Energetic vacuum deposition of niobium thin film and beyond

Genfa Wu

- Introduction
- Sample deposition system
- Cavity deposition system prototype
- Surface characterization
- Beyond niobium

United We ~~Stand~~ Succeed

JLAB ECR thin film collaboration:

JLAB: L. Phillips, R. Rimmer, A-M. Valente,
H. Wang, A. Wu, G. Wu

Cornell: H. Padamsee (LEPP), L. Hand (Physics)

College of William and Mary: M. Kelley

SANDIA: T. Renk

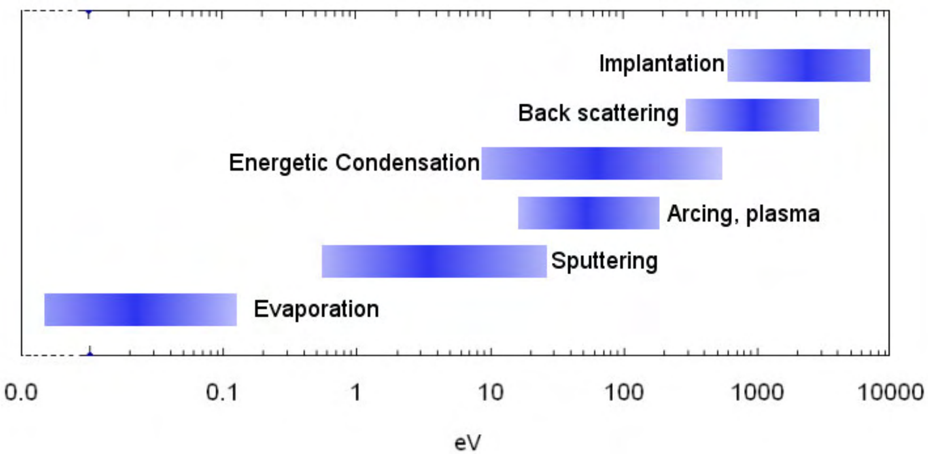
Black Laboratory: R. Crooks

ECR plasma deposition

"… a glow discharge can be established using only metal vapor but the discharge is very unstable and this method is generally not practical."

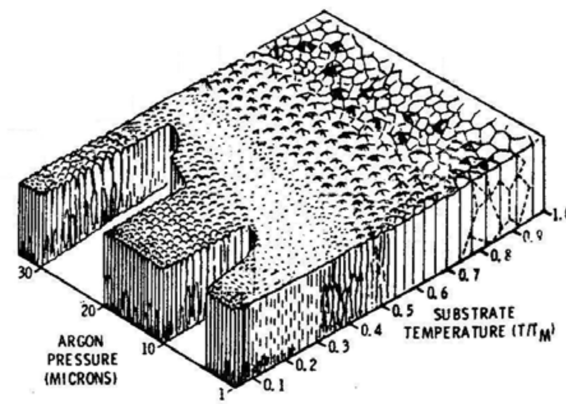
-- R. F. Bunshah, et., al., Deposition Technologies for Films and Coatings

Energetic deposition process



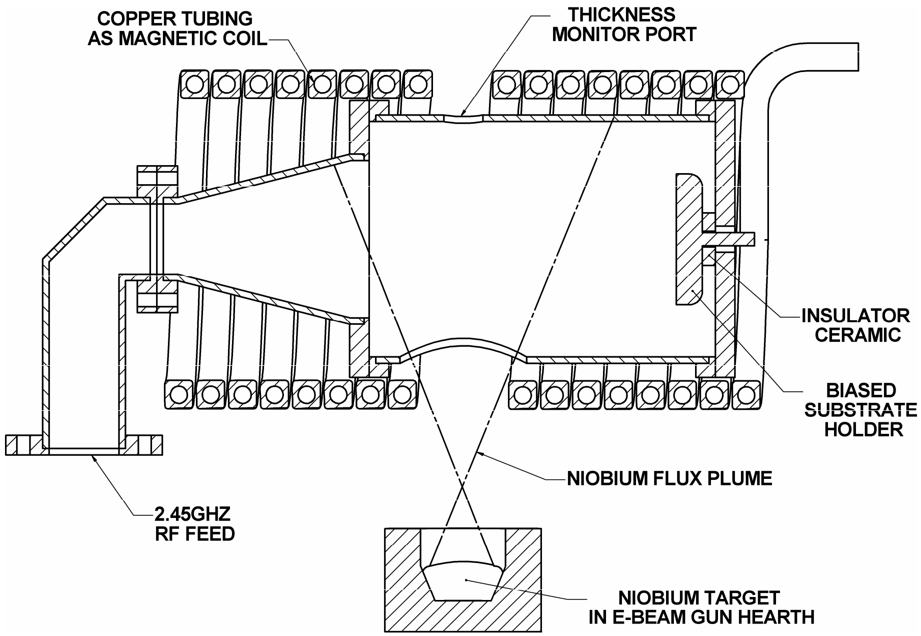
An illustration of approximate deposition energy is shown in above figure. Different materials will have different energy ranges.

