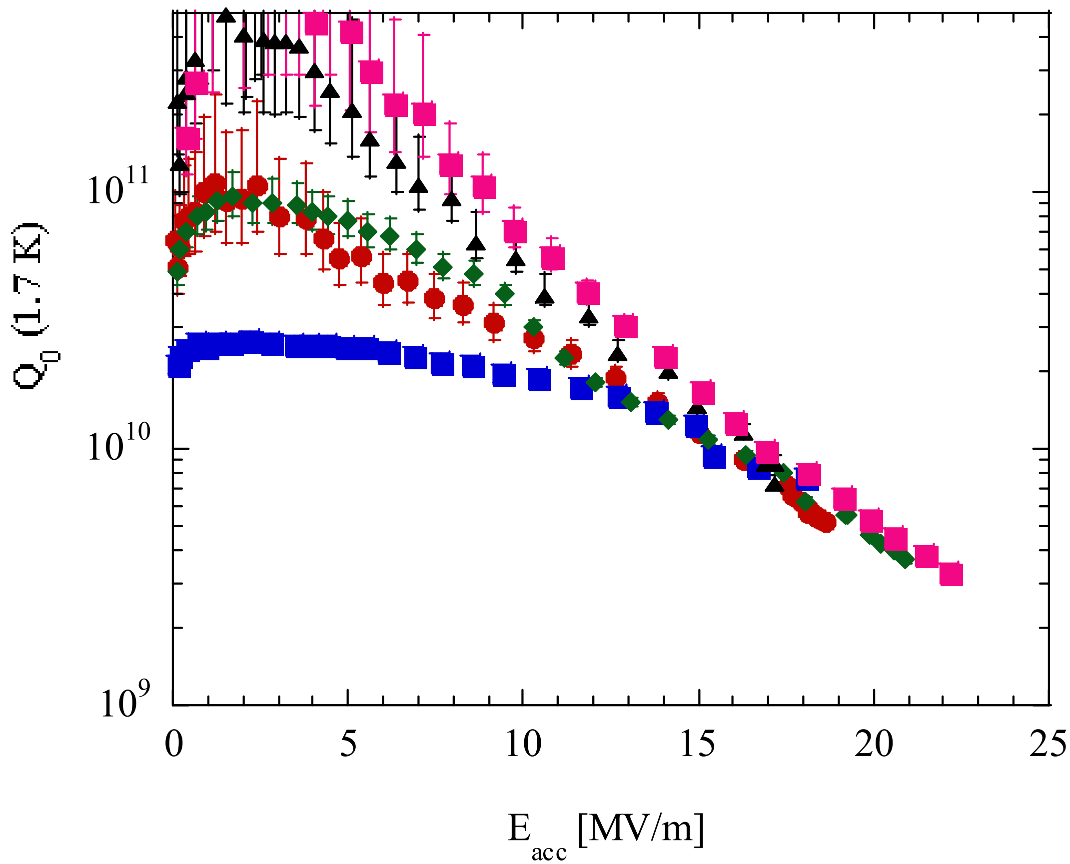
Thin Film Coatings for RF Superconductivity

G. Wu, H. L. Phillips

Jefferson Lab, VA, 23606

- Thin film coating activities in SRF laboratories.
- Current coating processes for niobium:
  The strength and the weakness.
- Alternative coating processes.
- Materials other than niobium.

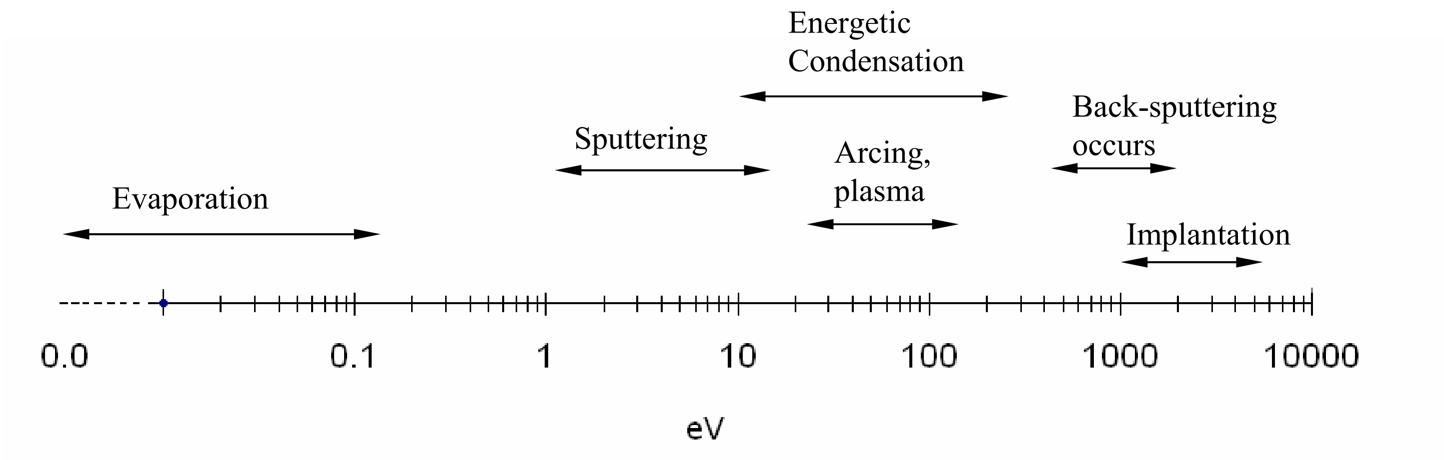
Q-drop seen in sputtered NbCu Cavities



CERN Report, Courtesy of A.-M. Valente

V. Abet-Engels, C. Benvenuti, S. Calatroni, P. Darriulat, M.A.Peck, A.-M. Valente, C.A. Van't Hof, NIM A 463 (2001)

Energetic Condensation (Deposition)



Thin film coating activities in SRF laboratories

- CERN, Nb/Cu Sputtering, biased Sputtering
- ACCEL/Cornell, Nb/Cu Sputtering, biased Sputtering
- INFN/Legnaro, new materials/varieties of processes
- Los Alamos, testing of MgB2
- Cornell/York, epitaxial magnetron sputtering
- Peking University, Nb/Cu Biased Sputtering
- Australia National University, PbSn/Cu
- INFN/Roma, Cathodic Arc Process
- Andrzej Soltan Institute, Cathodic Arc Process
- JLAB, Energy-Controlled ECR Plasma
- Alameda, Coaxial energetic arc deposition
- SANDIA, Pulsed ion ablation deposition

