CURRENT STATUS OF THE ALPI LINAC UPGRADE FOR THE SPES FACILITIES AT INFN LNL

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Abstract

The SPES (acronyms for “Selective Production of Exotic Species”) project is based at INFN LNL and covers basic research in nuclear physics, radionuclide production, materials science research, nuclear technology and medicine. The Radioactive Ion Beam (RIB) produced by SPES will be accelerated by ALPI (acronyms for “Acceleratore Lineare Per Ioni” in italian), which is a linear accelerator, equipped with superconducting quarter wave resonators (QWRs) and operating at LNL since 1990. For RIB acceleration it is mandatory to perform an upgrade of ALPI which consists of the implementation of two additional cryostats, containing 4 accelerating cavities each, in the high-ß section. The QWRs production technology is well established [1]. The production technology of Nb/Cu QWRs should be adjusted for high-ß cavities production. In the framework of the upgrade, several vacuum systems were refurbished, optimal parameters of the biased sputtering processes of copper QWR cavities and plates were defined. The process of mechanical and chemical preparation, sputtering and cryogenic measurement of the high-ß Nb/Cu QWR cavities were adjusted. Several QWR cavities were already produced and measured. Currently, the production of the Nb/Cu sputtered QWR cavities and plates is ongoing.

INTRODUCTION

SPES is a new ISOL facility, dedicated to the production of neutron-rich beams. The main aim of the SPES Project is to provide high intensity and high-quality beams of neutron-reach nuclei for the performing of the research activity in nuclear physics, reacting beams and interdisciplinary fields like medical, biological and material science [2].

The SPES facility starts with proton cyclotron by producing exotic species via the nuclear fission. The beam is delivered after, through the Wien filter and a high-resolution mass separator to the charge breeder (CB). The CB, followed by the Continuous Wave RFQ is the front-end part of the radioactive ion beam injector, after which the ion beam is delivered to the superconducting linac ALPI for acceleration. After the acceleration, RIB species of interest are delivered into three experimental halls of LNL. For accelerating RIB species of interest to the experimental halls, the ion beam should gain final energy $E_f \sim 10$ MeV/A [3].

The ALPI LINAC is a superconductive accelerator, based in Legnaro National Laboratories from the early 1990s. The linac is combined from three sections (low-β, medium-β and high-β branches) of the superconductive quarter wave resonators (QWRs) depending on the different velocity of the beam on its path. From the operation with lead electroplated QWRs at the beginning, ALPI linac was under continuous upgrade of the number of cavities and of the replacing of lead electroplated QWRs with sputtered niobium [4]. Upgrades in the numbers and performances of the ALPI cavities were made to increase the accelerating energy of the linac [2].

For its use as RIB accelerator for the SPES facility, an ALPI linac upgrade is required in transition and final energy. Part of the total ALPI upgrade is the upgrade of the high-β section, concerned the implementation of 2 new cryostats (4 QWRs each) in the end of the branch. Increasing of the QWRs number in high-β section will optimise the accelerating energy for the lightest ions and increase the final energy of the linac in total [5].

To perform the ALPI linac upgrade in the high-β section 8 new Nb/Cu superconductive QWR cavities are in production. The ALPI linac operates at the working power 7 W. The target performance of the produced QWRs is the following: quality factor (Q_0) is 10^9, energy of the acceleration field (E_{acc}) at 7 W higher than 4.5 MeV/m with quality factor at 7 W in the order of magnitude 10^8. The current status of production and low-temperature measurement of the high-β Nb/Cu superconducting ALPI QWR cavities for the ALPI linac upgrade will be described in this paper.

EXPERIMENTAL PART

Mechanical and Chemical Treatment

A Copper substrate for different QWR cavities was machined with two different techniques: lathing from bulk copper billet (cavities № HB5, HB6, HB7 and HB8) and deep drawing technique (cavities № DD0 and DD1).

