LOW TEMPERATURE DEPOSITION AND RF ANALYSIS of Nb_3Sn, an A-15 SUPERCONDUCTOR FOR SRF *

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Outline

- Alameda Applied Sciences Corporation: an Introduction
- Phase II Project Goals
- Relevance to NP Programs
- Schedule and Deliverables
- Current Status of Project
- Future Plans

Alameda Applied Sciences Corporation

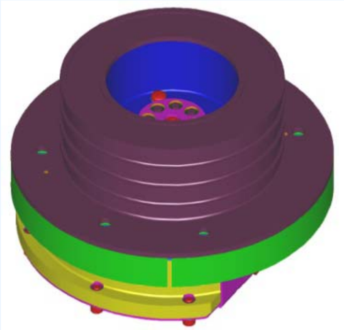
Superconducting Thin Films

RRR ~300, T_c =9.27K

Pulsed Neutron Source

2.5 and 14 MeV neutrons

Micro-propulsion



20W / 1kg/ 100mN / 2000s

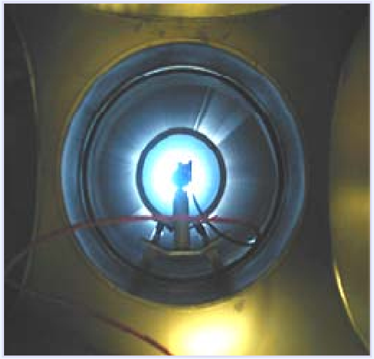
Diamond Radiation Detectors

UV and soft x-ray

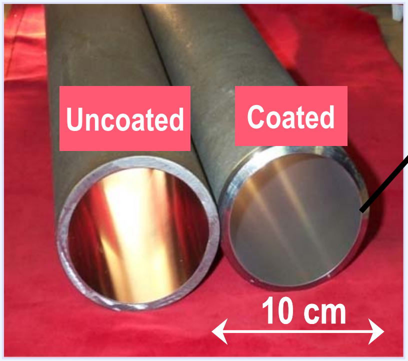
≤ 15 keV

- Founded in 1994, privately held CA Corporation
- 8 employees, ~$2 million 2009 revenue
- Develop/license IP via contract R&D
- Four Pre-commercial areas:
  - Cathodic arc coatings CED™
  - Fast pulsed x-ray sources for calibration
  - Fast pulsed neutron sources for WMD and HE detection
  - Space micro-propulsion thrusters

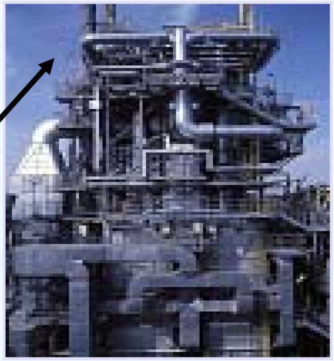
Cathodic Arc Coatings (CED™)



CED™ coating inside of furnace tubes



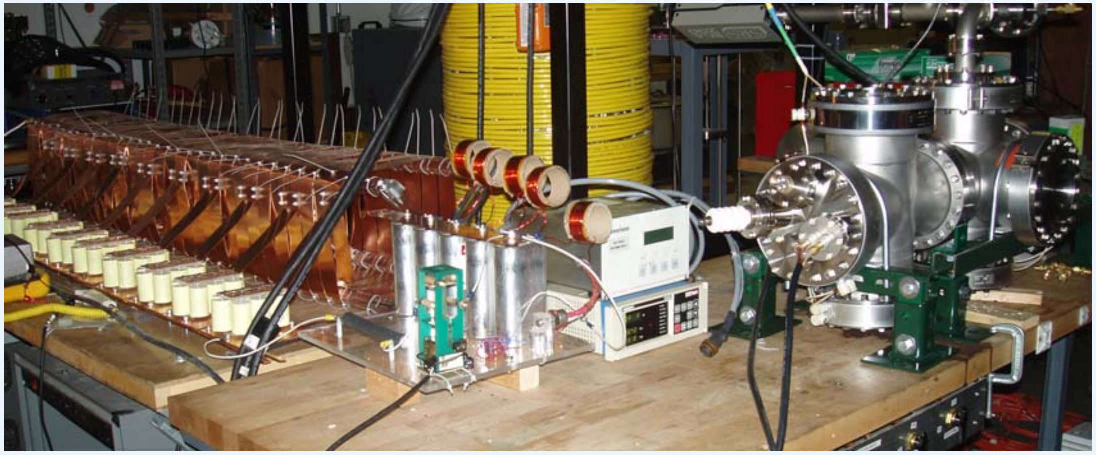
Anti-coking coating on furnace tube



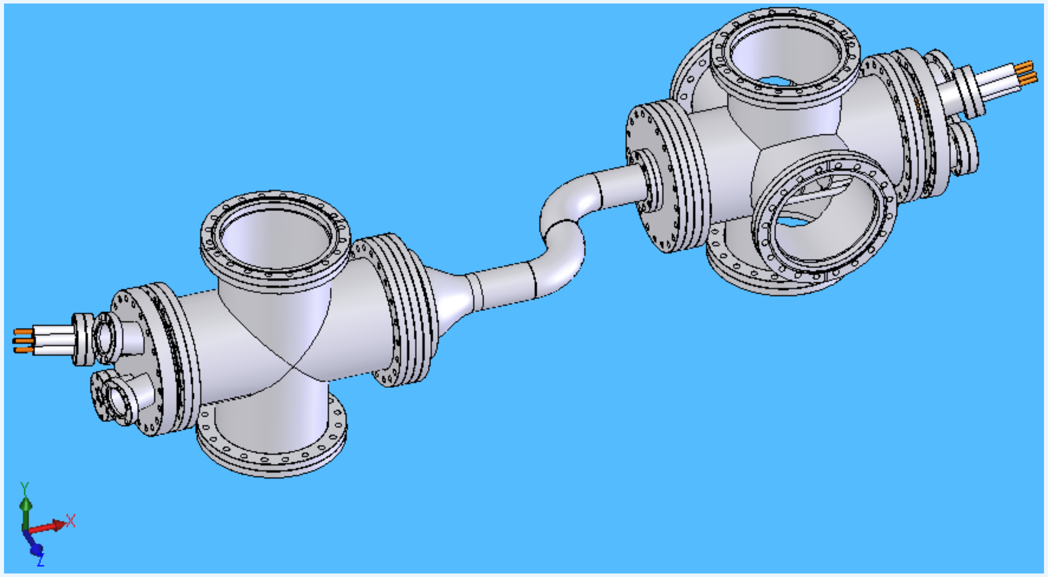
Benefit: extended interval between de-cokings

Three different Coaters at AASC

Coaxial Energetic Deposition (CED™)



Cathodic Arc Deposition (CAD)

