HIE-ISOLDE SRF DEVELOPMENT ACTIVITIES AT CERN

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Abstract

The HIE-ISOLDE project has initiated a new development phase in the SRF domain at CERN. In particular, the HIE-ISOLDE project aims at the construction of the 32 Quarter Wave Resonators using the Nb on Cu sputtering technology. This paper describes the refurbishment of the test infrastructure and the activities from the cavity production to the cold test, including quality assurance procedure for the correct handling of the resonators.

INTRODUCTION

An energy upgrade of the HIE-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 quarter wave resonator (QWR) cavities type in order to increase the energy of the machine from 3 MeV/u 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 Nb sputtered superconducting 101.28 MHz QWRs with independently phased gaps; 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 and the RF test of the QWR “high” β resonators.

QWR COATING FACILITY

Surface Treatment

Surface preparation prior to coating will be carried out by SUBU chemical etching [3]. After 20 µm removal the surface presents an average roughness Ra of 0.8 µm. The whole procedure takes about two hours. The cavity low pressure rinsing is performed in a class 100 clean room with ultrapure water at 6 bars with a monitoring of the resistivity, total organic carbon (TOC) and particles number in the water. After the coating, the cavity is rinsed at 6 bars with pure alcohol in a soft wall cleanroom ISO 5 and covered by a plastic bag in a nitrogen atmosphere.

An automated rinsing system is being studied in order to obtain an efficient rinsing (repeatability) of the cavity at high pressure (up to 100 bar) without risk of scratch and with monitoring of the water quality during the rinse.

Coating System

All parts of the coating system and the copper cavity are conditioned in an ISO 5 soft wall clean room (“baldaquin”) and assembled inside an ISO 5 clean room [3]. The closed chamber is then connected to the pumping system outside the clean room.

The coating chamber is pumped by a primary and a turbo-molecular pump and it is connected via a by-pass to a Residual Gas Analyser (RGA) system. The evacuation of the chamber from atmospheric pressure down to a few mbar is regulated by a flow controller in order to avoid turbulences.

A bake-out of the chamber is done at 120 °C. After 48 hours, the base pressure is around $5x10^{-9}$ mbar.

The cavity is cooled during coating with compressed air at 5 atm blown in a circuit inserted in the central shaft. In case of high coating power (more than 1 kW) a flow of a refrigerant liquid is used to cool the cavity and keeps its temperature around 120 °C.

The temperature is monitored by thermocouples fixed to the external wall of the cavity.

Coating tests were carried out in several configurations and will be presented below. For the two techniques the cavity is slightly negative (around 80 V) in order to assure a soft re-sputtering of the growing film.

Biased Diode and Magnetron Sputtering

The technology for niobium on copper QWRs started by developing the DC Bias Diode Sputtering technique: the cylindrical cathode is surrounded by an external and an internal grid. The cathode is biased negatively and the grids are grounded [3]. The plasma instability encountered initially is now completely eliminated.

For the magnetron sputtering, a multilayer coil is used with a magnetic field around 100 G parallel to the cathode. The main advantages of this configuration are: stable plasma, improvements on the thickness, more homogeneous distribution of the plasma between the external wall and the internal conductor [3].

The upper rounded part of the HIE-ISOLDE cavity is critical due to the presence of welds and the highest field during operation. In order to improve the coating rate in this critical area, a Nb torus at the top of the cathode was added. In fact ionization efficiency is higher when the electric field is perpendicular to the magnetic field.

The first coating tests showed a peel-off on the tip of the inner conductor [4]. To improve film adhesion, the coating is preceded by a soft sputter etching of the cavity surface followed by a one hour biased magnetron coating at 0.003 mbar. The coating did not show any peel-off after high and low pressure rinsing.

An endoscopic system is used after coating in order to perform an inspection of all the surfaces and welds of the cavity, avoiding scratching during the inspection.

Latest Tests of Nb Coating

The CERN facilities for the construction and the coating of QWR of the HIE-ISOLDE project are completely operational. For the coating it was chosen to maintain the cavity temperature around 150 °C based on optimal results obtained at CERN (R_{res}, effect of Earth's field) and for mechanical stability. The previous tests realized on copper and quartz samples showed a low RRR value (around 7-8). In order to improve the RRR in all the "critical" area where the electromagnetic field is high, tests were done by boosting the coating rate. In the first test we let the temperature increase. All parameters used for the coating are reported in the table 1.