The R&D activity on the deep drawing technique for the cavity substrate preparation is ongoing because of the possible advantages of this method. With the deep drawing technique, indeed, a seamless copper substrate can be produced with lower amount of copper material and easier machining process in general. Nevertheless, the influence of the copper substrate, machined by the deep drawing technique, on the performance of the Nb/Cu QWR cavity should be evaluated.

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After machining, the preparation of the substrate surface was done. Mechanical, chemical and electrochemical process were used. The Parameters of the surface preparation of the copper substrate are mentioned in Table 1.

Table 1: Parameters of the Substrate Preparation Methods

№	**Preparation method**	**Parameters**
1	Tumbling	12 hours
2	Electropolishing	Solution (H_3PO_4, Butanol)
3	SUBU treatment	Solution (Sulfamic acid, ammonium citrate, butanol, H_2O_2)
4	Passivation	Solution (sulfamic acid)
5	High Pressure Water Rinsing	

QWR Plates and Cavities Deposition

For the deposition of niobium coating on the QWR plates, the sputtering vacuum system was upgraded. After SUBU chemical treatment, passivation and high-pressure rinsing, the copper plates were mounted to the sputtering vacuum system. The Sputtering parameters of the QWR plates deposition process were defined experimentally [6] and are mentioned in Table 2.

The Definition of the sputtering parameters for the QWR cavities deposition was done, using quartz samples as a test substrate. Due to the complicate circular geometry of the QWR, it was necessary to define sputtering parameters for the deposition niobium coating with the close thickness along the internal cylindrical surface of the resonator. Quartz samples were placed in different positions of the stainless-steel mockup cavity (Fig. 1) and test sputtering processes were made. The next step was the evaluation of the thickness and the deposition rate in different places of the substrate surface. The influence of the cathode current on the deposition rate of the niobium coating was defined (Fig. 2).

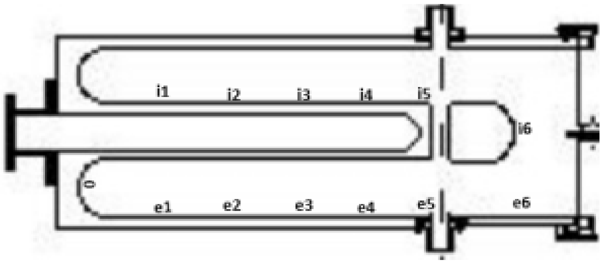

Figure 1: Placement of the quartz samples on the inner (i), outer (e) and zero (0) position of the cavity.

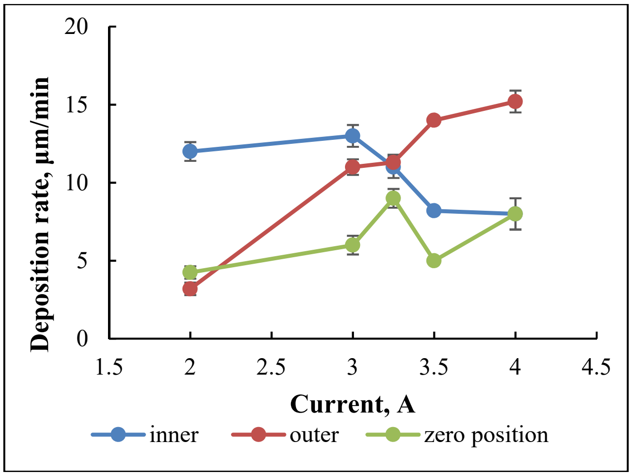

Figure 2: Deposition rate as a function of the sputtering current [7].

The closest deposition rate and thickness of the deposited niobium coating among all the QWR substrate was obtained with the sputtering current of 3.25 A. The defined sputtering parameters (Table 2) were used for the QWR deposition.

After the substrate preparation, cavities were assembled on the sputtering system. The optimal parameters for the process of high-β ALPI QWR sputtering were defined experimentally [7]. Baking and sputtering processes with the following parameters (Table 2) were done.

