Available online at www.sciencedirect.com
SCIENCE DIRECT®
Physica C 441 (2006) 102–107
PHYSICA C
www.elsevier.com/locate/physc

New magnetron configurations for sputtered Nb onto Cu

G. Lanza [a,c,*], J. Bermudez [a,c], A. Frigo [a,c], H. Padamsee [b], V. Palmieri [a,c], D. Tonini [c]

[a] *Laboratori Nazionali di Legnaro, Istituto Nazionale di Fisica Nucleare, Viale dell'universit 2, Legnaro 35020, Padova, Italy*
[b] *Laboratory for Elementary-Particle Physics, Cornell University, Ithaca, NY, USA*
[c] *Science Faculty, University of Padua, Italy*

Available online 27 April 2006

Abstract

Niobium sputtered film microstructure and morphology and consequently its superconducting properties, strongly depend on target-substrate deposition angle. In order to improve the Nb film quality for 1.5 GHz cavity coatings, we investigated the application of three main ideas to the sputtering process: (i) making niobium atoms impinging perpendicularly the substrate surface, (ii) promoting the effect of plasma bombardment of the growing film, and (iii) increasing the sputtering rate.

Therefore, several different sputtering configurations are under development.

The effect of Nb atoms arriving perpendicular to the substrate is explored either by using a cathode that follows the cavity shape or by increasing the plasma confinement efficiency by means of a target parallel to the magnetic field lines.

The removal of adsorbed impurities from the film surface and the increase of the film density are investigated by a biased third electrode that promotes the positive ions bombardment of the growing film. A mixed bias-magnetron has been built using a positively charged metal grid positioned all around the cathode.

PACS: 79.20.−m; 79.20.Rf

Keywords: Niobium; Superconductor; Nb/Cu; Magnetron; Bias; Sputtering; Pulsed current mode

1. Introduction

The adoption of the Nb/Cu technology at CERN for the LEP cavities and the successful operation of ALPI linac at INFN-LNL have demonstrated the feasibility of using large-scale copper accelerating cavities coated with a thin superconducting niobium film. At low fields, the BCS surface resistance of Nb/Cu cavities is lower than for bulk niobium cavities at the same RF frequency. Due to the small grain size, high process gas content and some oxygen contamination of the films, the mean free path of the sputtered Nb layer is lowered to 25–50 nm, corresponding to a residual resistivity ratio (RRR) of 10–20 [1]. This is the range where the BCS surface resistance reaches a minimum. The Nb/Cu films drawback – commonly referred to as the Q-slope problem – is that the surface resistance depends on the RF magnetic field [2].

One limit of the standard cylindrical magnetron sputtering deposition technique is the coating geometry, in fact assuming a cosine law for the atom emission mechanism, the incidence angle of the atoms on the cavity wall varies from $9 \pm 4°$ around the equator to $50 \pm 10°$ near the iris.

In a previous study a decrease in superconducting properties of niobium films has been observed when increasing the deposition angle between target and substrate, this effect is clearly due to change in the coating morphology and reproduce the film behaviour in cavity cell [3]. This dependence is confirmed by X-ray diffractometry, AFM analysis, magneto-optical images and electrochemical impedance spectroscopy.

* Corresponding author. Address: Laboratorio superconduttivit, LNL-INFN, viale dell'universit 2, 35020 Legnaro, Padova, Italy. Tel.: +39 049 8068665x666; fax: +39 049 8068817.
E-mail address: giulia.lanza@lnl.infn.it (G. Lanza).

0921-4534/$ - see front matter
doi:10.1016/j.physc.2006.03.041

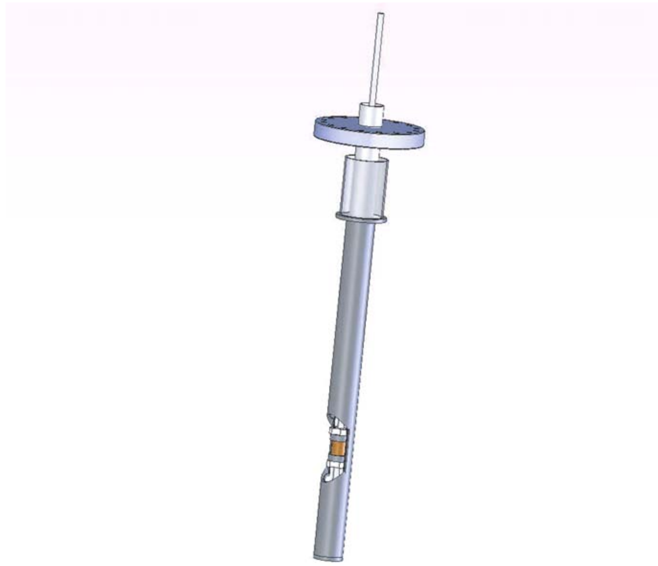

Fig. 1. Standard CERN cylindrical magnetron configuration. The cathode section shows the NdFeB magnet inside the niobium tube.