<u>Movchan-Demchishin Zone Model (MDT)</u>



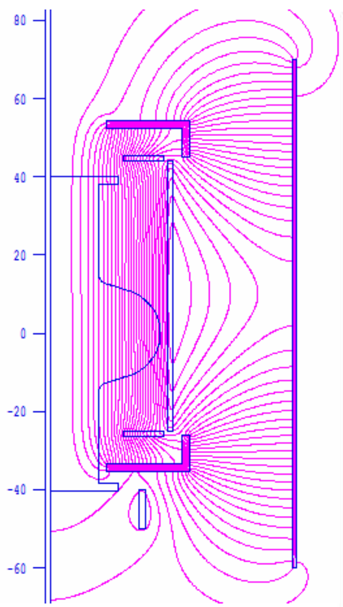
J. A. Thornton, JVST, Vol. 11, No. 4, (1974) p666

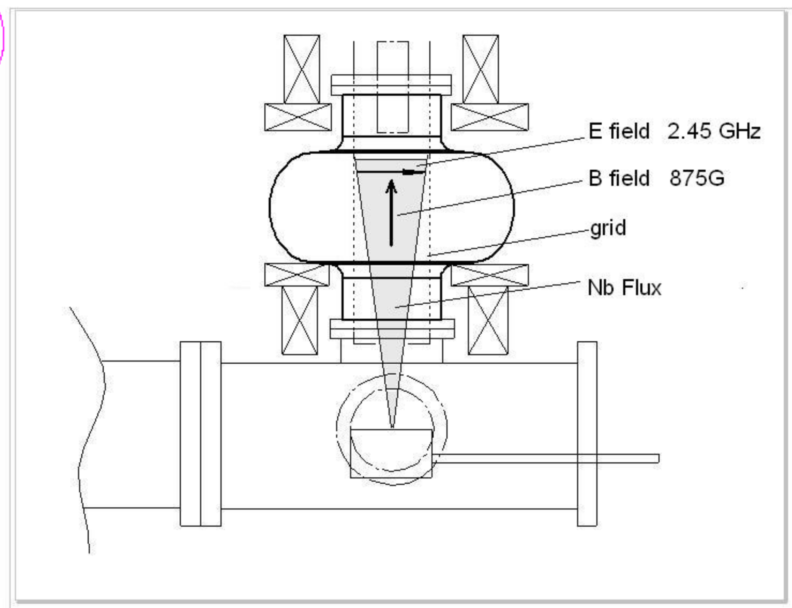
ECR plasma deposition

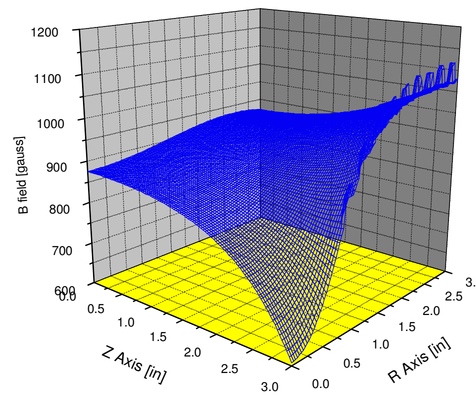