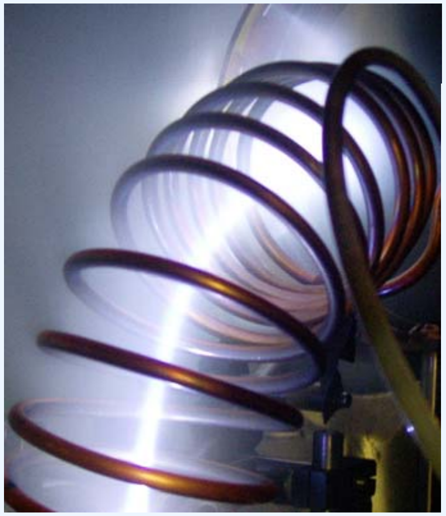


Filtered Cathodic Arc Deposition (FCAD)

Phase II Goals

Approach of the AASC-JLab-NSU collaboration

- Use CED™ and CAD/FCAD techniques to coat sapphire and Cu coupons
- Use surface analysis techniques at JLab/NSU to characterize morphology
- Measure RRR and T_c from sapphire coated coupons
- Use SIC facility at JLab to measure impedance of films in cavity
- Improve our understanding of the relationships between surface characteristics and superconducting properties



Relevance to NP Programs and Commercial Applications

- NP facilities:
  - The CEBAF facility at TJNAF (undergoing a 12GeV upgrade)
  - Facility for Rare Isotope Beams (FRIB).
    - *NSAC report states that as a result of technical advances, a world-class rare isotope facility can be built at ≈ half the cost of the originally planned Rare Isotope Accelerator (RIA), employing a superconducting linac*

- Commercial applications:
  - More than 1000 particle accelerators worldwide; most use normal cavities
  - Superconducting RF (SRF) cavities offer a ~10x improvement in energy efficiency over normal cavities, even accounting for cryogenic costs at 2K
  - Operating at higher temperatures (~10K) would further improve accelerator energy efficiency as the cryogenic cooling becomes less demanding and moves away from liquid He and towards off the shelf cryo-coolers such as those used in cryo-pumps
  - Replacing bulk Nb with Nb coated Cu cavities would also reduce costs
  - The ultimate payoff would be from cast Al SRF cavities coated with higher temperature superconductors (Nb_3Sn, MoRe, MgB_2, oxypnictides)

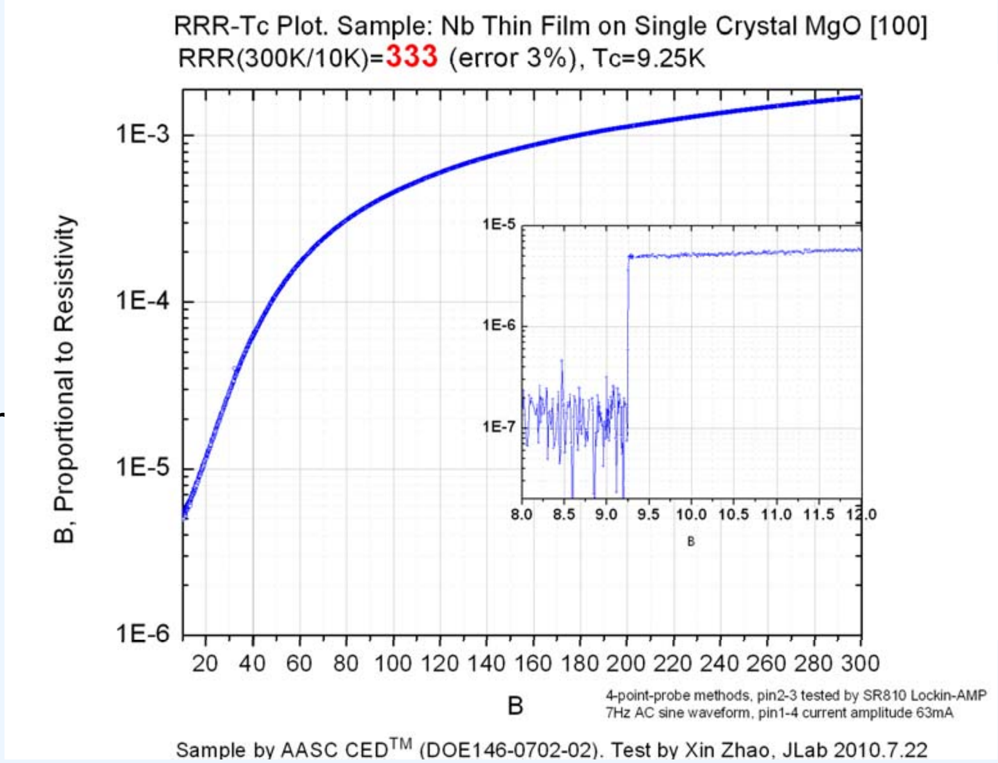
Our thin film superconductor development is aimed at these broad goals

Phase II Tasks and Schedule

- Coat pure Nb films on a-sapphire and Cu substrates using the CED™ coater (year I)
  - Measure the thin films (AASC and JLab and NSU)
- Coat pure Nb films on a-sapphire and Cu in the CAD chamber (year I)
  - (the CAD chamber was used in Ph-I to produce the Nb_3Sn films)
  - Measure the thin films (JLab and NSU)
- Coat Nb_3Sn on a-plane sapphire in CAD chamber (year II)
  - Measure the thin films (AASC and JLab and NSU)
- Coat the thin films using pulsed biased CAD (AASC) (year II)
  - Measure the thin films (AASC and JLab and NSU)
- Coat Nb_3Sn on Nb and/or Cu in CAD chamber (year II)
  - Measure the RF properties in the SIC facility (JLab)

Our CED™ coater has shown RRR>300 in 1.5µm thick Nb films!

