Surface Characterization of NbTiN Films for Accelerator Applications

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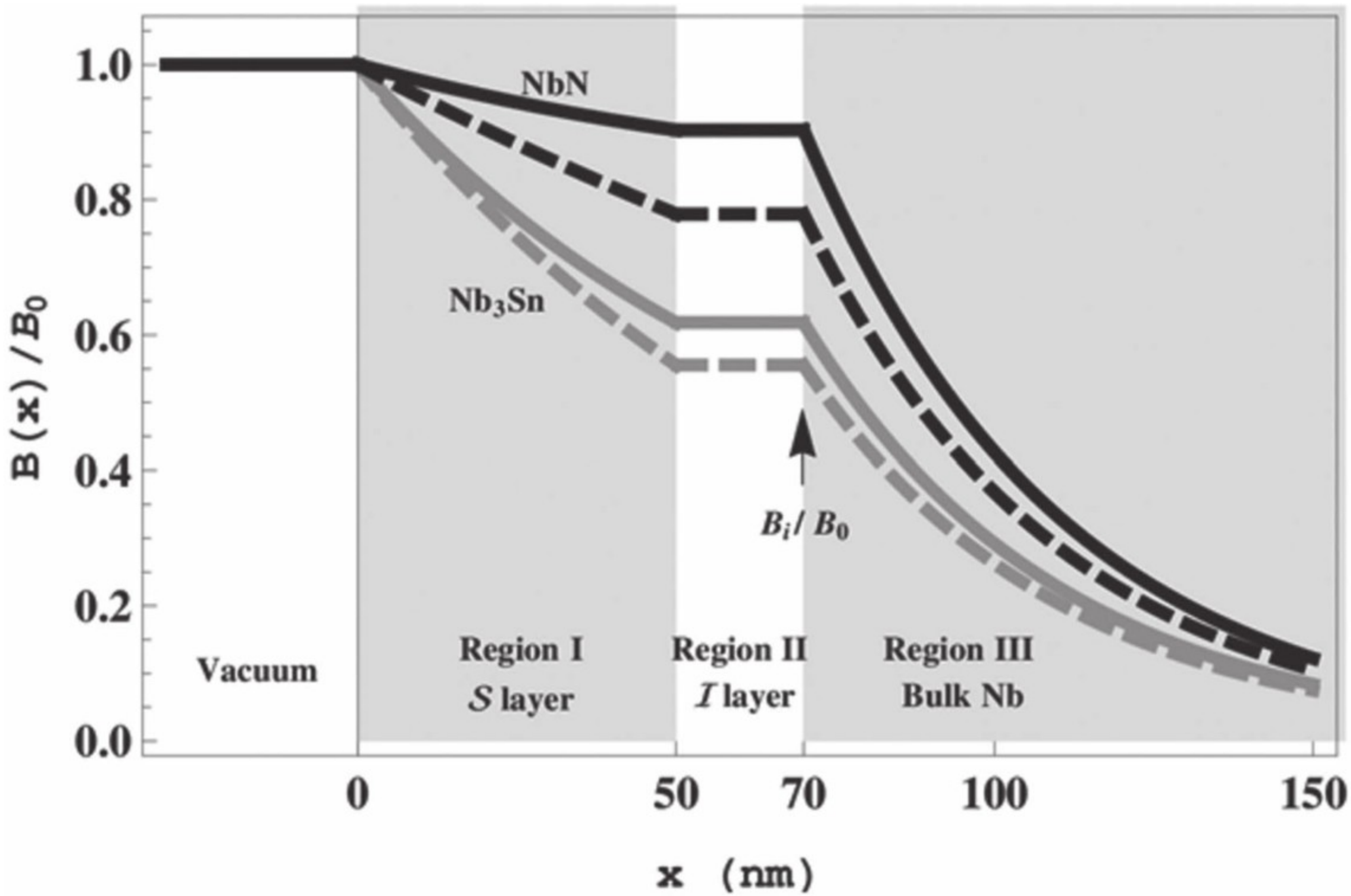
Multilayered Thin Films for Cavities



Schematic diagram shows how multilayer thin films can improve cavities magnetic screening.

T. Kubo, Applied Physics Letters 104, 032603 (2014)

Candidate Material NbTiN Superconducting Properties

Material	T_c [K]	H_{c1} [mT]	H_{c2} [mT]	λ [nm]	Lattice [Å]
NbTiN	17.3	30	15000	150-200	4.341[1]
Nb	9.23	180	282	40	3.322[2]
Nb_3Sn	18	50	28000	80-100	5.29[3]
AlN	N/A	N/A	N/A	N/A	3.938[4]

A-M, Valente-Feliciano. Superconductor Science and Technology 29.11 (2016).
[1] P. Duwez, and F. Odell. Journal of the Electrochemical Society 97.10 (1950): 299-304.
[2] K. Lejaeghere, et al., Critical Reviews in Solid State and Materials Sciences, 39, 1, (2014)
[3] S. Bender, J. Hill, Avco Corporation, Wilmington, MA, USA Private Communication, (1963)
[4] N.E. Christensen, I. Gorczyca, Physical Review, Series 3. B - Condensed Matter (18,1978-), 47, 4307 - 4314, (1993)