The illustration of the energetic vacuum deposition by ECR plasma

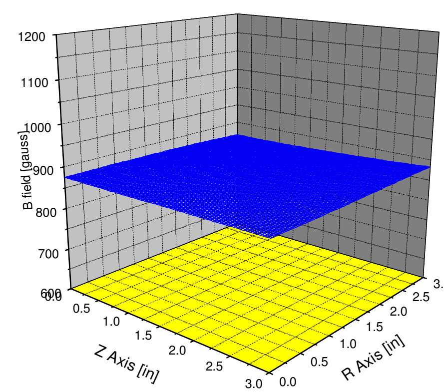
Cavity deposition prototype





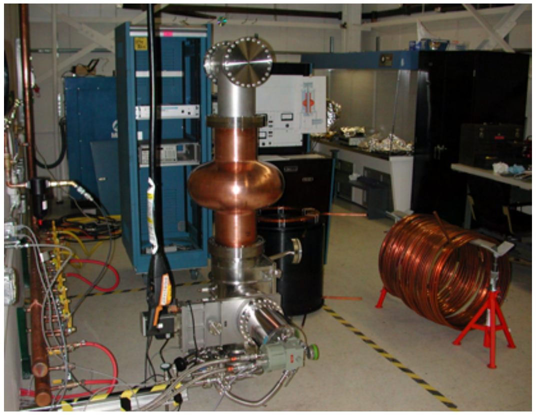


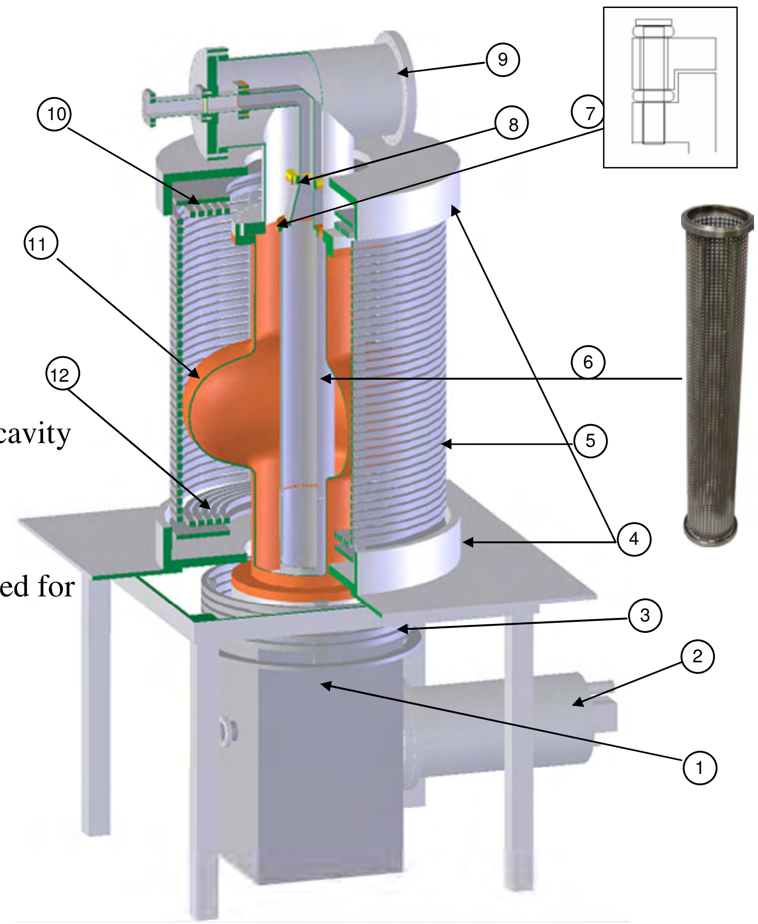
Sample deposition system 7.5kW hearth, 130 A/s



