O6

DEPOSITION OF SUPERCONDUCTING NIOBIUM FILMS INSIDE RF-CAVITIES OF PARTICLE ACCELERATORS

M.J. Sadowski [1], R. Mirowski [1], R. Nietubyć [1*], P. Strzyżewski [1], S. Tazzari [2], L. Catani [2], A. Cianchi [2], J. Lorkiewicz [2], and R. Russo [3]

1 Institute for Nuclear Studies, PL-05400 Świerk, Poland
2 University Tor Vergata and INFN Roma 2, I-00133 Rome, Italy
3 Institute of Cybernetics CNR, Naple, Italy

Keywords: RF cavities, superconducting films, film deposition

*) e-mail: r.nietubyc@ipj.gov.pl

The generation of electromagnetic fields in the radio-frequency (RF) cavities is the important long-studied issue in the accelerator physics and technology. The effective acceleration of electrons emitted from a cathode requires high electrical field gradients. This determines an amount of energy dissipated upon RF cavity walls. To avoid large energy losses, and particularly over-heating, which might lead to a large temperature rise, a film with an uniform and defects-free surface and characteristics, corresponding to the bulk superconductor, *e.g.* pure niobium, must be obtained.

In technical research activities concerning the construction of large linear accelerators, particular attention was paid to the possibility of depositing thin super-conducting layers. Originally, the magnetron sputtering has been proposed as a well established deposition technique. Unfortunately, some unwanted features of the layers deposited with this technique, appeared to be impossible to overcome, *e.g.* the Q_0 factor degradation, insufficient film quality and purity.

This paper reports on the development achieved in the ultra high vacuum cathodic-arc deposition technique [1-2]. The so-called linear- and planar-arc devices are described together with appropriate micro-droplets filters. The efficiency of the filtered deposition has been analyzed by performing model calculations and experiments. The structure and superconducting properties of the deposited Nb-films have been studied.

An experimental set-up with the UHV linear-arc [3] is presented in Fig. 1. The linear-arc configuration of the deposition facility was especially designed for coating the inner surfaces of TESLA-type resonator cavities with pure Nb layers. In this scheme the RF resonator cell itself constitutes a vacuum chamber enclosing the vertically oriented cylindrical, hollow niobium cathode surrounded by a cylindrical micro droplet magnetic filter (not-shown in Fig. 1). The model calculation of the magnetic field distribution in the inner part of filter have been conducted with a *Maxwell@D-v10* code.

In order to control the cleanliness of the deposited film, the pressure and composition of the residual gas was continuously analyzed (*i.e.* before and during the arc discharge) using a quadrupole mass spectrometer. The basic pressure was settled within the 10^{-10} mbar range. An optical spectrum in the visible range was measured during the discharge. It showed the appearance of neutral and singly-ionized niobium atoms.

The arc discharge was initiated by a 50 mJ Nd:YAG la-

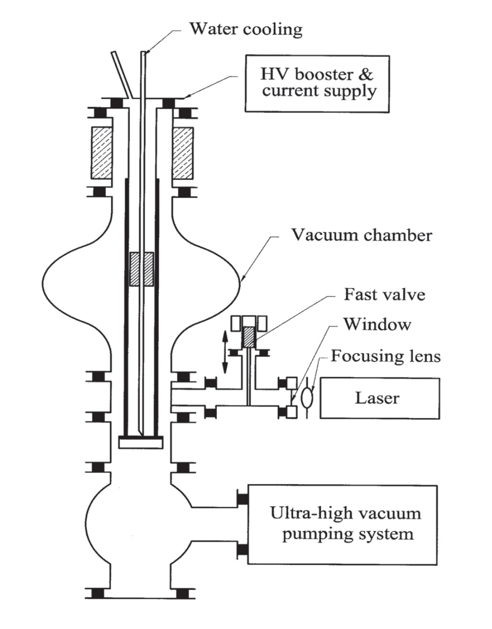

Figure 1. UHV linear-arc deposition set-up with a cylindrical cathode.

ser beam pulses (532 nm, 20 ns) focused upon the cathode surface. It resulted in the formation of an arc channel due to the ablation of the cathode material. As known, the arc discharge originates usually from a small spot moving upon the cathode surface. Due to high energy density in the spot area, atoms, ions and micro-droplets are ejected from the spot and move together with electrons within the arc channel

Energies of these species range from 10 eV up to 100 eV. Such a plasma stream can be directed with a magnetic field and deposited in the controlled way upon the substrate. Due to high purity of the cathode, high-vacuum environment and relatively high energy of the ions reaching the substrate, a dense, pure and defect-free film can be produced.

The planar-arc deposition facility was equipped with a truncated cone cathode [4-5], which was fixed upon a cooled support at the bottom of the vacuum chamber, as shown in Fig. 2.

In this configuration, the filtering was based on the guiding of the arc plasma column through a bent magnetic channel. Different knee-type filters as well as T-shaped ones have been designed and used for the micro-droplets elimination.

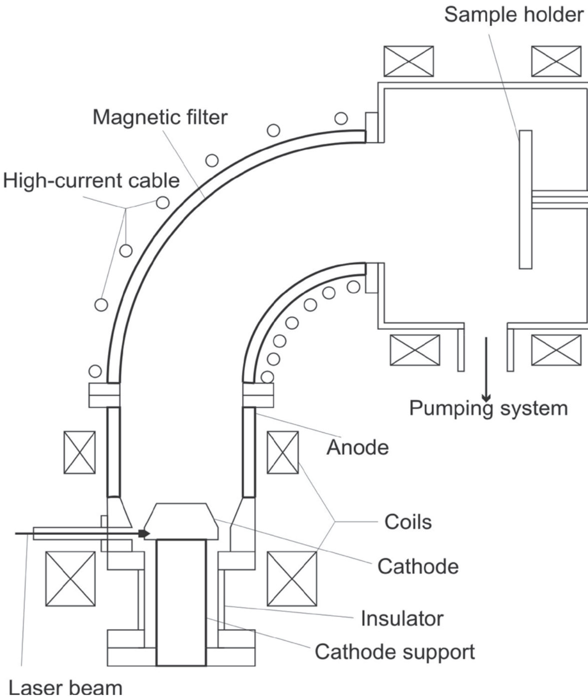

Figure 2. UHV planar-arc deposition set-up with a magnetic filter for the elimination of micro-droplets.

The performed model studies showed that for all the investigated filters, the magnetic flux transmitted through the filter is highly sensitive to the geometric conditions and magnetizing currents. An approximately homogenous field, which does not penetrate the wall, has been found as the optimum solution for arc plasma guiding. For the magnetizing current equal to 200 A, the field intensity has been varied from 16 mT in the cathode region down to 12 mT at the filter outlet [6].

The films of 2 μm in thickness were successfully deposited. The deposition rate within the system operated with arc currents of 80-100 A was about 1 nm/s The sample temperature during deposition rose up to 530 K. The observed residual gas pressure rise during the arc discharge was almost exclusively caused by hydrogen. Its partial pressure was more than 3 orders of magnitude higher than that of other contaminants.

The structure of resulting films has been studied in order to understand the influence of deposition conditions on the superconductive properties, *i.e.* RRR, T_c and ΔT_c values.

The RRR value equal to 80 has been reached at a temperature of 10 K within the planar source system applying a bias voltage of –70 V, while RRR = 40 was obtained within the linear source facility. The critical temperature Tc and critical current density Jc of the deposited Nb films were measured by an inductive method. The values typical for bulk Nb, *i.e.* T_c = 9.26 K, and $J_c = 3\times10^7$ A/cm^2 have been observed.

Such results indicate high purity of the deposited layers. This conclusion has been confirmed by results of measurements performed by means of SIMS and GD-OES techniques. They showed that the niobium hydride concentration was below 0.2%, while the concentrations of oxide, and metallic impurities were lower than 100 ppm.

X-ray diffraction studies have been performed with a DORIS III storage ring at the Hasylab. Results indicated that a thin, quasi-epitaxial Nb layer is formed in the interface region (see Fig. 3). The preferred orientation of 110 planes parallel to the surface was observed for the whole film. We have found that higher ion impact energy, resulting from applying -70 V of bias potential to the sample, leads to less-strained or less-defected crystalline lattice, but it does not improve the RRR value satisfactorily.

The SEM analysis of the surface morphology showed that droplets-free, homogenous and dense films were obtained during the filtered depositions. The surface roughness was of the order of a few tens of nanometers [7]. The micro-droplets concentration on the film surface was found to be significantly lower, and size distribution shifted towards smaller radii, as compared with the films obtained without filter. Some portion of micro-droplets is buried inside the film. These micro-droplets are not visible in the picture directly, but they modify the surface morphology.

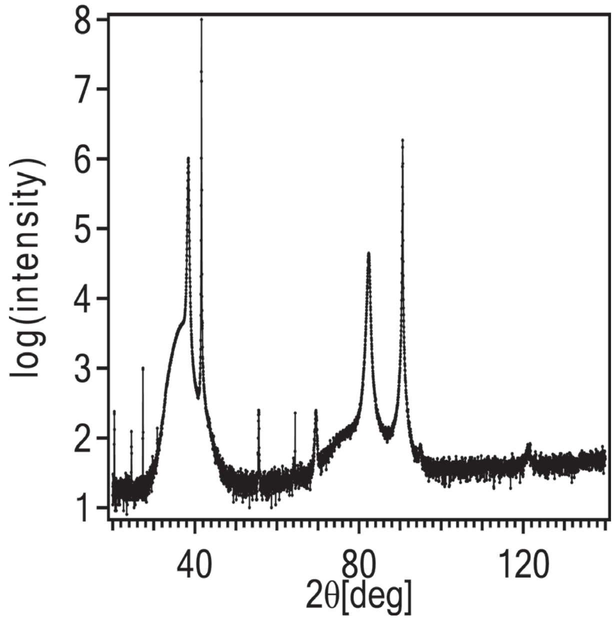

Figure 3. Nb/sapphire (0001) diffraction pattern.

Possibility of the elimination of micro-droplets by means of a magnetic filter has been proved by SEM measurements, as shown in Fig. 4.