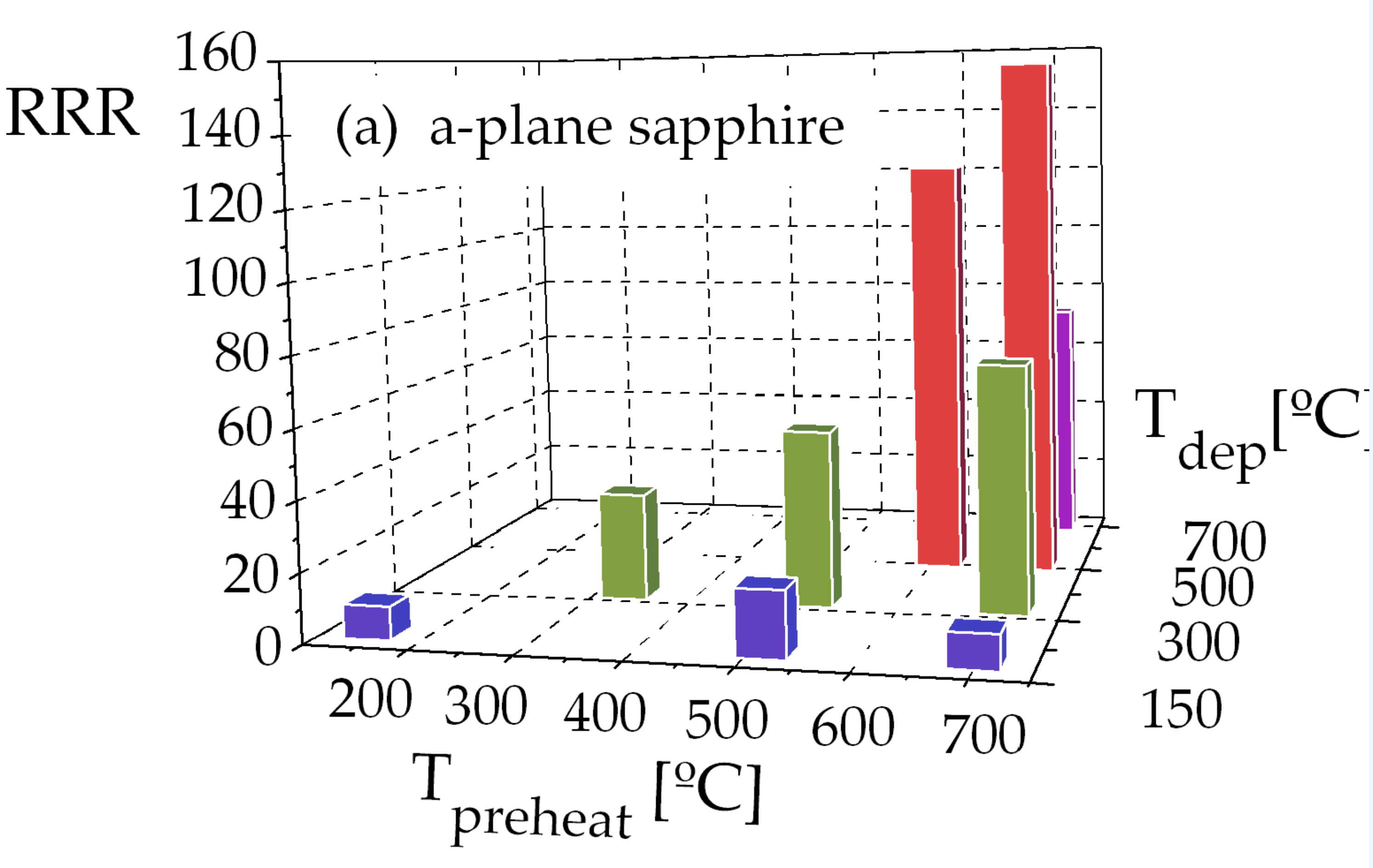
- Residual Resistance Ratio (RRR), defined as R_{300K}/R_{10K}, is a figure of merit for superconductors
- RRR is a 'normal' state measurement, but is related to the electron mean free path in the superconducting state
- bulk Nb cavities in superconducting RF accelerators show RRR~300 for high-Q, high field performance
- Over two decades of development, RRR in thin film Nb superconductors has slowly increased from ~10 to ~100
- Our recent work has pushed RRR in Nb thin films to >300, matching bulk Nb cavities



This could be a major breakthrough for thin film SRF

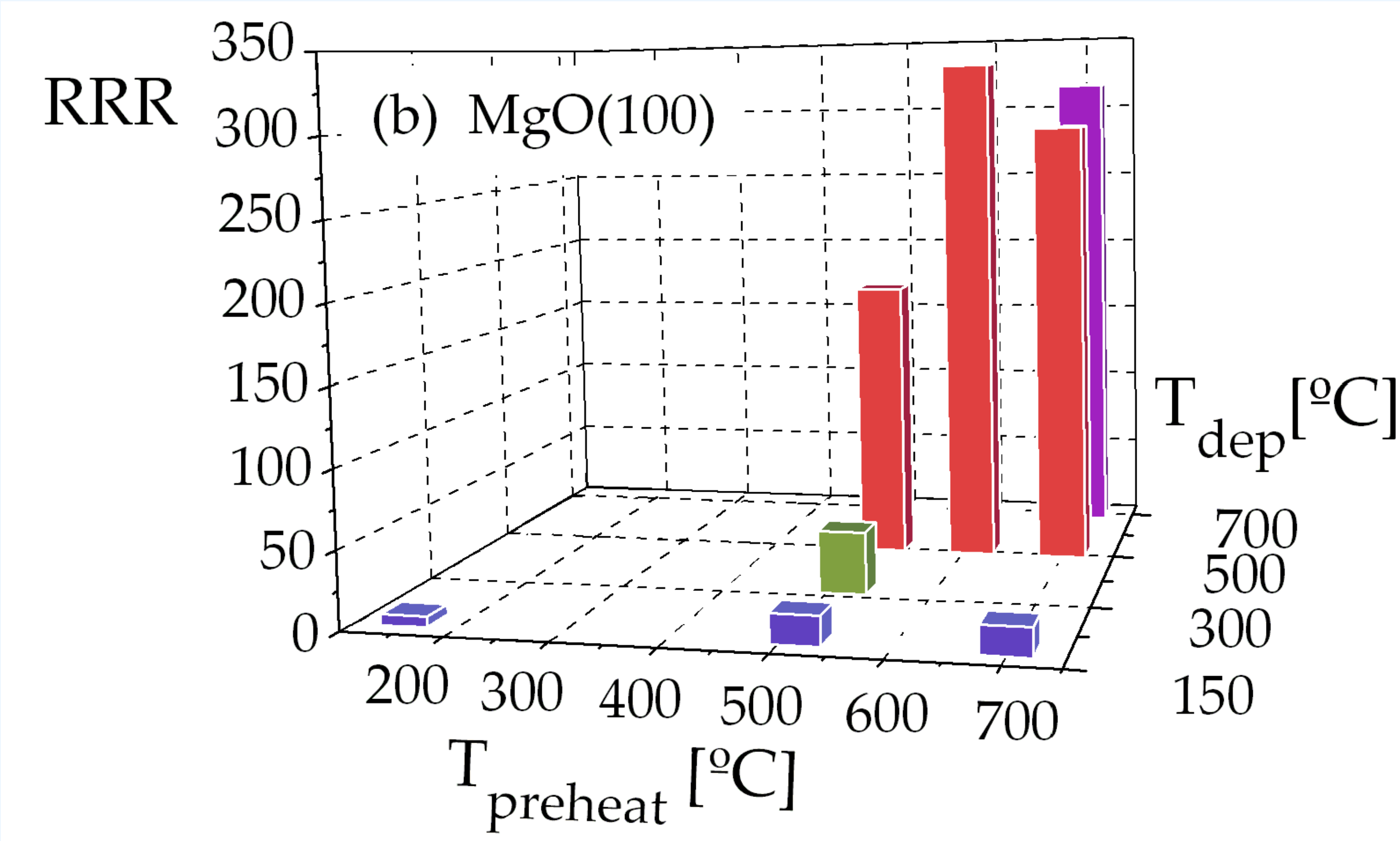
RRR of Nb thin films on a-sapphire

- Nb thin films grown on a-sapphire crystals have demonstrated record levels of Residual Resistance Ratio (RRR)

