SUPERCONDUCTING SPUTTERED Nb/Cu QWR FOR THE HIE-ISOLDE PROJECT AT CERN*

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Abstract

For the foreseen intensity and energy upgrade of the ISOLDE complex at CERN (HIE-ISOLDE project) a new superconducting LINAC based on sputtered Nb/Cu Quarter Wave Resonators (QWRs) of two different beta families will be installed in the next three to five years. A prototype cavity of the higher beta family is currently being developed. In this paper we will discuss the latest developments on the sputtering technique for this kind of cavity geometry. First cold RF measurements will be reported.

INTRODUCTION

An energy upgrade of the ISOLDE Radioactive Ion Beams facility is planned at CERN for the next 3-5 years [1]. Part of the present normal conducting linac will be replaced by new superconducting cavities of the quarter wave resonator (QWR) type in order to boost the energy of the machine from 3 MeV/u up to 10 MeV/u with beams of a mass-to-charge ratio of 2.5<A/q<4.5.

The new accelerator is based on two gap independently phased 101.28 MHz Nb sputtered superconducting QWRs and more details about this choice are given elsewhere [2]. Two cavity geometries, "low" and "high" β, have been selected for covering the whole energy range.

Up to now the work at CERN has concentrated on building a facility for the coating of the QWR "high" β resonators. After several tests on samples, the first cavity was measured at the TRIUMF cryogenic and RF facility in Vancouver. A second coating has now been performed on this cavity which is ready to be measured at the CERN.

COATING TESTS ON COPPER AND QUARTZ SAMPLES

CERN has designed and prepared new facilities for the surface treatment and the niobium sputter coating of the HIE-ISOLDE superconducting cavities. A detailed description of the pumping system and the cavity and cathode assembly are reported elsewhere [3], and will not be repeated here. Several tests were carried out in different coating configurations which will be discussed in detail in the next four sections.

Biased Magnetron Sputtering at 0.015 mbar

At the very beginning preliminary test with biased diode configuration showed a non homogeneous distribution of the plasma so that it was decided to test a cylindrical magnetron configuration. The magnetic field keeps the plasma stable on the outer side of the cathode while, inside the cathode, the plasma is extremely enhanced giving rise to an efficient sputtering as it will be shown in the following paragraphs.

The major part of the magnetron sputtering test and the first cavity coating were performed at 0.015 mbar, keeping the cavity either grounded or biased at -80 V.

Biased Magnetron Sputtering at 0.003 mbar

As described later in the text, the tip of the inner conductor of the coated cavity was affected by film peel-off.

To explore the possible causes several simulations with the Molflow+ code (based on the monte carlo method and a 3D raytracing algorithm) were run to study the sputtering rate on the internal conductor tip. The obtained response indicates that, considering a uniform erosion rate of the cathode and a cosine like angular distribution of the sputtered atoms, the number of niobium atoms arriving on the cavity surface should be uniform all around the tip of the internal conductor. This result suggests that the thickness degradation on the inner conductor tip is not due to the increasing distance between the cathode and the cavity, but that the niobium atoms arrival is mainly limited by collisions with the gas atoms. Tests were thus performed reducing the coating pressure down to 0.003 mbar.

Bias Diode Sputtering

The plasma instability encountered at the beginning were completely eliminated with an upgrade of the power supplies and changing the electrical circuit connecting the cavity, the cathode and the grids. Applied bias was always -80 V.

Combined Sputtering Configuration

To obtain a homogeneous distribution of the film thickness along the cavity walls a combination of the bias diode sputtering followed by magnetron sputtering was tested. The diode to magnetron coating time ratio was selected as 5:2 and the inner grid was installed in the system in order to reduce the sputtering rate on the internal conductors. In fact it was experienced that the insertion of a grid inside

