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CONSTRUCTION OF THIN-FILM COATING SYSTEM TOWARD THE REALIZATION OF SUPERCONDUCTING MULTILAYERED STRUCTURE

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Abstract

Although S-I-S (superconductor-insulator-superconductor) multilayered structure is expected to increase the maximum acceleration gradient of SRF cavities, in order for it to function in reality, it is necessary to develop a coating processing that can realize high purity and quality superconducting thin-films. In this study, we prepared several NbN-SiO_2-Nb multilayered samples which have different NbN film thickness to investigate the film thickness dependence of effective H_{c1} of S-I-S multilayered samples. In addition, we launched the co-sputtering system to get Nb_3Sn thin-film samples. The deposition rates of Nb and Sn cathodes were measured, and then the two cathodes were simultaneously sputtered aiming at appropriate composition ratio. Furthermore, we developed another experimental apparatus for coating on the inner surface of the 3 GHz TESLA type small cavities. A cylindrical Nb cathode was fabricated, and glow discharge was confirmed. This paper reports the specification of the two sputtering apparatuses and future experiment plans for demonstration and realizing of S-I-S multilayered cavities.

INTRODUCTION

S-I-S thin-film multilayered structure theory has been proposed to increase vortex penetration field of SRF cavities [1, 2]. According to this theory, the vortex penetration field of multilayered thin-film structures can reach approximately 250 mT when NbN is used for the superconducting layer and approximately 480 mT when Nb_3Sn is used. However, it is not clear whether this calculated value in this theory can really be achieved, in fact, multilayered thin-film cavities which exceed the maximum acceleration gradient of Nb cavities have not been realized. Thus, it is necessary to demonstrate the multilayered thin-film theory and to establish coating techniques for fabricating S-I-S thin-film multilayered cavities.

In order to demonstrate the theory, we firstly aimed to evaluate the effective H_{c1} of S-I-S samples [3, 4]. In previous studies, we have already established the reactive sputtering conditions for obtaining high quality NbN thin-films. Moreover, we have succeeded in preparing S-I-S samples which consist of 200 nm NbN layer, 30 nm SiO_2 layer, and pure Nb substrate. The XRD patterns of these S-I-S samples showed sharp Nb and NbN peaks [5]. In this study, we prepared several NbN-SiO_2-Nb multilayered sample which have different NbN film thickness to investigate the film thickness dependence of effective H_{c1}. Furthermore, we launched an experimental apparatus for co-sputtering of Nb_3Sn. Co-sputtering is a coating method for obtaining alloy thin-films by simultaneously sputtering two or more cathodes. In this method, it is possible to coat Nb_3Sn thin-films which have composition ratio of 3:1 by adjusting the input power ratio of Nb and Sn cathodes.

Table 1: Details of NbN-SiO_2-Nb Multilayered Thin-film Samples

Sample Name	NbN Layer Thickness [nm]	SiO_2 Layer Thickness [nm]
180814-1-A, B	50	30
180814-2-A, B	100	30
180814-3-A, B	150	30
180814-4-A, B	250	30
180814-5-A, B	300	30
180814-6-A, B	400	30

In order to realize S-I-S multilayered cavities, we also launched another experimental apparatus for basic test of the inner sputtering on TESLA type cavities. We will use this apparatus to deposit Nb or NbN on the inner surface of the 3 GHz cavities and evaluate film thickness distribution and the thin-film characteristics such as crystalline orientation.

MULTILAYERED SAMPLE PREPARING

NbN-SiO_2-Nb multilayered thin-film samples were prepared by using in-house sputtering apparatus. The Nb substrates (RRR > 300) were electro polished before NbN-SiO_2 coating. Our sputtering experimental apparatus adopts inter-back system, and a substrate carrier passes in front of Nb cathode (RRR > 300) and two Si cathodes at a regular speed. Therefore, the sputtered elements are uniformly deposited on substrate. The sizes of both Nb and Si cathodes are 5 inches by 18 inches. The base pressure of the sputtering chamber was about 2×10^{-4} Pa. Ar and N_2 (or O_2) gasses were introduced in the sputtering chamber, NbN or SiO_2 thin-films were reactively sputtered. The Nb cathode was powered by DC supply, and the two Si cathodes were powered by AC supply. In NbN coating, DC input power was set constant at 3.0 kW, and Ar partial pressure was 0.3 Pa. On the other hand, in SiO_2 coating, AC input power was set constant at 6.0 kW, and Ar partial pressure

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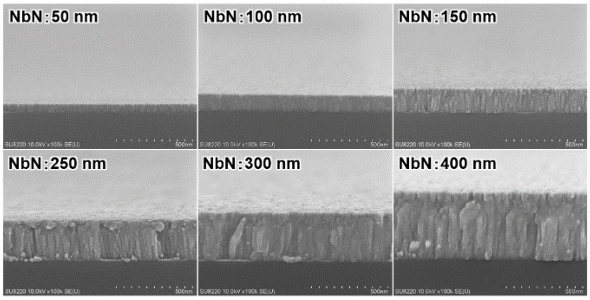

Figure 1: SEM cross-section images of $NbN\text{-}SiO_2$ thin-films.

