2021

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Original Publication Citation

Tiskumara, J.K., Delayen, J.R., Eremeev, G.V., Pudasaini, U., & Reece, C.E. (2021) Nb_3Sn coating of twin axis cavity for SRF applications. In K. Saito, T. Xu, N. Sakamoto, A. Lesage, V.R.W. Schaa (Eds.), *Proceedings of the 20th International Conference on RF Superconductivity* (146-150). JACoW. https://doi.org/10.18429/JACoW-SRF2021-SUPTEV011

ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-SUPTEV011

Nb_3Sn COATING OF TWIN AXIS CAVITY FOR SRF APPLICATIONS*

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Abstract

The twin axis cavity with two identical accelerating beams has been proposed for energy recovery linac (ERL) applications. Nb_3Sn is a superconducting material with a higher critical temperature and a higher critical field as compared to Nb, which promises a lower operating cost due to higher quality factors. Two niobium twin axis cavities were fabricated at JLab and were proposed to be coated with Nb_3Sn. Due to their more complex geometry, the typical coating process used for basic elliptical cavities needs to be improved to coat these cavities. This development advances the current coating system at JLab for coating complex cavities. Two twin axis cavities were coated recently for the first time. This contribution discusses initial results from coating of twin axis cavities, RF testing and witness sample analysis with an overview of the current challenges towards high performance Nb_3Sn coated twin axis cavities.

INTRODUCTION

In the high-intensity Energy-Recovery Linac (ERL) beam transits through the cryomodule at least twice with one pass for accelerating a high-quality beam and the other for decelerating the used beam to recover the beam energy [1]. Most of the ERL designs use standard TM010-type accelerating structures, in which the beam must pass along the same accelerating axis and thus occupy the same transverse position. Therefore to improve the performances of the ERL, the idea of using two beam-axis structures was first proposed by Noguchi and Kako in 2003 [2]. Then the similar concept was suggested again by Wang, Noonan and Lewellen in 2007 [1] with a proposal of superconducting cavity with two equivalent but separate axes for accelerating and decelerating beams while energy recovery is still performed within the same physical cavity and interact with the same rf dipole mode [3].

As proposed by Jefferson Lab (JLab) and designed by the Center for Accelerator Science (CAS) at Old Dominion University (ODU), two elliptical twin axes single cell cavities have been fabricated [4] with the intention of later growing a Nb_3Sn layer inside. Nb_3Sn is a potential alternative material with a higher critical temperature T_c close to 18 K, higher critical field, and lower surface resistance compared to Nb to replace Nb in SRF cavities, promising cost reduction and better performance. This Nb_3Sn gives a lower dissipation than that of niobium at the same temperature. Its superheating field of about 400 mT suggests a higher breakdown field is possible [5].

Among the methods used to coat thin films on niobium cavities, the vapor diffusion technique is used at Jefferson Lab to deposit Nb_3Sn thin layers on SRF cavities [6]. Although several basic elliptical cavity models have been coated and tested using this method, it has not yet been applied to coat cavities with complex geometries like the twin axis cavity. This paper discusses the recent Nb_3Sn coating of twin axis cavities at Jefferson Lab.

JLAB/ODU TWIN AXIS CAVITY

The new cavity designed by ODU CAS, was optimized to minimize the peak RF surface fields while providing the same longitudinal electric field profile in both beam tubes by operating in the TM110 rf dipole mode with 1497 MHz frequency [4] using CST Microwave Studio (Fig. 1). Making the cavity compatible with the Jefferson lab Nb_3Sn deposition system was also a goal of the mechanical design. Since the deposition chamber does not allow niobium-titanium inside the furnace, cavity flanges were made of niobium [7]. Two completed cavities are shown in Fig. 2. The cavity parameters and RF properties are given in Table 1.

