# NIOBIUM THIN FILM CAVITY DEPOSITION BY ECR PLASMA*

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*Abstract*

Nb/Cu technology for superconducting cavities has proven over the years to be a viable alternative to bulk niobium. Energetic vacuum deposition is a very unique alternative method to grow niobium thin film on copper.
This paper presents some exploratory studies of the influence of the deposition energy on the material properties of the Nb thin film. Single crystal growth of niobium on sapphire substrate has been achieved as well as good surface morphology of niobium on small copper samples. The design of a cavity deposition setup under development is also discussed.

## INTRODUCTION

Superconducting cavities for particle acceleration are mainly based on Nb bulk technology [1]. However, niobium thin film technology has been successfully used in several particle accelerators [2]. It presents many advantages over the Nb bulk technology as lower material cost, higher thermal conductivity, much less sensitivity to external magnetic fields. Despite past and recent efforts to solve a problem of fast degradation of the quality factor for coated cavities at high fields, the commonly used cylindrical magnetron sputtering technology needs further improvements [3] for broader adoption in very high-energy accelerator projects [4].
Past experience with thin film growth has shown that higher surface adatom mobility [5] helps to suppress the columnar growth that has been commonly seen in magnetron sputtered niobium thin film on copper substrate. However, copper substrate cannot support sufficiently elevated temperatures to achieve the needed mobility thermally. The electron cyclotron resonance (ECR) [6,7] plasma metal ion source is a promising tool for direct niobium thin film deposition in high vacuum condition with the flexibility to adjust the niobium ion deposition energy [8]. The advantages over other deposition techniques [9-11] are the absence of embedded working gas and of macroparticles.
This technique has been implemented in an energetic deposition setup to deposit niobium thin films on samples at different energies. Transition temperature and residual resistivity ratio (RRR) were measured. The crystallographic structure of the films was analyzed by X-ray diffraction (XRD) and cross sections transmission electron microscope (TEM). In parallel, a deposition system for elliptical cavity coating is being developed.

## NIOBIUM THIN FILMS

The energetic sample deposition system [12] uses ECR mechanism to create a niobium plasma. Small substrates of sapphire and copper were located at the end of the plasma chamber, where they were biased against the surrounding chamber. Changing the substrate bias voltage was the simple way to control the energy of the depositing niobium ion energy.
For niobium thin films deposited at different ion energies, the transition temperature and RRR were measured. Niobium film on sapphire substrate showed the best superconducting transition when made at 123-eV ion energy. While the RRR showed a close relation to the film thickness, 50 was reached when sapphire based niobium film thickness was 235-nm. In contrast, the niobium films based on copper substrate showed fairly consistent transition temperature and transition width even with the depositing energy changed from 123-eV to 153-eV.

### *Cross section TEM analysis for sapphire and copper based niobium films*

Previous results from X-Ray Diffraction [12] have shown that, for both sapphire and copper substrates, the film grows with a (110) preferential orientation.

For films based on sapphire substrates, most show good crystal orientation. The interface between sapphire and niobium is very sharp, and shows epitaxial growth of Nb as shown in Figure 1.

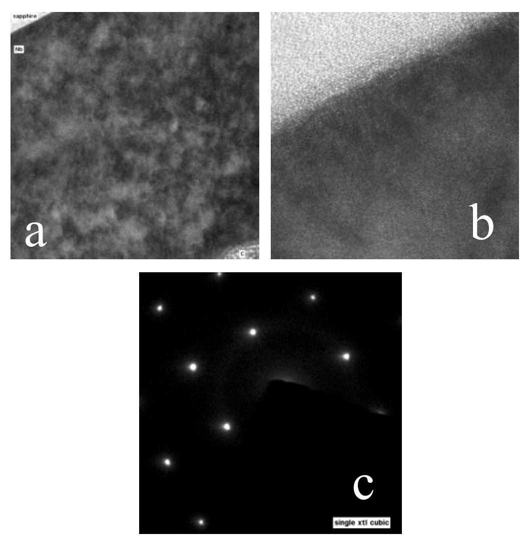


Figure 1 Niobium film on sapphire deposited at -90 V substrate bias: cross section TEM view (a), cross section view of niobium sapphire interface (b) and electron diffraction pattern showing (100) crystal orientation (c).

