

UHV ARC DEPOSITION FOR RF SUPERCONDUCTING CAVITY

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Abstract

Thin niobium film on copper coated RF cavities are a very interesting alternative to bulk-Nb ones since copper is cheaper than niobium, has higher thermal conductivity and better mechanical stability. The magnetron sputtering technology for such coating was successfully used for the production of the 350 MHz LEP SC accelerating cavities at CERN. Unfortunately, the observed degradation of the quality factor with increasing cavity voltage is so far limiting the maximum useful field and therefore the application of this technology to future large accelerators designed to operate with field gradients higher than 25 MV/m. The alternative vacuum arc coating method, discussed in this paper, is a powerful technique for the deposition of films on several materials. Its main advantages, as compared to the standard sputtering process, are the ionized state of the evaporated material, the absence of gases to sustain discharge, the higher energy of atoms reaching the substrate surface and the capability of higher deposition rates. To ignite the arc one needs to produce a small plasma burst of a sufficient density to form a high-conductivity path between cathode and anode. To eliminate all possible source of contaminants we used a triggering system based on Nd-YAG pulsed laser focused on the cathode surface. We built and put into operation 3 different UHV arc system: a planar arc, a filtered arc and a cylindrical arc system. It was demonstrated that using the UHV arc technique bulk-like films, suitable for superconducting applications, can be produced. The main disadvantage - the production of macroparticles that can increase the roughness and induce field emission - is being studied and methods to eliminate it are discussed. We present the different systems and discuss their possible application to cavity coating. Our recent results on the characterization of niobium film samples produced under different arc regime are also briefly presented.

INTRODUCTION

Superconducting (SC) cavities for particle acceleration are mainly based on Nb bulk technology.

The Nb/Cu technology was proved a valid alternative, for relatively low accelerating fields (up to ≈ 10 MV/m), by the successful operation of the LEP II acceleration system [1]. With respect to the Nb technology it offers several advantages: better mechanical stability, lower

costs, better thermal stability, easier conditioning on the machine, easier connection to the cryostat and less sensitivity to magnetic fields. Unfortunately the quality factor of magnetron sputtered cavities decreases with increasing accelerating field [2], thereby limiting their usefulness to the new very high-energy, high-field SC linear accelerators.

The reasons for the Q degradation are not well understood. Therefore investigation of alternative coating techniques, such as arc coating in ultra-high vacuum (UHV), that can lead to different film properties, is of particular interest. The main advantages of arc deposition over sputtering are the highly ionized state of the evaporated material, the absence of gases to sustain the discharge and the high energy (about 50eV) of atoms reaching the substrate surface. The main disadvantage is the production of macroparticles (also called microdroplets) of the cathode material that become embedded in the film. This paper presents the three deposition system we have developed to investigate the technique: a planar arc, a filtered planar arc and a cylindrical arc system.

EXPERIMENTAL SET-UP

To ignite the arc one must produce a small plasma burst of sufficient density to form a high-conductivity path between cathode and anode. Several millijoules of energy are usually needed to form the initial plasma, and several methods can be used to produce it. However, only a few are compatible with UHV operating conditions, which exclude all methods liable to introduce even very small quantities of unwanted impurities. A further condition for a UHV grade trigger is to be extremely reliable because any intervention, for adjustments or repair, which needs breaking the vacuum, must be avoided. In fact while an ordinary vacuum-arc chamber can be back in operation after a couple of hours after opening up a UHV system requires bake-out and at least 24 h before coming back to its operating base pressure. The most widely used triggers are based on a high-voltage breakdown, inducing the evaporation of a thin metallic film deposited on a dielectric surface. They are not very reliable and have been observed to produce dangerous impurities originating from the dielectric.

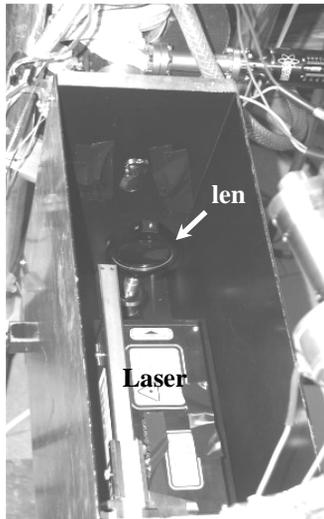


Figure 1: Picture of the black box containing the very compact laser head (only 15 cm long) and the optical lens for the beam focussing.

