,** 7695 (2018)

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Supplementary Pages (Optional)

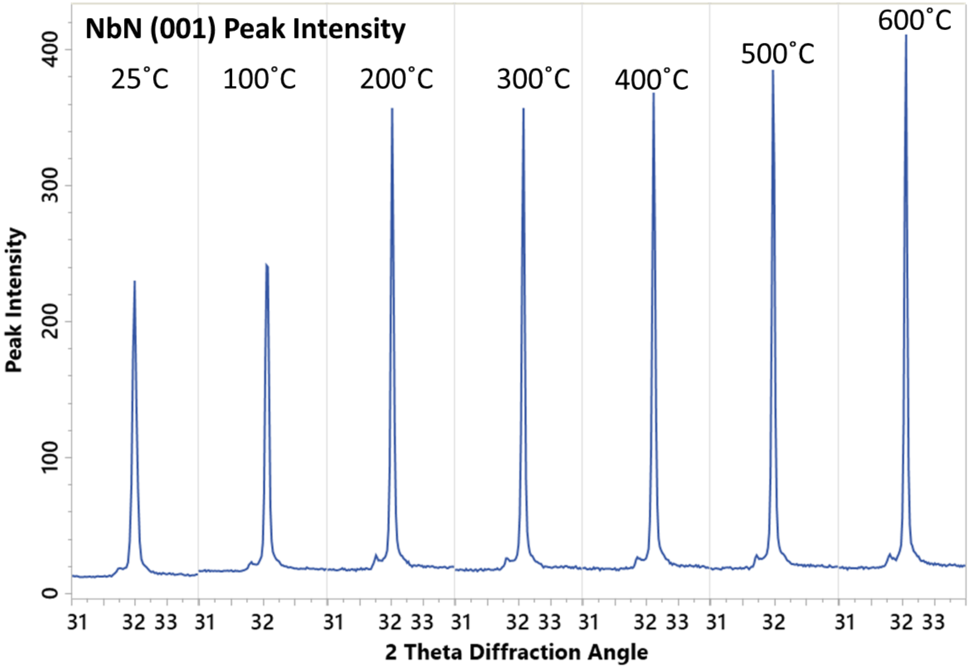

Figure 2: NbN (001) peak intensity at 250 angstroms thickness as a function of deposition temperature, indicating that increased growth temperature improves crystallinity.

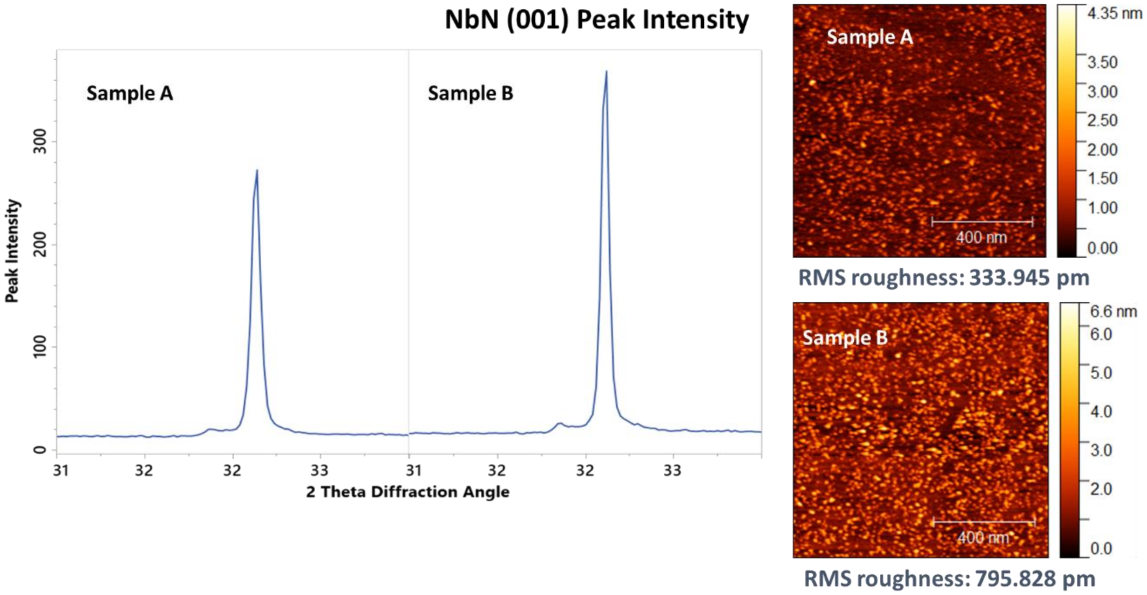

Figure 3: NbN (001) peak intensity compared to surface roughness of underlying semiconductor susbtrate, indicating the increased roughness at the interface promotes longer range crystalline growth.