Table 2: Parameters of the Baking and Sputtering Processes of the ALPI QWR Cavities and Plates

	Baking process	
Parameter	Cavity	Plate
Chamber temperature, [°C]	120 – 200	100 - 120
Substrate temperature, [°C]	400 – 450	300 – 350
Time, [hours]	72 - 96	
	Sputtering process	
Sputtering pressure, [mbar]	0,1 – 0,2	
Cathode current, [A]	3,25 – 3,5	12 – 14
Bias voltage, [-V]	120 – 130	100 – 120
Sputtering cycle time, [min]	15	6
Number of cycles	16 – 20	10 – 12
Initial cavity temperature, [°C]	300	200

ALPI QWRs RF Characterisation at Low Temperature

The sputtered plates were assembled to the coated QWRs. After that, the whole couple was mounted to the cryostat and the preparation to the low temperature measurements was held.

The baking of the resonator was made for outgassing and purifying the surface of the cavity before the low temperature measurements. High and low temperature cavity conditionings were made for reducing the multipacting effect and stabilising the cavity signal. The cooling down of the cavity from room temperature to superconductive state was made in two stages: the first stage with the liquid nitrogen (temperature decreased from 350 K to 73 K) and the second one with the liquid helium (temperature decreased from 73 K to 4 K). After the setup, low-temperature measurements of the cavity were performed to characterize it in the superconducting state.

In the case where the performance of the cavity in the superconducting state does not meet the target performance of the high β Nb/Cu QWRs provided by the ALPI specifications, the niobium surface is chemically removed by the stripping process [8].

RESULTS AND DISCUSSION

Following the methodology of production and measurement of the ALPI QWR cavities and plates, 5 cavities have been produced and measured to date at LNL. The dependence of the quality factor to the energy of the acceleration field of the measured cavities is showed in Fig. 3.

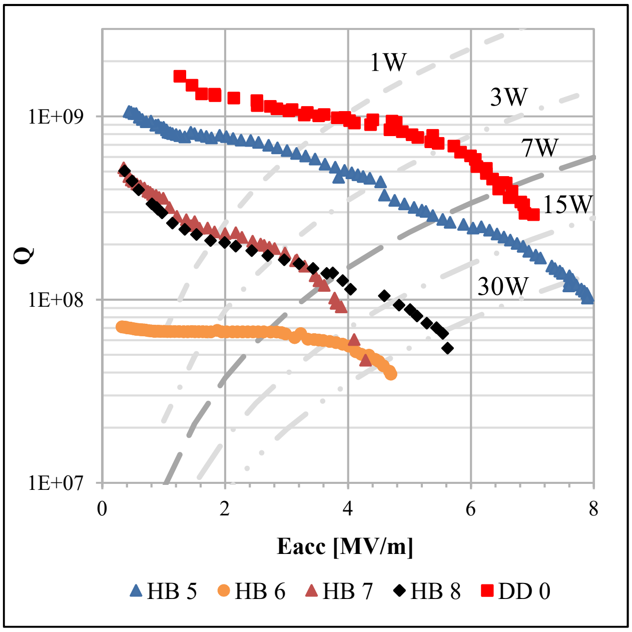

Figure 3: Q-slope of the measured ALPI QWR cavities.

From the Q-slope of the measured cavities it is seen that at the beginning of the slope there is a drop of the quality factor value. This can be connected with the bad thermal and electrical conductance between QWR cavity and the plate.

The results of the low temperature measurement of the cavities are mentioned in Table 3.

