

Supplemental Material: Low Temperature Baking Effect of the Nb₃Sn Radio Frequency Superconducting Cavity*

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The detailed coating process

The Nb substrate cavity is heated in a deposition system with a tin source, during which the saturated tin vapor arrives at the inner surface of the cavity and reacts with Nb to form a thin layer of Nb₃Sn material. There are two heating zones in our deposition system for Nb cavity and tin source, respectively. This allows for separate temperature control of the Nb substrate cavity and the tin source. The test samples were coated with Nb₃Sn thin film together with the Nb substrate cavity.

Before the coating, the 1.3GHz single-cell TESLA-shaped Nb substrate cavity labeled as X2X4 underwent standard preparation including heavy buffered chemical polishing (BCP) of ~130μm, degassing at 800⁰C for 3 hours, light BCP of ~20μm and HPR. Initially, the X2X4 Nb substrate cavity was coated by a recipe adopted from Siemens AG and Jefferson Lab (JLab) and labeled as X2X4-1. The substrate Nb cavity along with the test samples were lowered into the deposition system. After the degassing stage at 200⁰C for 24 hours, both the cavity and the tin source were heated to 500⁰C to the nucleation stage. During the nucleation stage, the evaporated SnCl₂ saturated vapor reached the surface of substrate Nb and formed Sn nucleation sites. After that, both the Nb cavity thermocouples and the tin source thermocouple were heated to 1200⁰C for the coating step. After 3 hours, the temperature was dropped to 1100⁰C and lasts for 30 minutes to give residual tin on the surface time to diffuse into the surface and react before turning off the furnace, which is called the annealing step. Then the deposition system was powered off, the cavity was carefully removed and vertically tested.

After the vertical test before and after low temperature baking treatment, the thin film of X2X4-1 Nb₃Sn cavity was removed by BCP with the removal amount of 40μm. Then the cavity was recoated using a recipe based on the temperatures and times specified by the University of Wuppertal and Cornell University. The parameters of degassing and nucleation stages are the same as those of the first coating process described above. However, at the coating step, the thermocouples of Nb cavity and tin source was heated to 1100⁰C and 1250⁰C, respectively. Three hours later, the tin source thermocouple was reduced to 1035⁰C and the annealing step lasts for 3 hours. Then the deposition system cooled down naturally and the newly coated Nb₃Sn cavity was prepared for vertical test.

Material analysis of the test samples

The X-ray diffraction (XRD) analysis was performed to detect the surface compositions of the Nb₃Sn thin films. The X-ray powder diffraction patterns of the test samples from the first coating and the second coating process were shown in Fig. S1. Peaks heights have been

normalized with respect to the strongest one and the graphs abscissa range goes from 10 to 90° . It can be seen that all the peaks have been associated to the Nb_3Sn phase and no undesired low- T_c phases such as NbSn_2 , Nb_6Sn_5 were detected.

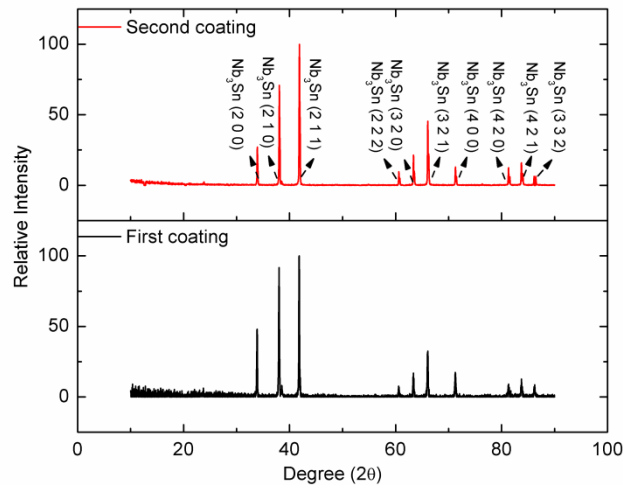


Fig. S1 X-ray powder diffraction patterns of the test samples from the first coating and the second coating.

