

# RESULTS FROM THE FIRST SINGLE-CELL Nb<sub>3</sub>Sn CAVITY COATINGS AT JLAB\*

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## Abstract

Nb<sub>3</sub>Sn is a promising superconducting material for SRF applications and has the potential to exceed the limitations of niobium. We have used the recently commissioned Nb<sub>3</sub>Sn coating system to investigate Nb<sub>3</sub>Sn coatings on several single-cell cavities. We attempted to use the same coating procedure on several different single-cells with different 'genetics' and pre-coating surface preparation. We report on our findings with four 1.5 GHz CEBAF-shape single cell and one 1.3 GHz ILC single cavities that were coated, inspected, and tested.

## CAVITY MATERIAL AND COATING PROCEDURE

Five cavities were used in these experiments. The cavity details are summarized in Table 1. Each cavity was measured at 2.0 K after the latest chemical treatment and the standard RF test preparation. After baseline tests, cavities were disassembled and prepared for Nb<sub>3</sub>Sn coating. Following our experience with the first coated cavity C3C4, we adopted the following procedure:

- High pressure water rinsing, the cavity is left drying over the weekend
- Cleanroom assembly for Nb<sub>3</sub>Sn coating
- Loading into the insert of Nb<sub>3</sub>Sn coating system
- Nb<sub>3</sub>Sn coating: 6 °C/min, 500 °C x 1 hr soak, 12 °C/min, 1200 °C x 3 hr soak. 3 gr of Sn and 3 gr of SnCl<sub>2</sub> used for each coating
- Visual inspection and KEK camera inspection
- Lapping of cavity flanges
- Low pressure water rinse
- Ultrasonic cleaning with 2% Liquinox detergent
- Assembly of the pick-up flange
- High pressure water rinsing
- Final assembly
- Slow pump down
- Leak check to 2·10<sup>-10</sup> ATM-CC/sec or better
- Cooldown to 4.3 K. ΔT across the cavity is maintained at less than 0.1K from 17.0 to 18.3 K.

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- RF test at 4.3 K
- Warm up to above 18.3 K and cooldown to 2.0 K. ΔT across the cavity is maintained less than 0.1K from 17.0 to 18.3 K.
- RF test at 2.0 K

Because of the roughing pump failure, the coating of C1C2 had to be stopped, when the chamber was at about 1000 °C. The cavity then sat in the insert, until the heating profile was re-run a few days later.

## OPTICAL INSPECTION

After the coating each cavity was moved to the optical inspection bench for optical inspection with KEK-style optical inspection bench [1, 2]. The focus of the inspection was largely the equatorial region, but pictures of beam tubes were also collected in several cases. The optical in-

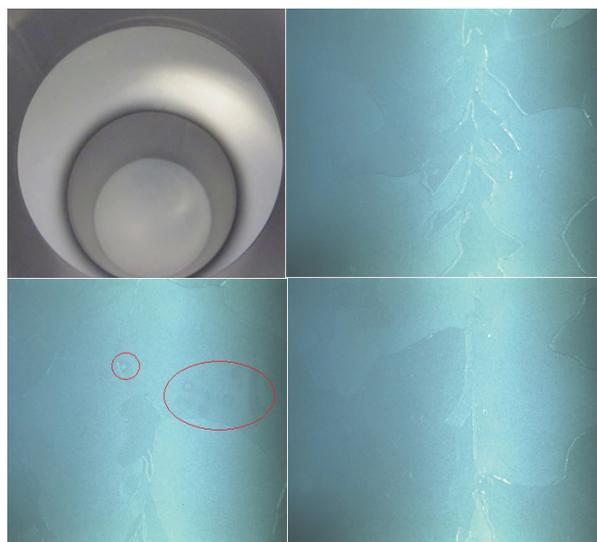


Figure 1: Optical inspection pictures of C3C4. Top left picture shows the coated surface of the cavity looking from one of the beam tubes. Top right and bottom right pictures show characteristic equatorial weld regions of the coated cavity. Bottom left picture shows the equatorial region with several observed features (marked with red circles).

spections of C3C4 and C1C2 revealed uniform complete coverage of the surface. In one place at the equator area of C3C4 we found several ≈ 100 μm-size features, Fig. 1. We did not find any outstanding features during the inspection of C1C2.

Table 1: Cavity Details

| Cavity #  | Cavity shape         | Material   | Treatment prior to Sn exposure   |
|-----------|----------------------|--|--|
| C3C4      | 1.5 GHz 1-cell CEBAF | RRR sheets from CEBAF production                                   | 20 $\mu\text{m}$ BCP + 800 $^{\circ}\text{C}$ x 2 hrs + 23 $\mu\text{m}$ BCP   |
| TE1G001   | 1.3 GHz 1-cell TESLA | RRR from Tokyo Denkai Co., LTD., Ingot:NC-1508, sheets No.1 & No.2 | 120 $\mu\text{m}$ BCP + 80 $\mu\text{m}$ BCP + 800 $^{\circ}\text{C}$ x 2 hrs + 25 $\mu\text{m}$ BCP + 25 $\mu\text{m}$ EP + 120 $^{\circ}\text{C}$ baking                                     |
| C1C2      | 1.5 GHz 1-cell CEBAF | RRR sheets from CEBAF production                                   | BP + 150 $\mu\text{m}$ BCP + 50 $\mu\text{m}$ BCP + 800 $^{\circ}\text{C}$ x 2 hrs + 10 $\mu\text{m}$ BCP + 800 $^{\circ}\text{C}$ x 2 hrs + 30 $\mu\text{m}$ EP                               |
| ALD3      | 1.5 GHz 1-cell CEBAF | RRR sheets from CEBAF production                                   | 120 $\mu\text{m}$ BCP + 50 $\mu\text{m}$ BCP + 30 $\mu\text{m}$ BCP  |
| Frank Jr. | 1.5 GHz 1-cell CEBAF | 'Stitched' reactor grade from CABOT [3]                            | 120 $\mu\text{m}$ BCP + 800 $^{\circ}\text{C}$ x 2 hrs + 40 $\mu\text{m}$ BCP + 1200 $^{\circ}\text{C}$ x 3 hrs + 40 $\mu\text{m}$ BCP + 1400 $^{\circ}\text{C}$ x 3 hrs + 30 $\mu\text{m}$ EP |

The optical inspection of Frank Jr. revealed that the coating was largely uniform and complete. However, one strip of niobium had multiple features, Fig. 2. The features were confined to that strip and were distributed over the whole strip. We note that Frank Jr. cavity was built out of several strips of niobium, which were electron beam welded together to form the sheets, which were then deep drawn to form the cavity half-cells [3]. Hence, the strip of niobium, which had features after  $\text{Nb}_3\text{Sn}$  coating, had received all the same heat and chemical treatments as the rest of the cavity after manufacturing. Similar variation was observed with TE1G001 between two half-cells of the cavity, which were exposed to the same treatment after manufacturing. One half-cell of TE1G001 had uniform gray appearance characteristic of  $\text{Nb}_3\text{Sn}$ . The other half-cell had darker grainy appearance. These findings with Frank Jr. and TE1G001 underscore the importance of the substrate for  $\text{Nb}_3\text{Sn}$  coating. We plan to perform temperature mapping and material analysis to understand the impact to RF performance and the cause of the coating variation.

The optical inspection of ALD3 revealed complete uniform coating of the cavity. Higher contrast between grains was observed with this cavity than with C3C4 or C1C2, cf. Fig. 1 and Fig. 3. A number of features was also found at the equator, Fig. 3. The cavity was limited at  $E_{acc} = 10.5$  MV/m in RF test at both 4.3 K and 2.0 K. A thermometry test to correlate surface features with RF performance is planned in the future.

## RF TEST RESULTS

After optical inspections the cavities were tested at 4.3 K and 2.0 K. Typically, four Lakeshore DT-670 diodes were attached to the cavity to monitor temperature spread across the cavity during cooldowns: one diode was attached to the bottom beam tube, one – to the bottom half cell, one – to the top half-cell, and the last diode was attached to the top beam tube. A network analyzer was used to monitor the resonance frequency and the quality factor (based on 3 dB measurement) of the cavity during cooldowns. The su-

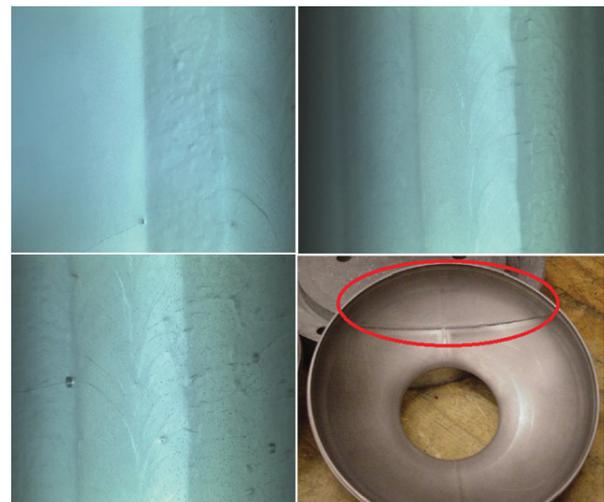


Figure 2: Optical inspection pictures of Frank Jr. Top right picture shows characteristic equatorial weld regions of the coated cavity. Top left and bottom left pictures shows equatorial region close to the region where features were observed. Bottom right picture shows the half cell of the cavity before welding from [3]. The red circle on the bottom right picture marks the niobium strip, where features were observed after the coating.

