APPLICATION OF ARC PLASMA FOR A DEPOSITION OF SUPERCONDUCTING FILMS

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INTRODUCTION

Large (TeV regime) linear coliders like TESLA require accelerating fields higher than 25MV/m at a quality factor of RF cavities $Q_o \approx 10^{10}$. Recently it was shown that such gradients are achieved in superconducting accelerating RF cavities based on the bulk niobium technology [1]. The resonators are made from 2.8mm thick sheet, very pure (RRR 300) niobium. Technology of Nb coated cooper cavities is an interesting alternative to bulk-Nb cavities. Copper cavities coated with thin niobium film have many merits if compared to bulk ones: a lower material cost, the higher thermal conductivity, much less sensitivity to external magnetic fields and also a simpler fabrication procedure. Since the late 80s the magnetron sputtering technology has been applied for coating copper RF cavities with superconducting thin niobium films. This technology is based on the deposition of pure niobium, in UHV conditions by means of a cylindrical magnetron [2]. Unfortunately, despite past and recent efforts in the magnetron spattering technology, a problem of fast degradation of the quality factor for coated cavities at higher fields has not been solved yet. Also the reason for the observed degradation of the Q_o is not completely understood.

In 2000 a new approach to the coating of cooper cavities was proposed – the vacuum arc deposition. The cathodic arc deposition technology, known since the 70 s, offers an interesting approach to producing, at very high rates, pure metal, alloy and compound films with excellent adhesion and density. Advantages of this technique are given by some characteristic features of arc metallic plasma, e.g. higher energy of ions in comparison with the magnetron sputtering technique, high ionization ratio of metallic plasma and also a higher purity of the deposition process due to absence of a working gas. These conditions result usually in the formation of denser films without voids. Molecular dynamics calculations indicate that the energies of ions generated in a cathodic arc discharge are within an optimal range for producing dense coatings. A possible problem of this technique is a production and a deposition of micro-droplets.

In order to study possibilities of the vacuum arc technique to form high quality superconducting thin films for a coating of RF cooper cavities some effort has been undertaken in the end of 2000. Within the framework of collaboration between the University of Rome "Tor Vergata" and the A.Soltan Institute for Nuclear Studies at Swierk and under the INFN grant ARCO the prototype set-up with planar arc source was designed, constructed and put into operation. Obtained, preliminary results were very promising [3].

In 2001 the new UHV set–up with two planar arc sources was assembled and put into operation at Rome. Also, an experimental device with the linear arc source was constructed and put into operation, at Swierk, in the frame of the cooperation of "Tor Vergata" University of Rome – IPJ Swierk, DESY Hamburg and IHCE Tomsk.

UHV ARC SET-UP

The crucial role during formation of thin superconducting niobium layer plays a purity of a deposition process [5].

The all set-up was designed and realized in accordance with UHV technology specifications. The arc source was fabricated using only high purity materials: stainless steel, OFHC copper and high quality ceramics. The conical cathode was fabricated from a 50mm diameter high purity Niobium rod (RRR 300) and fastened to a water-cooled Cu support. For better thermal contact between the Nb cathode and Cu support an eutectic mixture Ga-In has been used. A floating potential screen (Nb) surrounds the cathode to prevent the discharge from moving downwards, towards the bottom part of the arc source. The water-cooled conical chamber plays the role of the arc anode. The magnetic field component perpendicular to the planar cathode surface is in the range of 10÷20 mT. For 10 mT magnetic field the threshold arc current was in the range 80-90 A. To trigger of arc discharges we used a simple system, based on evaporation of a thin metallic film on dielectric surface. Construction details of the planar arc source are shown in Fig.1, and photo of the new experimental system is presented in Fig.2.

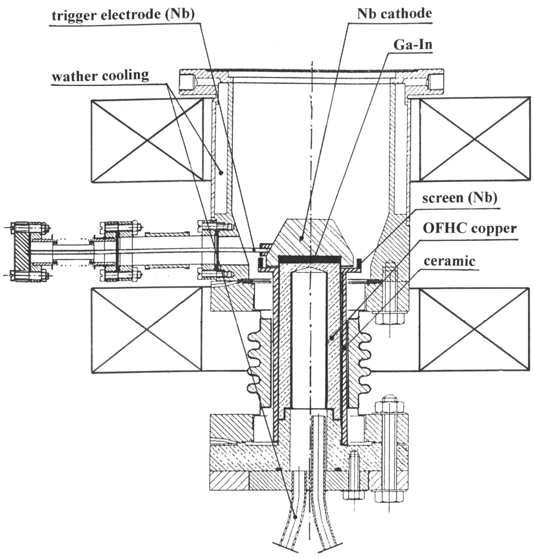


Fig.1 Layout of the planar arc source.