Cavity deposition system 15 kW Rod-fed, 100 A/s

Cavity deposition prototype

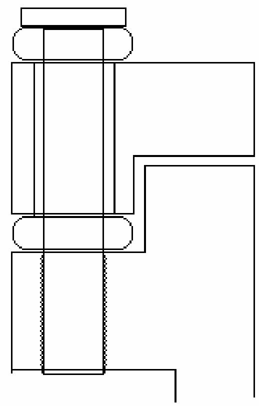


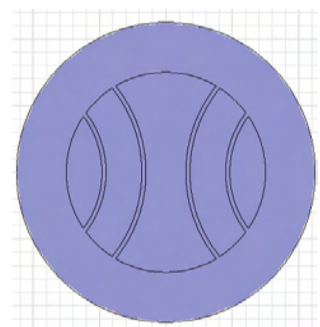


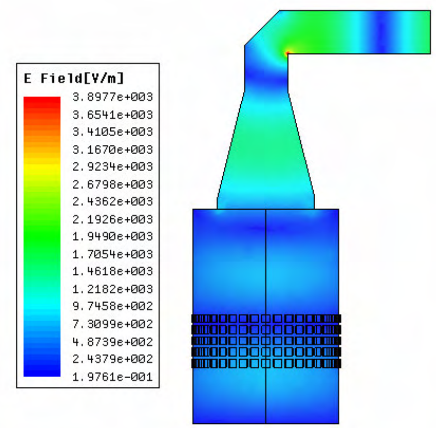
System design of the Nb thin film coating on a 500MHz Cu cavity

(1) 14kW rod-fed E-gun
(2) 9000 l/s cryopump system
(3) bucking coil for E-gun
(4) top and bottom iron yokes (outer iron shield is removed for illustration)
(5) center coils
(6) Nb grid tube
(7) bias insulator
(8) WR284 waveguide E-bend and horn to the grid tube
(9) "T" vacuum chamber
(10) top coil
(11) Cu cavity
(12) bottom coil.

RF radiation



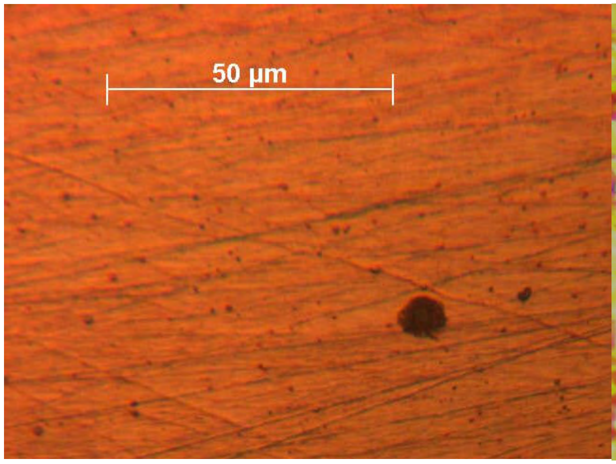


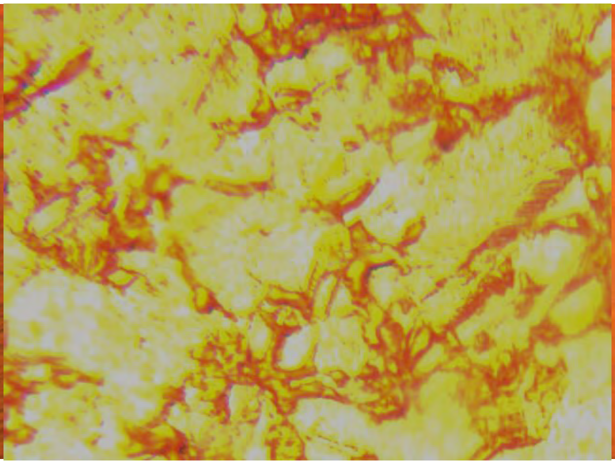


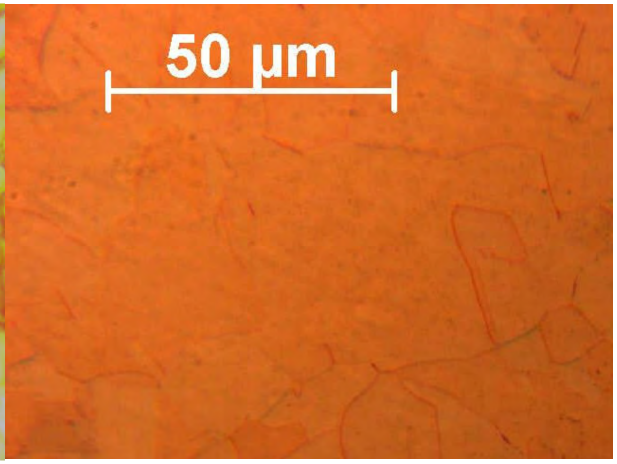
	Without plasma	With plasma
RF	Standing wave	Traveling wave
Insulator gap	0%	1.7%
Bottom opening	9%	0%
Grid radiation	2.9%	1.5%
Total	11.9%	3.2%