For films on copper substrates, as shown in Figure 2, the size of domains or grains increases with higher bias voltage. At –90 V bias voltage, the grain size is about 100 nm in diameter.

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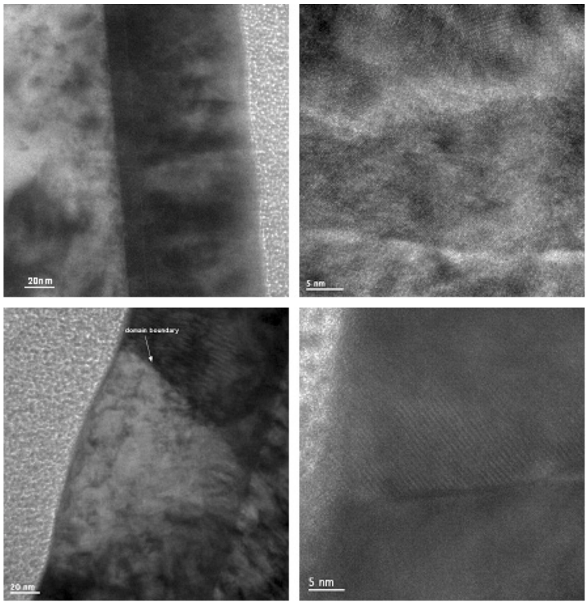

Figure 2: Cross section TEM micrographs of niobium film on copper deposited at -60V (top) and -90V (bottom) substrate bias.

Electron diffraction patterns (Figure 3) reveal a more oriented (110) crystal structure for films deposited at higher energy. The –60 V and –90 bias correspond to the deposition energy of 123eV and 153eV.

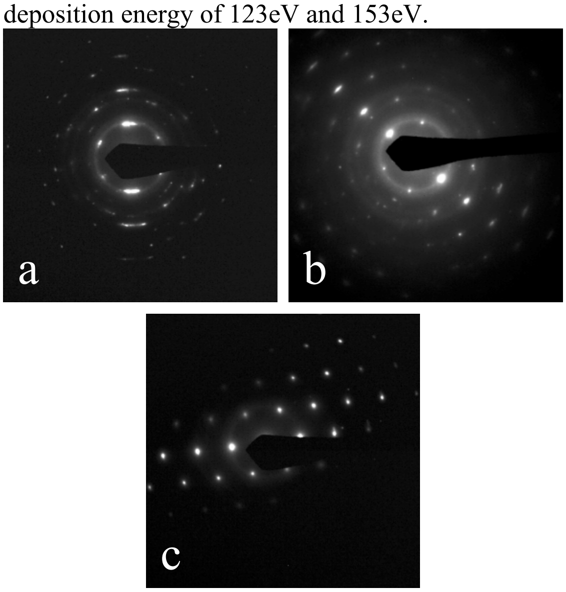


Figure 3: Electron diffraction pattern of niobium film on copper deposited at -60V (a), -70V (b) and -90V (c) substrate bias.

Further TEM results will be given in a future publication.

## NB/CU CAVITY DEPOSITION DESIGN

Based on the encouraging results on samples, an energetic vacuum deposition system for elliptical cavity coating (Figure 4) is being developed.

The generation of plasma inside the cavity requires, as for the sample system, three essential components: neutral Nb vapor, RF power at a certain frequency, proper static magnetic field which is perpendicular to the electric field of RF power and satisfies the ECR condition.

In this system, the cavity itself will be part of the vacuum chamber. As a starting point, the cavity deposition will be performed in a 500MHz single cell elliptical cavity. The system is designed so it can be adapted to various cavity frequencies. The vacuum will be generated by a cryopump coupled with a mechanical roughing pump. In addition, a getter pump will pump the residual hydrogen, mostly generated by the E-beam gun operation.