Our new experimental apparatus consists of two vacuum chambers (10 dcm^3) and two identical planar arc sources. One of them is equipped with a 90^0 magnetic filter in order to compare deposition by means of no filtered and filtered Nb plasma.

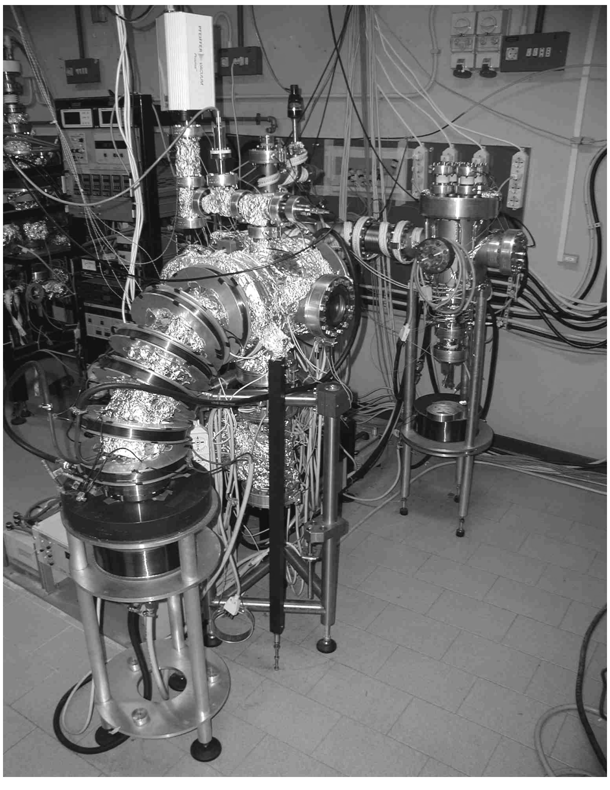


Fig.2 Photo of the new arc system.

The chambers are pumped down simultaneously or separately by an oil-free pumping system consisting of membrane pumps and drag turbo molecular pumps (180 l/s). A base pressure of 1×10^{-10} Torr is reached after one night baking of the whole system at 200°C. To check the composition of the residual gases before and during coating the vacuum chambers are equipped with own Quadrupole Mass Analyzers (QMA).

A typical behavior of partial pressures of residual gas species versus time is shown in Fig. 3. In particular Fig.3a shows the partial pressure rise due to triggering sparks in a situation when the arc discharge does not start. Fig 3b shows the behavior in time of partial pressures when a stable arc current is established. The total pressure increases up to 10^{-6} Torr as soon as the arc discharge starts, and stays almost stable during deposition. Note though that in such conditions the residual gas is almost exclusively hydrogen, its partial pressure being usually more than 3 orders of magnitude higher than that of other contaminants. This excess of hydrogen can be understood as generated by the bulk Nb cathode this provides a practically 'infinite' source of this gas. All other gases are emitted only by the chamber walls surface which makes their partial pressures drop below the detection limit of our instrument after only a few minutes of operation.

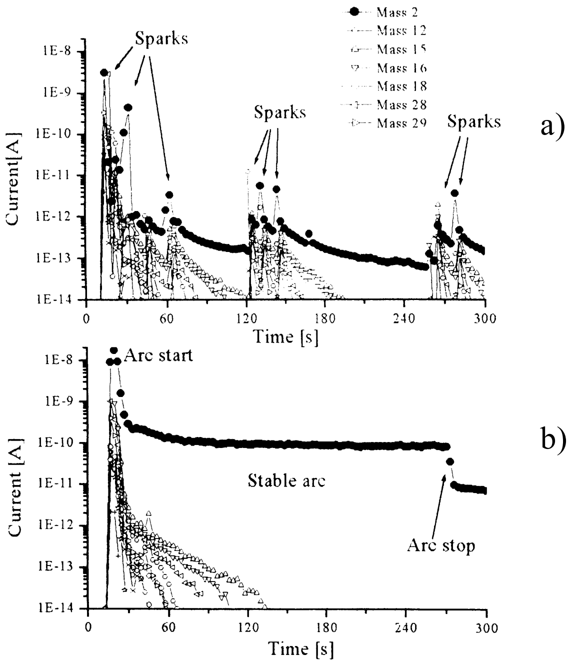


Fig. 3. Ion current vs time for different mass gases: a) triggering, but no arc; b) arc starts with the firs spark.