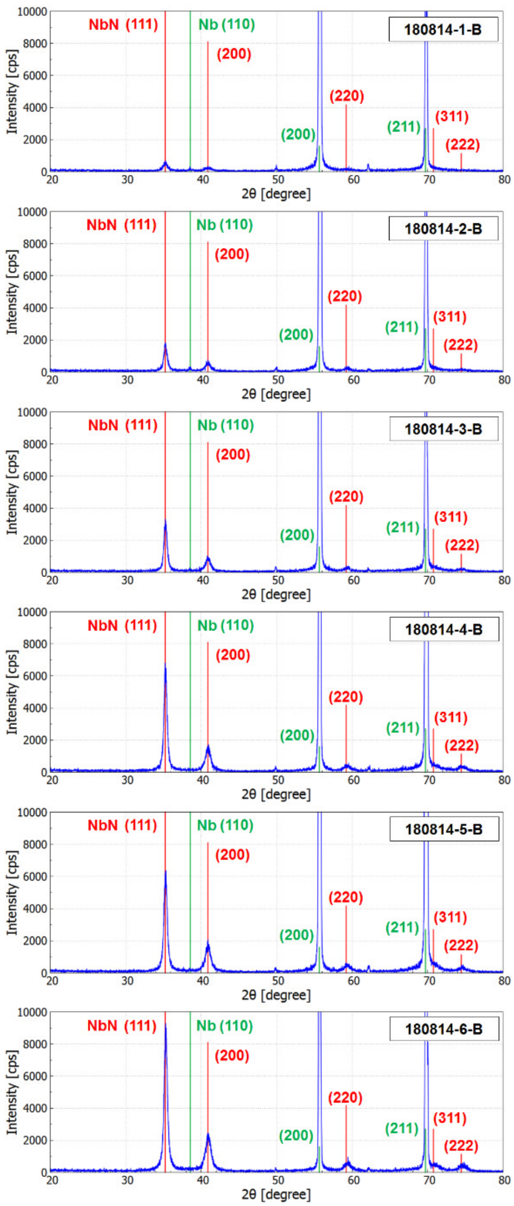

Figure 2: XRD patterns of $NbN\text{-}SiO_2\text{-}Nb$ samples.

was 0.3 Pa. Table 1 shows the details of the samples prepared this time. The notation "-A" or "-B" attached to the end of the sample names mean that the films were coated with the same deposition lot. Figure 1 shows the SEM cross-section images of $NbN\text{-}SiO_2$ thin-films coated on Si

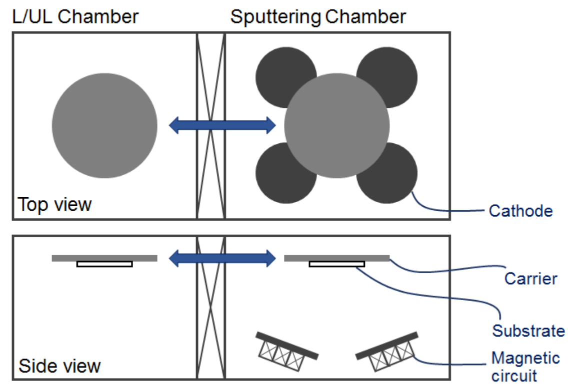

Figure 3: Schematic diagram of our co-sputtering system.

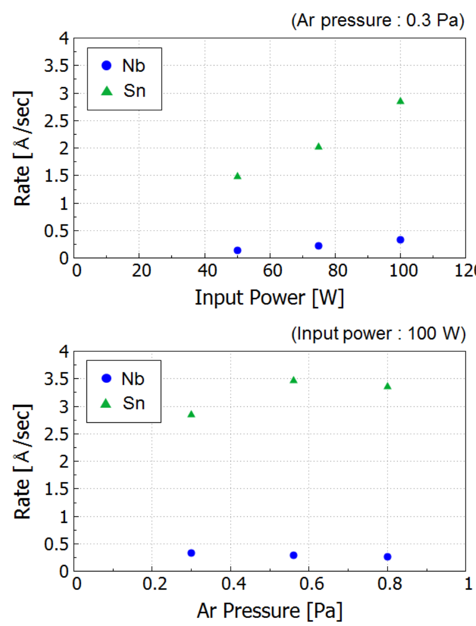

Figure 4: Deposition rates of Nb and Sn for varying input power (top) and Ar pressure (bottom).

wafer with the same deposition lot as the $NbN\text{-}SiO_2\text{-}Nb$ samples. Figure 2 shows the XRD patterns of the $NbN\text{-}SiO_2\text{-}Nb$ samples measured by out-of-plane method.