Measurements of the resistivity versus temperature, which were performed for Nb films deposited on sapphire

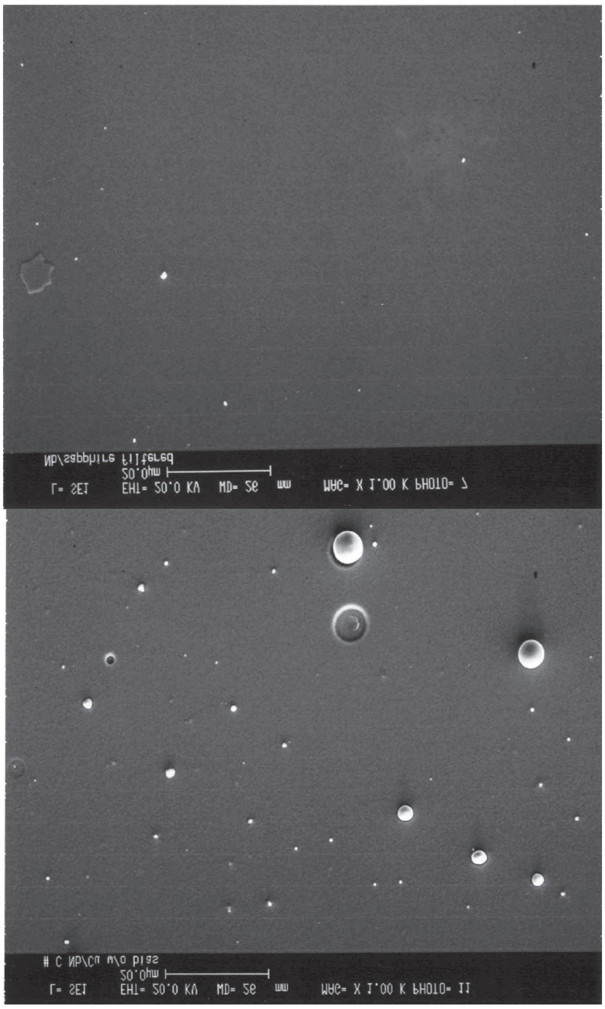

Figure 4. SEM pictures of Nb layers deposited using the filter (upper part) and without filter (lower part).

in the range up to 500 K, showed evidences for a re-arrangement of the grain morphology occurring in the temperature range of 610 K up to 670 K.

The RF performance of the filtered Nb coated samples has also been investigated. The quality factor Q equal to 3×10^8 has been measured within the test resonator [7]. This value is of the same range as values typical for the bulk Nb cavities. It should be added that the investigated sample sustained the magnetic field of 300 Oe.

In the conclusion it might be stated that we have developed an experimental system for the UHV cathodic arc deposition and we have proved that superconducting, high-purity, smooth and micro-droplet-free films, having crystalline structure similar to bulk niobium can be produced. Samples of the Nb films on the cupper and on sapphire substrates, as well as the inner wall of a test cavity were coated and studied in order to optimize the technological process. The performed studies showed that this technique can be considered as a valuable option for the constructing superconducting RF cavities. Particularly, it makes an interesting alternative for the RF sputtering deposition.

Acknowledgements: We acknowledge the support of the European Community Research Infrastructure Activity under the FP6 Structuring the European Research Area Program (CARE, contact number RII-3-CT-2003-506395).

The authors wish to thank Wojciech Paszkowicz, Jerzy Pełka and Ryszard Sobierajski from the Institute of Physics PAS for their work with the XRD measurements.

References

[1] J. Vyskocil, J. Musil, *J. Vac. Sci. Technol. A* **10** (1992) 1740.

[2] A. Anders, *Vacuum* **67** (2002) 673.

[3] J. Langner, M.J. Sadowski, K. Czus, R. Mirowski, J. Witkowski, L. Catani, A. Cianchi, R. Russo, S. Tazzari, F. Tazzioli, D. Proch, N.N. Koval, Y.H. Akhmandeev, *Czech. J. Phys.* **54** (2004) C1.

[4] J. Langner, R. Mirowski, M.J. Sadowski, P. Strzyżewski, J. Witkowski, S. Tazzari, L. Catani, A. Cianchi, J. Lorkiewicz, R. Russo, *Vacuum* **80** (2006), 1239.

[5] L. Catani, A. Cianchi, J. Lorkiewicz, J. Langner, P. Strzyżewski, M.J. Sadowski, A. Andreone, G. Cirafello, E. Di Gennari, G. Lamura, R. Russo, *Physica C* **441** (2006) 130.

[6] P. Strzyżewski, J. Langner, R. Mirowski, M.J. Sadowski, S. Tazzari, J. Witkowski, *Phys. Scripta* **T123** (2006) 135.

[7] L. Catani, A. Cianchi, J. Lorkiewicz, S. Tazzari, J. Langner, R. Mirowski, M.J. Sadowski, P. Strzyżewski, J. Witkowski, B. Ruggiero, R. Russo, *International Workshop on Thin Films and New Ideas for Pushing the Limits of RF Superconductivity* (9-12 Oct. 2006, Padua-Legnaro, Italy).