Moreover texture analysis show clearly the sputtered film directional growing: sputtered films tend to grow with the normal to the 1 1 0 crystal plane aligned to atoms arrival direction [4]. On the contrary in arc deposition the substrate is negatively biased so the electric field lines intersect the surface of substrate holder always at right angles; as a consequence ions collide nearly perpendicularly to the substrate regardless of the angle between target and substrate and preferential orientation shows no angular dependence.

To explain theoretically the thin films behaviour, the key parameters are the electrons mean free path l in normal state and the coherence length ξ. Low values of l/ξ give high Q and higher slope. For film coated cavities there is no hope to get rid of the slope, unless RRR is increased, but in this case Q values will be lower than the actual value [5].

The CERN standard film coating procedure consists of covering the inner wall of copper resonator using the cylindrical magnetron sputtering technique (see Fig. 1) [6]. The aim of the present work is to improve the film quality modifying or completely changing the coating configuration starting from three main ideas:

- making niobium atoms impinging perpendicularly the substrate surface;
- promoting the effect of plasma bombardment of the growing film in order to remove impurities weakly bonded to the surface;
- increasing the sputtering area and the plasma ionization efficiency in order to increase the sputtering rate.

2. Deposition technique: magnetron sputtering

Since film morphology is strictly correlated to the deposition angle and electrical and superconducting film properties degrade vs. deposition angle, comprehension of sputtering principles is compulsory for conceiving new magnetron configurations.

2.1. Sputtering technique

In sputtering deposition technique magnets are added to enhance the plasma ionization efficiency by increasing the electron path length: an electron in a uniform magnetic field B will drift along the field 1lines with a speed $v_{\parallel}$ that is unaffected by the field and orbit them at a gyro or Larmour radius ($r_g = 3.37 \times 10^{-6}\, W_{\perp}^{1/2}/B$), and with a gyro or cyclotron angular frequency ($\omega_c = 1.76 \times 10^{11} B$), where $W_{\perp}$ is the energy associated with the electron motion perpendicular to the field.

Near the target surface electrons are reflected by both electric and magnetic fields. Electrons tend to conserve their magnetic moment $\mu_M (\mu_M = m_e v_{\perp}^2/B)$; thus conservation of energy may cause electrons passing in the direction of $\nabla B_{\parallel}$ to be reflected by magnetic field before they reach the cathode surface.

When there is a component of electric field $E_{\perp}$ perpendicular to B, the drift of speed $v_E = E_{\perp}/B$ develops in a direction perpendicular to both $E_{\perp}$ and B and combines with the orbiting motion. This is the $(E \times B)/B^2$ drift collective motion.

Since ions have much higher mass than electrons, only the latter are affected by magnetic fields used in magnetron devices (order of 100 G). Over the range of parameter investigated, the current density at the cathode of the planar magnetron is peaked where the $E \times B$ drift is maximum. Accordingly the higher sputtering rate is achievable where the magnetic field lines are tangent to the surface, as well as perpendicular to the electric field [7,8].

2.2. Sputtering rate

The fraction f_i of impurities of species i trapped in a film is given by

$$f_i = \frac{\alpha_i N_i}{\alpha_i N_i + R} \quad (1)$$

where N_i is the number of atoms of species i bombarding unit area of film in unit time during deposition, α_i is the effective sticking coefficient of the species i during deposition and R is the deposition rate of the film. It is clear from Eq. (1) that f_i can be reduced by increasing R [9].

According to this basic principle it's possible to test some magnetron configurations starting from 2 in. circular planar magnetron. The idea is to modify the target shape as it follows the magnetic field lines. In this way the electric field is always perpendicular to the magnetic field (see Fig. 2).

Three different target shapes has been tested: planar, squared and rounded (Fig. 3). The three $I-V$ curves have been compared.