CO-SPUTTERING APPARATUS

Our co-sputtering apparatus can mount four disk cathodes, which are 2 inches in diameters, in one chamber. Pure Nb (RRR > 300) and pure Sn cathodes were prepared and attached for obtaining Nb_3Sn thin-films. Figure 3 shows a schematic diagram of this apparatus. The base pressure of the sputtering chamber was about 3 x 10^{-6} Pa. The substrate can be heated up to approximately 800 degrees. Firstly we measured the deposition rates of Nb and Sn cathodes while changing the input power applied to Nb and Sn cathodes or Ar gas pressure. Figure 4 shows the measured deposition rates of Nb and Sn. We confirmed that the rates of both Nb and Sn change linearly with input power. Secondly, we coated Nb-Sn alloy thin-films on 2 inches Si wafer. Since the deposition rate of Sn was about 10 times the rate of Nb, the input power ratio of Nb and Sn was set to be around

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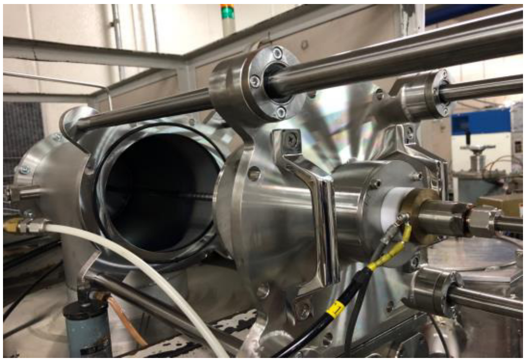

Figure 5: Experimental apparatus for inner sputtering.

Figure 6: Cylindrical pure Nb cathode.

30:1 in order to obtain Nb_3Sn thin-films having appropriate composition ratio. We plan to evaluate the actual composition ratio and the superconducting characteristics of the Nb_3Sn alloy thin-films in the future.

INNER SPUTTERING APPARATUS

We conducted a discharge confirmation experiment using a newly launched inner sputtering apparatus. Figure 5 shows the appearance of the apparatus. The base pressure of the sputtering chamber was about 1 x 10^{-3} Pa. Ar and N_2 gases can be introduced in the chamber. A pure Nb (RRR >300) cylindrical cathode which has a diameter of 12 mm and a length of 800 mm was fabricated and used (Figure 6). As several stick-shaped permanent magnets were inserted into the Nb cathode in a row so as to arrange the N pole and S pole of the adjacent magnets alternately in opposite directions, by the magnetic field lines generated between the adjacent magnets, several ring-shaped glow discharge can be made on the circumference of the Nb cathode. The length of the discharge area is 200 mm because the permanent magnets is inserted in the same area. The DC power source is connected to the both ends of the Nb cathode protruding outside the sputtering chamber. The cooling water was flowed inside the Nb cathode. Figure 7 shows the glow discharge state of the Nb cathode when Ar gas was introduced at 0.3 Pa and 200 W power was applied. After checking the apparatus work normally, we deposited pure Nb on glass substrate for 300 seconds under the same sputtering conditions as above. The distance between cathode surface and substrate was 11.5 mm, and the thickness of the deposited Nb thin-film was 510 nm with a deposition time of 300 seconds. We designed this apparatus so that a 3 GHz small cavity can be mounted in a jig attached to the door of the chamber. We will coat Nb thin-film on the inner surface of a 3 GHz small Cu cavity in the future experiment. The distribution information of the thin-film thickness will be obtained by measurement of cavity cut. Thus, we will be able to decide the optimum coating method and apparatus design for depositing a uniform thin-film thickness on the inner surface of the cavity based on that information.

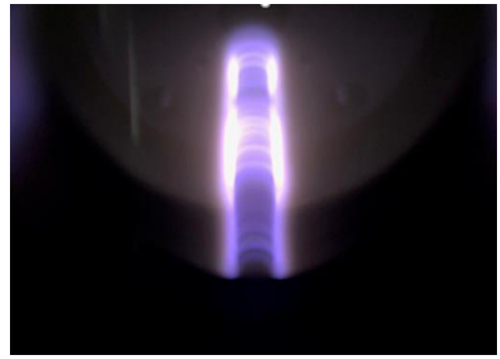

Figure 7: Glow discharge of cylindrical Nb cathode.

CONCLUSION

We prepared several NbN-SiO_2-Nb multilayered samples which have different NbN film thicknesses. All the crystalline orientations of these samples were good. From now on, we will measure the effective H_{c1} of these samples and clarify the film thickness dependence of superconducting characteristics of S-I-S multilayered structure.

Furthermore, we launched two more experimental apparatus. One is for preparing Nb_3Sn thin-film multilayered samples and the other is for carrying out basic inner sputtering tests. For both apparatuses, glow discharge was confirmed normally, and first coating tests were completed. We plan to evaluate the co-sputtered Nb_3Sn thin-films and the inner-sputtered Nb or NbN thin-films in the future.

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