Table 3: Low Temperature Measurements Results of the Produced ALPI QWRs

Cavity №	Q_0	Eacc 7W, [MV/m]	Q (at 7W)	ΔT (plate – cavity)
Target		>4,5	>E+8	
DD 0	1,1E+9	6,7	3,9E+8	1,7
HB 5	7,6E+8	5,5	2,8E+8	1,66
HB 8	1,5E+8	3,8	1,4E+8	2
HB 7	3,2E+8	3,7	1,35E+8	2,8
HB 6	7,6E+7	2,6	6,7E+7	3,2

For the better control of the low-temperature measurement process, several thermometers were placed in different positions of the cavity and plate. After the data analysis of the low temperature measurements and thermometers signal it was observed a dependence between superconductive properties of the cavity and temperature difference between cavity and plate. With the increasing of the temperature difference, the energy of the acceleration field and the quality factor of the measured cavities at 7 W decreased.

The protocol for the cavity assembling required upgrade for providing stable contact between plate-cavity surface, homogeneous temperature and electric contact between the superconducting surfaces of the couple. View of the upgraded plate-cavity mounted system is shown in Fig. 4.

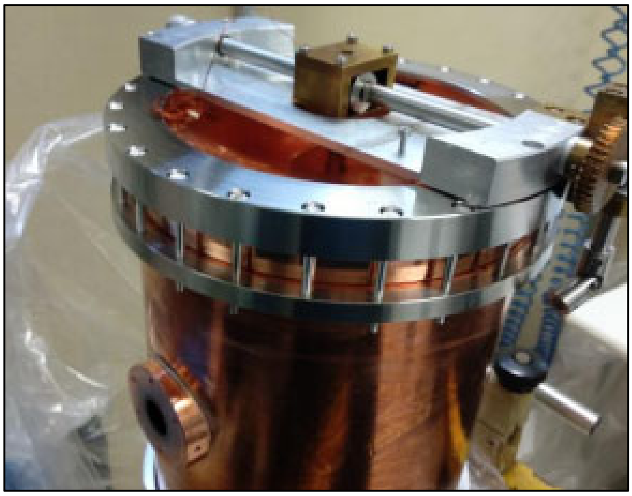

Figure 4: Upgraded cavity-plate fixing system.

The updating of the assembling system has increased and uniformed the contact force between the two Nb coated surfaces of the plate and the cavity in order to guarantee a good electrical and thermal contact. Within the upgrade, the amount of screws for the plate-cavity fixing was doubled and the system was tightened with a torque wrench with the force of 3.2 N.m. New plate-cavity mounting system was already designed and machined and will be tested in the near future.

According with superconductive cavity measurements, HB5, HB8 and DD0 cavities show slight dependence of quality factor with respect to the increasing of the acceleration field energy.

HB6 cavity shows low superconducting performance, but the quality factor of this cavity was stable with the increasing of the acceleration field energy. Q-slope of the HB7 cavity shows strong dependence onto the energy of the acceleration field and non-appropriate superconductive performance to the target of the ALPI linac upgrade project. Niobium film of the cavities HB6 and HB7 will be stripped. After stripping, surface of these cavities will be treated chemically, and cavities will be re-sputtered.

Superconductive measurements of the cavities show the highest performance for the DD0 cavity. Copper substrate of the DD0 cavity was machined with the deep drawing technique. For confirming the positive influence of substrate machining within deep drawing technique on the superconductive performance of the QWRs, a new DD1 cavity produced with the same techniques will be sputtered and measured in the nearest future.

CONCLUSIONS AND FUTURE ACTIVITY

In the framework of the ALPI linac upgrade for the SPES facility 5 cavities at LNL were sputtered and measured.

Several produced cavities (DD0 and HB5) show appropriate superconductive properties to the target performance of the QWRs for the ALPI upgrade project. One cavity (HB8) will be re-tested. Other cavities (HB6 and HB7) will be re-sputtered.

The measurement of the cavity DD0 with copper substrate, made with deep drawing technique, shows promising results. SC properties of these cavity were the highest within the other cavities. However, the influence of the substrate machining technique on the superconductive properties should be confirmed by production and measurement of the other cavity with the same machining technique (DD1).

An upgrade of plates fixing system to the cavities is developed and will be tested.

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