Table 1: Parameters for Nb coating on copper and quartz samples

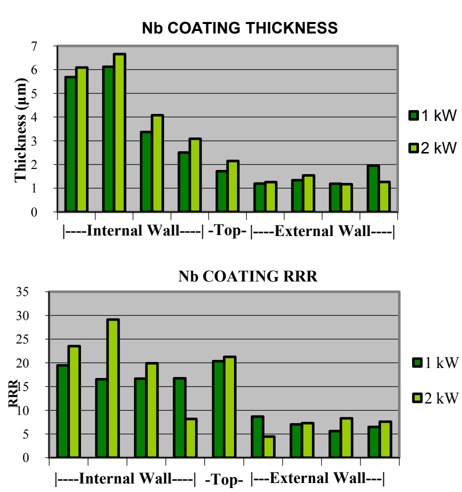
	Biased Magnetron sputtering		**Biased Diode sputtering**	
Coating power	**1kW**	**2kW**	**1kW**	**2kW**
Pressure (mbar)	5.1×10^{-3}		0.15	0.16
Temperature °C	280	360	260	340
Coating time	8 h 30′	4 h 15′	31 h	15h30′
Thickness	1 µm	1 µm	0.5 µm	0.5 µm

To measure the critical temperature and the RRR of niobium coating on quartz samples, a fixed four points probe is used.

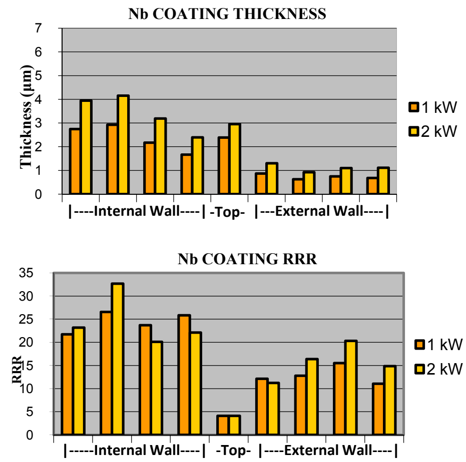
The thickness and the surface of the Nb coating on sample (quartz and copper) are determined by X-ray Fluorescence (XFL) technique and by Scanning Electron Microscopy (SEM).

Figure 1 presents the thickness and the RRR value obtained for 1 kW and 2 kW for magnetron (a) and diode (b) coating. We can see that we had increased the coating rate by a factor two for the two configurations, with always a ratio around four between the inner conductor and outer wall due to the geometrical factors.

The RRR values obtained are around 20 on the inner conductor, but remain low on the outer wall, around 7-8, where the thickness is smaller. To improve the thin layer properties and to have an homogenous RRR value on all positions of the cavity, future studies will include the use of liquid cooling in order to increase the coating power and keep a coating temperature around 150 °C.



(a)



(b)

Figure 1: Thickness and RRR value obtained for coating power of 1 kW and 2 kW without cooling, on copper and quartz samples by biased magnetron (a) and diode sputtering (b).

RF TEST QWR FACILITY AT CERN

RF Test Stand for HIE-ISOLDE Cavity

To validate the RF performance of the cavity, an insert was designed and manufactured at CERN [5]. The insert is composed of a Helium tank on which the cavity is fixed, and a heat shield circuit connected in series with the cavity cooling by a flexible tube. There is a single vacuum system, i.e. the insulation vacuum is the same as the cavity vacuum. To avoid dust and pollution, the cavity is mounted on the insert in an ISO 5 soft wall clean room, inside which we can monitor the particle count during the installation. The entire insert with the support is covered by a plastic bag and then brought to into the cryostat area.

To keep the benefit of clean room assembly when connecting the insert to the heat screen and inserting the cavity into the cryostat, a metallic structure closed with PVC curtains had been installed around the HIE-ISOLDE cryostat area (Figure 2) [6].

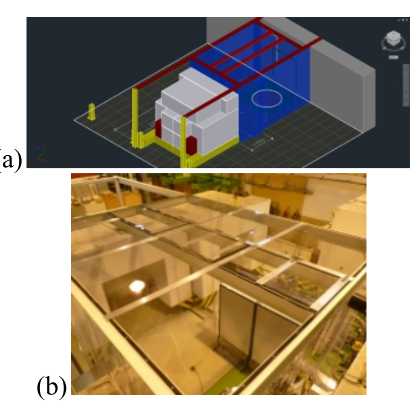

(a) (b)

Figure 2: (a) Schematic view and (b) picture of the vertical cryostat area with the clean space for HIE-ISOLDE RF test at CERN.

