NbTiN & NbN Thin Films for the Enhancement of Superconducting Radio Frequency Cavities

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Introduction

At present, bulk niobium SRF accelerating cavities suffer from a fundamental upper limit in maximally sustained accelerating field gradients; however, a scheme involving multi-layered superstructures consisting of superconducting-insulating-superconducting (SIS) layers has been proposed to overcome this fundamental material limit of ~50 MV/m [1]. The SIS multi-layer paradigm is reliant upon implementing a thin shielding material with a suitably high Hc1 which may prevent early field penetration in a bulk material layer and consequently delay the high field breakdown. It has been predicted that for thin superconducting films — thickness less than the London penetration depth (~151nm in the case of NbTiN) — the lower critical field Hc1 will be enhanced with decreasing thickness. Thus, superconducting thin films with suitably high Hc1 values and critical temperatures are prime candidates for such SIS structures. Here we present our study on the structure and superconducting properties of epitaxial NbTiN thin films and NbN Trilayer films while correlating the effects of target stoichiometry and film microstructure with observed Hc1 enhancements.

Thin Films

•NbTiN Films:
- •Films grown at W&M using a 70/30 (wt%) NbTi target in Ar/N atmosphere on MgO(100) substrates using DCMS
- •Films grown at Jlab by Anne-Marie Valente using an 80/20 (wt%) NbTi target in Ar/N atmosphere on MgO and AlN substrates using DCMS

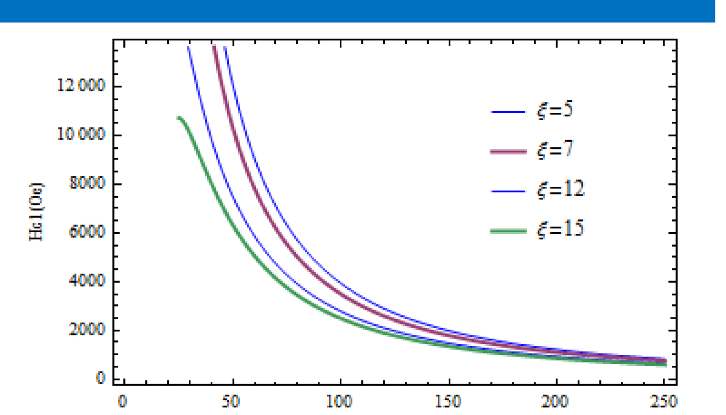
•NbN Trilayers
- •Films grown on 2" MgO(002) substrate using DCMS with a 250nm Nb layer, a 15nm thick MgO layer and an 85nm thick NbN(002) top layer

Theoretical Enhancement

1) Improvement of Hc1 in thin films

Phenomena exhibited in films with thicknesses less than their london penetration depth

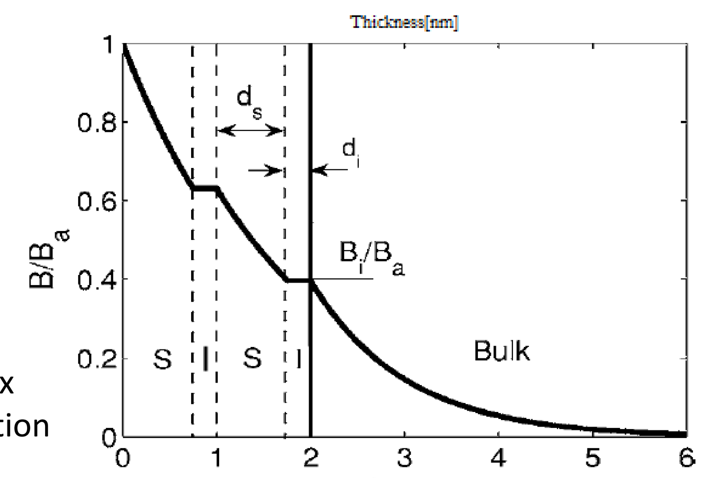
$$H_{C1} = \frac{2\phi_0}{\pi d^2}\ln\frac{d}{\xi} \qquad d < \lambda_L$$



2) Shielding of Bulk Cavity by SIS Layering

Superconducting thin films shield bulk SRF cavity below.