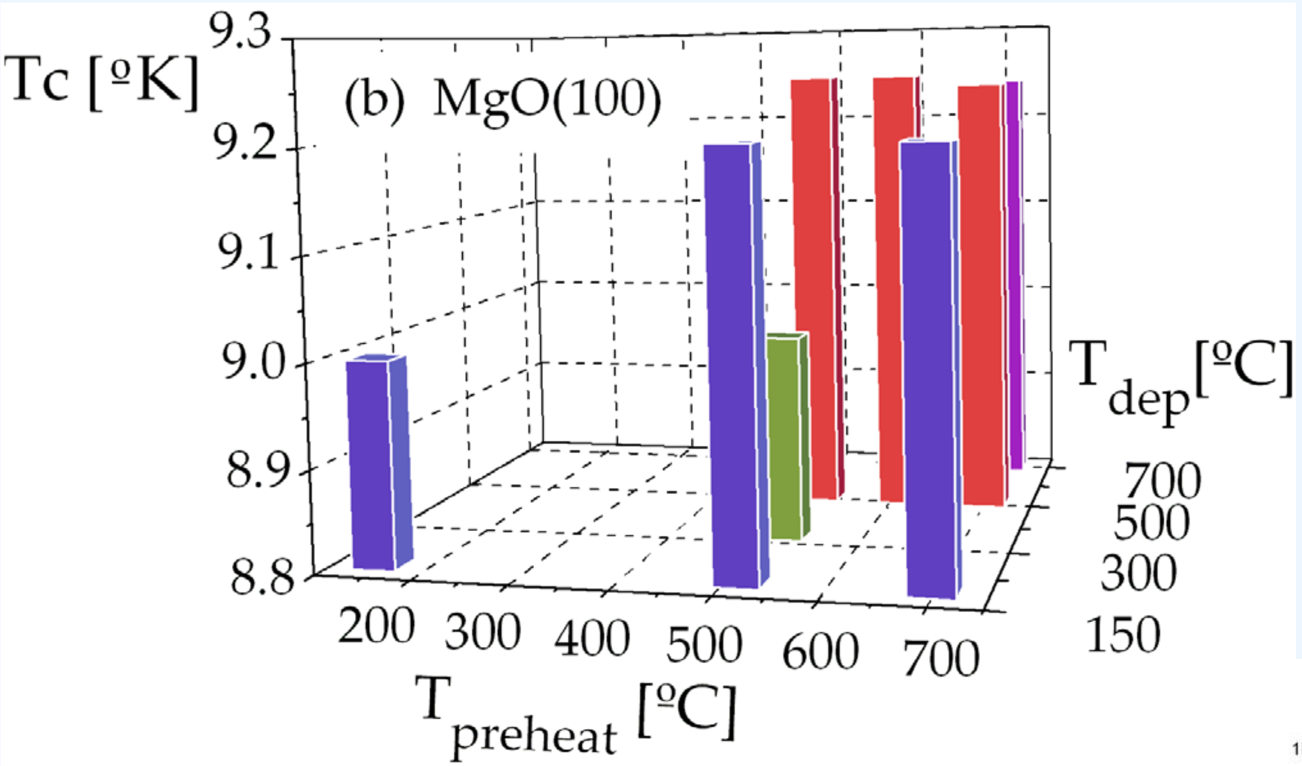


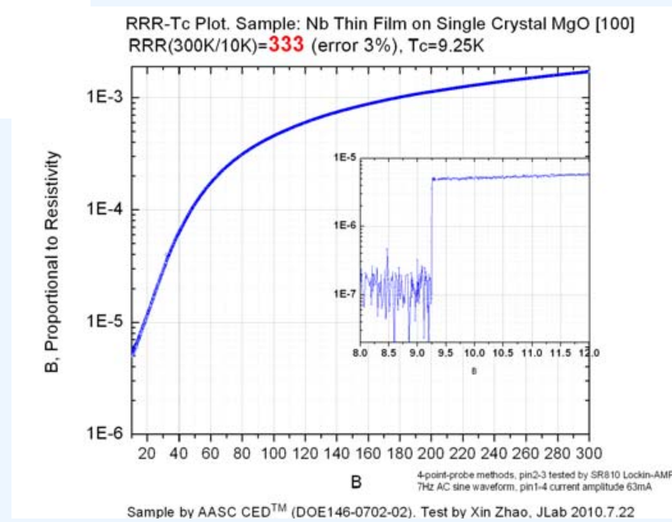
MgO gives the highest RRR ever measured in Nb thin films

- Historically, MgO has not been used for Nb film growth because its fcc structure has a 10.9% lattice mismatch for the bcc Nb [110] direction and 21.6% for the Nb [200] direction. We included MgO because its fcc structure was expected to better match to Cu



T_c vs. substrate heating conditions: MgO





Why is our RRR so high relative to other sources?

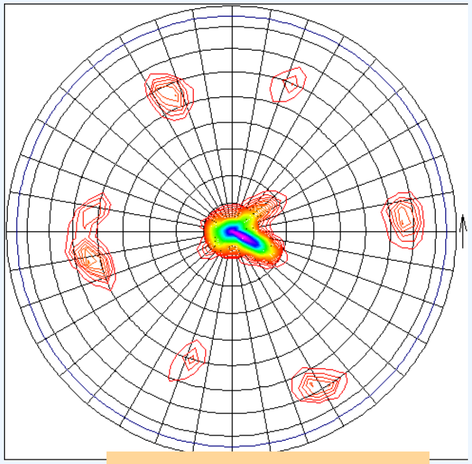
Reference	Method	RRR	Thickness	Sub. Temp. deg. C	Time /monolayer (s)	ratio	ion energy (eV)
Morohashi et la, Jpn. J. Appl. Phys. Vol 40(2001) pt. 1 No. 2A	e-beam evap	3	500 Å	850	15	7500	1
Rairden et al, patent #3,432,416. (1969)	Glow Disch. Sputt.	7	?	690	5	2500	1
Igarashi et al, J. App. Phys. 57 (3) 1 Feb (1985)	Vacuum Arc	44	2000 Å	550	6	3000	1
Russo et al, Proc. Of 10th Wrkshp on RF Superconductivity (Tsukuba, Japan, Sep. 2001)	DC Vacuum Arc	50	15000 Å	150	0.2	100	100
Wu et al, Thin Solid Films 489 (2005) 56-62, Elsevier pub.	ECR	50	2500 Å	?	1	500	120
A-M Valente at al, Proc. of PAC10, Kyoto, Japan, (2010)	ECR	71	2320 Å	>900	1	500	120
Langner J, et al, Czech. J. Phys. 54 (2004) C914	DC Vacuum Arc	80	15000 Å	125	0.15	75	100
Russo et al Supercond. Sci. Tech. 18 (2005) L41-L44	DC Vacuum Arc	80	10000 Å	125	0.2	100	100
Wolf et al, J. Vac. Sci. Technology A4 (3) (1986), p254	MBE	87	6000 Å	900	0.6	300	1
AASC, JLab and NSU (submitted to APL, 2010)	CED™	333	15000 Å	600	0.002	1	100

- RRR increases with substrate temperature, thickness and ion energy; dep. rate effect?