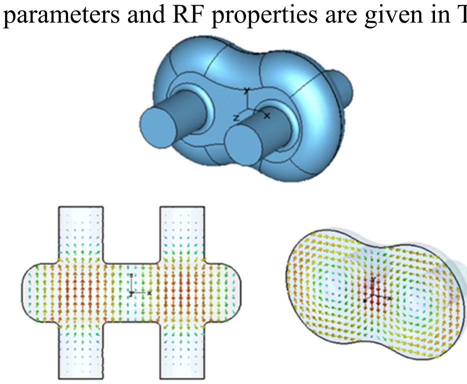

Figure 1: Twin axis cavity model (top) and electric (left) and magnetic (right) field profile at the twin cavity cross section (bottom) from CST microwave studio [3].

Figure 2: Twin axis cavities.

* Research supported by DOE Office of Science Accelerator Stewardship Program Award DE-SC0019399. Partially authored by Jefferson Science Associates under contract no. DEAC0506OR23177. This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics and Office of High Energy Physics .
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ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-SUPTEV011

Table 1: Cavity Parameters and RF Properties of the Fabricated 1497 MHz Twin Axis Cavity #1 [4]

Parameter	**Value**	**Unit**
Cavity height	202.5	mm
Cavity width	300.0	mm
Cavity length	100.13	mm
Beam aperture	60.0	mm
Beam axis separation	136.5	mm
E_p / E_{acc}	2.68	-
B_p / E_{acc}	5.5	mT/(MV/m)
[R/Q]	60.1	Ω
Geometric factor, G	320.8	Ω
LOM	1103	MHz
Nearest HOM	1806	MHz

RF test results of the twin axis cavities are shown in the Fig. 3. Cavity #2 has reached an accelerating/decelerating gradient of 23 MV/m with a maximum quality factor of 1.2×10^{10} in the low field regime while cavity #1 quenched around 7 MV/m due to weld defects at the equator [4].

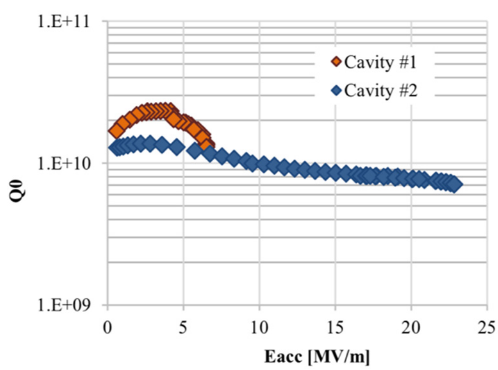

Figure 3: RF test results of the twin axis cavities [4].

CAVITY DEPOSITION SYSTEM AT JLAB

The Nb_3Sn deposition system at JLab contains two main parts: the coating chamber that hosts a cavity to be coated and the furnace that provides the desired heating to the coating chamber (Fig. 4) [8].

Figure 5 shows a typical coating process at JLab consists of a nucleation step that involves tin chloride evaporation at 500 °C for 1-hour, followed by a deposition step which involves the evaporation of tin for 3-hours at 1200 °C, which is favorable to form Nb_3Sn phase on substrate niobium [9].

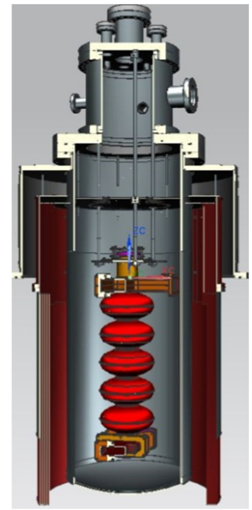

Figure 4: A sketch of the JLab Nb_3Sn coating system with a 5-cell cavity [8].

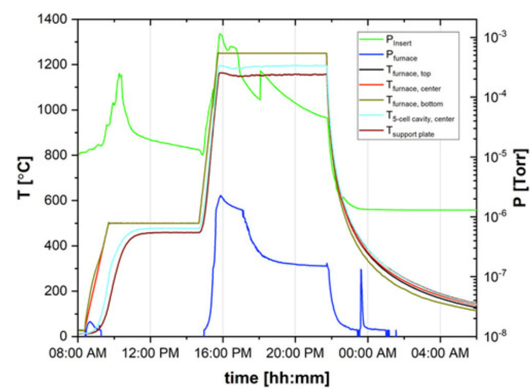

Figure 5: The temperature profile used for coating Nb cavities at JLab [10].