Mechanical devices that bring an additional electrode in momentary contact with the cathode can be used, if properly designed, but are usually not reliable enough for our purposes. We have therefore opted for a triggering system based on a Q-switched Nd-Yag laser, with a 7÷8ns pulse length, 50mJ per pulse and 1÷20 Hz repetition rate, whose beam is focused onto the cathode through an optical vacuum-tight window. Sufficient energy density is produced at the laser focal spot to produce a plasma plume that initiates the arc. The laser is enclosed in a (blackened) box (see Fig.1) also containing the lens, mounted on a 10cm rail, that focuses the laser beam onto the cathode. By changing the focal length of the lens and its position on the rail the system is readily adapted to anyone of our vacuum chambers.

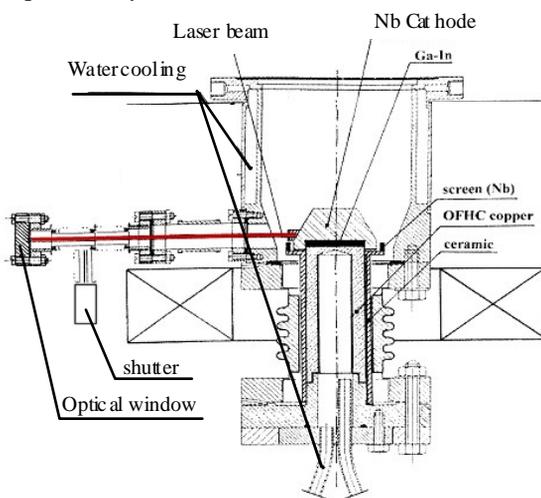


Figure 2: A schematic drawing of the cathode arc source with the new laser trigger.

A shutter, open during triggering and closed during deposition, is used to prevent coating of the optical window. Shutter and laser can be computer controlled to allow for (planned) depositions in a pulsed mode. The box mechanical connection to the vacuum chamber window ensures that the laser beam is properly aligned with respect to the cathode.

The system has proven very effective, extremely reliable and allowing for extremely clean working conditions [3]. Design and characteristics of our different UHV arc devices are discussed in the following section.

The Planar Arc System

A prototype UHV planar arc source was put in operation in 2001 and has shown that the quality of the deposited Nb films can be high [4]. Since then the system has been upgraded to improve its reliability and the film quality reproducibility. A schematic drawing of the electrodes and trigger mechanical assembly is shown in Fig.2, while Fig.3 shows a picture of the complete planar system.

The system has been extensively studied. In particular the arc stability has been improved by adding a series inductance (not shown in the picture) in the power supply circuit. The inductance lets the voltage increase as the arc current tends to decrease, thereby providing a stabilizing feedback action. The circuit allows for several minutes long, stable arc operation down to currents of $\approx 80A$.

Operation down to 60A is possible but the mean time

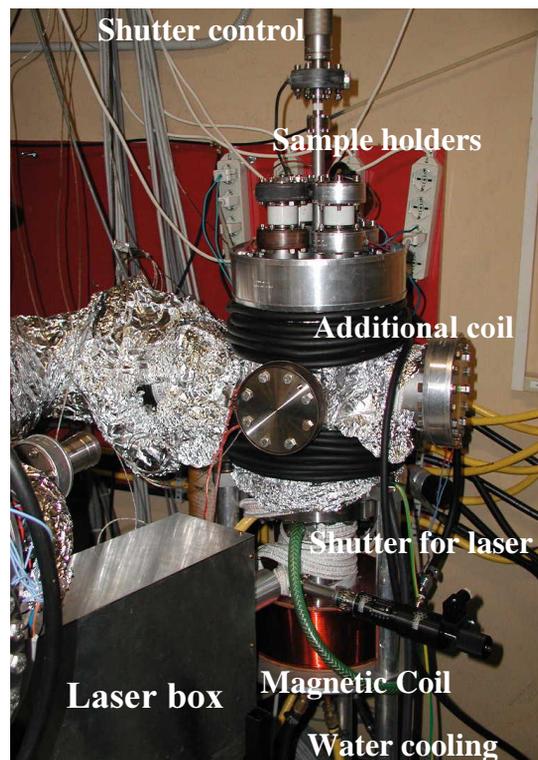


Figure 3: Picture of the UHV planar arc system. Samples are placed at a distance of $\approx 50mm$ from the cathode.