Physics Dept. at Cornell/York

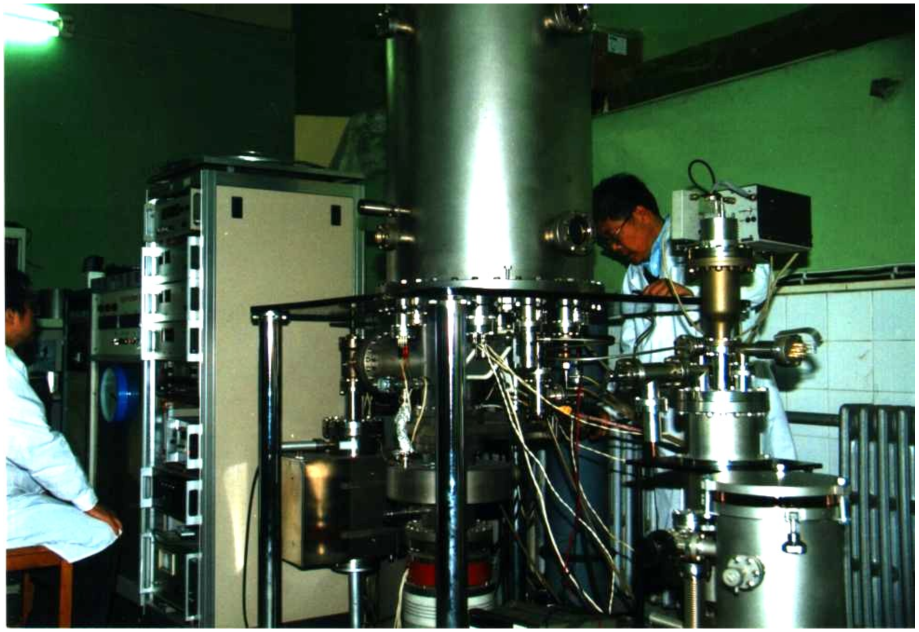
Magnetron Sputtering

L. Hand, W. Frisken

Sample	H_{c1}(1.9K) [Oe]	E_{av}[MeV/m]
Pure Nb[9]	1676	39.9
DESY	1653 +/- 70	39.4
CERN	1471 +/- 60	35.0
Film 19	1454 +/- 80	34.6
Film 30	1946 +/- 50	46.3

- Impurities need to be very low
- Smooth, oxidation free surface to preserve high H_{c1}
- Low grain density and defect free grains reduce vortex trapping.

Peking University



QWR Nb/Cu Cavity
for CIAE

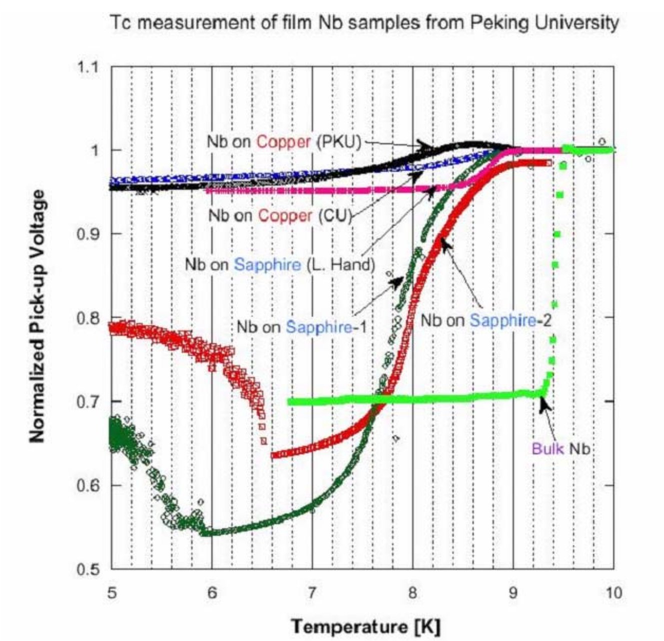
4-5MV/m at 4.2K
$Q_0 < 10^9$

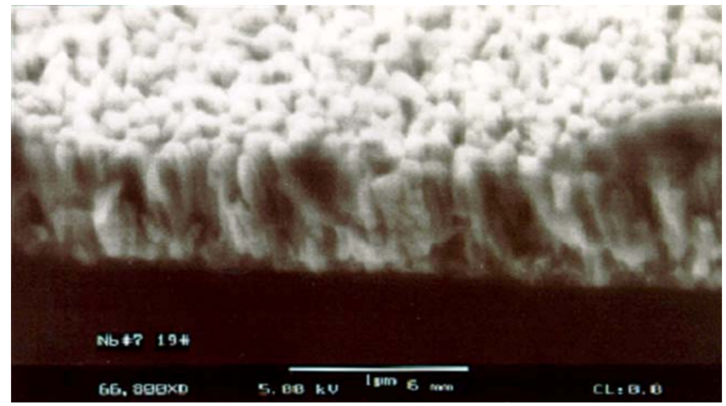
Nb Sputtering System,
three target capability

Peking University

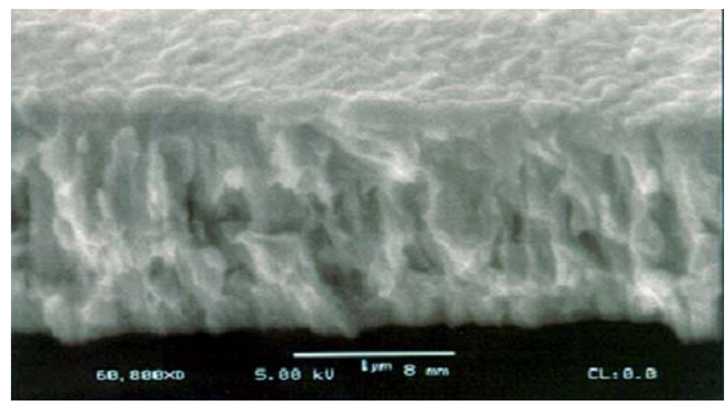
Biased Magnetron Sputtering

- Bias voltage was applied, with which the film structures are significantly improved.
- An intermediate layer of NbN was inserted, which was prepared by reactive sputtering.





No bias



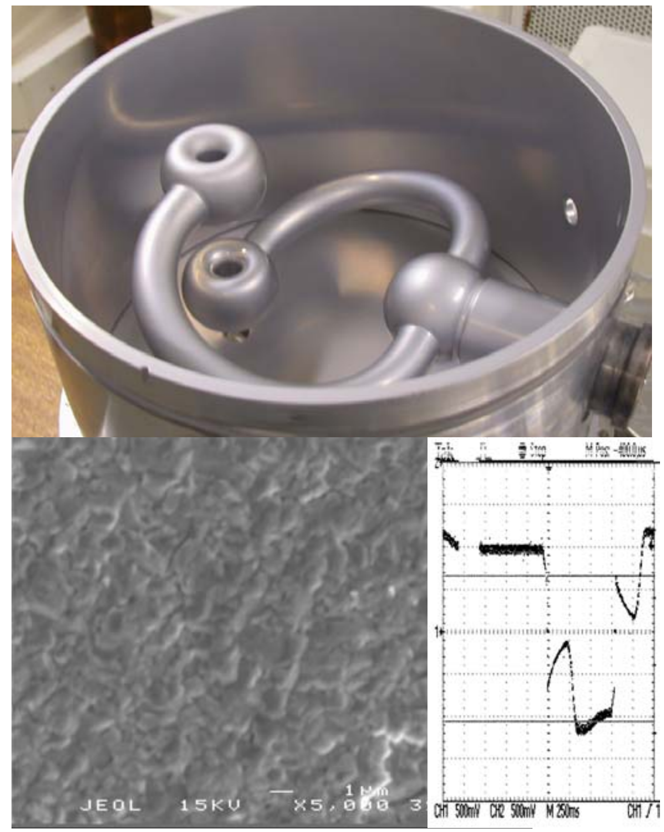
With bias

Australia National University

Electroplating

PbSn (96:4)

- Low cost oriented.
- H_{sh} = 1200 Oe
- E_{pk} = 19-21MV/m, limited by field emission

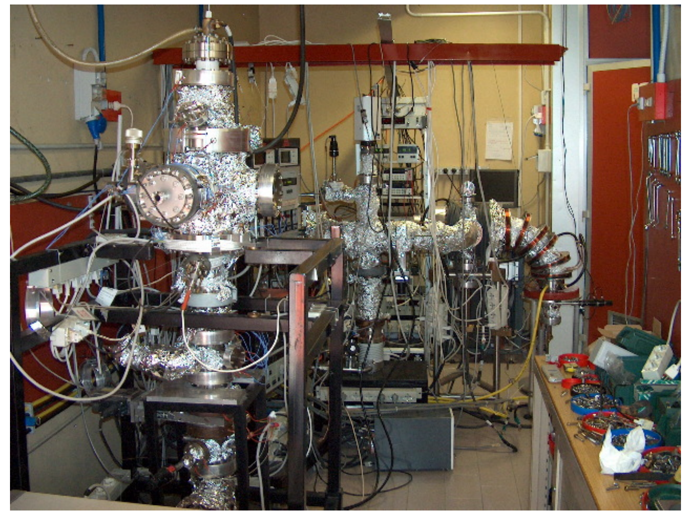


Solderon MSA plating solution for PbSn (96:4)

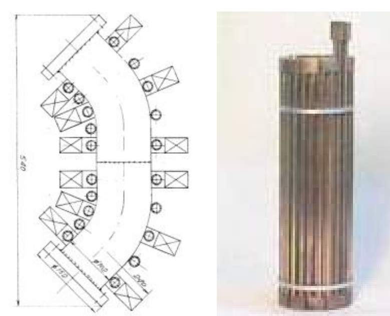
INFN/Roma and Andrzej Soltan Institute

Cathodic Arc Deposition

- No working gas (UHV)
- Ionized niobium (up to 95%)
- High ion energy (10-100eV)
- Excellent adhesion
- High purity
- Possible to apply bias and magnetic field
- Chemical process capable (i.e. NbN)



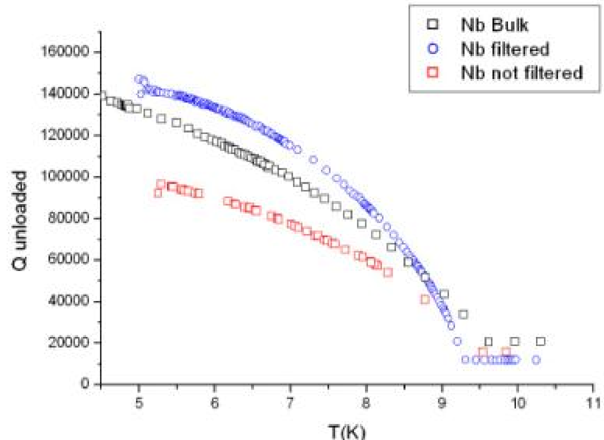
Linear, Planar arc systems



Macro particle filters

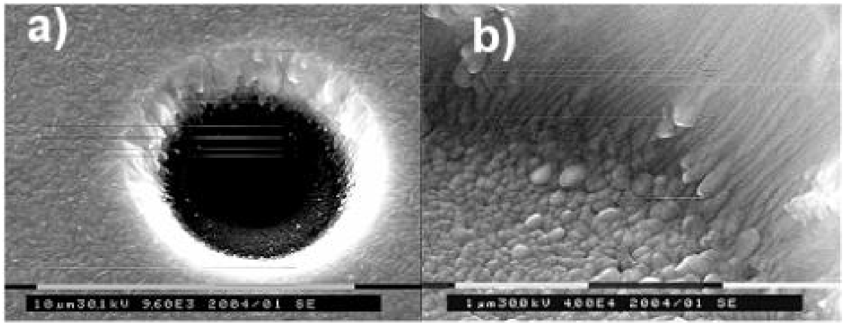
INFN/Roma and Andrzej Soltan Institute (cont.)

- RRR 20-100
- SC transition width comparable to bulk
- Low field Rs no worse than bulk
- Columnar growth but densely packed.



Q measurement implying Rs.

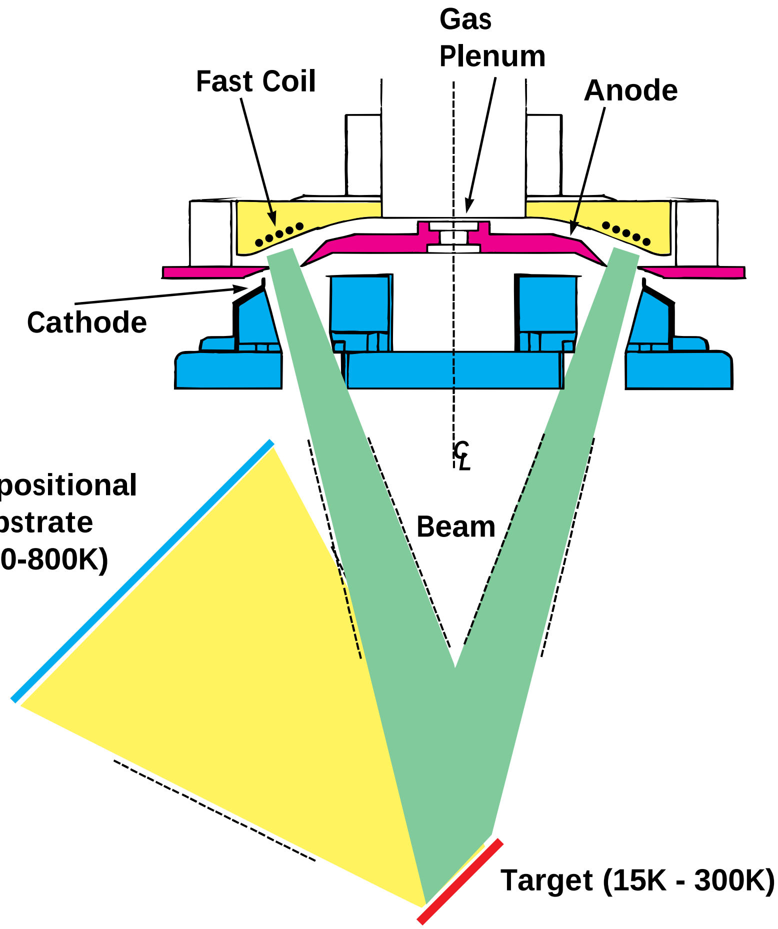
SEM pictures of film surface with/without macro particle filter



SEM pictures of film structure

SANDIA/JLab

Pulsed Ion Beam Ablation Deposition



- High-energy pulsed H/C ions (600 kV, 200 A/cm^2) vaporize and redeposit material. Target - substrate distance ~ 30 cm
- Congruent high-energy deposition of materials for optical coatings, hard-coatings, flat panel displays
- Unlike pulsed laser deposition, scalable to commercial applications
- Examples:
  - 1) fine-grain Er and Pt layers
  - 2) Rare-earth doped SiO_2
  - 3) YBCO and $BaTiO_3$ films
- Heatable/coolable targets and substrates

Alameda Applied Science Co./JLab

Coaxial Energetic Deposition (CED)

--A Vacuum arc process

- Trigger-less arc system
- Unique macro-particle filter
- Capable of compound material

Fig. 3. Picture of one of the CED deposition system at AASC.