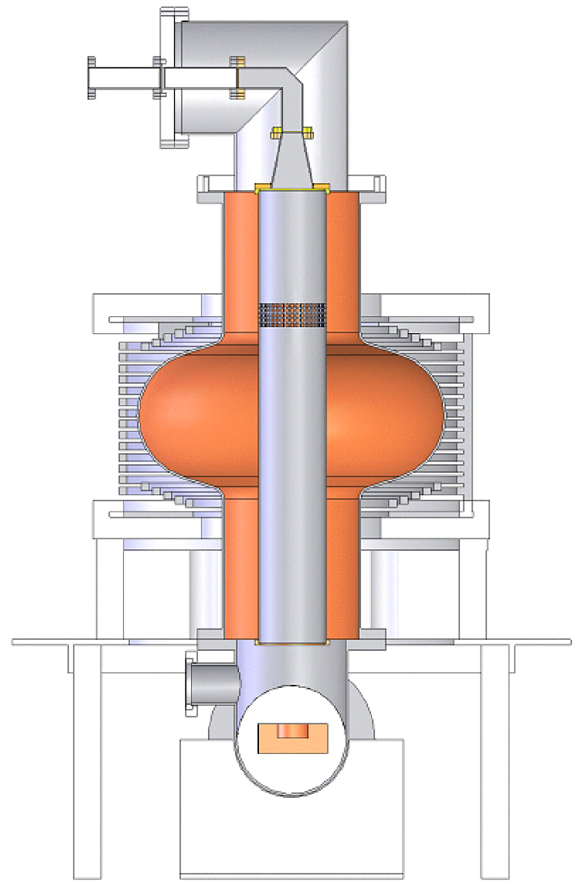

Figure 4: ECR plasma creation inside an elliptical cavity

The neutral niobium flux will be provided by 15kW rod-fed E-beam gun evaporation. To create energy controllable Nb ions, a cylindrical grid, insulated by a ceramic is inserted in the cavity vacuum. The bias voltage (0-150V) will be applied to the grid, providing controllable accelerating voltage for Nb ions. At the same time, the grid confines the RF field. This grid will be made of a Nb sheet perforated of 6.35 mm holes. The use of niobium will both reduce contamination and provide high heat tolerance. The analysis shows that for a typical 250 Watt input RF power, the grid temperature should be lower than 500°C. In order to allow the niobium flux through, the grid has an opening at the bottom. The radiation through the grid is influenced by the open gap between the grid and the insulator, the opening at the bottom and the grid itself. Theses contributions have been modeled and evaluated as shown in table 1.

Table 1: Radiation contributions of the grid

| | 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% |

The RF power, 500W at least, will establish $TE_{11}$ mode in the grid cylinder by a commercial 2.45GHz power source.

The magnetic field is configured to have a relatively large area uniform field of 875G, to meet ECR condition. For more flexibility and simplicity, coil magnets have been preferred to permanent magnets. The coil magnet system will be composed of a center coil and top and bottom coils. To enable uniform coating in the beam pipes as well, two additional coils could be used to coat the beam pipes prior to the cell coating. The generated heat power by all the coils is estimated at 20kW. To allow enough heat removal, the ensemble is water-cooled and the center coil is split in three sections. Figure 5 represents the designed field.

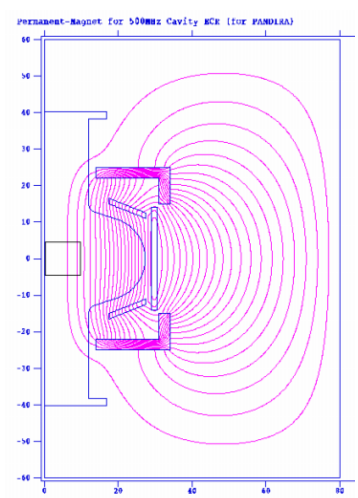


Figure 5: The magnetic field produced by coils and yokes for ECR condition. Center square shows the region where field has a great uniformity.

The cavity deposition system will be built in the next few months, as well as a cavity equipped with sample holders placed at various positions around the cell profile. The samples produced in such a cavity will be analyzed to verify the quality of the films produced. In parallel, the RF performance of cavities coated in the same conditions will be tested.

## SUMMARY

Films deposited at different energies on both sapphire and copper substrates have been produced. Cryogenically, a reasonably high RRR with good superconducting transition temperature and width are achieved. For sapphire substrates, epitaxial growth of niobium has been achieved. For films on copper substrate, a similar quality seems to require higher deposition energy, which needs further studies.

A cavity deposition system with the energetic vacuum deposition technique is under development and will be built in the next few months.


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