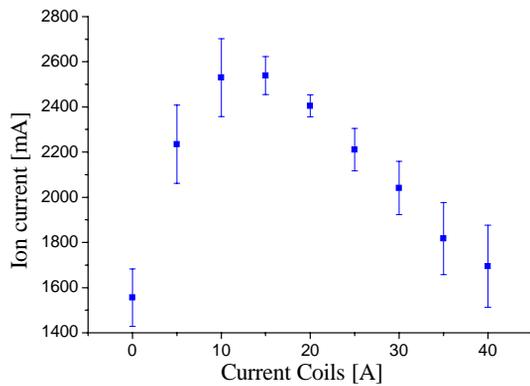


Figure 4: Ion current on the sample holder as function of the current in the additional coils. Arc current 80 A, Voltage bias -40 V.

between arc breaks becomes of the order of a minute or less.

To improve the deposition rate two additional coils have been wound around the main chamber. They generate a magnetic field that better confines the plasma and increases the deposition rate on the samples by up to 50%.

The application of a negative bias higher than 30 V to the sample holder makes it possible to collect and record the Nb ion current, directly related to the deposition rate.

The ion current is plotted in figure 4 as a function of the current in the additional coils mentioned above (arc current 80A, voltage bias -40V). It increases with the coil current reaching a maximum at about 15A. A simultaneous reduction in the amplitude of ion current fluctuations during deposition has also been observed, the amplitude reaching a minimum at a coil current of 20A, corresponding to a magnetic field of about 15G. While

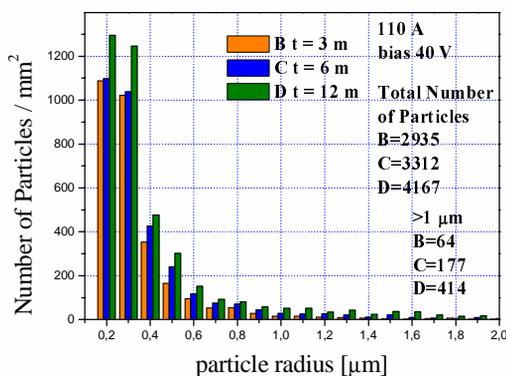


Figure 5: Macroparticle distribution for 3 samples deposited at the same conditions for different times. The main difference is the amount of particles with a radius larger than the film thickness (about 1µm).

the increase in ion current is well understood as a consequence of the improved magnetic field configuration letting a larger number of magnetic field lines reaching the substrate, the reason for the reduced fluctuations is still not understood.

We have also studied the influence of arc current on the film characteristic. In particular, we did investigate the droplet distribution dependence on the discharge parameters, at constant film thickness.

On each produced sample 5 to 10 pictures have been taken at different locations, using a 500X magnification optical microscope. Photographs have been analyzed using a LabView computer code giving as output the number of macroparticles and their dimension. A typical result is shown in Fig.5. More details on samples characterization can be found in [5-6].

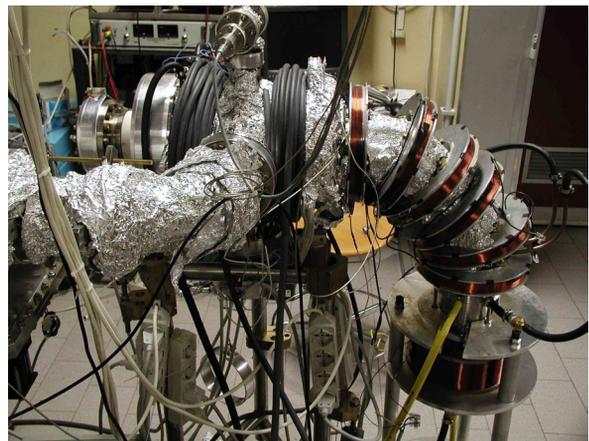


Figure 6: UHV filtered arc. Coils on the elbow are designed to force electrons and ions to follow the elbow radius, while the large mass macroparticles will hit the chamber wall and stop.

