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NEW PROGRESS FOR Nb SPUTTERED 325 MHz QWR CAVITIES IN IMP*

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Abstract

Comparing with bulk niobium cavities, the Nb/Cu cavities feature a much better stability at 4.5 K. Last year, two 325 MHz QWR copper cavities coated with biased DC diode sputtering Nb for CiADS has been accomplished at IMP. But vertical tests showed the cavities had low Q_0 at 4.2 K. In order to improve the coating quality, a new coating system was designed and built. The sputtering target was redesigned and manufactured. With more coating parameters controllable, the thin film SRF group at IMP started a new round of coating optimization at the beginning of year 2019. Besides regular parameters, including power, Ar pressure, and temperature during coating the coating process, we found an unsymmetrical structure can significantly improve the film quality. The paper covers resulting film characters with the evolution of the sputtering process, and improvements we made since last year.

INTRODUCTION

The operational stability of SRF cavities is one of the foremost challenges that hinder CiADS linear accelerator from continuous running. Let Nb/Cu cavities replace the bulk niobium cavities could be an effective solution, because Nb/Cu cavities come up with advantages in terms of both thermal stability and mechanical stability [1]. At 4.2 K, the heat conductance of high purity bulk Nb is about 75 W/(m·K), while the number is as high as 300-2000 W/(m·K) for high purity oxygen free copper [1]. The poor thermal conductivity of Nb put an upper limit for SRF cavity wall thickness, in order for the inner surface to be effectively cooled, which impairs the mechanical strength of SRF cavities. Replacing bullk Nb cavities with Nb coated thick-wall copper cavities can effectively solve the major problems from both the poor thermal conductivity and the weak mechanical strength at the same time. Furthermore, Nb/Cu cavities are more economic than bulk Nb cavities in terms of fabrication and processing cost. The material cost for OFHC copper is only about 4% of the cost for SRF grade bulk Nb. In addition, copper is easier to anneal, polish, and machine than niobium, the cavity processing cost for Nb/Cu cavities would be much lower than that for bulk Nb cavities [1].

IMP launched its Nb/Cu cavity project in 2016. Two dummy QWR cavities had been produced and coated with an existed diode sputtering system to understand the sputtering setup and process last year. According to the results of experiment last year, a new coating system was redesigned and built, and the coating parameters were re-selected to obtain a Nb/Cu cavity with better RF performance.

IMPROVEMENT IN SYSTEMS

The new coating system employed in this project is modified from coating setup at NIN, which produced the first Nb coated copper QWR at IMP [2]. The most important modification is adding an extra bias electrode and having a larger coating chamber. Figure 1(a) showed the outlook of this new system. Same as the experiment last year, a 325 MHz QWR dummy cavity without a beam line was used for the purpose of R&D tests [2]. The dimension of the dummy cavity is shown in Fig. 1(b). A QWR-like sample holder with 10 samples positions along the outer and inner conductors had been used before the actual cavity coating (Fig. 2(a)). This setup allows the investigation of thickness and T_c distribution of the coating film all over the cavity. The surface treatment of small sized samples is similar to the dummy cavity. The samples' locations and their distance to the bottom plate are marked on Fig. 2(b).

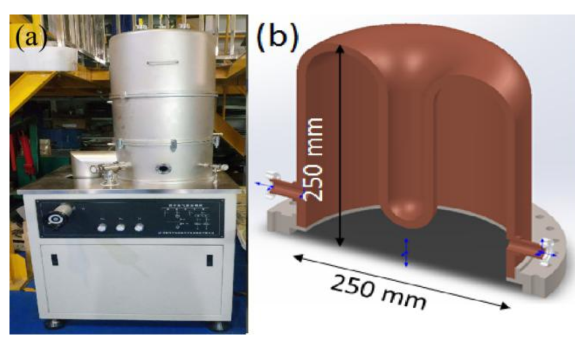

Figure 1: (a) the new coating system and (b) the dimension of the 325 QWR cavity.