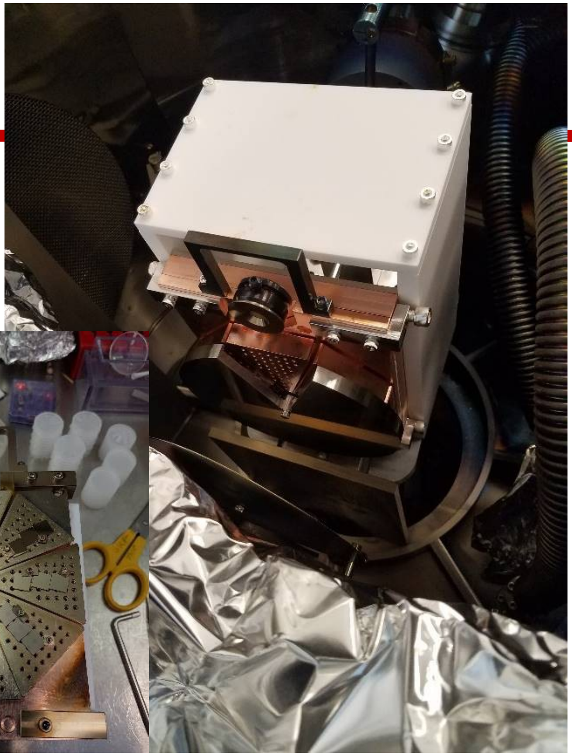
Applications of NbTiN

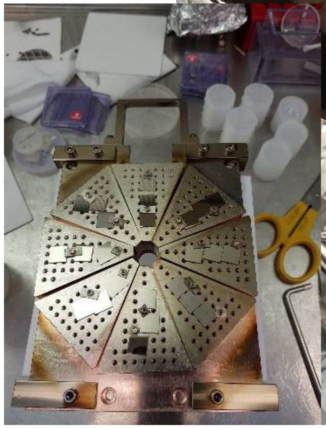
- Tool coatings.
- Medical implant coatings.
- Superconducting Nanowire Single Photon Detectors (SNSPDs).
- Terahertz (THz) applications:
  - Cosmological microwave background.
  - Airport security.

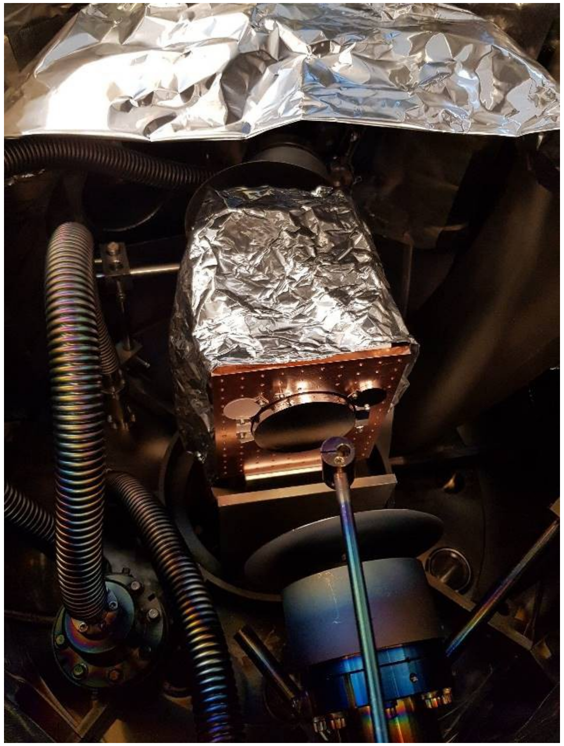
There is promise for NbTiN in superconducting radio frequency (SRF) applications, in particular to improve accelerator cavity performance.

Deposition System

- 3 DC/RF magnetron guns.
- Central sample stage can be heated up to 700 ^{o}C.
- Base pressure of 10^{-9} Torr by a CTI-10 cryopump via a throttle gate valve.





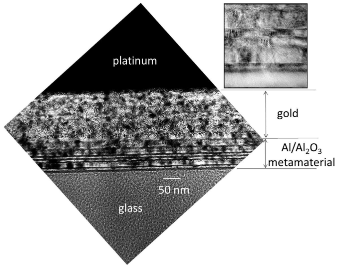


- Stage is mounted on a differentially pumped rotating conflat system allowing to position the substrates in front of the magnetrons and thus allowing in-situ sequential deposition of different layers.
- Rotatable shutter allows the variation of multiple deposition parameters within the same environmental conditions.

Emerging applications for NbTiN based multilayers

Engineer artificial metamaterial superconductors with considerably enhanced superconducting properties.

Nature Scientific Reports 6, Article number: 34140 (2016)



Nanofabrication of thick film Al-based hyperbolic metamaterials with a Tc =2x $Tc_{Al\ bulk}$ with excellent transport and magnetic properties.

Metamaterial superconductor based on NbTiN: (DARPA-BAA funded)

Multilayer structure of NbTiN = 3 nm and AlN = 2 nm.

Metamaterial superconductor of NbTiN and AlN can enhance T_c compared to NbTiN.

Low roughness of sequential films is necessary to accomplish sharp interfaces.

# bilayers	NbTiN [nm]	AlN [nm]
16	3	2.5
8	3.3	2.4
4	4.3	2.5
2	3.4	2

Bilayers were deposited on NbTiN/MgO.