Ways of planar arc coating of SC RF cavity type geometries, by using two arc sources, depositing from both cavity openings and guiding ions magnetically for better coating uniformity, are being studied.

The Filtered Planar Arc

While not contaminating the film, macroparticles increase its surface roughness and may become sources of field emission. To reduce the effect a magnetic macroparticle filter has been studied and built. The filter coil arrangement is designed to force electrons to follow magnetic field lines with orbit radii smaller than the vacuum chamber elbow one. Samples are mounted on a sample holder placed 30 cm downstream from the 90° elbow. A picture of the system is shown in Fig 6.

Since the plasma is quasi-neutral the ions follow the electrons through the elbow, while massive macroparticles hit the chamber walls and are stopped.

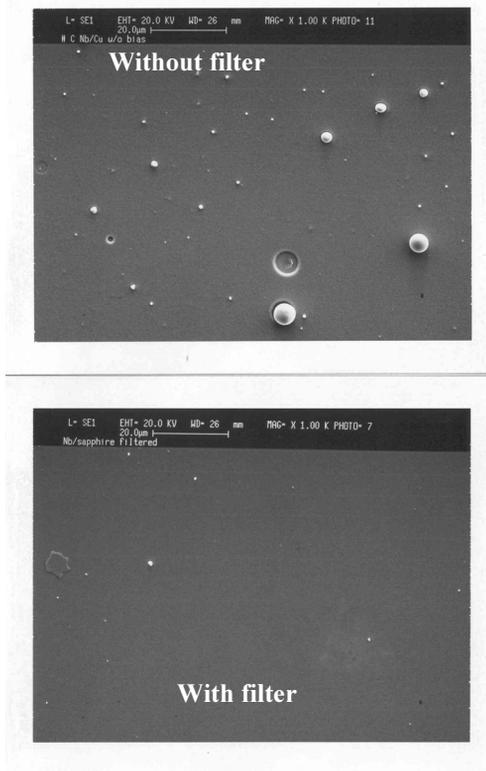


Figure 7: SEM images of niobium samples deposited on sapphire substrate with and without the magnetic filter.

The magnetic filter reduces number and dimensions of macroparticles drastically, over the whole range of coil currents explored, at the expense of the deposition rate being reduced by a factor of ≈ 5 with respect to that of the unfiltered arc. Quantitative data on the macroparticle content have not so far been obtained because the number of droplets in the observed field is often below the detection threshold, as shown in Fig.7.

In the filtered arc system the energy of electrons reaching the substrates is higher than that in the planar case and about 80V polarization is needed to reflect all electrons and collect ions only. These differences in the voltage bias and in deposition rate should improve the film properties, if only marginally. All measured properties other than droplet content are in fact very similar to those of the samples produced with the unfiltered planar arc system.

The Cylindrical Arc

In a “cylindrical” arc system the arc current, flowing along the cathode, generates a magnetic field that interacts with the arc plasma. This interaction forces the arc spot to spiral around the cylindrical cathode in the direction of the current flow.

Two possible modes of operation, **a)** and **b)**, are schematically shown in Fig.8 :

in case a) the arc, started at the positive, lower end of the cathode, stops on a floating potential electrode mounted

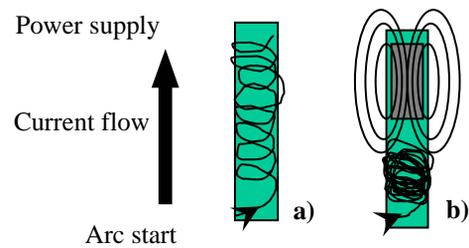


Figure 8: Two possible modes of cylindrical arc operation: a) the arc starts at the bottom and moves up to the cathode upper end, b) The arc spot is confined to the region just below a strong field permanent magnet.

next to the cathode negative, upper end. The current flow can be inverted as the spot reaches the cathode upper end by inverting the supply polarity.