Table 1: Radiation contributions of the grid

Optical image of copper surface







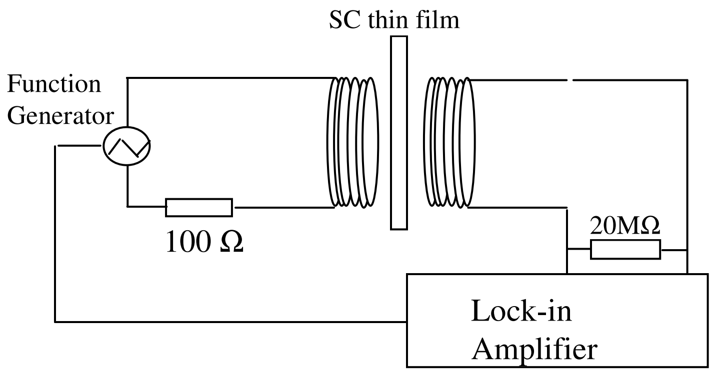
Mechanical polished 100 μm

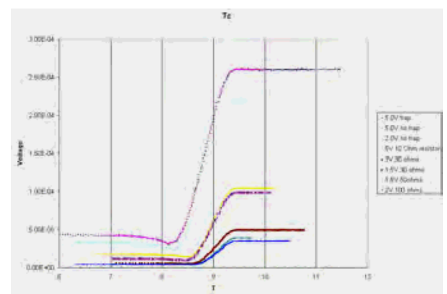
chemical polished 120 μm

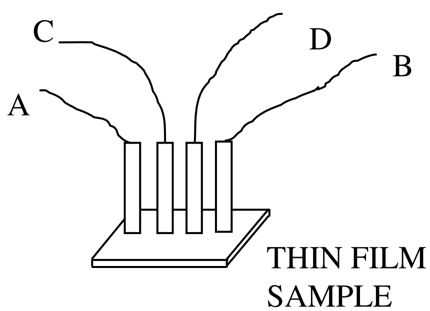
Electropolished 15 μm after chemical etching

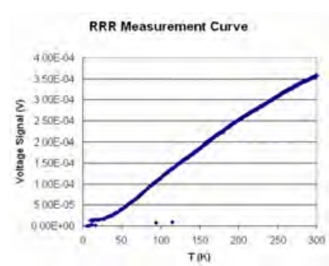
Surface from BCP/EP was wavy
Time consuming for Mech/EP

Low temperature Characterization

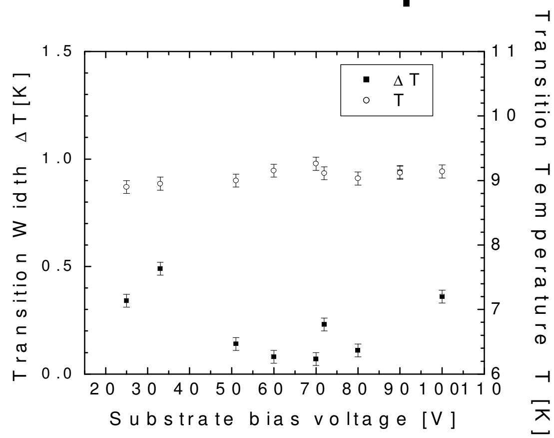


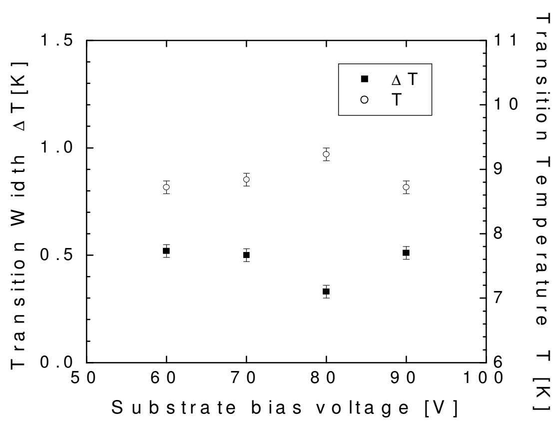






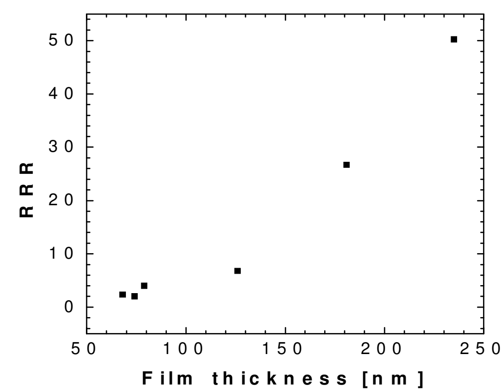
Transition temperature and RRR





Bias voltage effect on transition temperature and transition width, measured by an inductive method. Substrate is A-cut sapphire (left), Substrate is electropolished copper (right).