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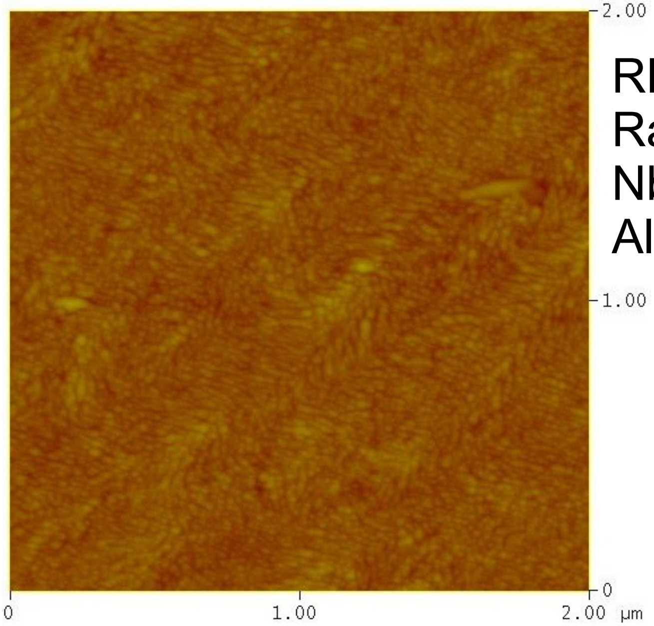
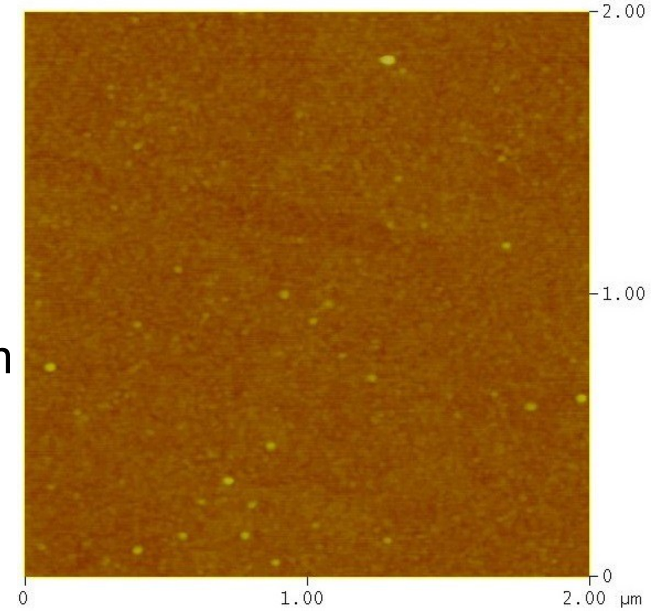
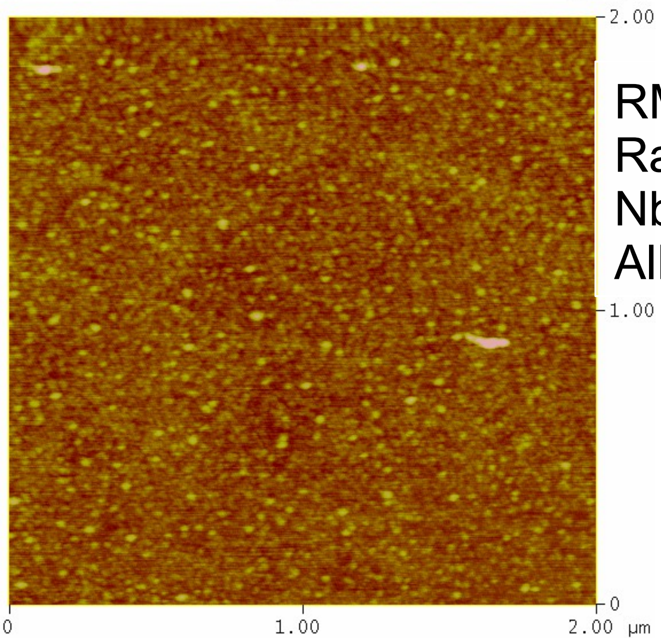
Topography of bilayer NbTiN/AlN/MgO



RMS = 1.064 nm
Ra = 0.838 nm
NbTiN = 2054 nm
AlN = ~20 nm

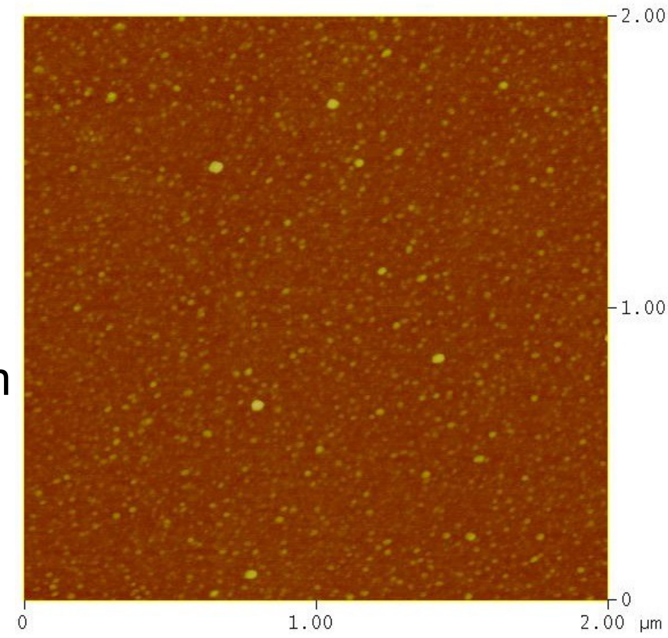
RMS = 0.317 nm
Ra = 0.231 nm
NbTiN =117 nm
AlN = 14 nm