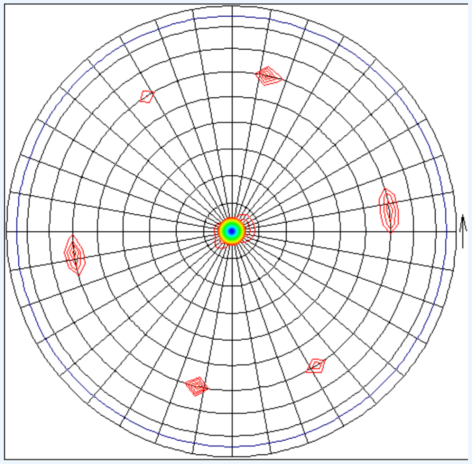
XRD measurements show hetero-epitaxial growth of single crystal Nb on a-sapphire and on MgO

Nb on a-sapphire thin films: crystal structure

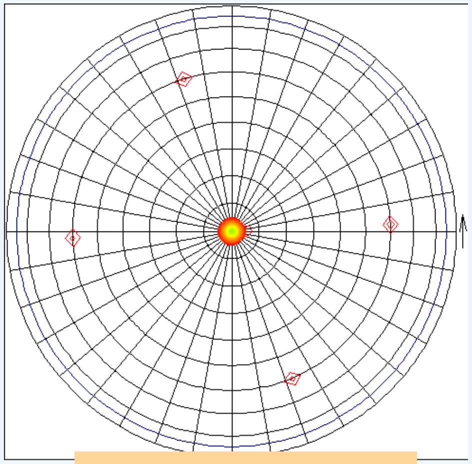
◆ XRD Pole figures and Bragg-Brentano spectra show improved crystal structure of Nb (110) on a-sapphire as temperature is increased



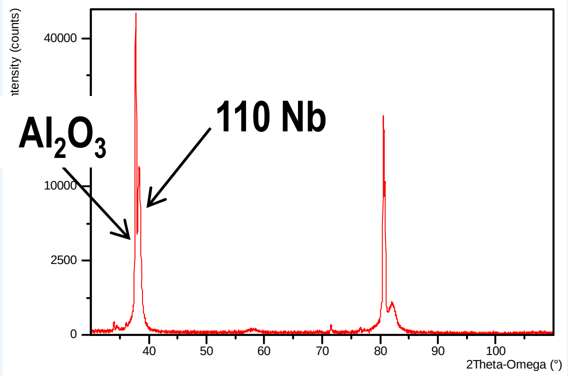
RRR=10, 150/150

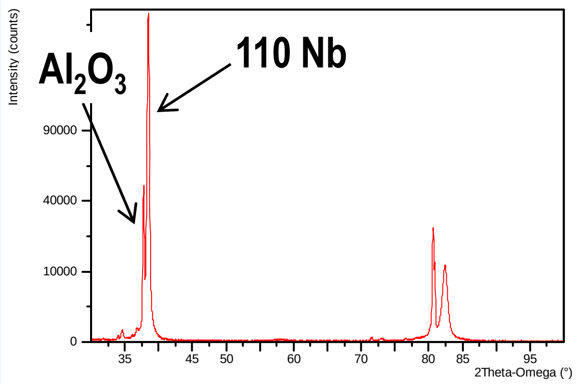


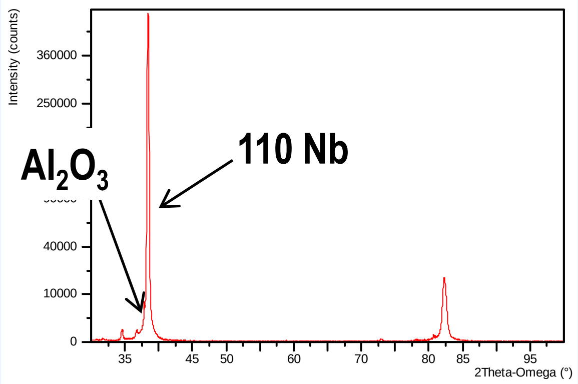
RRR=31, 300/300



RRR=155, 700/500



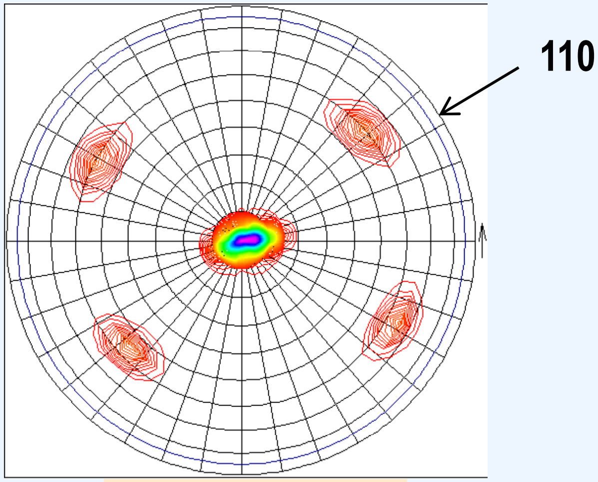




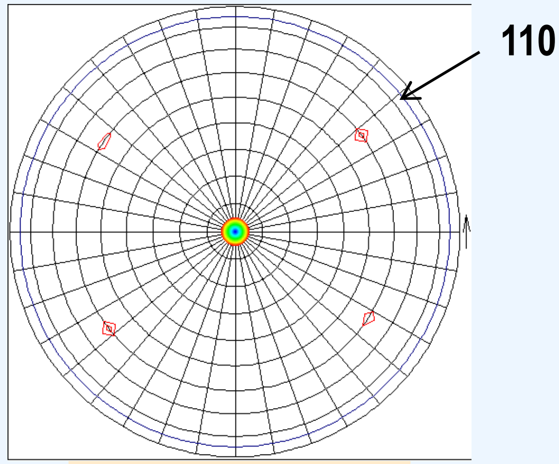
Hetero-epitaxial, single crystal growth is correlated with higher RRR