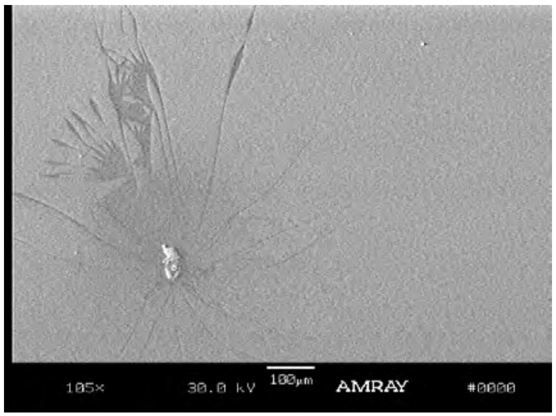
Film	RRR	Thickness (nm)	B_{c2} (4.2K)
02-SA-1	2.31	68.2	>1.5T
25-SA-3	6.8	126	>1.5T
51-SA-1	2	74.1	>1.5T
51-SA-3	50.2	235	0.96T
72-SA-5	26.7	181	1.28T
100-SA-1	4	79	



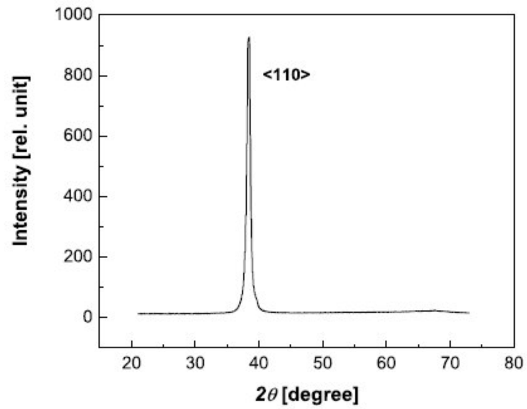
$T_c = (T_{90\%} + T_{10\%})/2$

$\Delta T_c = (T_{90\%} - T_{10\%})/2$

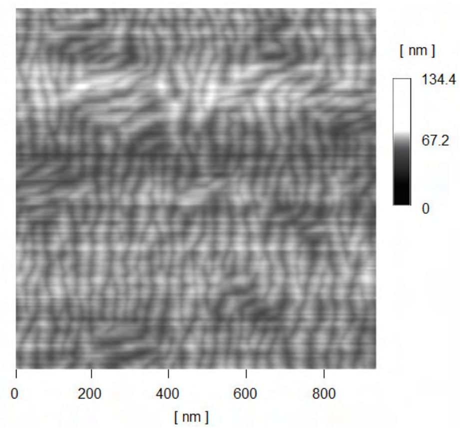
Film characterizations



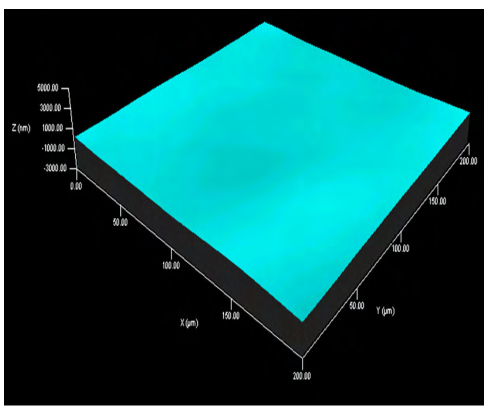
SEM



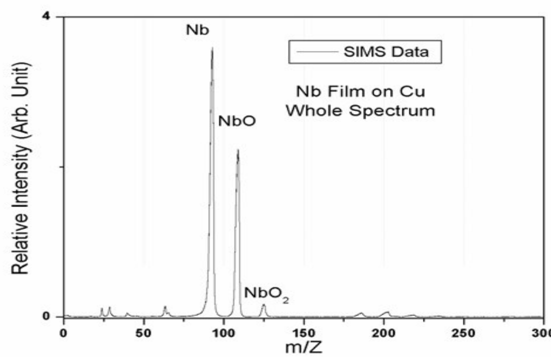
X-ray diffraction



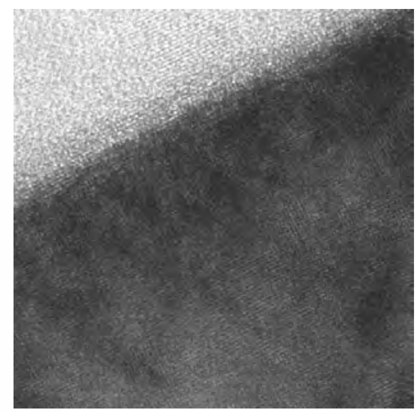
AFM



Nb/Cu-90 Film RMS=94 nm, profilometer



SIMS



TEM

Summary of thin film sample

- Niobium Ion Energy is around 63 eV without bias voltage, and controllable.
- Cryogenically, the process achieves a reasonably high RRR niobium thin film with excellent superconducting transition temperature and width.
- RRR appears to be more closely related to the film thickness than to the deposition energy.
- Epitaxial growth of niobium on sapphire has been achieved. The substrate bias voltage of -60 V is believed to be the preferred value based on the transition width, the crystal orientation spread, and the AFM results.