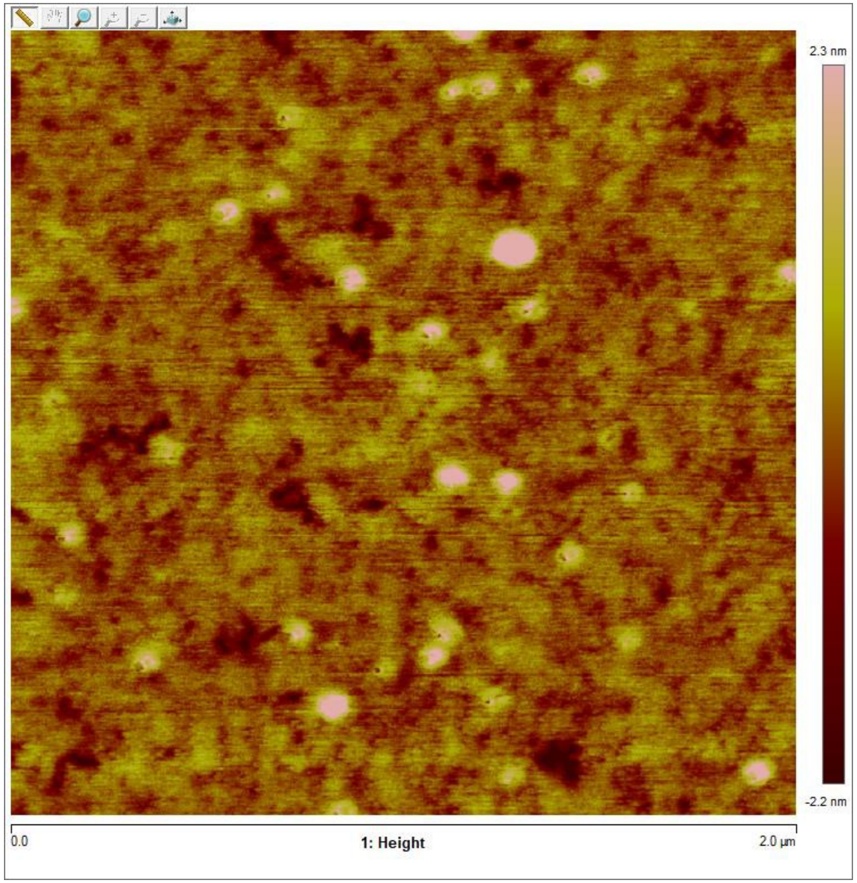


RMS = 0.280 nm
Ra = 0.204 nm
NbTiN = 66.5 nm
AlN = 21.5 nm

RMS = 0.608 nm
Ra = 0.395 nm
NbTiN = 33 nm
AlN = 15 nm



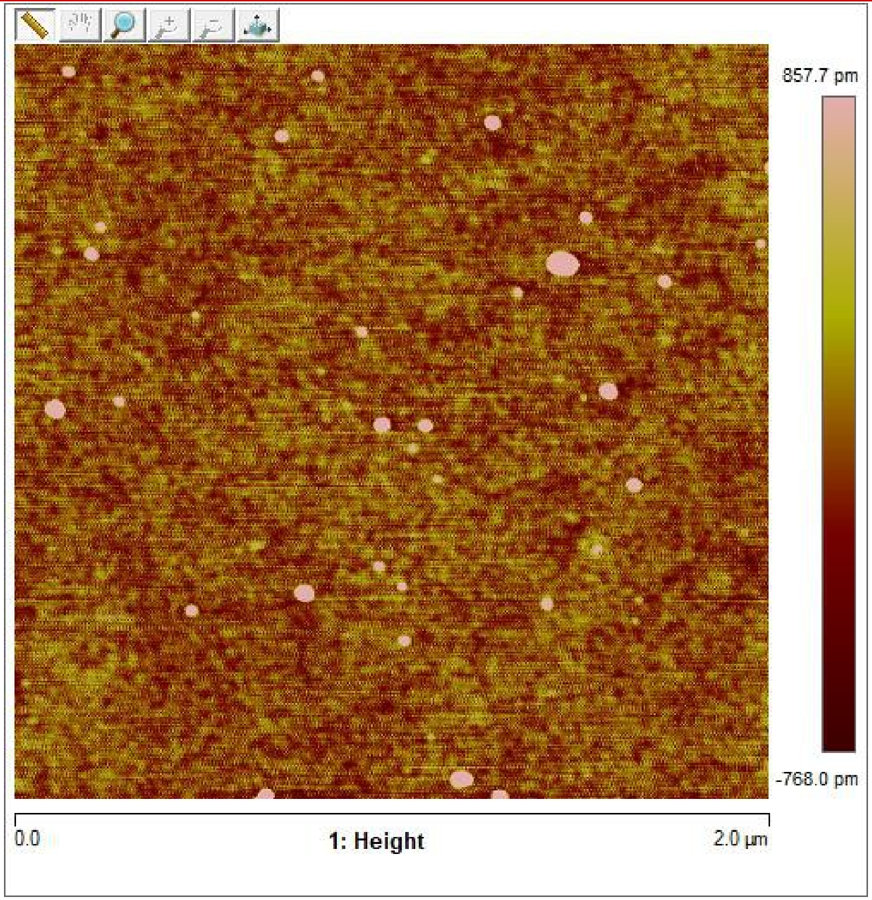
Topography of Multilayer Thin Films



16 layers of NbTiN/AlN on NbTiN/MgO

RMS = 0.556 nm, Ra = 0.355 nm

NbTiN = 3 nm, AlN = 2.4 nm

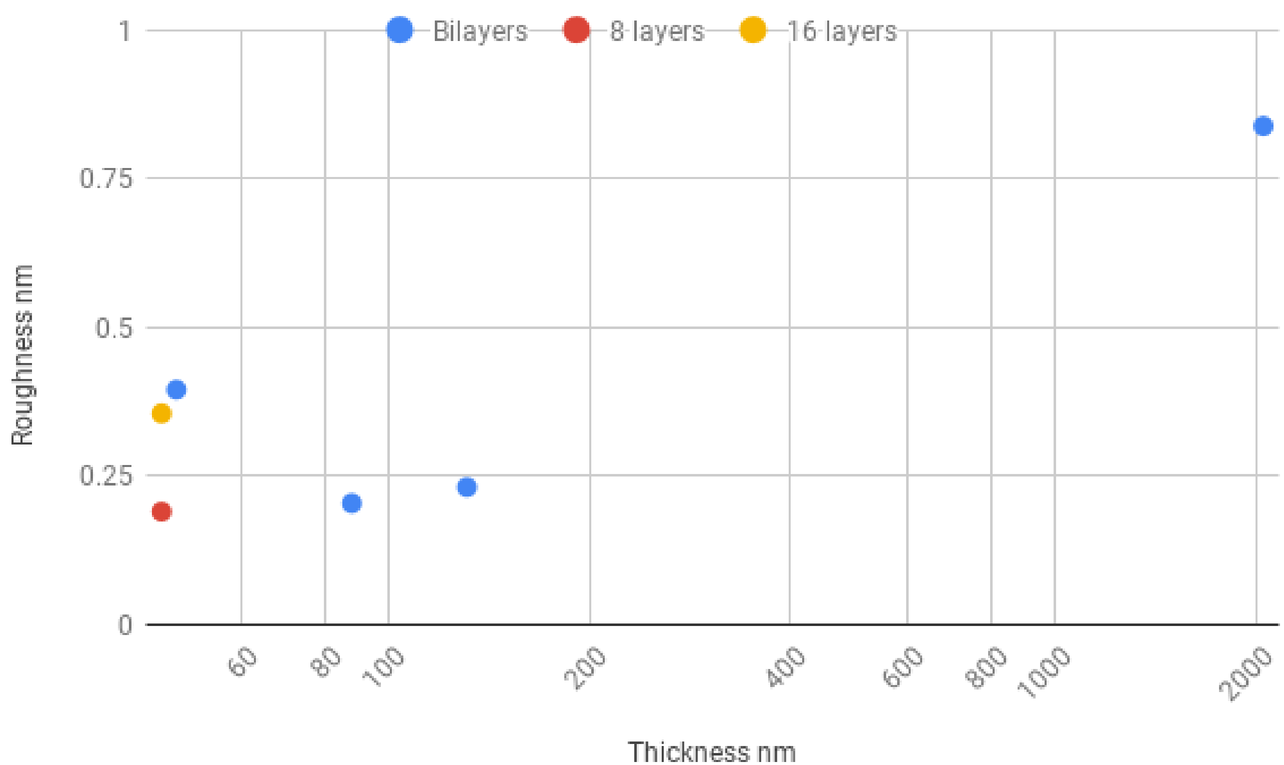