The thickness of the Nb_3Sn film was measured by using a focused ion beam (FIB), during which steep trenches were etched so that SEM could be used to look at the layers in profile. The FIB-SEM measurements in Fig. S2 showed that the thickness of the Nb_3Sn films from the first and second coating process was $\sim 2.23\mu\text{m}$ and $\sim 3.01\mu\text{m}$, respectively. This is consistent with the depth profiles of Sn^+/Nb^+ ratio by the time of flight secondary ion mass spectrometry (TOF-SIMS) measurements in Fig. S3.

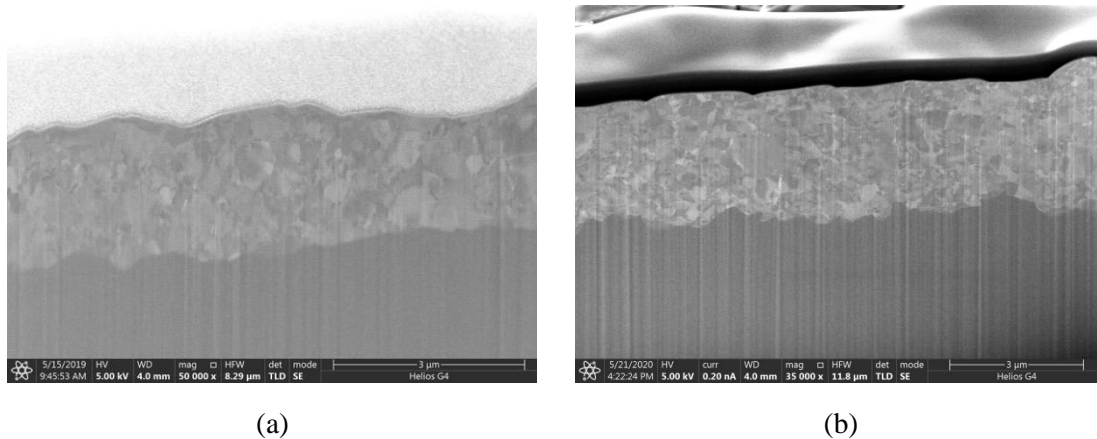


Fig. S2 FIB-SEM measurement shows that the thickness of the Nb_3Sn films from the first coating (a) is $\sim 2.23\mu\text{m}$, and that from the second coating (b) is $\sim 3.01\mu\text{m}$.

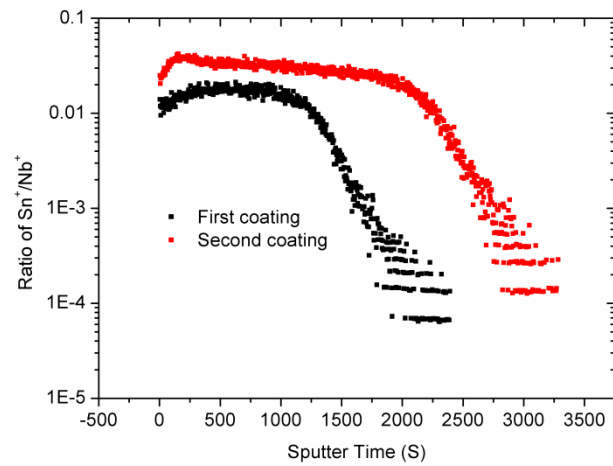


Fig. S3 Depth profiles of the Sn^+/Nb^+ ratio of the test samples.

The difference between the properties of the Nb_3Sn films deposited in the first and second coating process is due to the difference in the coating conditions. The tin vapor pressure is controlled by the temperature of the Sn source and therefore determines the rate at which tin arrives at the cavity surface. However, the rate of interdiffusion of niobium and tin is controlled by the cavity temperature. Thus, the recipe of the first coating resulted in a lower Sn content, a surface of defects and a smaller film thickness.