COATING OF TWIN AXIS CAVITIES

At JLab, a typical procedure to coat a cavity involves only one tin source, which is placed at the bottom of the cavity. But with the advanced geometry of the twin axis cavities, the usual coating approach developed for typical elliptical single-axis cavities could result in non-uniform coating inside the cavity caused by low tin flux coming from a single tin source [11]. Therefore to withstand this challenge a new tin source was introduced, which will be from the other port so that enough tin vapor is allowed to flow into the both sides of the cavity equally.

We planned to coat the twin cavity #1 first (cavity with limited rf performance due to the weld defects) and then move into cavity #2, which does not have weld defects.

Coating of the Twin Cavity #1

The cavity was prepared for coating by soaking the flanges in nitric acid to remove any leftover indium from the previous assembly and then then an ultrasonic degreasing. The cavity was then setup for the coating as in the Fig. 6. We used 1.5g of Sn and 0.5g of $SnCl_2$ on each side,

ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-SUPTEV011

where the amounts were selected from the previous coatings aiming to avoid patchy regions and Sn residue and divided equally among the two tin sources to give equal vapor on the both side of the cavity. Witness samples were also placed inside to evaluate the coating after the process [11].

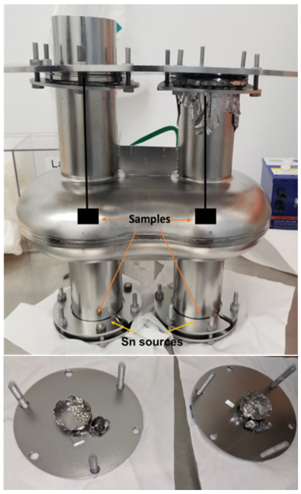

Figure 6: Twin cavity #1 setup for coating (top) and tin sources (bottom).

Cavity setup was then inserted into the furnace. After the pumping down, the usual temperature profile in Fig. 5 was followed for the coating.

Coating Evaluation

The cavity was inspected visually after the removal of the coated cavity from the coating system. The cavity was coated uniformly with consuming almost all the tin that we placed. There were no visible tin spots on the cavity coating (Fig. 7), and the weld defect also looks coated as in Fig. 8.

Figure 7: Inside the twin axis cavity #1 before (left) and after the coating (right) [11].

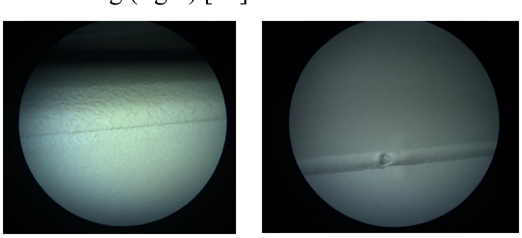

Figure 8: Inside view of the twin axis cavity #1 after coating using the borescope. The right image shows the coated weld defect.

There were no patchy regions, and a uniform coating was observed in the SEM images (Fig. 9). EDS measurement showed the Nb to Sn atomic ratio was 75.14: 24.86, close to the nominal composition of Nb_3Sn. We could identify some nano-sized tin residues on the sample from the AFM images (Fig. 10).

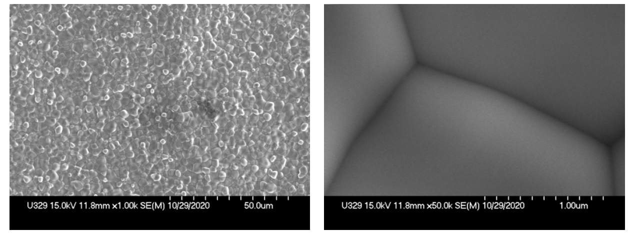

Figure 9: SEM images of the coated samples.

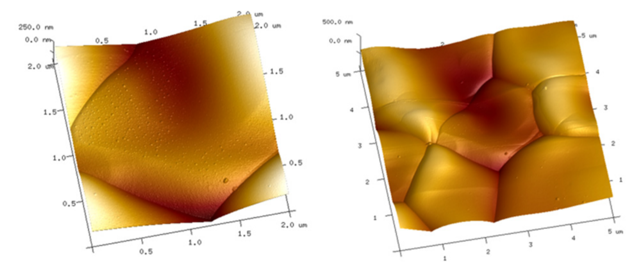

Figure 10: AFM analysis of the coated samples [11].