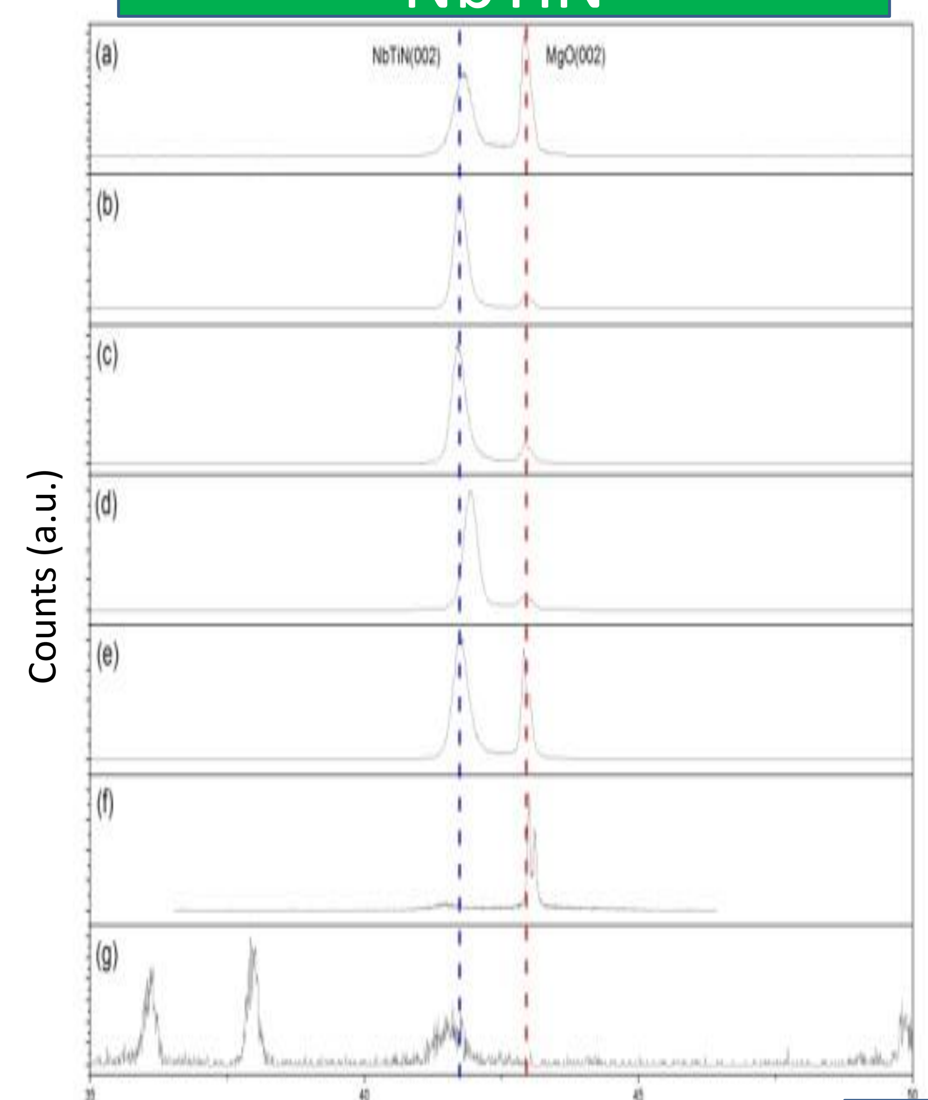
Insulating layers help pin the vortices due to magnetic flux penetration from causing increased surface dissipation



[1] A. Gurevich, *Appl. Phys. Lett.* **88**, 012511 (2006).