Coating Chamber

In the experiment last year, two coating cavities were obtained (Figure 3(a)). it was observed that particles falling from the target produced severe defects at the bottom part, with typical size 1~2 mm (Fig. 3(b)). To avoid these defects, the whole sputtering setup was turned up-side-down by placing the tube cathode under the dummy cavity. The large coating chamber allowed an extension being added to

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the QWR opening to ensure that the plate could be coated with a film of proper thickness [3] (Fig. 4).

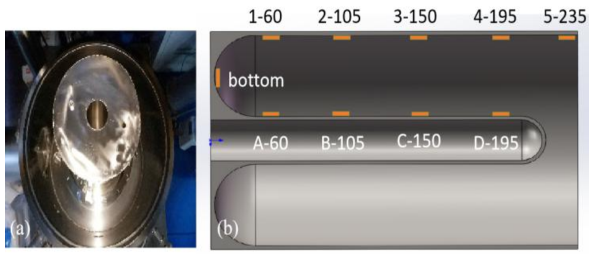

Figure 2: The sample holder's (a) appearance and (b) the exact location of the samples' locations.

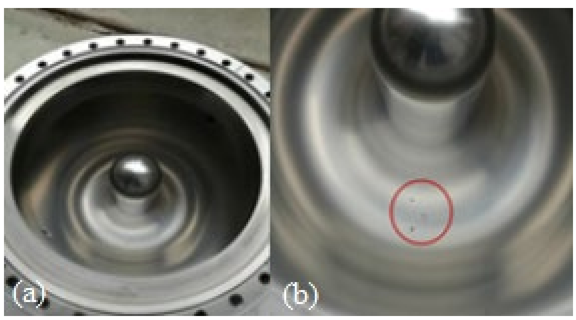

Figure 3: (a) The QWR Cu/Nb Cavity made in NIN and (b) the defects in the bottom of the cavity.

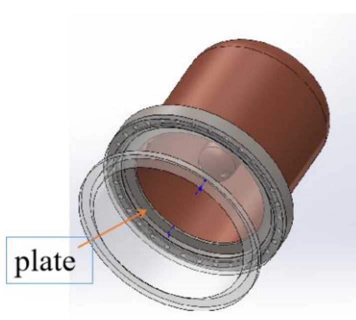

Figure 4: An extension is adder to the QWR opening to ensure that the plate could be coated.

Tri-electrode Scheme

In the beginning of the experiment, referring to the experimental parameters of NIN, a double electrodes scheme was used to coat both the inner and the outer conductors. Tuning the growth rate and file properties was achieved by adjusting only the Ar pressure and the voltage between the electrodes (Fig. 5(a)). The sputtering utilized a tube-like target sitting closer to the inner conductor. However, such layout always resulted in a non-uniform growth rate distribution along the inner surface of cavity, no matter how we adjust the sputtering power or the Ar pressure. With a maximum ratio of 50:1 [2], the niobium film coated on the sample at point **5** could not be thick enough before the film at point **D** started to break-off (see Fig. 4).

To improve the uniformity of film thickness, a tri-electrode scheme was proposed, the core of which was by adding a niobium mesh electrode between the outer conductor and the target (Fig. 5(b)). In this way, the voltage between the target and mesh and the voltage between the target and the inner conductor were both tunable, bringing about the possibility to alter the plasma density on both sides of the target. By applying appropriate negative bias on the cavity, the potential difference between the target and the inner conductor was reduced, while the voltage between the target and the outer conductor remained unchanged. Thus, similar growth rate could be obtained on both inner and outer conductor. Furthermore, by reducing the growth rate on the inner conductor, the rapid surge of target temperature brought by intense ion bombardment during the coating process was also alleviated, leading to a more stable and long-lasting coating process. The tri-electrode scheme also benefitted from its lower Ar pressure during coating process, because lower pressure helped increase sputtering voltage and gave better film compactness.