RF Testing

The cavity was then processed for rf testing. Unfortunately, the cavity was deformed after pumping down, see Fig. 12. The deformation may have caused because of 1200 ^{0}C heating that might have softened the material. And this deformation may have limited the rf performance of the coated cavity compared to the bulk niobium cavity (Fig. 11).

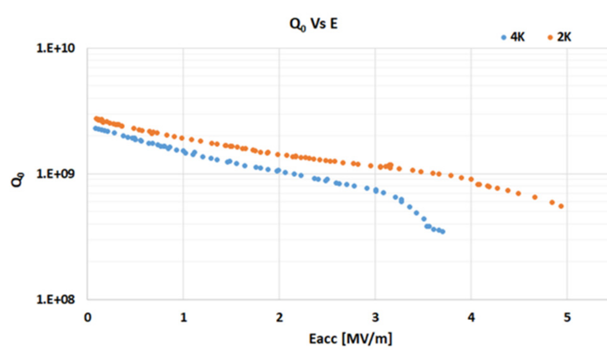

Figure 11: Q curve from the rf testing [11].

Deformed twin cavity #1 (Fig. 12, left) is straightened back. A new set of hardware is introduced to prevent future mechanical deformation when pumping down for testing, as shown in the following Fig. 12, right.

ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-SUPTEV011

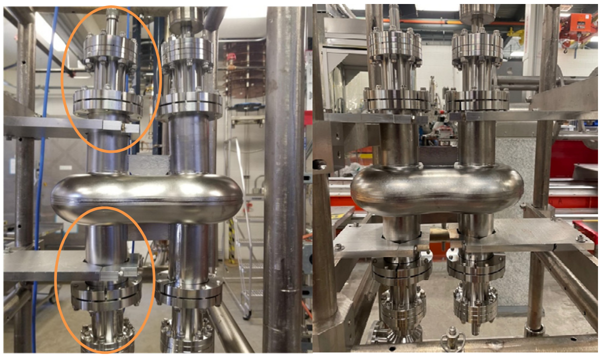

Figure 12: Deformed twin cavity #1 after pumping down (left) and straightened cavity assembly with new set of brackets introduced to prevent deformation (right).

Second Coating of the Twin Cavity #1

After straightening the deformed twin axis cavity#1 was coated again using the temperature profile that has given promising results recently. The temperature profile consisted of three steps 1200 °C, 1150 °C, and 1100 °C for the growth instead of 1200 °C for the whole time. Then the cavity was parked at 950 °C for 1 hour before cooled down, hoping to mitigate potential Sn-condensation. The chosen temperature profile was expected to produce a smoother coating than that obtained with longer coating time at 1200 °C [12]. The short coating time at 1200 °C, ~40 min, was also expected to help to avoid mechanical deformation compared to the 3hr treatment in the past. Here we only used 2g of Sn and 1g of $SnCl_2$, and distributed in the two bottom sources equally like the previous coating.

Figure 13: Inside the twin axis cavity #1 after the second coating.

Coating looked uniform (Fig. 13), but high-resolution SEM images showed Sn residues on the surface (Fig. 14). The Nb to Sn atomic ratio was 75.82 % to 24.18%.

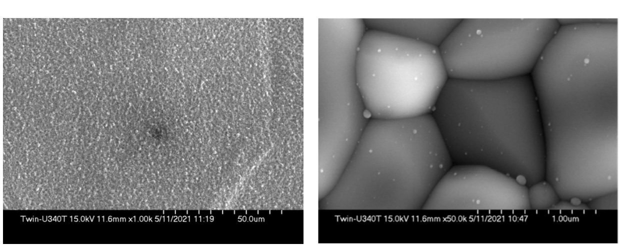

Figure 14: SEM images of the coated samples. Note Sn residues in the right side image.

