Available online at www.sciencedirect.com
SCIENCE DIRECT®
Physica C 441 (2006) 130–133
PHYSICA C
www.elsevier.com/locate/physc

Cathodic arc grown niobium films for RF superconducting cavity applications ☆

L. Catani [a,*], A. Cianchi [a], J. Lorkiewicz [a], S. Tazzari [b], J. Langner [c], P. Strzyzewski [c], M. Sadowski [c], A. Andreone [d], G. Cifariello [d], E. Di Gennaro [d], G. Lamura [d], R. Russo [e]

[a] *INFN-Roma2, Roma, Italy*
[b] *Università di Roma "Tor Vergata" and INFN-Roma2, Roma, Italy*
[c] *Soltan Institute for Nuclear Studies, Swierk, Poland*
[d] *University of Napoli "Federico II" and INFN-NA, Napoli, Italy*
[e] *Seconda Università di Napoli, INFN-NA, Napoli, Italy*

Abstract

Experimental results on the characterization of the linear and non-linear microwave properties of niobium film produced by UHV cathodic arc deposition are presented. Surface impedance Z_s as a function of RF field and intermodulation distortion (IMD) measurement have been carried out by using a dielectrically loaded resonant cavity operating at 7 GHz. The experimental data show that these samples have a lower level of intrinsic non-linearities at low temperature and low circulating power in comparison with Nb samples grown by sputtering. These results make UHV cathodic arc deposition a promising technique for the improvement of RF superconducting cavities for particle accelerators.

Keywords: Cathodic arc; Microwave; Niobium; Superconducting RF cavities; Thin films; Superconducting RF

1. Introduction

The superior performances and advantages of super conducting (SC) cavities for particle acceleration is now worldwide established, at the point that the project of the new International Linear Collider is based on the superconducting technology. Nowadays the SC cavities for particle acceleration are mainly based on Nb bulk technology [1]. 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 [2] and it offers well known advantages with respect to the bulk Nb one. So far though, the quality factor of magnetron sputtered cavities slopes down with increasing RF magnetic field [3], thereby limiting their applicability to the new very high energy, high field SC linear accelerators.

The reasons for the Q degradation are still a hot discussion topic and no agreement has been reached so far. Several models have been presented in the recent years to explain the Q-slope in the SC Nb cavities. In our opinion the most promising one is the model proposed by Palmieri [4] that explains most of the observed behaviour in film and bulk cavities. According to the Palmieri's picture the electron mean free path in the superconductor is the dominating parameter in determining the Q-slope for film and bulk cavities. Following this idea alternative coating techniques able to produce niobium film of high quality and purity, such as arc coating in ultra-high vacuum (UHV) [5], are extremely promising. The main advantages of arc deposition over sputtering are the highly ionised state of the evaporated material, the absence of gases to sustain the discharge and the high energy (larger than 100 eV, tunable with bias) of ions reaching the substrate surface.

☆ We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 Structuring the European Research Area programme (CARE, Contract Number RII3-CT-2003-506395).
* Corresponding author.

0921-4534/$ - see front matter © 2006 Published by Elsevier B.V.
doi:10.1016/j.physc.2006.03.028

Another possible cause for the Q degradation is the small incidence angle of arriving sputtered atoms on the cavity surface [3]. In this respect the arc deposition technique offers the advantage that ions arrive almost perpendicular to the substrate surface. Recent results show that the morphological and structural properties of films deposited by arc are not affected by the angle between the cathode and the substrate [6] as it happens for sputtered deposited films. The niobium arc grown films promise to be less sensitive to substrate roughness in respect to the sputtered films and therefore less sensitive to the sample chemical preparation.

The main disadvantage of the technique is the production of microdroplets (also called macroparticles) from the cathode material that become embedded in the film. A magnetic filter to remove macroparticles from the plasma (and therefore from the film) has been developed and a new version with possible better performance is under construction.

2. Experimental

Niobium film samples have been deposited using a planar arc set-up filtered against macroparticles. The planar arc source is housed in a UHV chamber pumped down to 10^{-10} Torr. For arc ignition one must produce a small plasma burst of sufficient density to form a high conductivity path between cathode and anode, which in our case is generated by a 50 mJ Nd-YAG pulsed laser focused onto the cathode surface. Such a triggering system provides ultra-clean and reliable ignition. A sketch of the deposition system is shown in Fig. 1; a detailed description of the deposition system can be found elsewhere [7]. The samples are deposited on sapphire and copper substrates and structural and electrical properties similar to bulk have been obtained with excellent reproducibility [5,8].