8 layers of NbTiN/AlN on NbTiN/MgO

RMS = 0.389 nm, Ra = 0.19 nm

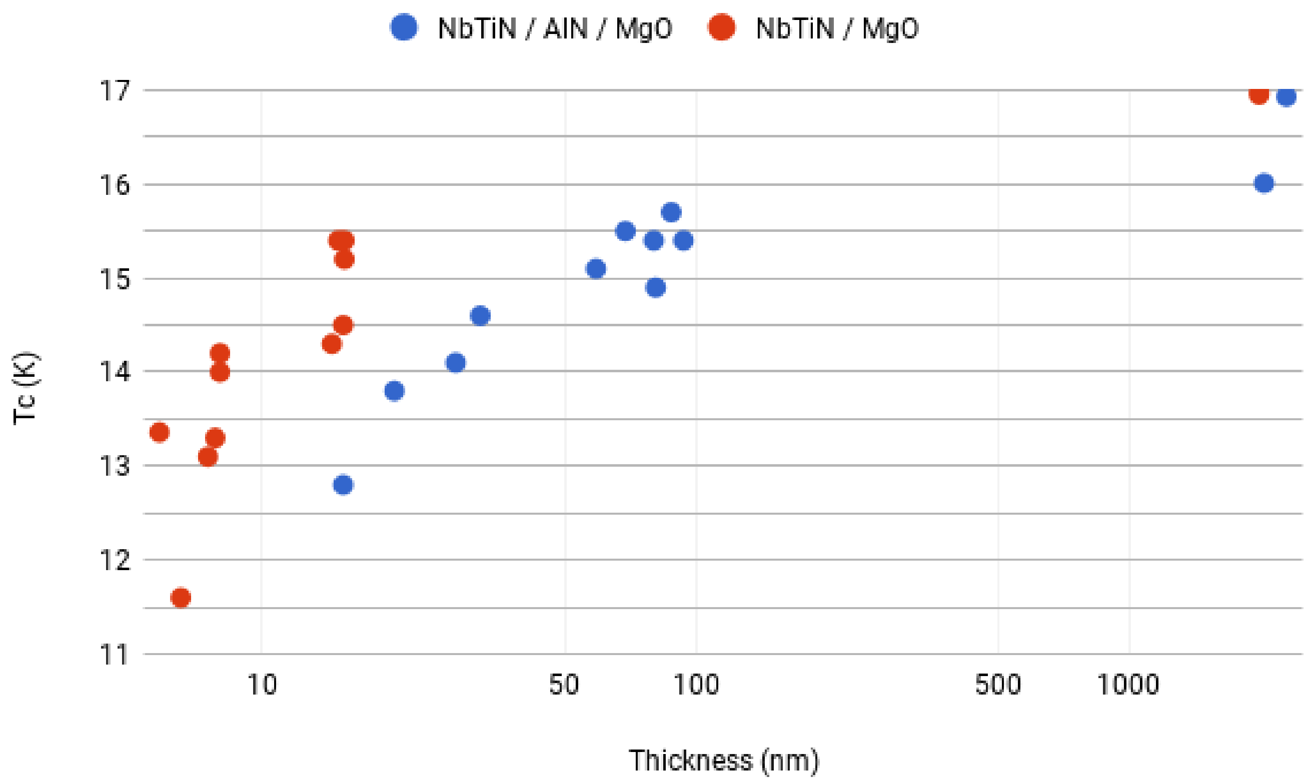
NbTiN = 3.3 nm, AlN = 2.5 nm

Overall roughness of Multilayer Films



The addition of layers does not increase the roughness of the films.
Preserving the potential for sharp interfaces

Critical Temperature T_c versus Thickness



Measured by four point probe and XRR.