DEPOSITION OF SUPERCONDUCTING FILMS

Substrates (sapphire and OFHC Cu) to be coated were mounted on a temperature controlled, massive Cu flange placed on top of the vacuum chamber at a distance of about 50cm from the cathode. The all substrates before deposition were cleaned in an ultrasonic bath, using acetone, alcohol and de-ionized water, and dried in nitrogen.

Several samples have been produced in UHV conditions with arc currents in the range from 100A to 200A and bias voltages in the range from 0 to 100V. First samples coated in UHV conditions (mid of 2001) showed unexpectedly good properties of the deposited niobium. We obtained samples with RRR in the range from 10 to 50 even for very thin (100nm)films Fig.4.

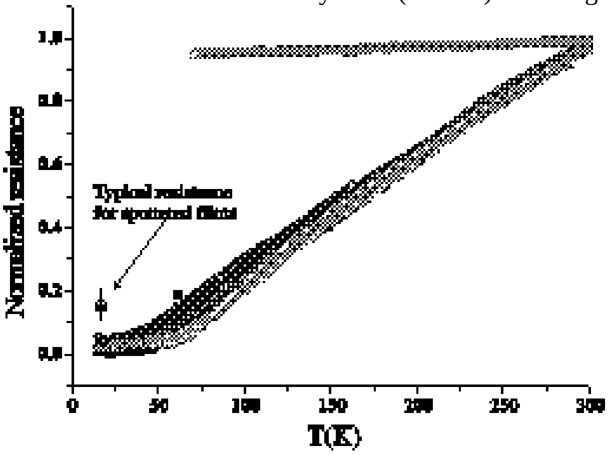


Fig.4. Resistance versus temperature for different samples. The resistance values are normalized to their values at room temperature.

This result was very encouraging since it is higher by a factor of 2 to 5 than what usually obtained under similar conditions (same thickness and coating temperature) by cylindrical magnetron sputtering (RRR usually between 5 and 10). After optimization of our set-up for more stable arc discharge the thicker (1μm) niobium films have been produced. The pressure in the chamber during these depositions was less than 10^{-7}Torr.

Critical current density (J_c) and transition temperature to superconducting state (T_c) of the films were measured on Cu and sapphire substrates using an inductive method, Fig.5.

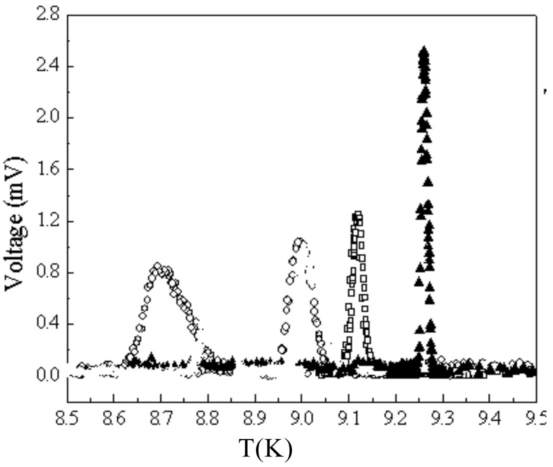
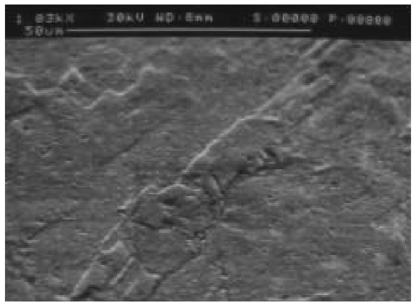


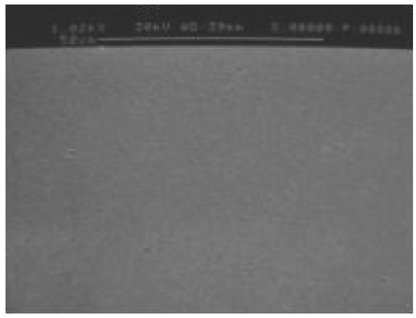
Fig. 5. Critical temperature measurements on Nb samples deposited by UHV arc.

The best samples show values identical to bulk metal, T_c=9,26 K, ΔT_c=0,02 K and J_c=3x10^7A/cm^2 [4].