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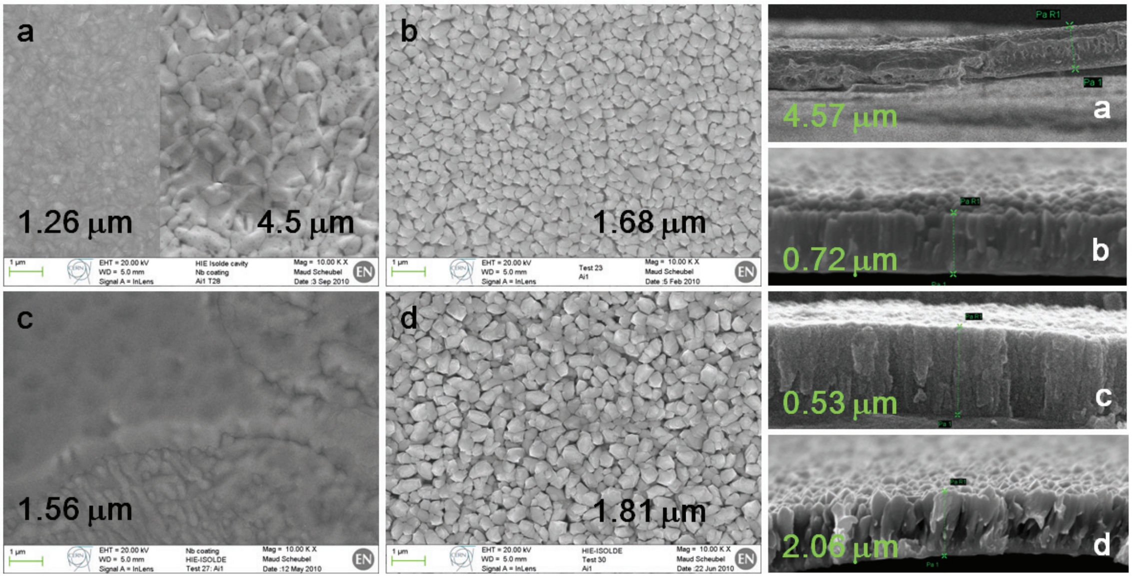

Figure 1: SEM images of: a) Biased Diode sputtering; b) Biased Magnetron sputtering at 0.015 mbar; c) 5 hours of Diode Sputtering followed by 2 hours of Magnetron sputtering; d) Biased Magnetron sputtering at 0.003 mbar. Insets in the figures are the coating thickness.

the cathode cuts completely down the plasma in magnetron mode: the electrons are all attracted by the positive grid and no plasma ignition is possible.

Results

During the first part of the R&D program the tests were performed with a stainless steel dummy cavity with a shape similar to the QWR. Quartz and copper samples are positioned along the sampleholder, on representative places of the cavity: internal wall, tip of the inner conductor, outer wall and top part where the inner conductor is welded to the cavity outer wall.

Table 1 shows the sputtering rate of each configuration. In the diode configuration the deposition rate is higher on the external wall and on the bottom part of the cavity. The biased magnetron sputtering configuration has a higher sputtering rate inside the cathode. Decreasing the pressure produces an increase of the rate on the top and the tip but doesn't play a role for the rate on the outer wall.

A good combination of sputtering rate could be obtained combining the two technique but we still don't know how the morphology will affect the cavity performances. In fact, as shown in figure 1 the surface aspect of samples coated with diode and magnetron sputtering are extremely different.

COLD TEST OF THE FIRST CERN COATED QWR

Cavity Preparation

The first CERN QWR was coated with a biased magnetron sputtering configuration. The parameters of the coating are: pressure 0.015 mbar, cavity biased at -80 V, cathode current 3 A, coil current 40 A producing a magnetic field of 100 G on the cathode surface. After the coating the cavity was rinsed with ultrapure water at low pressure (6 bar).

RF tests were performed at the TRIUMF SCRF lab in Vancouver, Canada. The cavity was shipped with the tuning plate already installed and it was inserted in a plastic bag backfilled with filtered nitrogen gas to prevent contamination of the sputtered surface. The cavity was then prepared for installation in the test cryostat by a low pressure water rinsing and then mounted into the cryostat. During rinsing a small fraction of the Nb coating of a ring shape peeled off from the tip of the inner conductor, in the high electric field region. It was decided to proceed with the RF test anyhow.

Cooldown

The cavity was inserted in the cryostat, pumped and precooled by filling the heat screen with ℓN2. After one night

Table 1: Sputtering Rate (nm/min) for Each Configuration. The values are calculated from X-Ray Fluorescence thickness measurements.