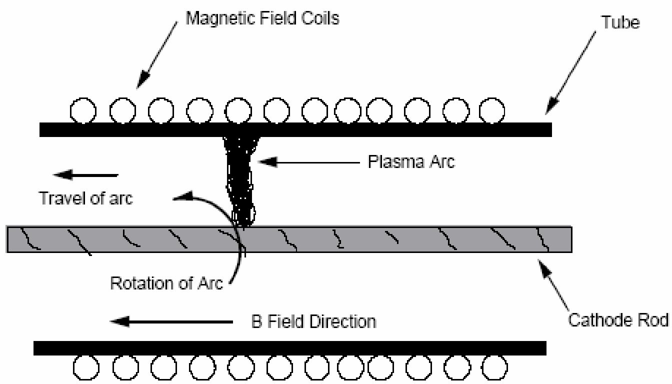


Fig. 1. Schematic drawing of CED setup with no filter or grid installed.

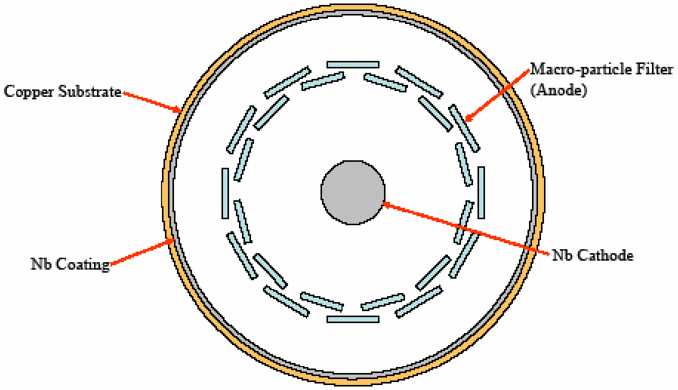
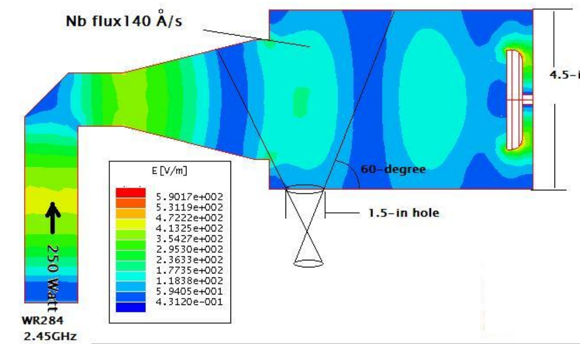


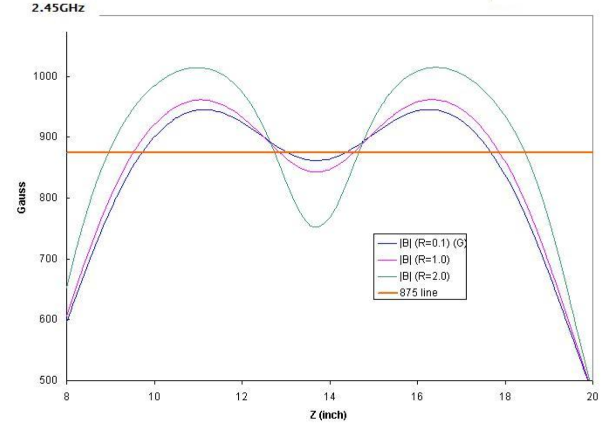
Figure 6. Schematic of CED macro-particle filter.

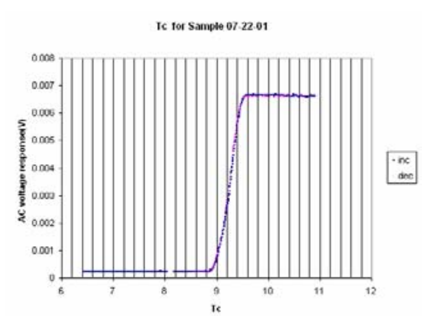
Jefferson Lab

Energy-Controlled ECR Plasma

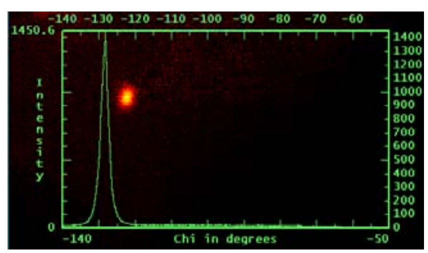
- Niobium Ion Energy is around 63 eV, and controllable.
- Deposition Energy of 114 eV yields better film quality for sapphire substrate.
- Epitaxial growth of niobium on sapphire
- Bias voltage affects Nb film crystal orientation