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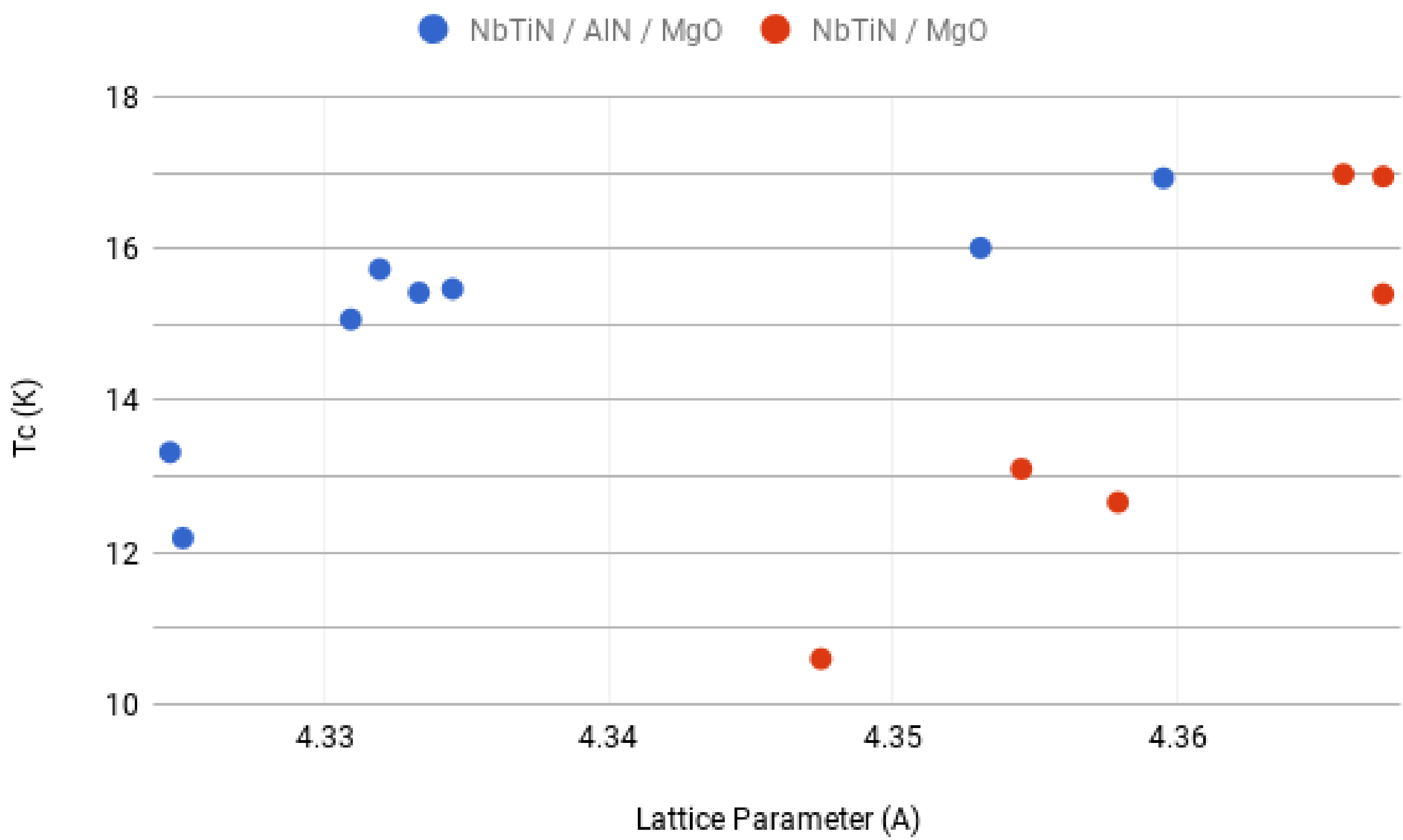
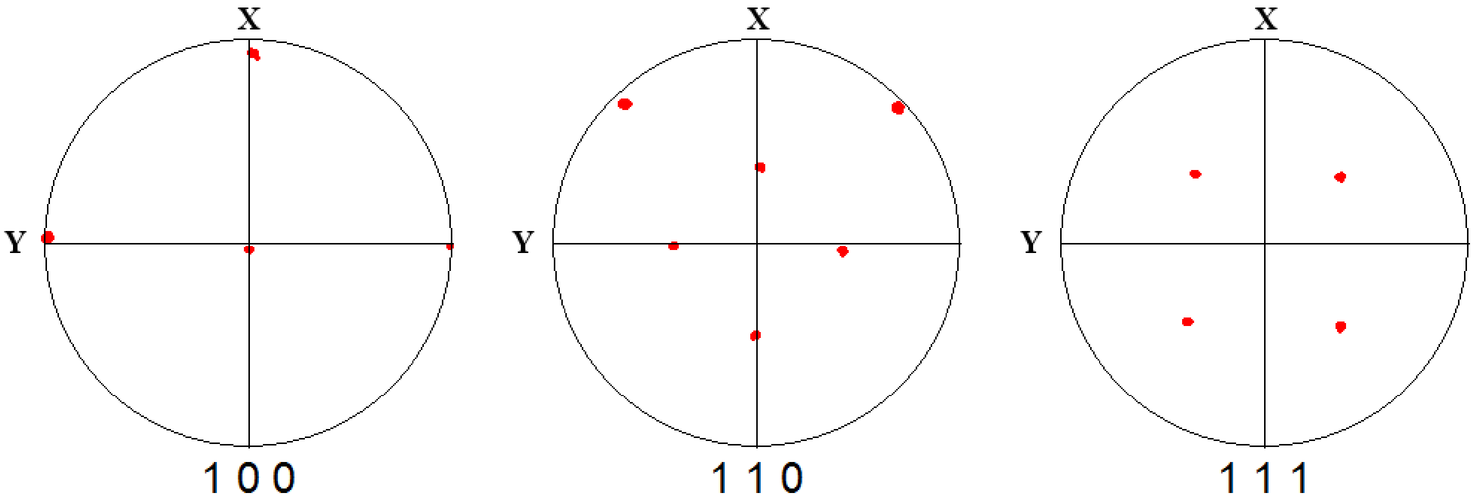
Critical Temperature and Lattice Parameter