Nb on MgO thin films: crystal structure

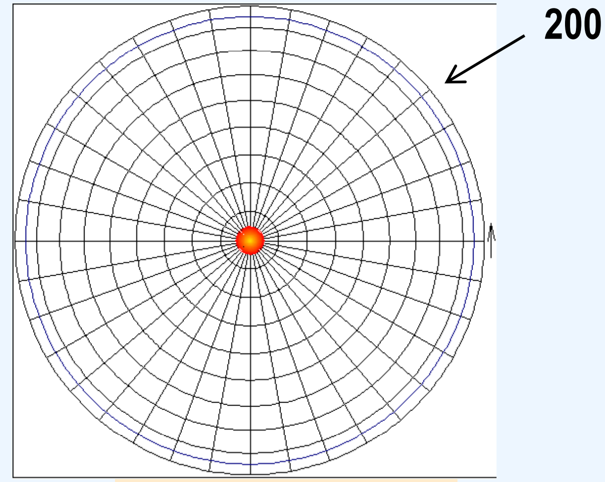
- XRD Pole figures and Bragg-Brentano spectra show change in crystal structure of Nb from (110) to (200) on MgO as temperature is increased



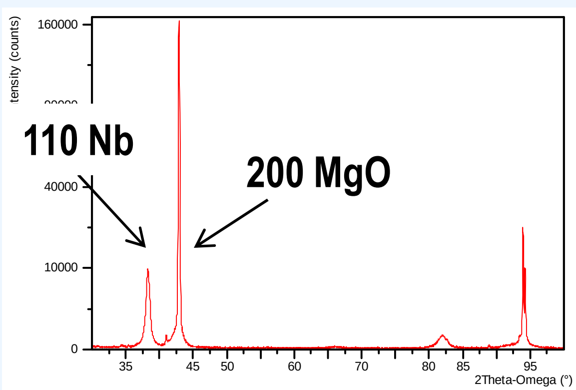
RRR=7, 150/150

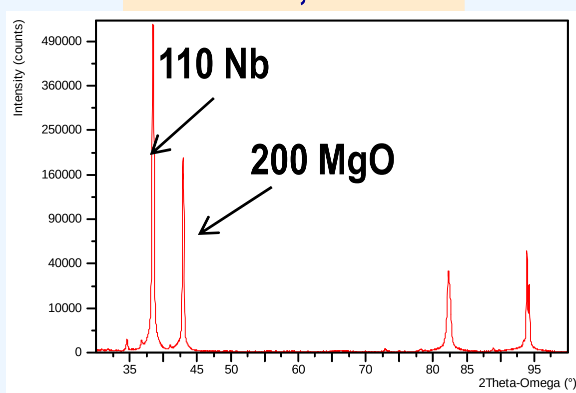


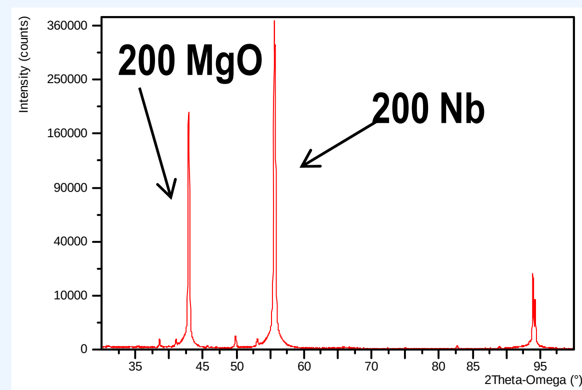
RRR=181, 500/500



RRR=316, 700/700



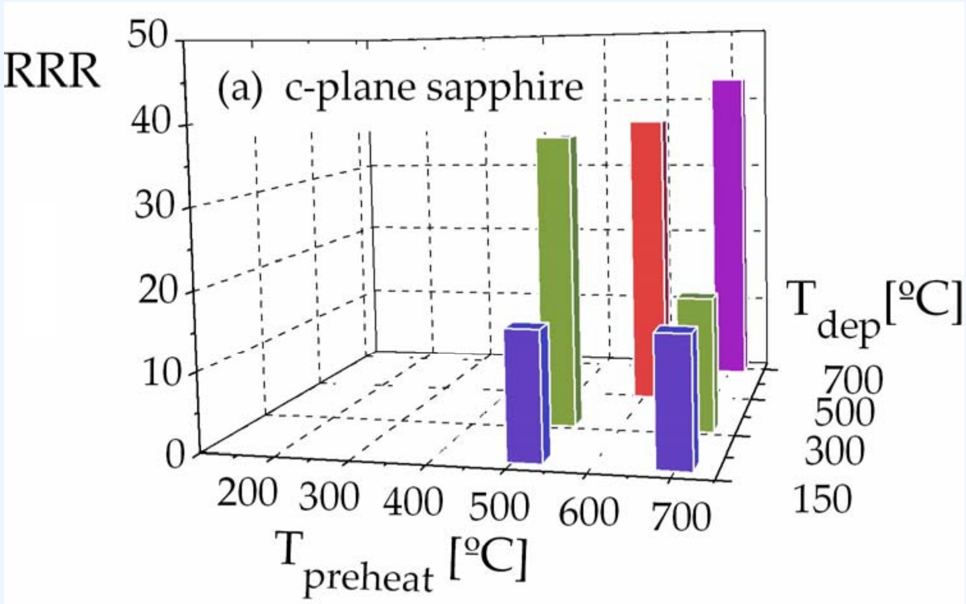


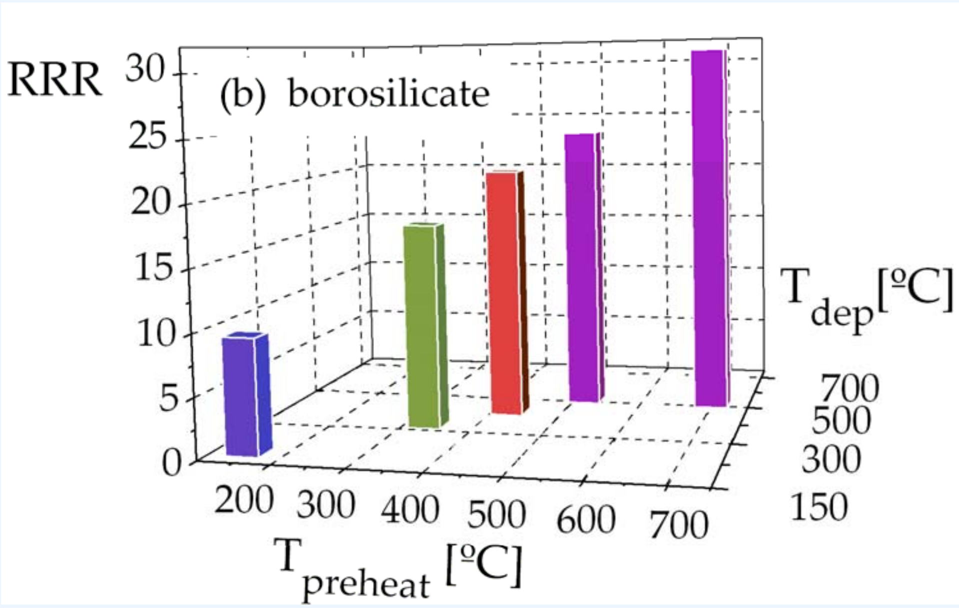


Nb crystal planes shift from 110 to 200 as temperature (& RRR)