The laminar flow, still covering the cryostat, injects fresh and clean air inside this clean space, and therefore increases the general cleanliness by diluting the particle concentration. First particle measurements show an improvement by an order of magnitude of the particle concentration and lead to a cleanliness level close to ISO 5.

The cryostat is pumped by a primary pump to a level of 10^{-2} mbar and subsequently by a turbo-molecular pump. The operational cavity vacuum is around 10^{-5} mbar.

The Helium is provided to the cryostat where its level is kept constant in a tank sitting right above the cavity. Then the liquid Helium is filling the cavity. The heat exchange to the cavity is increased by a "thermosiphon" mechanism [5]. The tank evaporated Helium gas is used to cool down the thermal screen. The cavity cool-down is done after the thermal shield and the tank reach their nominal cryogenic temperature. Thus the residual gas is cryo-pumped on the thermal shield and the reservoir.

During cool-down, the temperature is monitored by seven thermometers: one on the tuning plate, one in the antenna, one on the liquid He tank, two on the cavity side and three on the thermal shield. The Helium level is monitored by sensors installed inside the tank and the antenna.

The cavity cool-down process lasted nearly 5 hours. After the cool-down, the pressure is around 10^{-8} mbar; the cavity and the thermal shield temperature are respectively 4.5 K and 50 K.

RF Tests

When the temperature is stabilized, RF power is applied. The latest tests were realized on two copper cavities Q1 and Q2. The temperature was maintained at 160 °C. The coating parameters are summarized in Table 2.

Table 2: Parameters for Nb coating on HIE-ISOLDE QWR copper cavities Q1 and Q2.

	Biased Magnetron sputtering		**Biased Diode sputtering**
Copper cavity	**Q1(series1 and 2)**	**Q2**	**Q1**
Pressure (mbar)	1.5 10^{-2}	0.8 10^{-2}	1.5 10^{-1}
Coating power	0.8 kW	0.9 kW	0.8 kW
Time	8 h 20'	8 h	38 h
Thickness	1 µm	1 µm	0.5 µm

During the test, we saw a strong multipacting barrier at very low field (≈ 60 kV/m). We tested different coupler positions to see if it was helpful to overcome this multipacting barrier, but tests were not conclusive. A successful method to pass by this barrier was to give a high power pulse (+20 db). Figure 3 shows the *Q*-value as function of the accelerating field for the different tests. The four *Q* (Eacc) curves obtained are lower than the expected value $Q = 5{\cdot}10^8$ at 6 MV/m (red point in Figure 3), with a maximum accelerating field around 2 MV/m. We can see that at low field, the *Q*-value is as expected for the test series 1 (black crosses) and not so far off for the series 2 (blue diamonds). But the curves have a steep slope when the accelerating field increases. For the diode test (orange squares), the *Q*-value is also lower with a flat curve. The best value was obtained with the Nb coating on Q2 with the magnetron sputtering method (green triangle). Unfortunately, we had to stop the RF test due to a Helium leak on the insert.

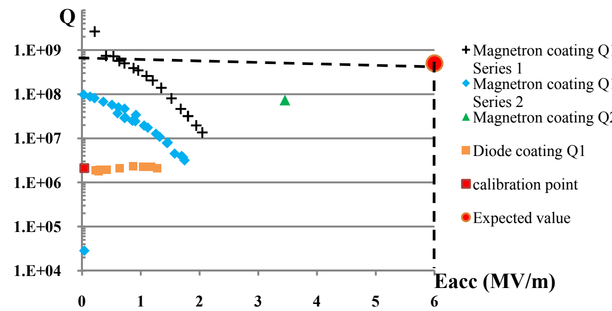


Figure 3: *Q* (Eacc) for different Nb coatings on copper QWR cavities. The red point is the *Q* value expected: 5.10^8 at 6 MV/m for the HIE-ISOLDE QWR cavity.

CONCLUSIONS

The CERN facilities for the construction, coating and testing of QWR cavities for the HIE-ISOLDE project are operational.

The first RF tests showed lower performances than expected. The cavity optimization is still in progress. Future studies for the coating aim at increasing the coating power and at homogenizing the niobium film RRR. Improvements are planned for the RF test facility: a new cryogenic line expected for next year, a better monitoring of the cavity temperature will be done by increasing the thermal contact between the cavity and the thermometer. A third copper QWR cavity is planned with a new design to increase the stability, to reduce sensitivity to the Helium pressure fluctuation and to lower the number of welds.

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