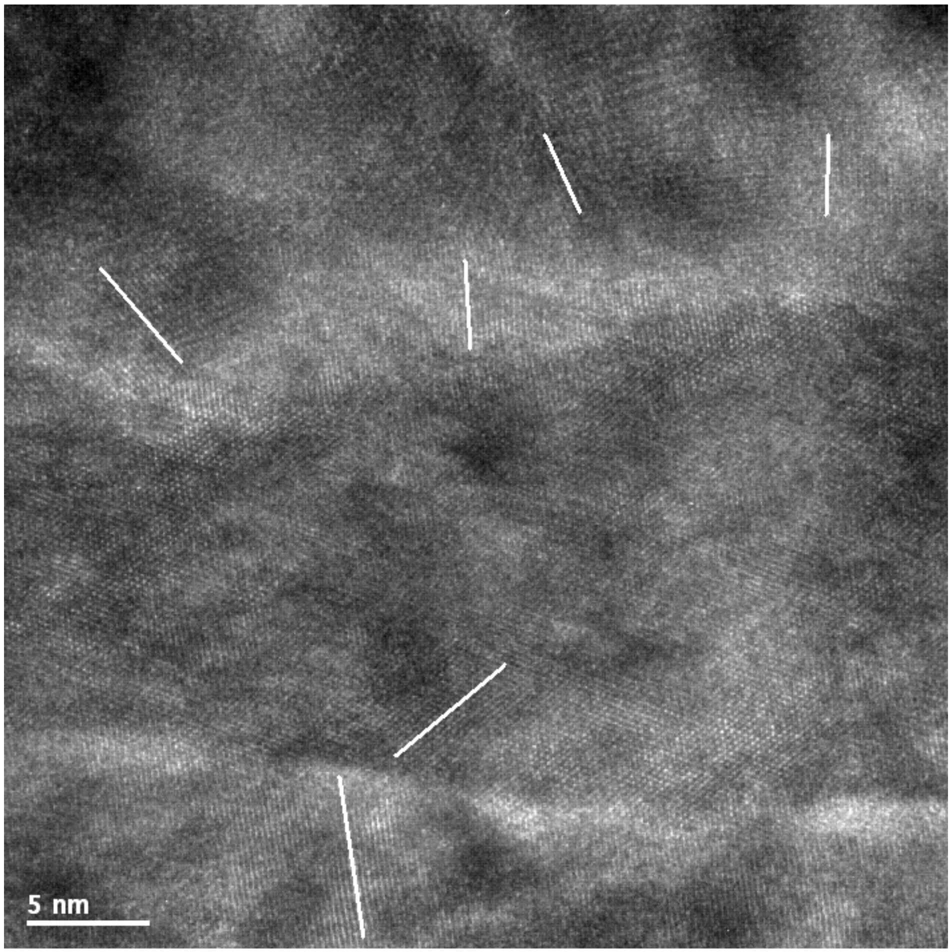


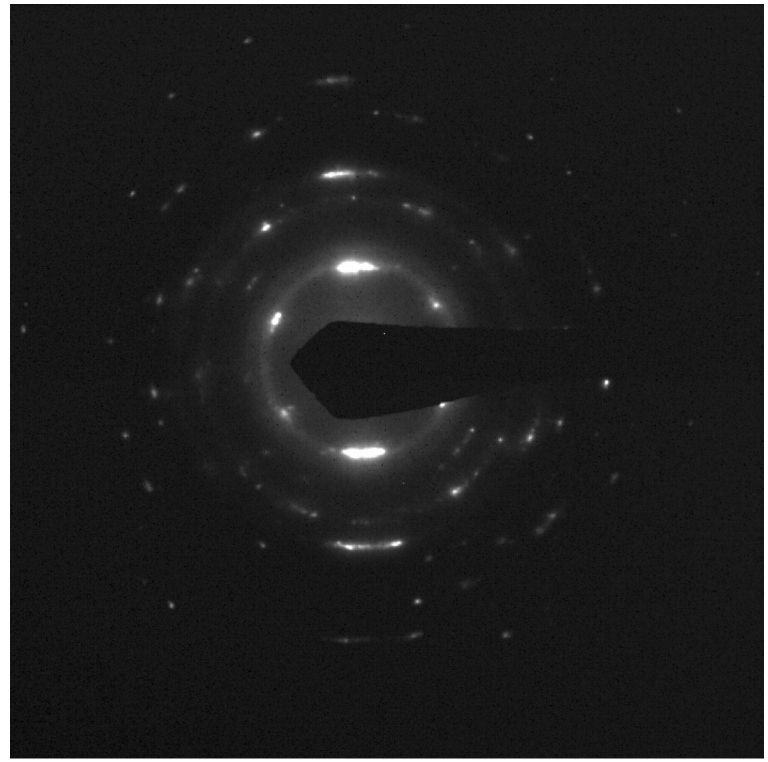
T_c



XRD

TEM cross section view – JLNB-CU-60

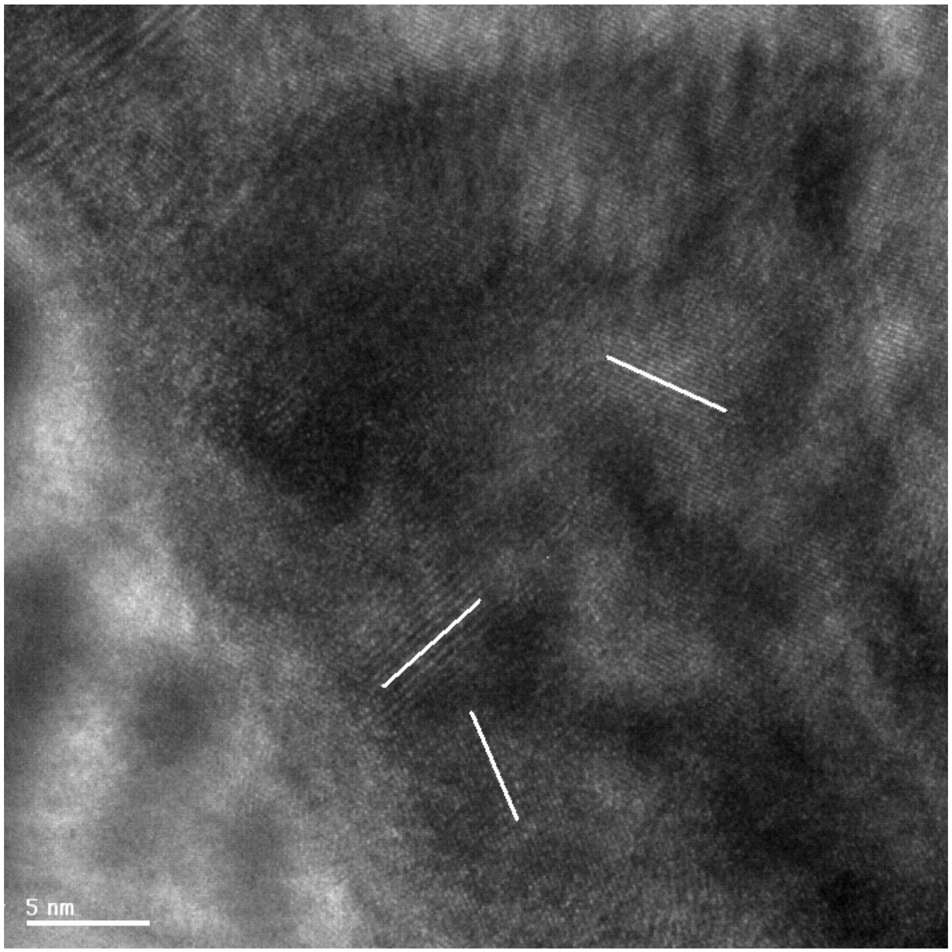


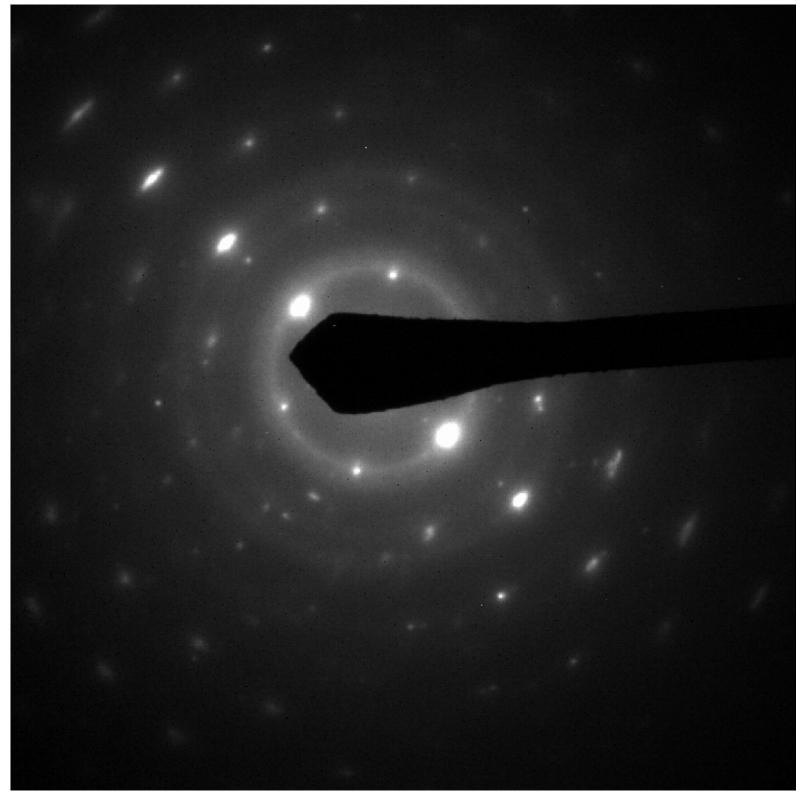


Electron diffraction pattern

Crystal orientation not very aligned.