Configuration Position	Diode	Magnetron High p	Combi	Magnetron Low p
Inner	4.5	6.5	2.9	10.6
Tip	0.6	1.4	1.0	3.7
Outer	2.4	1.4	4.1	1.9
Top	4.2	1.7	4.5	6.2

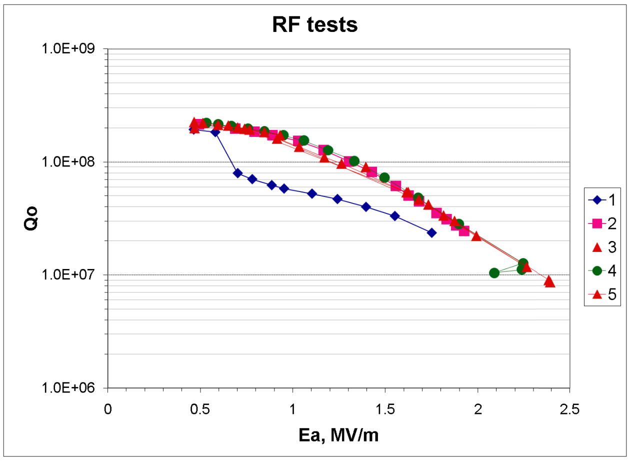

Figure 2: Q vs E measurements. The first measurements showed a Q switch effect that has not been observed in further tests

the vacuum reached about 2*10e-6 Torr and the heat screen was at 100 K. A small tube in the inner conductor let then ℓHe cool the cavity from the lower point of the central conductor, initially by spraying cold gas inside it and then by building up liquid. The cavity cool down process lasted nearly 3 hours. The maximum temperature gradient in the cavity during cool down was around 80 K (between the top and the bottom). Unfortunately a cryogenic problem with the cold box resulted in a sudden reduced capacity to produce more liquid and the cool down process was stopped. The cavity was left without refilling and warmed up during the night up to 100 K. When the cavity reached 4.5 K the vacuum level was 5e-9 Torr. The problem with the cryogenics was then solved overnight and the new cool down of the cavity lasted less then 30 minutes from 100 K to 4.5 K.

RF Conditioning

As soon as the temperature stabilized the RF power was applied but the test stopped due to a strong multipacting barrier at very low field. Cavity conditioning with high power pulsing (up to 400 W from the amplifier) with the intent to punch through this level was not successful. The cavity was equipped with a fixed RF coupler and hence it was not possible to overcouple more and have a faster rise of the power in the cavity. A successful method to pass by this barrier was then to warm up the cavity above 20 K and cool down again. On the subsequent high power pulse the first multipacting level was overcome. The conditioning of the cavity was however not very efficient and it was possible to pass through the low level barrier ($\sim$ 50kV/m corresponding accelerating field) only with high power pulse.

RF Measurements

Q-E measurement were performed each time it was possible to pass through the low multipacting barrier and results are showed in figure 2. The measurements reveal a lower than expected Q-value at low field, and a steep slope. The measurements were quite repeatable and a 2MV/m maximum gradient was reached. The achievable value was limited by the amount of power available in the amplifier. The copper substrate proved to be a very good thermal stabiliser as even with the highest power pulses the cavity never quenched and different points of the cavity showed always quite stable temperatures.

Other parameters of the cavity were investigated, namely the Lorentz force detuning and the sensitivity to ℓHe pressure difference and found respectively $k = -9.5$Hz/(MV/m)^2 and δf=-1.3Hz/Torr. In addition the measurement of the microphonics noise allowed to detect the stronger mechanical resonances of the cavities which are at at 40, 70 and 100 Hz.

THE SECOND CERN QWR COATING

The cavity measured in Vancouver was stripped and chemically treated to undergo another coating. To improve film adhesion the coating was preceded by a soft sputter etching of the cavity surface. The coating was then made by biased magnetron sputtering and performed for one hour at a lower pressure (0.003 mbar) to guarantee better uniformity on the tip of the inner conductor and higher atom energy to improve mobility and hence adhesion. Pressure was then increased to 0.015 mbar to ensure good film quality and overall thickness uniformity as already demonstrated on sample testing. The coating did not show any peel-off after high and low pressure water rinsing.

CONCLUSIONS

Several test coatings have been performed, with different configurations and parameters. A uniform coating thickness is obtained guaranteeing a good RRR in all the "critical" position where the electromagnetic field is high.

The first niobium coated copper cavity performed unfortunately below specifications. An evident peel-off from the tip of the central conductor was certainly at least in part cause for the performance degradation. This problem was overcome with a change of sputtering parameters and the cavity is at present ready to be tested. A new copper cavity, dedicated entirely to the coating test, is under construction and it will allow focussing directly on the correlation between the coating parameters and the cavity performances.

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