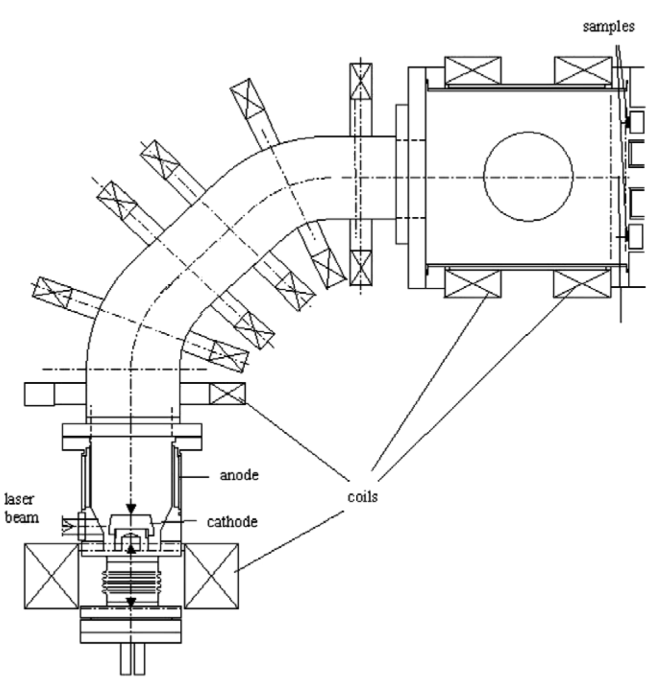

Fig. 1. Schematic drawing of the UHVCA system in the filtered configuration. The plasma is generated on the cathode and the magnetic field transport it through the chamber on the samples. The macroparticles are trapped on the chamber walls.

For the investigation of the microwave response shown by the arc produced films, we used an open-ended dielectric single-crystal sapphire puck resonator [9] excited with a transverse electric mode (TE_{011}) and operating at 7 GHz. The resonator enclosure is made of oxygen free high conductivity (OFHC) copper, as well as the sample holder, placed in the centre of the cavity in close proximity with the dielectric single-crystal. The sapphire puck is of 8 mm height and 16 mm diameter, separated by the copper wall by a sapphire spacer. The puck-to-sample distance is chosen, depending on the material under test, by using a micrometer screw. The cavity is taken under vacuum using a copper can, which includes a double layer μ-metal shield, and inserted in a liquid helium cryostat. To investigate the non-linear microwave properties, we performed in the same system configuration the measurement of the surface losses and of two-tone intermodulation as a function of the input power.

Power dependence measurements were performed using a Vectorial Network Analyser. For the measurement of IMD third order products, two closely spaced tones with equal amplitudes at frequencies f_1 and f_2 are generated by two phase-locked CW synthesisers. The signals, symmetrically separated around the centre frequency of the cavity by an amount δf, are combined and applied to the resonant structure. All IMD data presented here are taken with $\delta f = 10$ kHz, whereas the 3 dB resonance bandwidth is at least a factor 10 larger at all temperatures below T_C. The output signals coming from the cavity (the two main tones at f_1 and f_2 and the two third order IMDs at $2f_1 - f_2$ and $2f_2 - f_1$) are detected using a spectrum analyser. No amplifier is used to avoid unwanted non-linearities.

The small puck-to-sample distance (less than 1 mm) ensures a very good signal-to-noise ratio even at very low input power level. Further details are given elsewhere [9].

3. Results

We measured three Nb films 1 μm thick, deposited on sapphire, whose RRR ratio range between 20 and 40. All the samples under test have a similar behaviour as a function of power. For the sake of clarity we will show the experimental results obtained on one sample only, which is the one better and more carefully characterised. This film shows $T_c = 9.24$ K, $\Delta T_c = 0.02$ K (inductive measurement), $RRR = 30$.

The surface resistance as a function of the power circulating in the cavity P_{circ} is measured at $T = 4.2$ K. The power circulating in the dielectrically loaded cavity is evaluated using the following expression [9]: