ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPWI011

COMMISSIONING OF Nb_3Sn CAVITY VAPOR DIFFUSION DEPOSITION SYSTEM AT JLAB*

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Abstract

Nb_3Sn as a BCS superconductor with a superconducting critical temperature higher than that of niobium offers potential benefit for SRF cavities via a lower-than-niobium surface resistance at the same temperature and frequency. A Nb_3Sn vapor diffusion deposition system designed for coating of 1.5 and 1.3 GHz single-cell cavities was built and commissioned at JLab. As the part of the commissioning, RF performance at 2.0 K of a single-cell 1.5 GHz CEBAF-shaped cavity was measured before and after coating in the system. Before Nb_3Sn coating the cavity had a Q_0 of about 10^{10} and was limited by the high field Q-slope at $E_{acc} \cong 27$ MV/m. Coated cavity exhibited the superconducting transition at about 17.9 K. The low-field quality factor was about $5{\cdot}10^9$ at 4.3 K and $7{\cdot}10^9$ at 2.0 K decreasing with field to about $1{\cdot}10^9$ at $E_{acc} \cong 8$ MV/m at both temperatures. The highest field was limited by the available RF power.

INTRODUCTION

Niobium is the the material of choice for the present SRF accelerators. Advances in the material fabrication and treatment has brought SRF niobium technology close to the superconducting limit of niobium material. Recent advances with mean free path variation has improved surface resistance by a factor 2-3[1, 2]. However, the present state-of-the-art for niobium is believed to be close to the fundamental limit of the material. Among other materials that have been considered for SRF applications, the most promising results in SRF cavities have been shown with Nb_3Sn[3, 4]. The Nb_3Sn transition temperature of about 18 K offers the opportunity of RF dissipation lower than that of niobium at the same temperature, while its superheating field expected at about 400 mT promises a higher breakdown field. In pursuit of Nb_3Sn coating on Nb cavities, we have built and commissioned a coating system that features a coating chamber of about 11" in diameter and 22" long.

CAVITY DEPOSITION SYSTEM

The deposition chamber comprises two main parts: the furnace that provides a clean heating environment to the coating chamber and the coating chamber that hosts the process vapors. The furnace was procured from T-M Vacuum Products Inc. The furnace was requested to be able to reach 1250 °C with the vacuum in 10^{-7} Torr range empty and the vacuum must be established by dry pumps. The furnace must be able to fit a 33" long by 11.5" diameter coating chamber with 24" long uniform (±5 °C) hot zone. A 14" mating conflat on the top must be provided for mating the insert to the furnace.

The coating chamber was built at JLab. The coating chamber was built as a cylinder 32" long x 11.5" diameter out of niobium, Fig. 1. Initially, the chamber was built to be inserted into JLab existing horizontal furnace 'Big Blue'. A

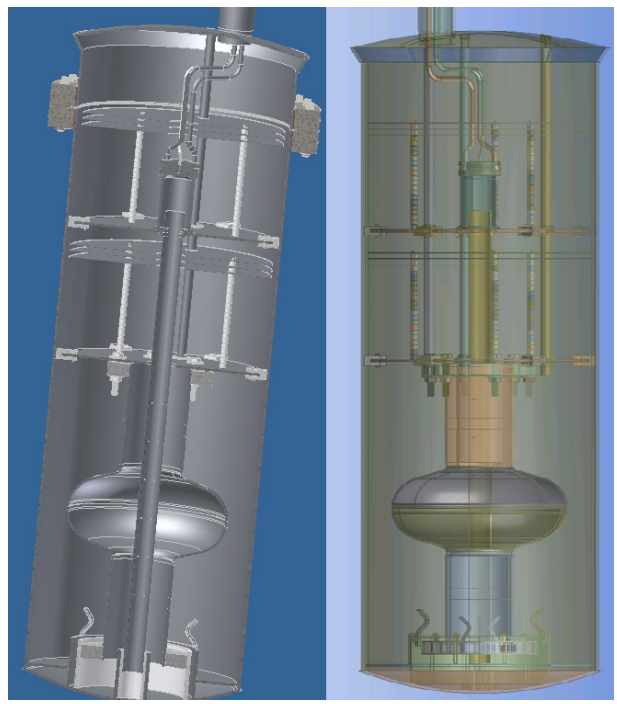

Figure 1: The Nb_3Sn insert drawing with a 1.3 GHz single cell cavity after(to the left) and before(to the right) conversion to vertical position. Note that Nb cylinder was split at the top with wire EDM to allow for 14" conflat stainless steel flange.

3" viewing port opening on the furnace door was adopted to allow niobium tube to extend from furnace space to the

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outside. The tube was simultaneously used as the conduit for instrumentation and as a pumping line. After a couple runs in the horizontal furnace, the chamber was converted into vertical insert to fit the new furnace. The conversion was done by cutting the insert with wire EDM, and then electron-beam welding Nb spool piece with a 14" conflat brazed to it. The brazing was done using .050" diameter 50%Au/50%Cu alloy wire and the step-wise temperature ramp up to 1010 °C with about 30 minutes soak at each step. The top portion of the insert, which sits on the furnace lid was replaced with a multiport spool piece. The bottom end was hydroformed to create a dome shape in order to improve the mechanical stability of the chamber. On the bottom end a centering fixture was built to support cavity flange. The centering feature is not utilized in current coating runs and the cavity flange is allowed to float above the fixture. The cavity is attached to the cavity support plate with ceramic (99.5% Al_2O_3) parts. The support plate is attached to three niobium rods with molybdenum pins. The rods extend from the furnace space to the SS blank on the top of the spool piece. Niobium rods are inserted into the 0.5" SS sleeve and fixed with SS pins. There are six niobium heat shields between the cavity support plate and the top SS blank.

SINGLE CELL NB_3SN COATING

As part of system commissioning we coated a 1.5 GHz CEBAF-shape single cell cavity C3C4. C3C4 was made of original CEBAF material. After the first experiments the cavity sat on a shelf for about four years. For the baseline test at 2K before the coating, the cavity was BCPed(1:1:2) for about 20 μm inside and 5 μm outside, HPRed, assembled, and evacuated. At 2 K the cavity was limited by the high field Q-slope at $E_{acc} \cong 27$ MV/m. The low field quality factor was about $1.6{\cdot}10^{10}$ at 10 MV/m. After the baseline test the cavity was removed from the test stand in the cleanroom, HPRed and left drying in the cleanroom over the weekend. For Nb_3Sn coating Peter Kneisel provided us with 99.9999% Sn shots and 99.99% $SnCl_2$ powder purchased from American Element in 2004. Sn and $SnCl_2$ were packaged in niobium foil. Each package contained either $1\pm.1$ gr of Sn or $.5\pm.05$ gr of $SnCl_2$. Three packages of Sn containing 3 gr total and six packages of $SnCl_2$ containing 3 gr total were placed inside the cavity onto the niobium foil covering the bottom flange. The top flange of the cavity was covered with loosely attached Nb foil as well. Nb foil was commercial grade unalloyed niobium purchased from Eagle Alloys. The cavity was assembled in the cleanroom for coating and double bagged before being transferred to the thin film lab. In the thin film lab the cavity was attached to the deposition chamber and installed in the Nb_3Sn deposition chamber. The setup was pumped down for a couple hours and the heating profile was initiated. In Fig. 2 the heat profile from the three heat zones of the furnace and the furnace pressure are shown. After the heating run and furnace cooldown, the insert and the

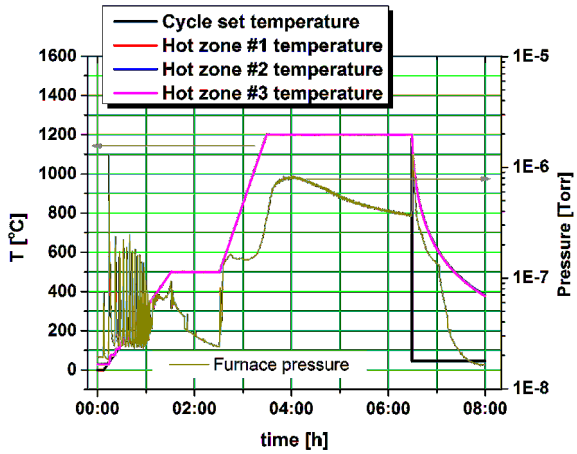

Figure 2: In this plot the temperature and pressure profile from the first Nb_3Sn cavity coating run are shown. Note the three separate regions: first, the temperature is increased at 6 °C per minute, then, it is parked at 500 °C to allow for $SnCl_2$ evaporation, then, the temperature is increased at 12 °C per minute to 1200 °C, where the furnace is parked for 3 hours, finally, the heat is turned off and the furnace is cooled down.

furnace were purged with N_2 to atmospheric pressure and the cavity was removed from the insert. In Fig. 3 (top left) the cavity sitting on the table after removal from the insert is shown. When the Nb cover foils were removed, several

Figure 3: C3C4 after the coating run. Note discoloration on the NbTi cavity flange (top right) and 'Tin' droplets on the niobium foil from the cavity top flange.

features were observed: discoloration was seen on NbTi flanges (top right), contaminants were observed on the bottom Nb cover foil and the Nb foils that contained Sn and $SnCl_2$ (bottom left), condensation (presumably, Sn) on on the top Nb foil (bottom right). After disassembly, the cavity was inspected with the KEK optical inspection system. The inspection revealed complete coverage of the cavity surface without any notable features, Fig. 4 (left image). In one place on the equator a couple features were observed, Fig. 4 (right image).

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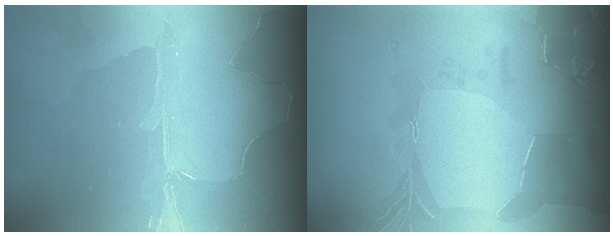

Figure 4: Coated Nb_3Sn surface as seen with KEK inspection system. The left picture shows characteristic equatorial weld regions of the coated cavity. The right picture shows equatorial region with a couple observed features.

RF RESULTS OF NB_3SN-COATED CAVITY

After the optical inspection the cavity was assembled onto the RF test and tested. Two Lakeshore DT-670 temperature diodes were placed on the cavity before the cooldown: one on the bottom beam tube and one on the top beam tube. The quality factor and the resonant frequency as a function of temperature were recorded with a network analyzer during cooldown. The critical transition temperature was measured to be 17.9±0.25 K, Fig. 5. There was no transition around 9 K, which indicates a complete thick coverage of the surface with Nb_3Sn. The quality factor vs.

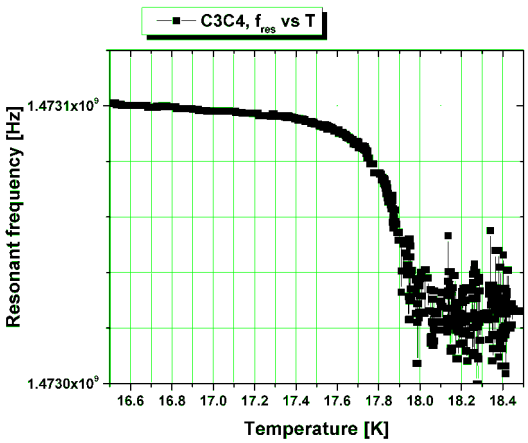

Figure 5: C3C4 resonant frequency vs. average diode temperature. The critical transition temperature is 17.9±0.25 K.

E_{acc} was measured after several cooldowns. The highest quality factor was measured after a slow cooldown with the smallest temperature gradient across the cavity. The low-field quality factor was about 5.10^9 at 4.3 K and $7{\cdot}10^9$ at 2.0 K decreasing with field to about $1{\cdot}10^9$ at $E_{acc} \cong 8$ MV/m at both temperatures.

SUMMARY AND FUTURE PLANS

Nb_3Sn deposition system has been commissioned to expose single-cell niobium cavities to Sn and $SnCl_2$ vapor up to 1200 °C for diffusion-based Nb_3Sn coatings. The first coated 1.5 GHz CEBAF-shaped single cell cavity had the transition temperature of about 18 K close to the maximum reported in the literature. The low-field quality factor was about 5.10^9 at 4.3 K and $7{\cdot}10^9$ at 2.0 K decreasing with field to $1{\cdot}10^9$ at $E_{acc} \cong 8$ MV/m at both temperatures. The highest field was limited by the available RF power. We are applying our coating process to more cavities to establish the effect of coating conditions and substrate, e.g., surface preparation, on superconducting properties of coated cavities.

ACKNOWLEDGMENTS

We would like to thank Philip Denny, Harry Fanning, Danny Forehand, Joe Preble, Tony Reilly, Jennifer Williams for valuable suggestion during the design phase of the project; Peter Kneisel for providing us with the cavity and Sn supplies; Larry Phillips, Charlie Reece, Josh Spradlin, and Anne-Marie Valente-Feliciano for comments and suggestions during various phases of the project; and John Mammosser and Robert Rimmer for continued support.

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