TEM cross section view – JLNB-CU-70

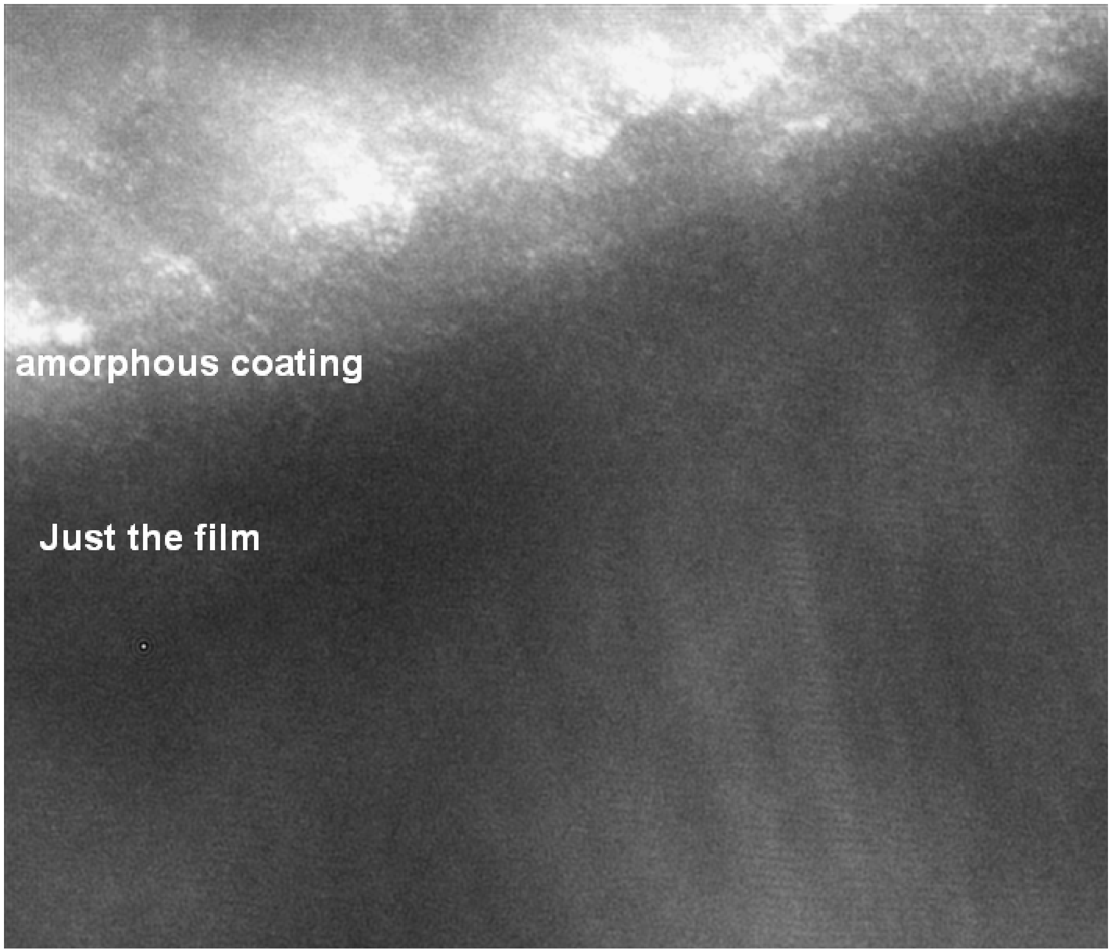


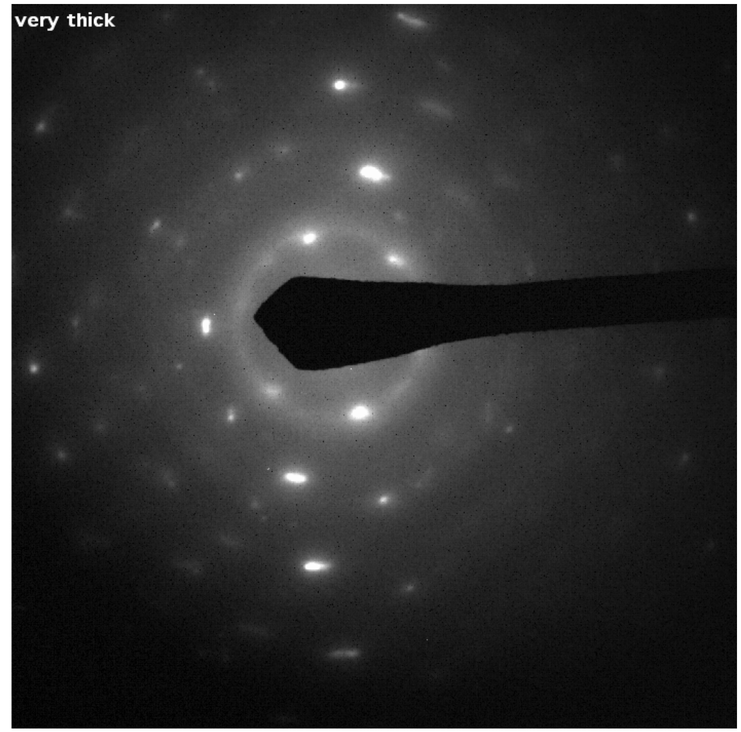


Electron diffraction pattern

Orientation aligned better than last one

