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Systematic Materials Study of NbN and Ta_xN Thin Films for SNS Josephson Junctions

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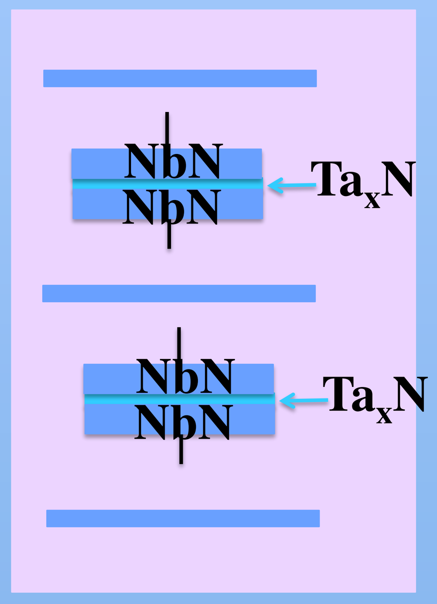
Can nitrides offer advantages over Nb/Al-AlOx/Nb JJs for low power high-performance computing?



- Thermal stability – can use optimized dielectric, potential for 3D scaling
- Barrier properties can be tuned – self shunting, may be less susceptible to electronic defects
- High quality films and JJs previously demonstrated on crystalline substrates and/or with high temperature growth (see refs.)

Explore materials properties of NbN and Ta_xN grown at *ambient temperature* on *SiO_2/Si* substrates (for future scaling)

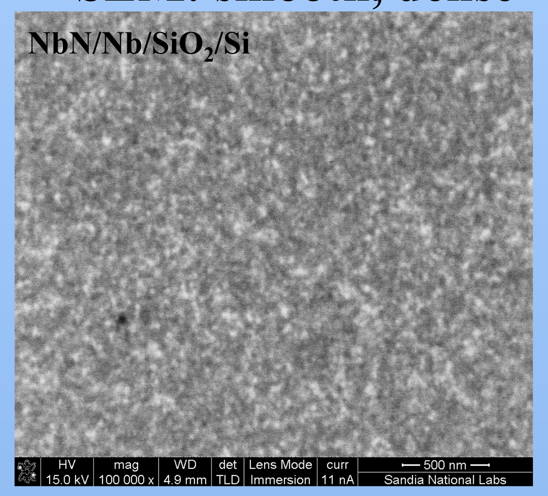
Parallel Approach:

1) Pulsed Laser Deposition (PLD)
- small-scale - cm^2 chips
- flexible deposition conditions, materials
- explore materials properties of individual layers

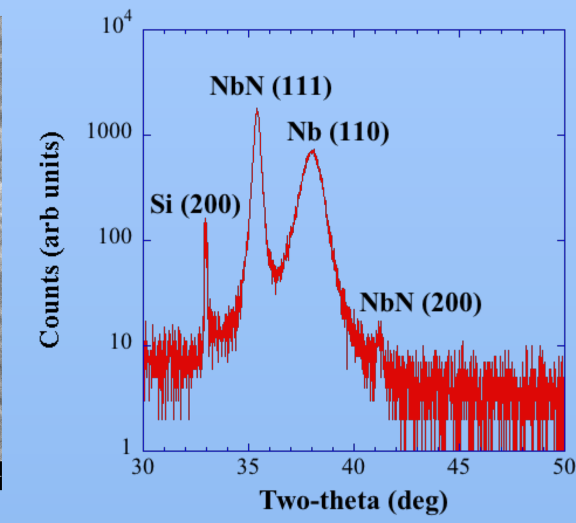
2) DC Reactive Magnetron Sputtering (MS)
- large-scale, 6 in wafers
- explore materials properties
- develop processing (dielectric, CMP, lithography)
- fabricate devices

NbN/Nb/SiO_2/Si PLD: Smooth, oriented single phase, high T_c only grow within 0.06 sccm N_2 on MFC