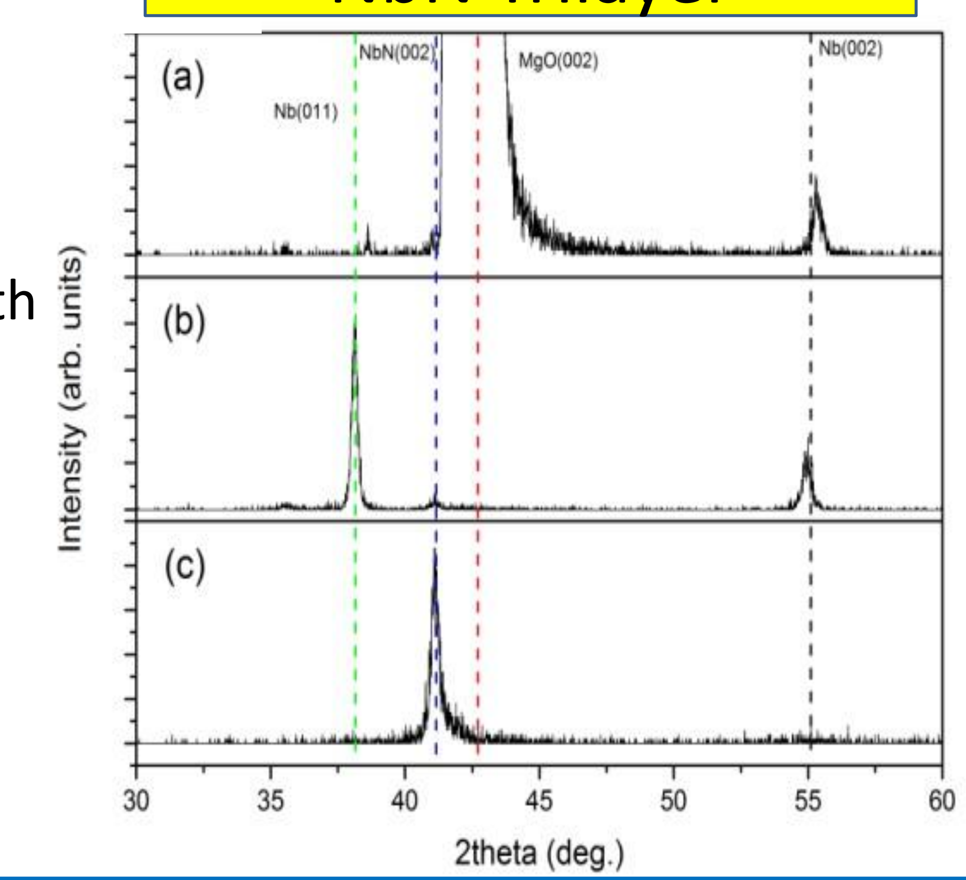
X-Ray Diffraction

NbTiN



- •Samples exhibit epitaxial growth with the MgO(001) substrate in the nominal, delta, superconducting structure
- •No other phases of NbTiN observed
- •Variation in lattice parameter between samples shows difficulty in getting consistent film deposition for ternary alloys

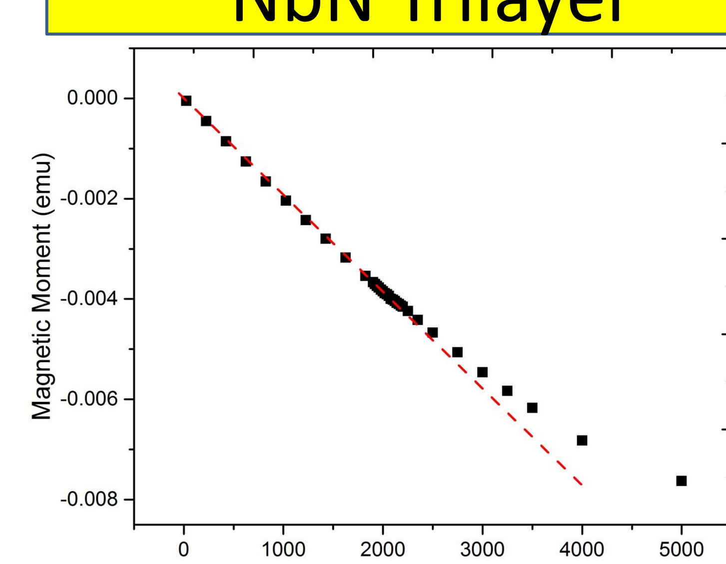
NbN Trilayer



•Samples exhibit epitaxial growth of the NbN layer with the MgO(001) substrate in the nominal, delta, superconducting structure even with two interlayers