Nb thin films grown on c-sapphire and on Borosilicate

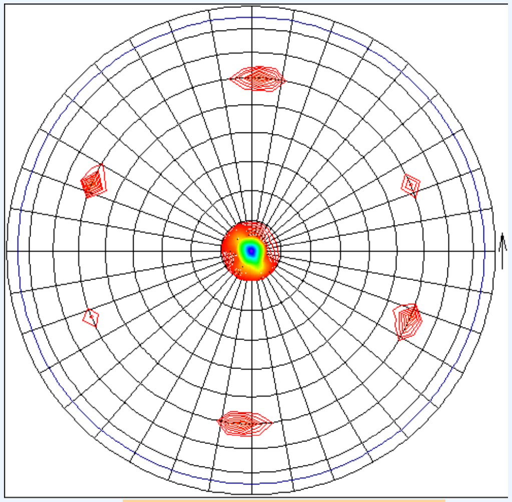
◆ Nb thin films grown on c-sapphire crystals and on amorphous borosilicate show a similar trend of higher RRR with higher substrate temperature



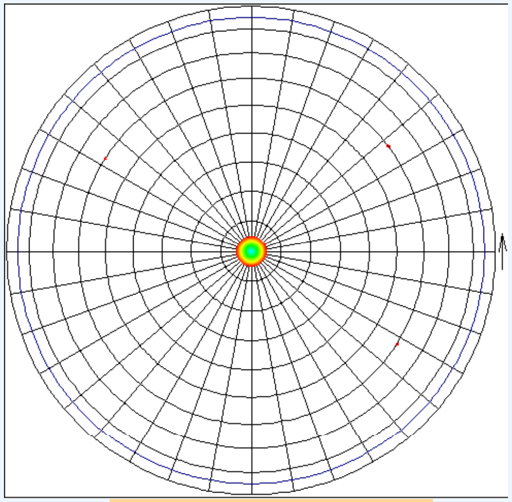


Nb thin films on c-sapphire: crystal structure

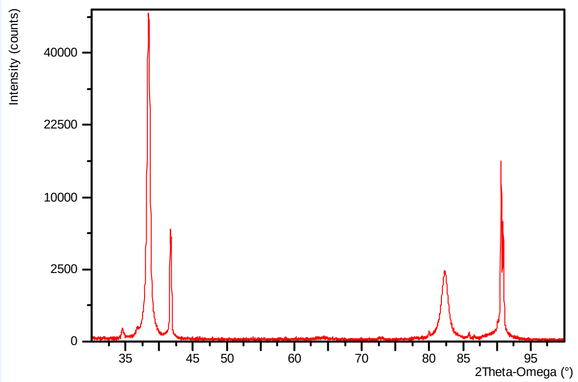
- XRD Pole figures and Bragg-Brentano spectra show change in crystal structure of Nb from textured (with twins) to hetero-epitaxial, as temperature is increased

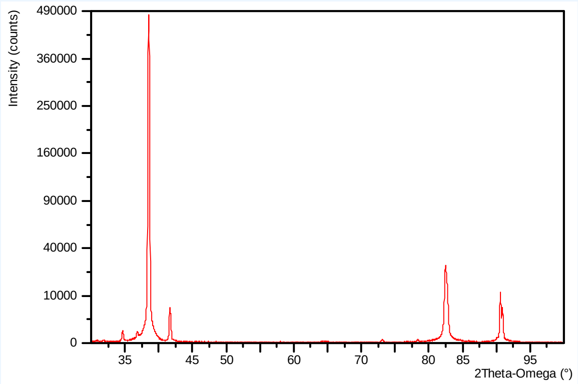


RRR=16, 700/150



RRR=43, 700/700





Textured structure (twins) disappears at higher temperature (RRR)

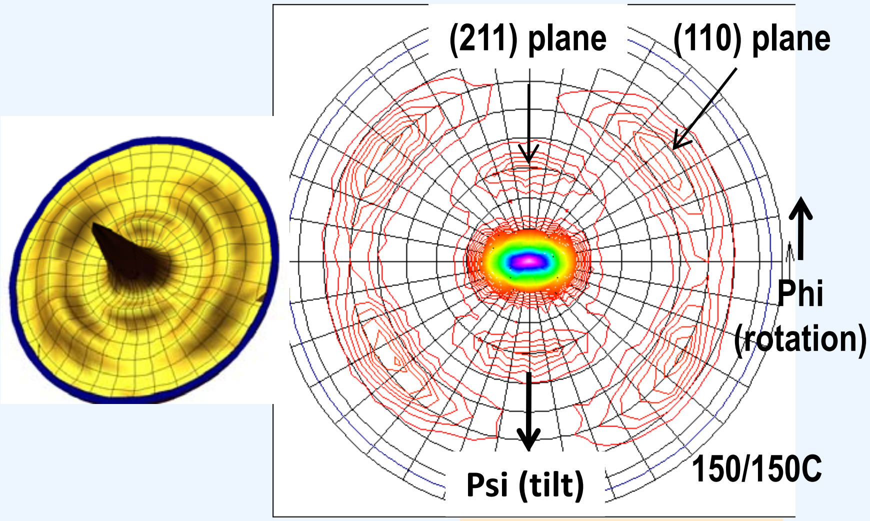
Nb crystals grown on amorphous borosilicate

XRD measurements show crystalline Nb with reduced texture grown on amorphous borosilicate

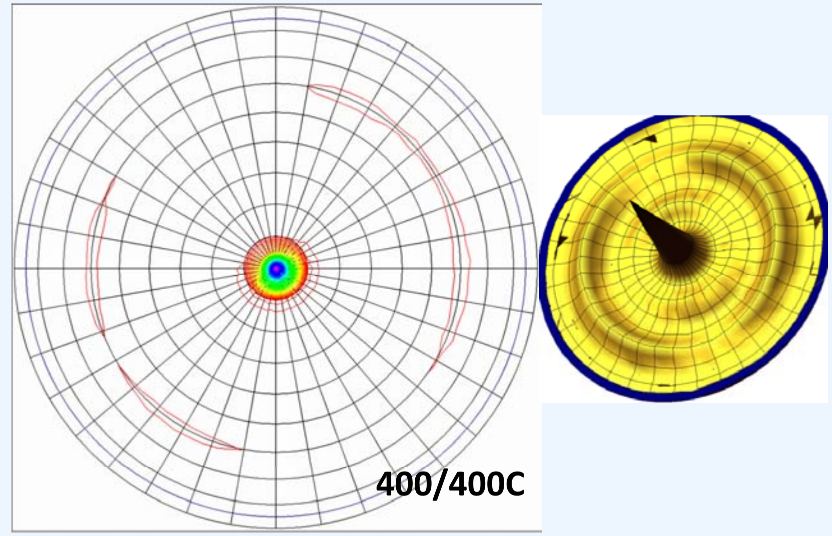
This opens the possibility of Nb superconductors on cast Al cavities of the future