- For a copper substrate, a better film quality likely requires higher deposition energy than sahhpire substrate, which needs further studies.

Summary of thin film sample (cont.) based on SIMS analysis

- Nb-Cu sample surfaces are smooth locally
- Nb-Cu surfaces may have much less hydrocarbons and other residuals or contaminants as compared with those on the Nb surfaces obtained conventionally (BCP or EP).
- Nb-Cu samples appear to have more oxygen on the surfaces and oxygen penetrates deeper into the interior of the samples. This may be resulted from the residual gases in the deposition chamber and from the fact that the grain size of Nb-Cu is small.

Beyond niobium,

- Material, we will look at:

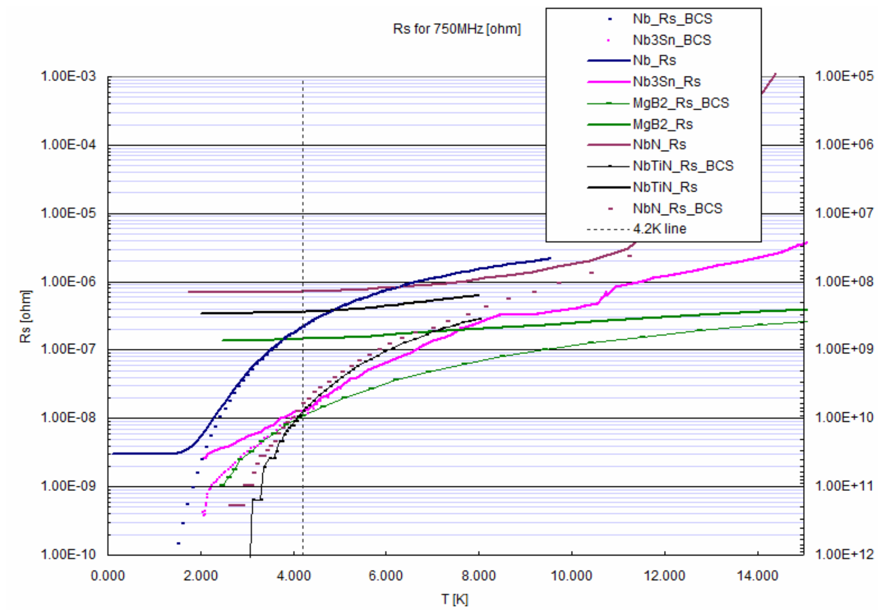
  NbN, NbTiN, Nb_3Sn, MgB_2

- Process we can setup:

  (Bias) Sputtering, Plasma, PLD.

- Collaboration process:

  Vacuum Arc, pulsed ion ablation



- Low power application: 4k medium performance for university or hospital operation.
- High power application: 4K high performance for compact, high power FEL