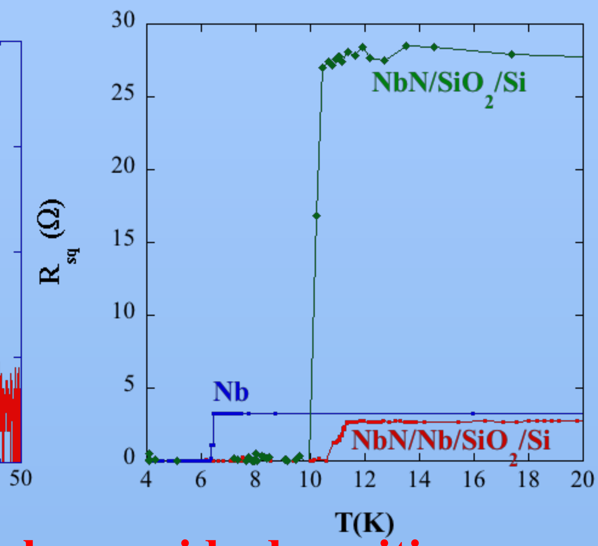
SEM: smooth, dense



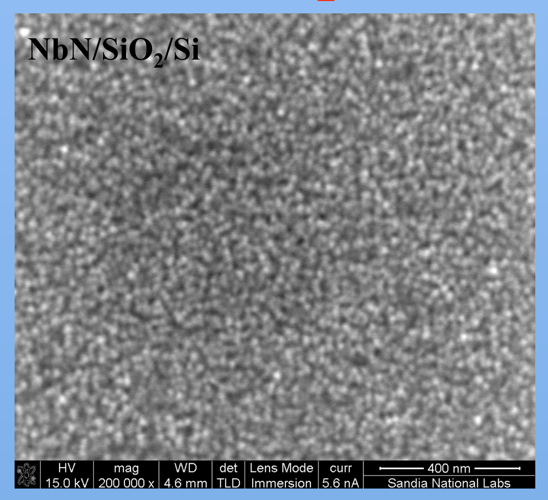
XRD: single phase

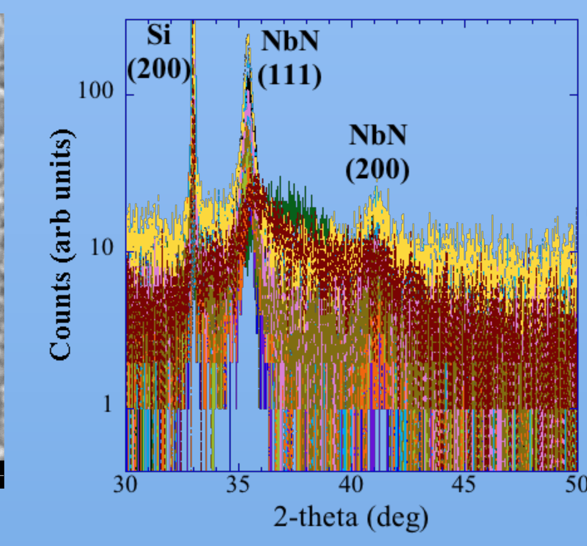


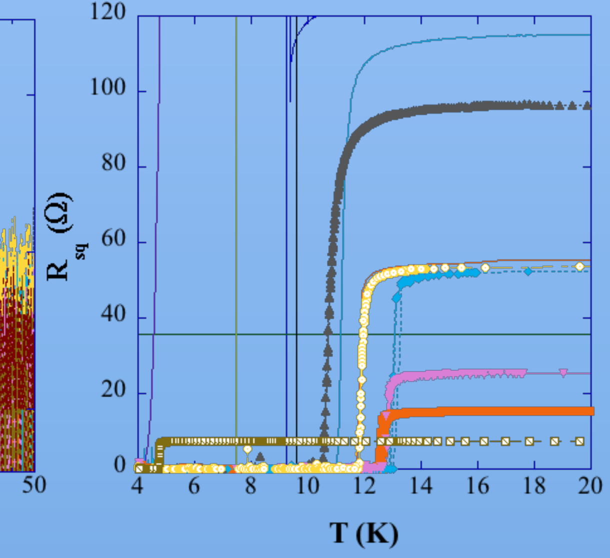
High T_c



NbN/SiO_2/Si MS: Smooth, oriented single phase, wide deposition range