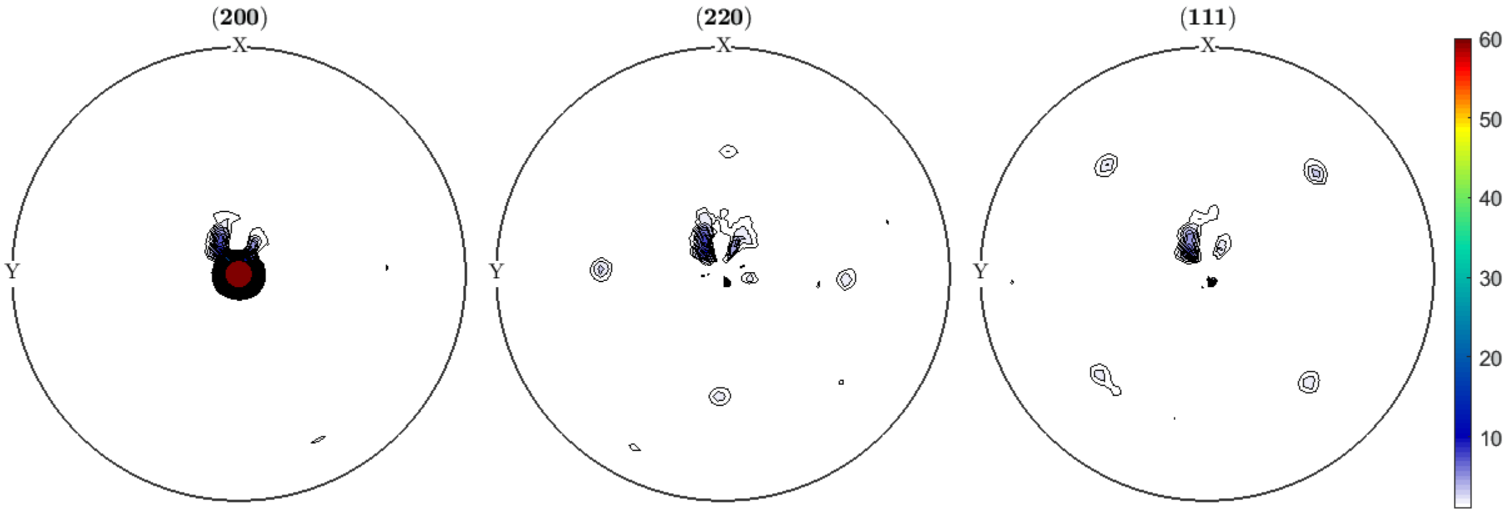


Measured by four point probe and XRD

Texture of Monolayer NbTiN/MgO

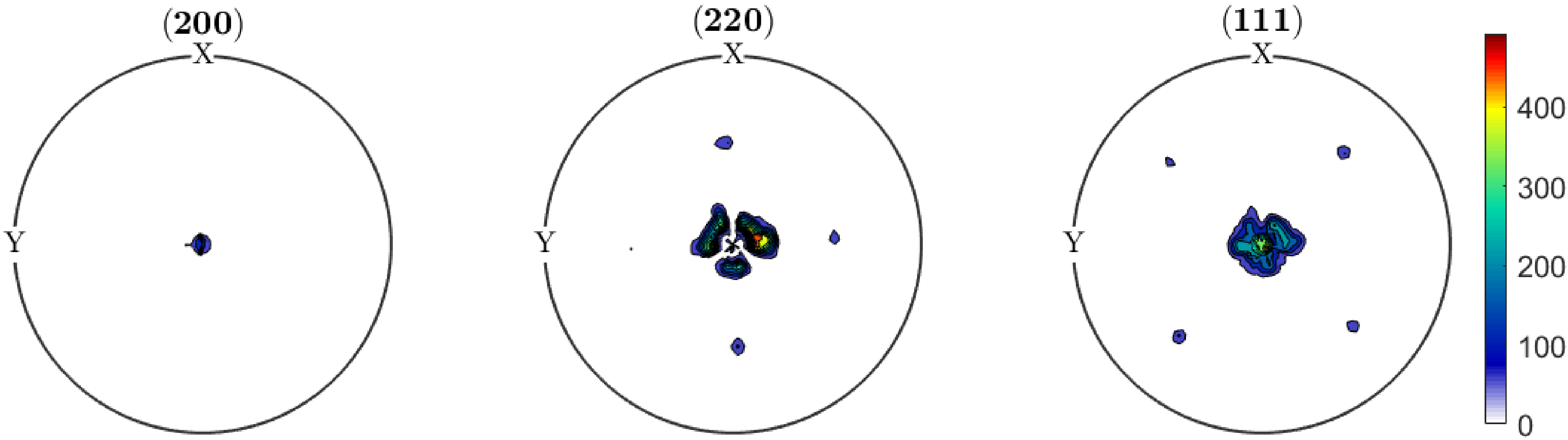


Pole figure of NbTiN measured by EBSD.