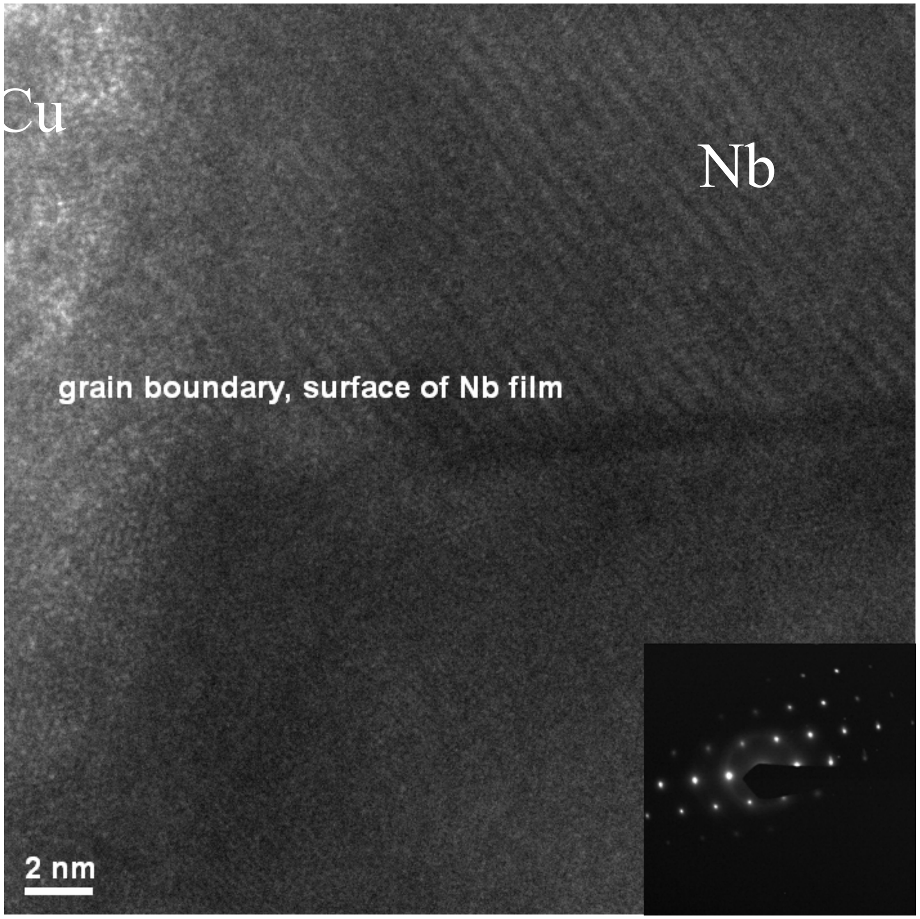
TEM cross section view – JLNB-CU-80

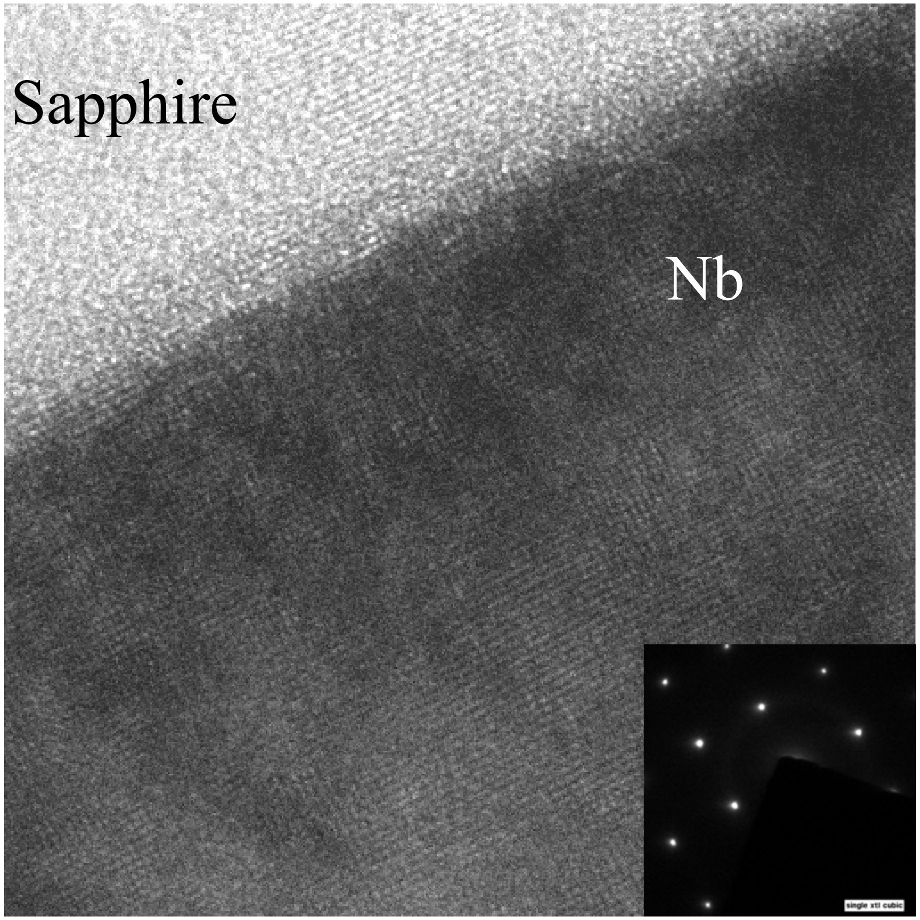




Electron diffraction pattern

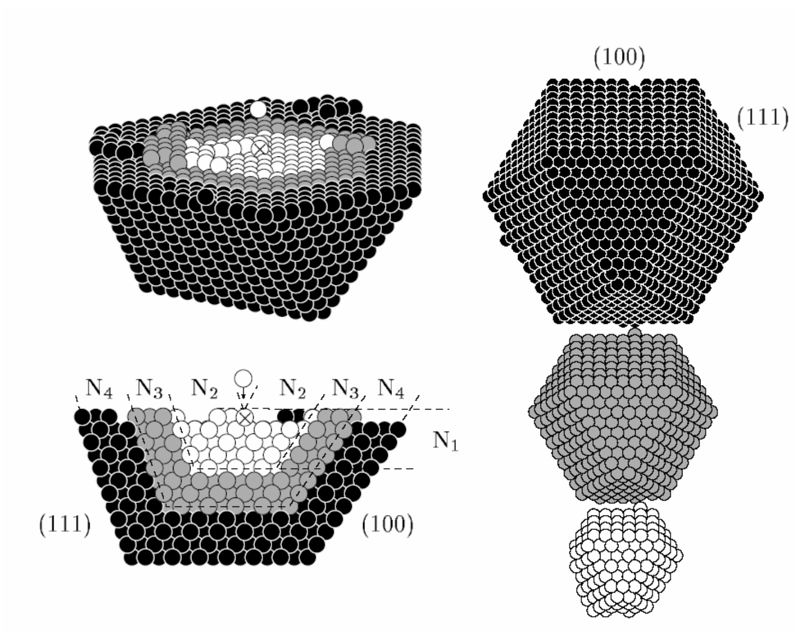
Jefferson Lab (cont.)