Nb thin films on borosilicate: crystal structure

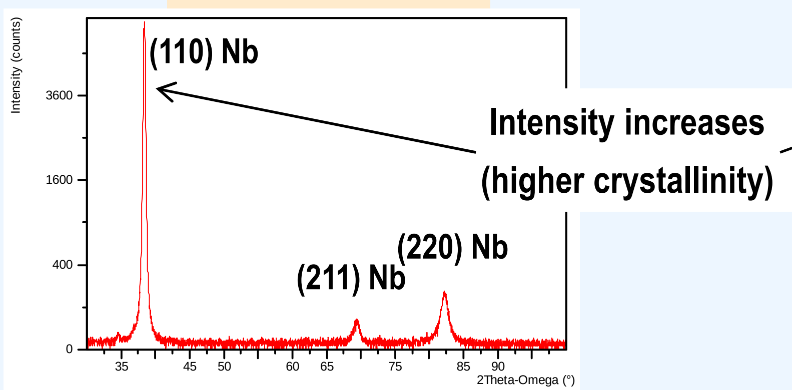
- XRD Pole figures and Bragg-Brentano spectra show improvement in crystal structure of Nb as temperature is increased

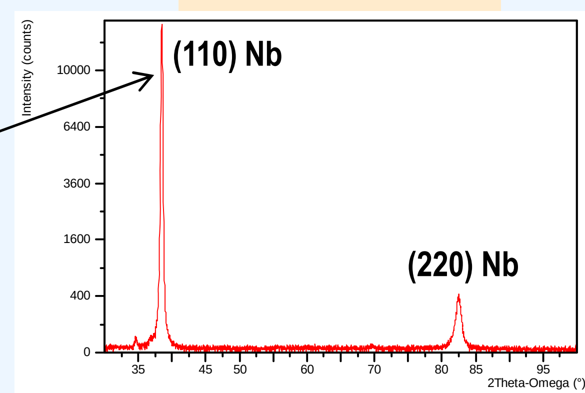


RRR=10, 150/150



RRR=21, 400/400

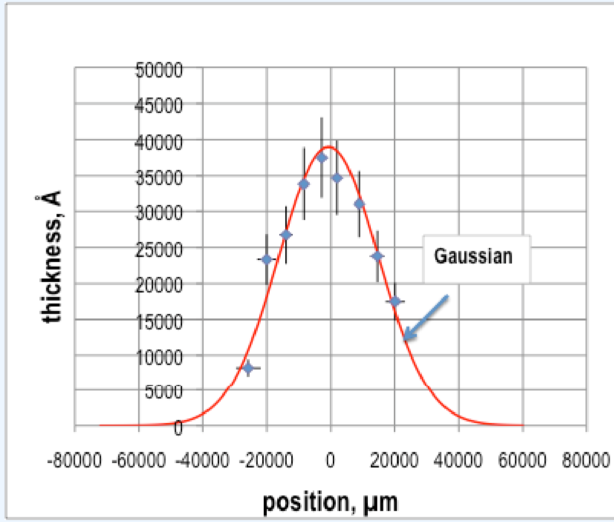




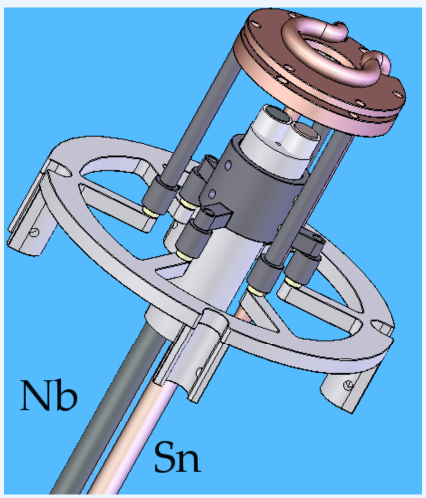
Nb crystal growth (low texture) despite amorphous substrate

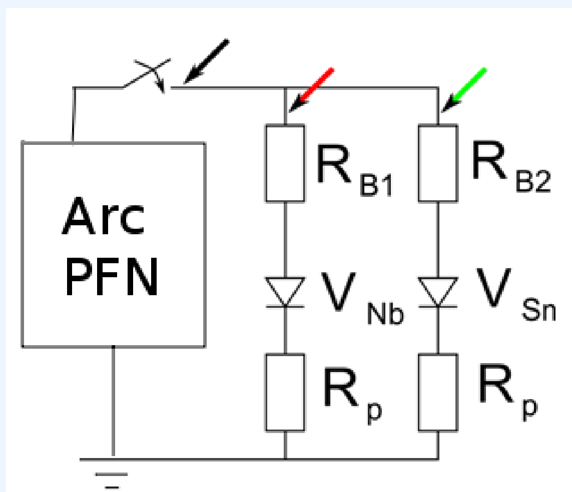
Initial results from CAD Coater

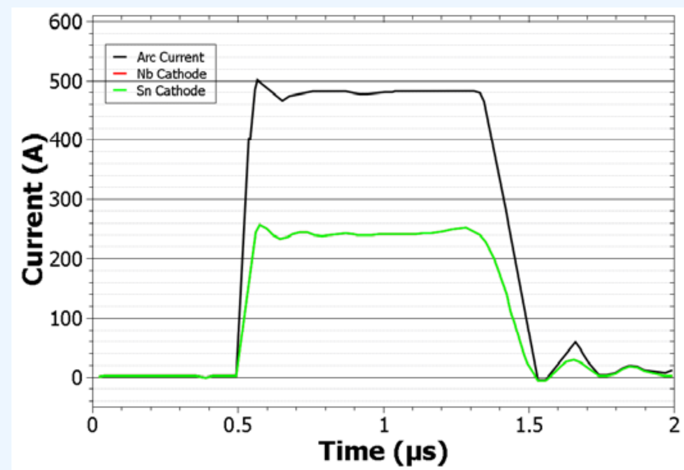
Cathodic Arc Deposition (CAD)



vol under gaussian=	0.012	cc
mass under gaussian=	0.100	g
mass/shot=	14.3	µg
charge/shot=	0.5	C
anode transm.=	0.7	
erosion rate=	41	µg/C
peak thickness/pulse=	5.6	Å
instant. rate=	5600	Å/s







- We aim to demonstrate single-step growth of Nb_3Sn superconducting films

The AASC/JLab/NSU team hopes to continue our methodical investigation of Nb, Nb_3Sn, MoRe and other thin film SRF candidates, culminating in high field cavity tests after better understanding