In case b) a permanent magnet “reflects” the arc spot, confining its movement to the region below the magnet. Displacement of the arc discharge along the cathode is then obtained by moving the magnet.

Our system is of the b) type. The configuration allows controlling the arc movement like in the magnetron sputtering case and is expected to make it easier to coat multicell cavities and to control the film thickness along the structure.

Two cylindrical systems are in operation, one in “Tor Vergata” University, shown in Fig.9, and one at SINS in Swierk.. The 35mm diameter cylindrical cathode is electron beam welded and cooled by water flowing inside it. The present system drawback is that, should cathode



Figure 9: Picture showing the UHV linear arc system mounted in “Tor Vergata” University. The 200mm central chamber allows an easy mounting of samples to check quality and uniformity of the niobium deposited film.

erosion due to deposition produce a hole in the cathode wall, water could penetrate the vacuum chamber. Solutions are under study to overcome the problem, at present the favored one under study being to have an inner copper lining in good thermal contact with the niobium outer cylinder.

First results on the macroparticles distributions on samples produced under different arc conditions seem to indicate that, as expected, there are more microdroplets than in the planar case. Macroparticle filters for the cylindrical arc are being designed and prototyped in Swierk.

MAIN PROPERTIES OF ARC DEPOSITED Nb FILM SAMPLES

Results on structural and superconducting properties of Niobium films produced on copper and sapphire substrates are presented in more detail at this conference in a separate paper [6]. Concerning parameters most relevant to the film performance, we note that measurements of the superconducting critical temperature (see fig.10) show T_c 's very close to bulk values and very narrow transitions widths (about 0.01K). This, together with the measured X-Ray diffraction patterns, indicates that the films are less stressed and more homogeneous than standard Nb films produced by sputtering. The measured RRR values range from 10 to 40 for samples deposited at room temperature ($T < 50C$) and reach as high as ≈ 80 for niobium films deposited at 200C.

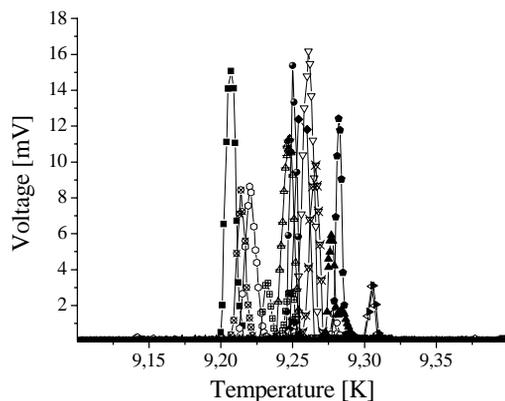


Figure 10: Transition curve of several Niobium films deposited on copper and sapphire. T_c is 9.25K within 0.05K and transition widths are smaller than 0.02K.

CONCLUSIONS AND FUTURE PLANS

Several cathodic arc sources - planar, filtered and cylindrical - all working under UHV conditions have been built and operated. All such geometries may be used to coat a single cell cavity, but the cylindrical one is, we believe, the best suited for coating multicell structures. We have shown that high quality Nb films can be deposited by means of the UHV arc technique. The critical temperature of film samples coated in planar geometry is very close to the bulk values and the very narrow transition, together with X-Ray diffraction patterns, indicate that films are less stressed and more homogeneous than standard Nb ones produced by sputtering. The planar DC arc source has been studied in detail and the best operating conditions from the point of view of macroparticle production identified. In addition, filtering of the planar arc proved to be very effective providing an almost macroparticle free surface with a filter transparency ranging up to 20%.

Next steps will be:

- the production and characterization of samples in cylindrical geometry to define the best parameters for coating TESLA like single cells;
- design and commissioning of a prototype macroparticle filter for cylindrical geometries;
- investigate pulsed deposition since it is important, during coating at high current, to maintain the temperature rise of the cavity within acceptable limits;
- investigate the possibility of removing droplets from the niobium surface by HPWR or by annealing with short excimer laser high energy pulses. Very preliminary results indicate that a smooth surface free of microdroplets may be obtained.

It is planned to start coating single cell cavities by the end of 2004.

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