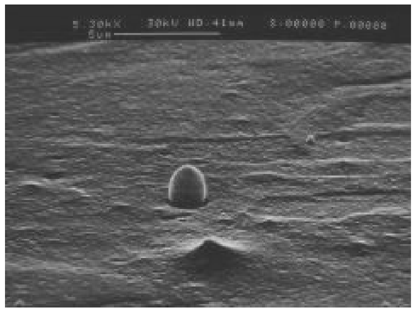
The main disadvantage of arc coating is the production of microdroplets that are embedded in growing film. In our case, microdroplets are made of high purity molten Nb and, while not contaminating the film, increase its surface roughness. The presence of microdroplets in our films was studied by optical and electron microscopy and by roughness measurements. In Fig. 6 SEM pictures show a general view of a film on Cu (Fig. 6.a)and sapphire (Fig. 6.b). SEM image at higher amplification (Fig. 6.c) shows small (1μm) niobium microdroplet.



a)



b)



c)

Fig.6. SEM images of the Nb film surface: a) on Cu, b) on sapphire, c) Nb micodroplet.

The roughness measurements performed on Cu samples indicate surface roughness similar to that of the Cu substrate: R_a =0.15 μm for the Cu alone and 0.18 μm for 1 μm Nb film on Cu. The roughness of the Nb coated sapphire was 0.1 μm.

LINEAR ARC SOURCE

The prototype linear arc source was also designed and realized in accordance with UHV technology specifications. The cathode (450mm in length and 34mm in diameter) made from a RRR150 niobium tube is directly water cooled. Niobium / OFHC Cu / stainless steel electron welded transitions were used to prepare vacuum tight connections. To control an arc discharge position a small magnetic coil or the SamCo permanent magnet is placed inside the niobium tube. For displacement a discharge along the cathode remote controlled, water tight system is used. From both ends of niobium tube the cathode is surrounded by ceramic rings play a role of floating potential screen. The cathode is vertically introduced into the vacuum chamber evacuated by the oil-free pumping system. The trigger electrode is placed in down part of the cathode. The schematic drawing of the system with the prototype linear arc source is sketched in Fig. 7

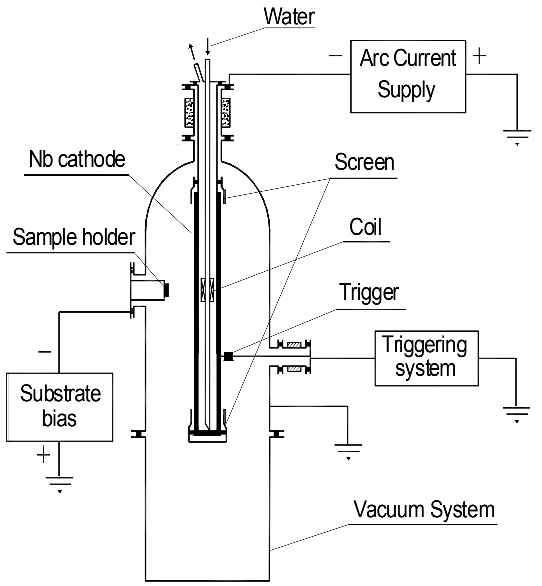


Fig.7 The schematic drawing of the system with the prototype linear arc source.

The linear arc source was put into operation in the end of 2001. An optimization of its work has been performed in oil-free, high vacuum conditions (10^{-6} Torr). The stable arc discharges have been obtained with the arc current as low as 50-60A. Various version of the cathode-anode system were tested. The configurations with small diameter (75 mm) spiral and tubular anode were checked also. The version with tubular anode is presented in Fig.8.

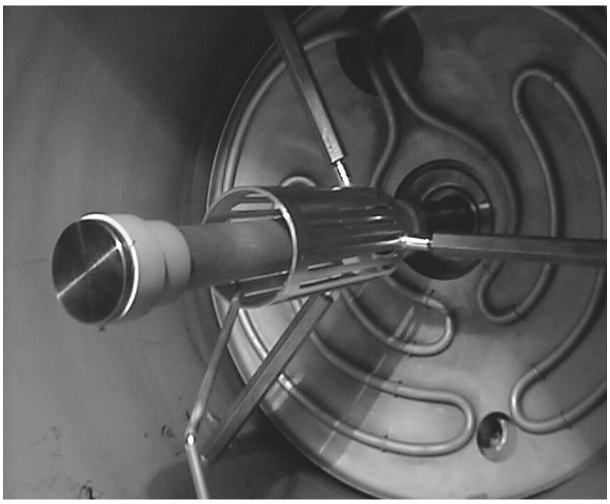


Fig.8. The linear arc source with the tubular anode.

SUMMARY

We have presented the recently obtained results on application of arc plasma for a formation of thin superconducting films. The experimental UHV apparatus equipped with planar arc sources to study the deposition of superconducting niobium films has been designed and realized. The obtained results are very promising. Prototype linear arc source as well as filtered arc source to study arc coating in actual cavity geometry is under development.

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