Superconducting Properties

NbN Trilayer

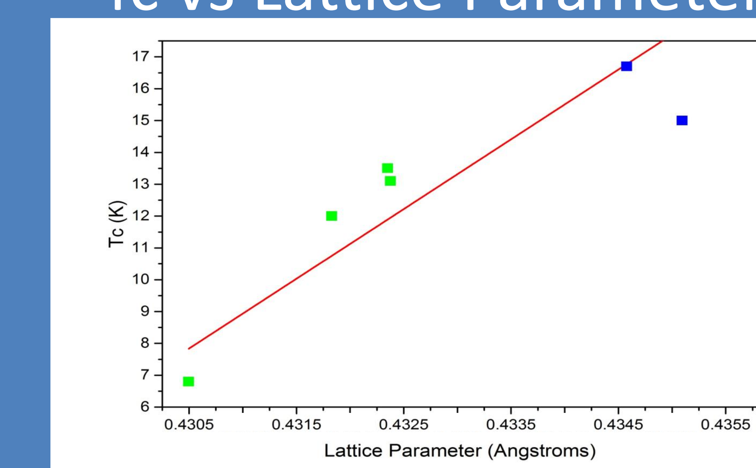


- •NbN Trilayers exhibited extremely high Hc1 values for DC measurements reaching up to 2100 Oe
- •Procedure for Hc1 measurement outlined in Bohmer et al. [2]

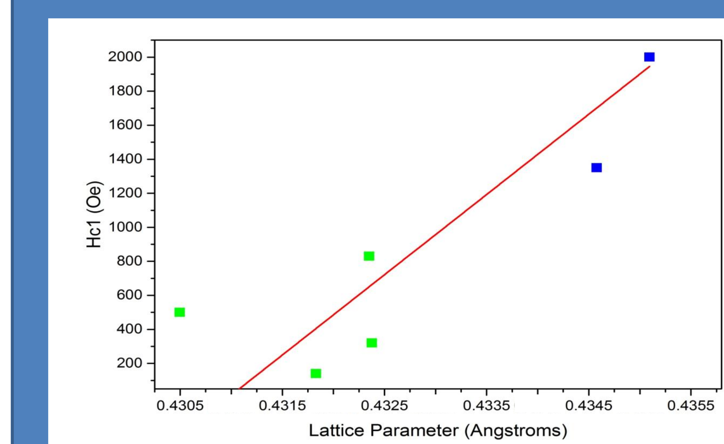
NbTiN

•Bulk Lattice parameter are ~ 0.434 & 0.4355nm, for 70/30 & 80/20 Nb/Ti ratios respectively

Tc vs Lattice Parameter



Hc1 vs Lattice Parameter



•Samples exhibit strong linear dependence of Superconducting Properties (Hc1 and Tc) on Lattice Parameter

Conclusions & Future Work

- •Observed an enhancement of Hc1 for NbTiN thin films & NbN trilayers with thicknesses less than their london penetration depth
- •Films with larger lattice parameters had improved superconducting properties in both Hc1 and Tc
- •Future work includes:
  - •Sensitivity of ternary alloys (NbTiN) superconducting properties to lattice parameter (& stoichiometry) show need for careful deposition process control studies
  - •Perform surface morphology studies
  - •Explore Nb HiPIMS deposition onto Cu cavities at Jefferson Lab
  - •Test multilayer theory on SRF cavities

References & Acknowledgements

[1] A. Gurevich, *Appl. Phys. Lett.* **88**, 012511 (2006).
[2] C. Bohmer *et al.*, Supercond. Sci. Technol. **10**, A1-A10 (1997)

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