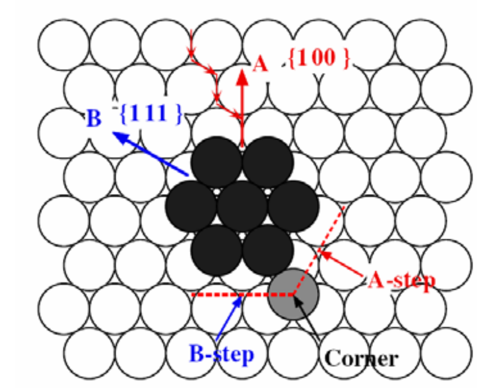


TEM cross section view with Electron diffraction pattern at corner

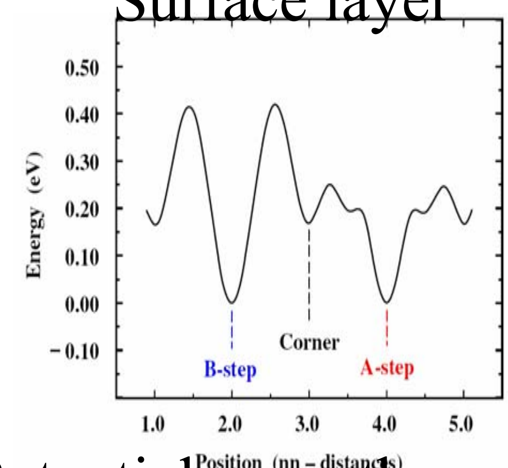
Some samples of the simulation by J. Pomeroy



A MD domain



Surface layer

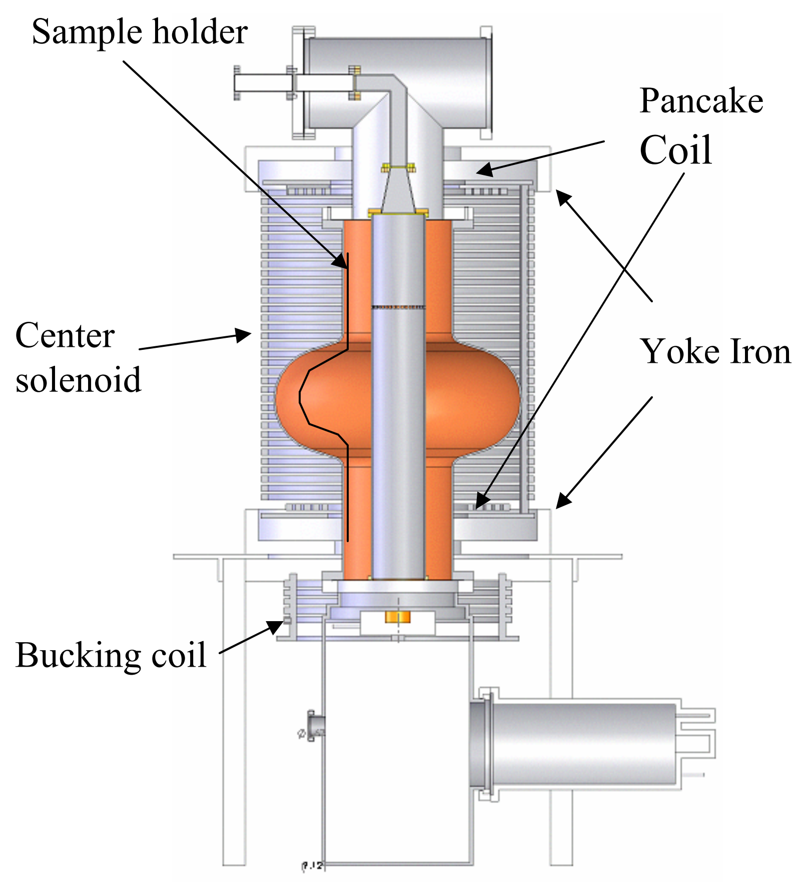


Potential cross the surface

Jefferson Lab/Cornell

- No working gas like argon
- High vacuum means reduced impurities
- Controllable “single” deposition energy,
- Near 90-degree deposition angle
- Excellent bonding
- No macro particles
- Faster rate (Conditional)
- Smooth surface (also shown in Cu hyperthermal deposition)

500MHz Deposition System



Jefferson Lab/Cornell (cont.)

Planned Explorative Studies: Nb_3Sn, MgB_2

- ECR plasma assisted
  - Serial process: Nb, then Sn
  - Parallel process: Nb, Sn within the same plasma
- MgB_2 : Similar processes?

	Nb	Nb_3Sn	MgB_2
T_c (K)	9.27	18	39
B_{sh} (Oe)	1800	4000 (or 1033?)	
R_s (nΩ) $_{4.2K}$	500	15	

Process(Nb) comparison

Table 1. Comparison of niobium films on sapphire by several coating processes

Coating process	T_c(K)	ΔT_c(K)	RRR ***	Crystallization measured by (X-ray diffraction)	Film structure by XTEM analysis
Magnetron Sputtering	9.5	0.3	5-10	Range from oriented to less oriented, depends on deposition angle.	Columnar growth Some voids present at high deposition angle
Biased Magnetron Sputtering	9.6	>1K	7-15	N/A	Columnar growth
Vacuum Arc deposition *	9.25	<0.02	20-100	Preferred orientation, other orientations exist	Columnar growth, densely packed
Energetic Vacuum deposition **	9.1	0.07	50	Perfectly oriented	Epitaxial in some films.

* T_c measured by different process
** Sample made at deposition energy around 123 eV on sapphire.
*** RRR as measured on sapphire substrate

Weakness

- Magnetron sputtering:impurity+low energy
- Arc deposition: macro-particle
- ECR plasma: thickness uniformity(maybe)

All: inappropriate for complex geometry, and more H than necessary

Alternative coating processes

Chemical Coating Processes

- Niobium compound
  - NbF_5 234 °C
  - $NbCl_5$ 250 °C
  - $NbBr_5$ 360 °C
  - $NbBr_3$ 400 °C
- Vapor phase
  - Chemical vapor deposition(CVD),
  - plasma-assisted CVD,
  - Photo-enhanced CVD,
  - Laser-assisted CVD.
- Liquid phase
  - Electroplating

Thin film materials other than niobium

- NbN, NbTiN, Nb3Sn
  - Cathodic arc
  - Magnetron sputtering
  - Vapor diffusion
  - Physical chemical vapor deposition
- MgB2
  - Pulsed laser deposition
  - Physical chemical vapor deposition
  - Ion beam ablation deposition
  - Electroplating
  - MBE

Thin film in next few years

- Niobium cavities from varieties of processes.
- Correlate surface physics with the superconducting properties, especially R_s
- Path to the high field Q-drop free coating should be clearer
- Alternative processes and material will likely emerge.

Acknowledgement

- S. Calatroni, CERN
- H. Padamsee, ACCEL/Cornell
- T. Tajima, Los Alamos
- L. Hand, Cornell/York
- K. Zhao, J. Hao, F. Zhu, Peking University
- N. Lobanov, Australia National University
- R. Russo, S.Tazzari, INFN/Roma, Andrzej Soltan Institute
- M. McFarland, A. Gehran, Alameda, Coaxial energetic arc deposition
- T. Renk, SANDIA, Pulsed ion ablation deposition