perconducting transition temperature was found to be the same for all tested cavities at  $17.9 \pm 0.25$  K. We did not observe any transitions at 9 K, which indicates thick complete  $\text{Nb}_3\text{Sn}$  coverage. During RF tests all three cavities had the low field quality factor close to  $1 \cdot 10^{10}$  at both 4.3 K and 2.0 K, but exhibited medium field Q-slopes varying in strength, Fig. 4. While there is a significant variation in the low-field quality factor between cavities, we also measured similar variation in low-field  $Q_0$  between RF tests of the same cavity, Fig. 5. We believe that this variation is caused by the environment during cavity cooldown, and plan to investigate it further with a better instrumented test stand.



Figure 3: Optical inspection pictures of ALD3. Top left picture shows the coated surface of the cavity looking from one of the beam tubes. Top right and bottom left pictures show characteristic equatorial weld regions of the coated cavity. Bottom right picture shows equatorial region with a couple observed features (marked with the red circle).

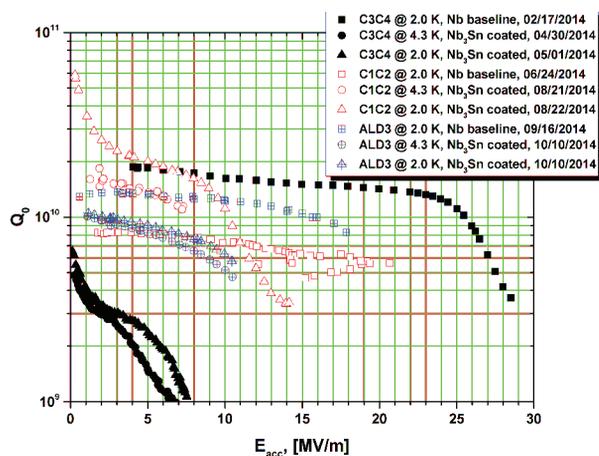


Figure 4:  $Q_0$  vs  $E_{acc}$  for C3C4, C1C2, and ALD3 at 4.3 and 2.0 K. Squares are the 2.0 K RF data for bare Nb cavity. Circles show the 4.3 K test data after  $Nb_3Sn$  coating. Triangles present the 2.0 K RF data after  $Nb_3Sn$  coating.

## CONCLUSION

Several single-cell cavities have been coated to explore diffusion-based  $Nb_3Sn$  coatings on niobium cavities in the recently commissioned  $Nb_3Sn$  coating system. We attempted to use the same coating procedure on several different single-cell cavities with different "genetics" and pre-coating surface preparation. In one striking case the optical inspection of the internal surface showed that the niobium prepared and coated under identical conditions has very non-uniform coating and potentially varying RF properties.

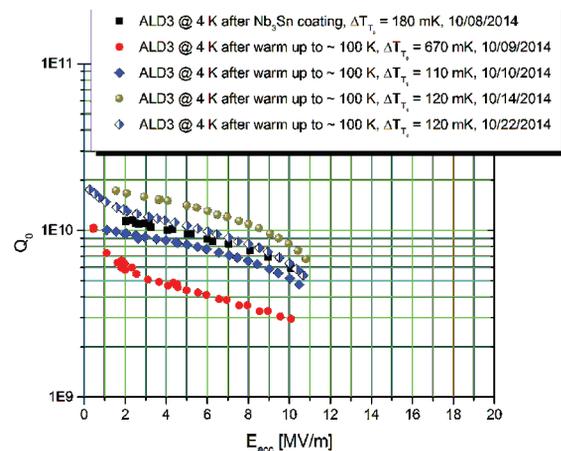


Figure 5:  $Q_0$  vs  $E_{acc}$  for ALD3. Note that the cavity remained in the dewar from October 8<sup>th</sup> to 14<sup>th</sup>.  $\Delta T_{TC}$  shows the measured maximum temperature difference among four diodes crossing 17.9 K during cooldown. The accuracy of the temperature sensors is 0.25 K. The accuracy of  $Q_0$  measurement is about 18%, and the accuracy of  $E_{acc}$  measurement is about 8%.

Three cavities that exhibited visually uniform coatings were tested at 4.3 K and 2.0 K. All cavities had the critical transition temperature of  $17.9 \pm 0.25$  K. Low-field quality factor was around  $1 \cdot 10^{10}$ , but the cavities had a strong medium-field Q-slope. The highest measured accelerating gradient was 14 MV/m at 2.0 K limited by a strong medium field Q-slope. We observed a significant variation in low-field quality factor between different tests of the same cavity cooled under seemingly identical conditions, which we plan to further investigate using more accurate instrumentation.

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