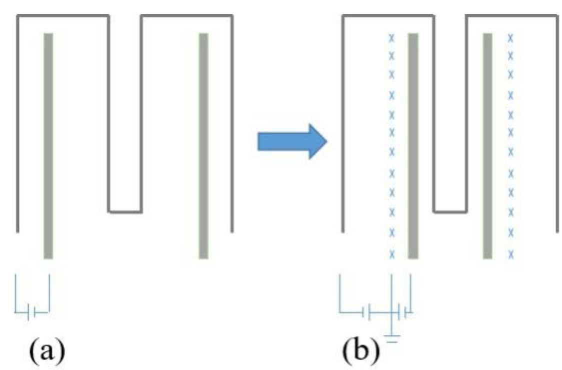

Figure 5: (a) double electrodes scheme and (b) tri-electrode scheme.

Temperature Control

Even with the tri-electrode scheme, the inner conductor sputtering rate was still larger than the outer conductor. Such phenomenon could result from the fact that the inner conductor faces more target per unit area comparing with the outer conductor. Similar difference could be seen on the heat flux, which caused the inner conductor to be much hotter than its counterpart during the sputtering process. Higher sputtering rate and temperature would help the inner conductor to get a thicker and denser film, together with more stress from thermal expansion. The SEM images showed that excessive thermal accumulation caused the films on the inner conductor had higher risk about cleavage than film on the outer conductor (Fig. 6). Two types of substrates had been utilized in our experiment, OFHC copper and *c*-sapphire. Inner conductor film deposited on copper had a larger chance to survive comparing with film deposited on sapphire at the same location. Because copper has

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better thermal conductivity and a closer thermal expansion coefficient than those of sapphire, such results supported the conclusion that stress was the main cause for film breaking (Fig. 7) and necessitated the control of cavity surface temperature. Later, we discovered that by adopting a 50% duty cycle sputtering power profile, the inner conductor was cooled while the outer conductor was heated by the tube radiation, and the film uniformity improved.

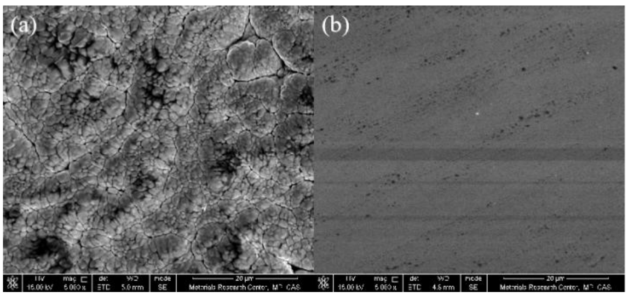

Figure 6: SEM images of the sample D' surface in the inner conductor(image a), and the surface of the sample 5 in the outer conductor(image b), c-sapphire substrate.

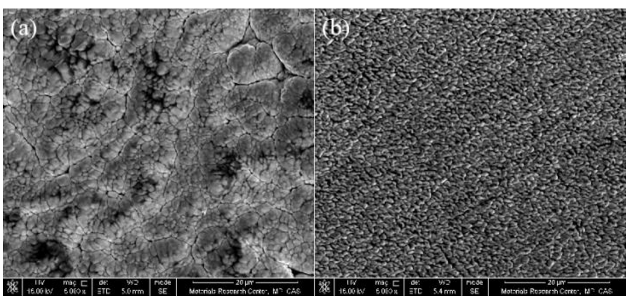

Figure 7: Under the same coating parameters, SEM images of the sample used c-sapphire substrate(image a) and OFHC copper substrate(image b) at the D position of the inner conductor.

SAMPLES RESULTS

Thanks to the clean environment during the experiment, no other elements except Nb, O, and Al were found in the composition of the obtained samples films with EDS (Table 1). At this point, the main factor affecting the films' superconducting transition temperature (T_cs) was the thickness of films. With optimization between each run, several test runs with c-sapphire samples were performed before the cavity coating. The T_cs of samples after several rounds of optimized all reached 9.3 K. Results from the last run of experiments showed an almost complete superconducting coating was achieve on the QWR-like sample holder.

Table 1: The EDS Result Of Sample 5 in the Outer Conductor

Elements	Weight Percent	Atom Percent
O K	9.51	23.93
Al K	34.80	51.93
Nb L	55.70	24.14
Total	100.00	

CONCLUSION

The results of samples tests of the cavity showed that we are close to the final production of Nb/Cu QWR cavities with acceptable SRF performance. With proper optimization of our deposition system, the actual cavity coating plan has been scheduled.

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