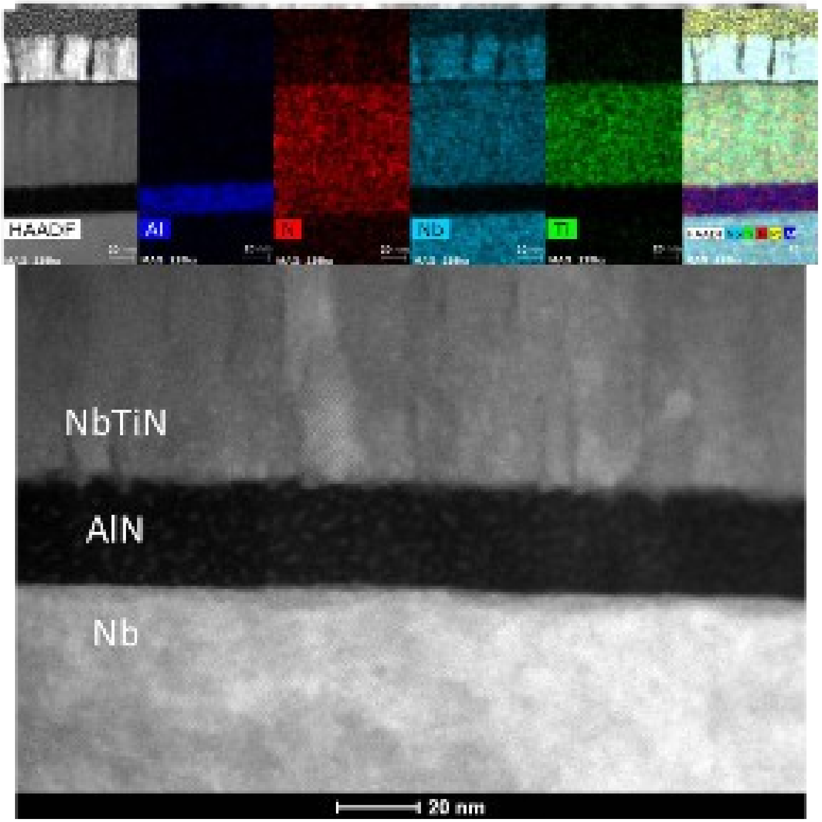
Pole figure of NbTiN measured by XRD

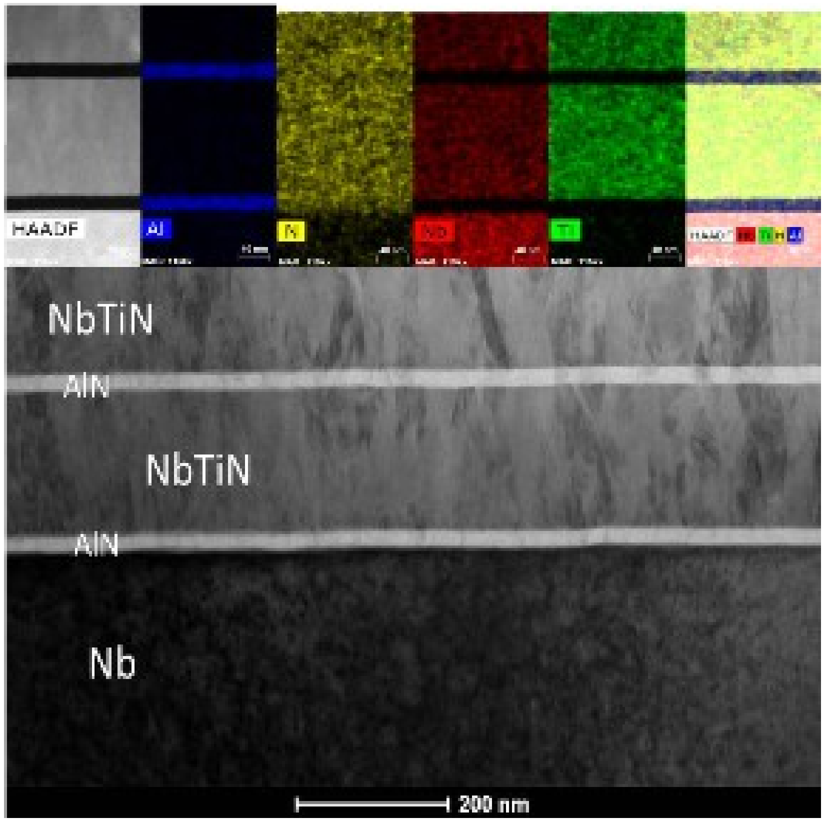
Texture of Multilayers $(NbTiN/AlN)_{16}/NbTiN/MgO$



Pole figure of NbTiN in a 16 layer film.

TEM Cross Sections of “Thick” Multilayers on Bulk Nb





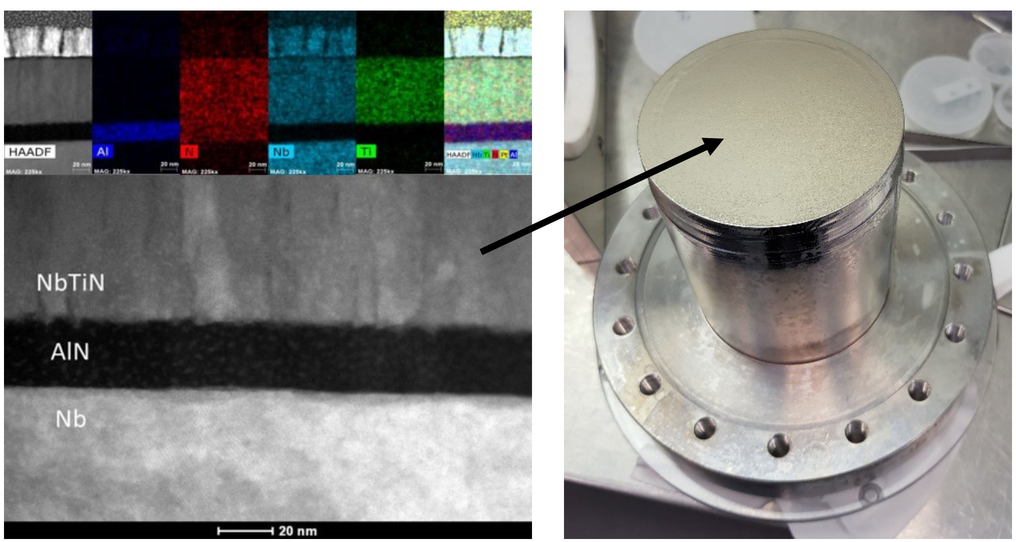
The interfaces are very sharp with no diffusion of Al.

Note: the change in scale

Ongoing Measurements

First flux penetration by SQUID for
NbTiN/MgO, NbTiN/AlN ceramic,
NbTiN/AlN/MgO, $(\text{NbTiN/AlN})_x$/NbTiN/MgO
NbTiN/AlN/Nb
Thickness variation

Quadrupole resonator measurements at HZB – See next talk, S. Keckert



Thank you for your attention.