Coating of the Twin Cavity #2

With the experience from the twin cavity#1 coatings, a similar procedure was followed to coat the twin cavity#2 but with a reduced amount of Sn. The reduction was based on the previous coating (1.7g of Sn and 1g of $SnCl_2$). The temperature profile for the coating was kept the same as before with three steps.

Figure 15: Inside the twin axis cavity #2 after the coating.

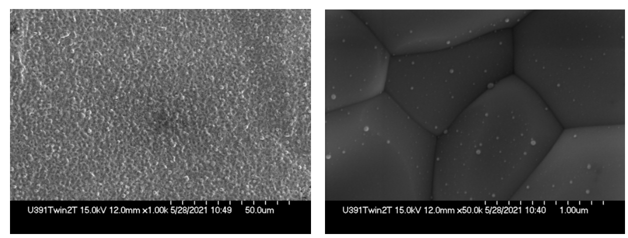

Figure 16: SEM images of the coated samples with twin axis cavity #2.

Figure 15 shows the uniform coating inside, but the SEM examination of the witness samples showed Sn residues were still present (Fig. 16). The results from RF testing is shown in Figure 17. Although the cavity had a higher accelerating gradient than the last one, the quality factor was lower than the expected. Sn residues may have contributed to higher surface resistance. The coating around the high magnetic field area, which cannot be assessed visually and typically the furthest from the Sn sources, could also be problematic with non-uniform coatings.

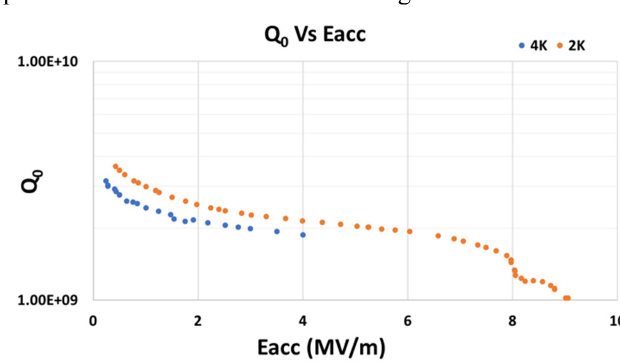

Figure 17: Q Vs E curve from the twin #2 rf testing.

Annealing of the Twin Cavities

To remove Sn residues, we annealed a coated twin axis cavity#1 along with the initial witness samples to compare the changes. The annealing was done at 950 °C for 45 minutes to avoid potential Sn loss and surface degradation observed while annealing at higher temperatures. SEM

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analysis after the annealing showed no Sn residues, as shown in the Fig. 18. The SEM images also showed some features on the surface (Fig. 18, right) typically seen in other samples while annealed at higher temperature but less pronounced. Following sample results, the annealed twin axis cavity#1 is progressing for RF testing.

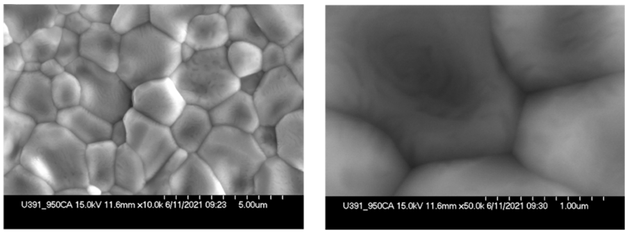

Figure 18: SEM images of the annealed samples.

SUMMARY AND FUTURE PLANS

We coated the twin axis cavities proposed for ERL applications with Nb_3Sn for the first time at JLab. We were able to produce a uniform coating with two tin sources. Different coating profiles have been used to understand the coating process better and to optimize the coating. One of the coated cavities is annealed later to remove Sn residue that was observed in witness samples. We plan to test the annealed cavity and further optimize the coating process in near future. These coated cavities will be used to take measurements to study the superconducting RF properties in the future.

ACKNOWLEDGEMENTS

We are thankful for Jlab staff who helped us with designing, fabricating, testing and coating of the twin axis cavities. And Applied Research Center Core Labs at College of William & Mary for allowing us to use the SEM instrument and Olga Trofimova for helping with AFM analysis.

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