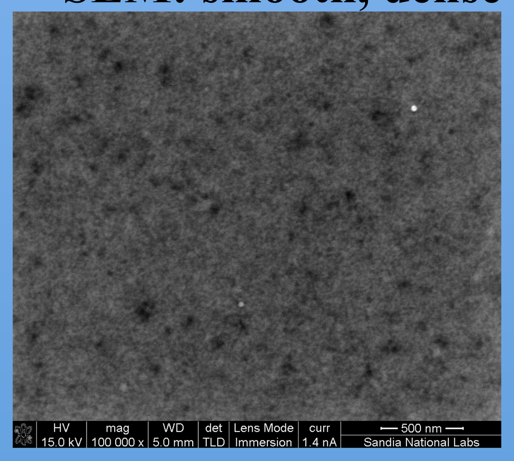




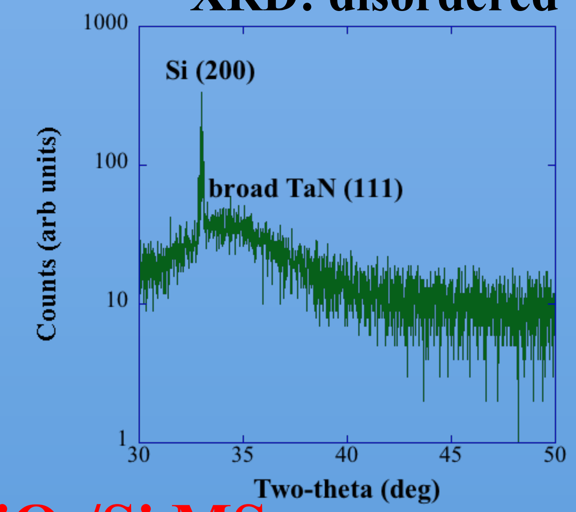


Ta_xN/SiO_2/Si PLD: Smooth, disordered, tunable R_{sq}

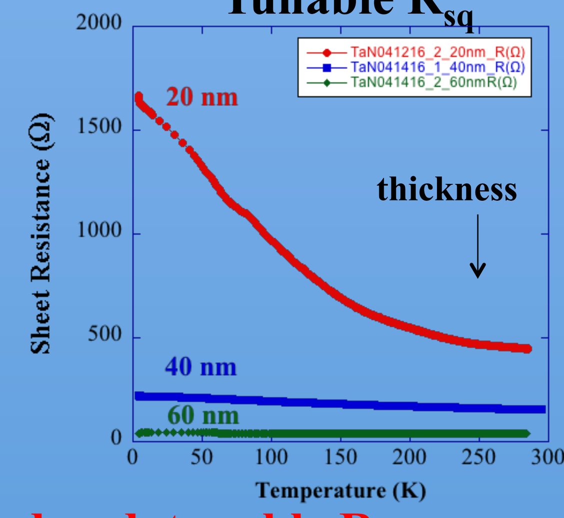
SEM: smooth, dense



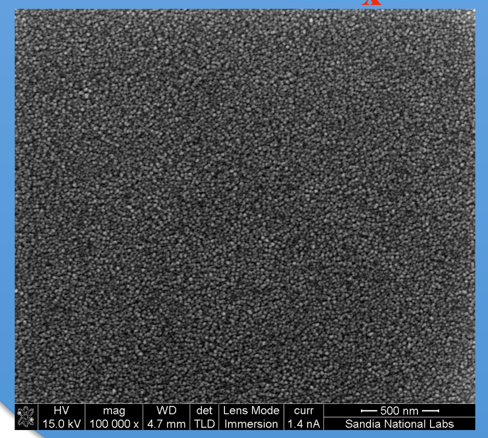
XRD: disordered

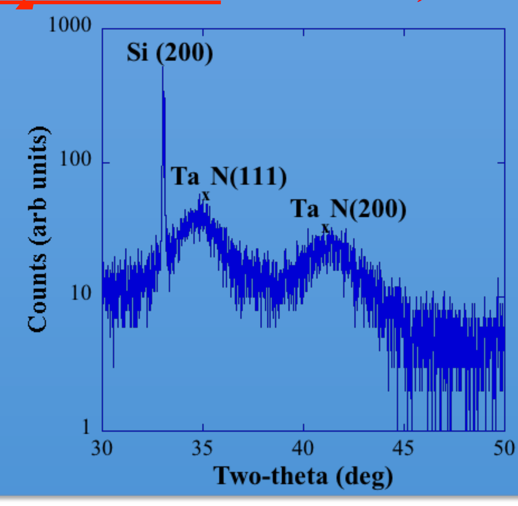


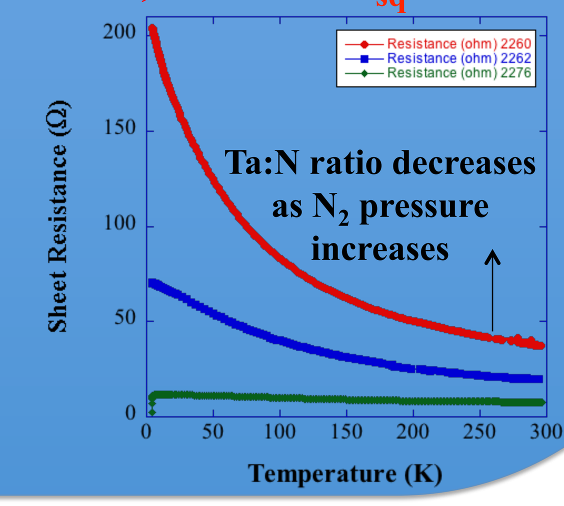
Tunable R_{sq}



Ta_xN/SiO_2/Si MS: Smooth, disordered, tunable R_{sq}

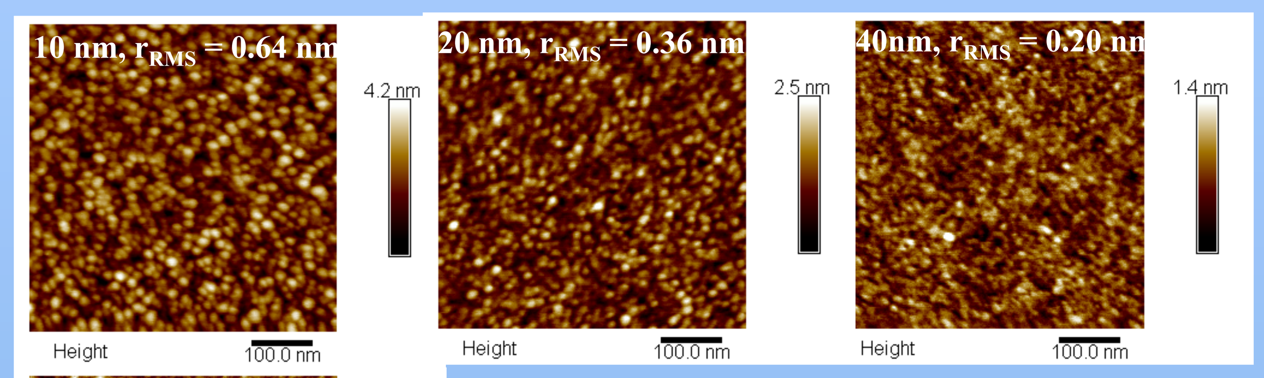


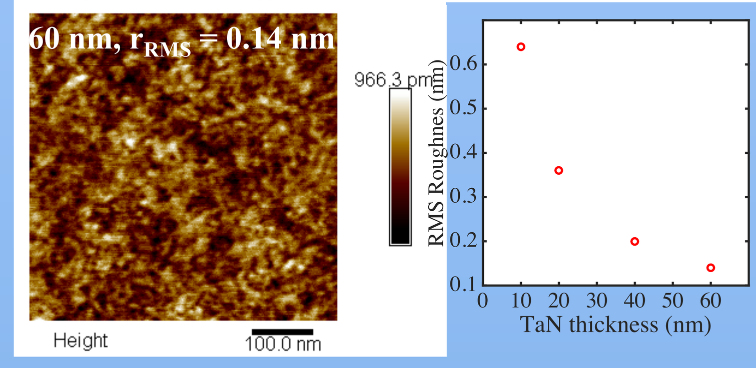




Ta_xN/SiO_2/Si MS Morphology:

Roughness decreases as films get thicker

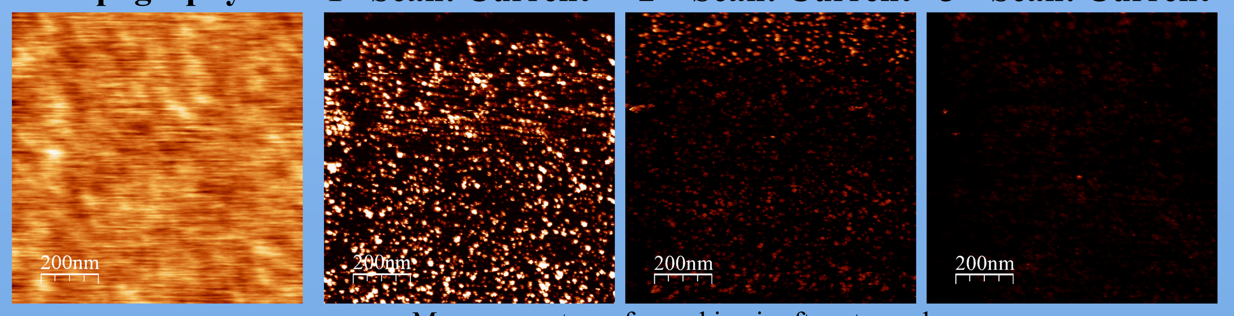




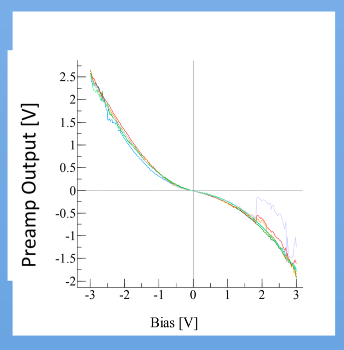
Dependence of resistance and roughness on Ta_xN thickness suggests > 20 nm for continuous, smooth barrier

Ta_xN/NbN/SiO_2/Si PLD:

Conducting AFM – is current flow uniform?



Measurements performed in air after atmosphere exposure



- Non-linear I-V, loss of current with subsequent scans suggests presence of surface oxide on Ta_xN – consistent with surface oxide observed on NbN
- In JJs Ta_xN will be capped with NbN counterelectrode, so oxidation will not occur
- Current distribution through Ta_xN layer can only be measured by protecting surface from oxidation

Summary:

- Ambient temperature growth of NbN on SiO_2/Si substrates by PLD and MS result in smooth, single phase films with T_c up to 11K
- Ambient temperature growth of Ta_xN on SiO_2/Si substrates by PLD and MS result in smooth, disordered films with tunable sheet resistance
- Ta_xN/SiO_2 morphology improves with thickness
- Investigation of perpendicular current flow uniformity in Ta_xN films will require protection from surface oxidation

References:
1) Westra, K.L, J. Vac. Sci. Tech. A, 8, 1288, (1990); 2) Treece, R. E. et. al., Appl. Phys. Lett. 65 (22), 2860, (1994).; 3) Wang, Z. et. al., Supercond. Sci. Technol.,12, 868, (1999)., 4) Kaul, A. B. et. al., Appl. Phys. Lett., 78, 99, (2001); 5) Kaul, A. B. et. al., IEEE Trans. Appl. Supercond. 11, 88, (2001), 6) Terai, H. et. al., IEEE Trans. Appl. Supercond., 11, 525–528, (2001).; 7) Yu, L. et. al., Phys. Rev. B, 65, 245110, (2002).; 8) Setzu, R. et. al., J. Phys. Conf. Ser. 97, 012077 (2008); 9) Nevala, M. R., et. al., IEEE Trans. Appl. Supercond. 19, 253, (2009); 10) Villegier, J.-C., et. al., IEEE Trans. Appl. Supercond. 19, 3375, (2009); 11) Villegier, J.-C., et. al., IEEE Trans. Appl. Supercond. 21, 102, (2011); 12) Yamamori, H. et al., IEICE Trans. Electron., E95-C, 329, (2012); 13) Makise, K. et. al., IEEE Trans. Appl. Supercond. 23, 1100804, (2013); 14) Akaike, H. et. al., IEEE Trans. Appl. Supercond. 23, 1101306, (2013).

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NNSA National Nuclear Security Administration

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