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DEVELOPMENT OF Nb_3Sn MULTICELL CAVITY COATINGS*

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Abstract

Nb_3Sn films have the potential to augment niobium in SRF cavities. Besides single-cell cavity efforts to improve Nb_3Sn films, we are working to replicate single-cell results onto the practical 5-cell CEBAF cavities. High quality factors (10^{11} at 2.0K and 10^{10} at 4.3 K) have been measured, but the cavities are typically limited by strong low-field Q-slopes and early quenches. Two of the cavities were selected to be assembled into a 'mock-up' cavity pair unit, the standard step before installation into a cryomodule. Comparison of test results between VTA and pair test offered the first glimpse into post-processing effects on the cavity performance.

INTRODUCTION

Nb_3Sn films are a promising alternative for superconducting RF applications. Progress in Nb_3Sn coating onto niobium cavities using vapor diffusion techniques have been achieved in recent years, and accelerating gradients of E_{acc} $\approx$ 20 MV/m with high quality factors at 4.3 K seem to be within the reach [1–4]. An important step forward is to use Nb_3Sn-coated cavities to accelerate particle beams and to study cooldown, magnetic field, "aging", irradiation, and other effects related to accelerator operation, which have not been studied: except for a short test [5], Nb_3Sn cavities have not been employed to accelerate beams. Towards these goals, CEBAF 5-cell cavities have been systematically coated at Jefferson Lab. Albeit the gradients achieved to date are lower than the target E_{acc} = 10 MV/m, two cavities were processed through the standard preparation steps towards cryomodule assembly after Nb_3Sn coating and testing, and the test results before and after pair assembly were analyzed. These first tests point to the potential challenges regarding integration of Nb_3Sn cavities into accelerating modules.

5-CELL CAVITY COATINGS

Cavities IA110 and IA114, both produced by industry in 90s for CEBAF construction, were selected to be assembled into a "mock-up" cavity string unit after Nb_3Sn coating. Before Nb_3Sn coating, both cavities received 25 μm electropolishing and high pressure water rinsing. Each cavity was assembled in the cleanroom for Nb_3Sn coating. HOM and FPC couplers were covered with niobium blanks using molybdenum fasteners. A crucible with 7 g of Sn and 3 g of $SnCl_2$ was attached to the bottom of the cavity, and a top cover with a suspended small crucible hosting 3 g of Sn was used to cover the other beam port of the cavity. The cavity was then moved to the deposition system and loaded into the coating insert. Once the insert vacuum reached 10^{-6} Torr range, coating cycle was initiated. The coating comprises 6 degree per minute ramp to nucleation temperature of 500°C, where nucleation is done for 5 hours. The temperature is then ramped up to 1200 °C at 12 degrees per minute, where Nb_3Sn growth takes place for 24 hours. Once the cycle is complete, heat shuts off and the cavity cools in vacuum to 45°C, which takes about 12 hours. Coating assymetry, which was often seen in earlier 5-cell cavity coatings, was resolved with the addition of a secondary Sn source at the top. In Fig.1, pictures of coated IA110 cells taken through each of the beam tubes are shown. Both the first and fifth cells have a similar uniform complete appearance of a typical Nb_3Sn coating. Following the visual inspection, the cavities were also inspected with KEK optical inspection system [6]. A number of weld defects were observed at the equators in different cells during as-received inspection. Similar defects at the equator were seen after coatings, Fig.2.

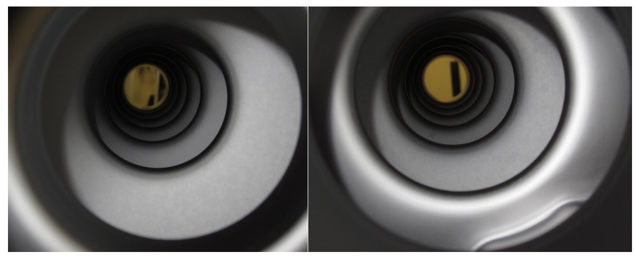

Figure 1: A picture of the inside of IA110 coated with Nb_3Sn. The left picture is taken through the beam tube on the fundamental power coupler side, which is at the bottom during coating. The right picture is taken through the beam tube on the high order mode couplers side, which is at the top during coating. Note similar coating appearance at both sides.

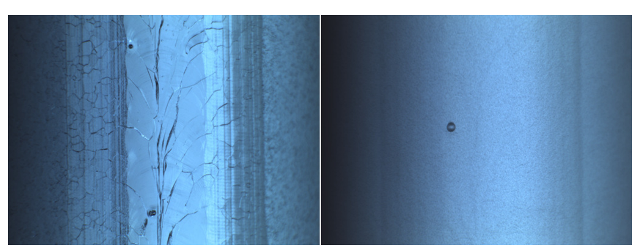

Figure 2: IA110 pictures from optical inspections. Left image shows camera images of the equator region in the 3^{rd} cell and the right image shows camera images from about the same area after Nb_3Sn coating. Note defects in both images.

Two witness samples were put inside each cavity during assembly for Nb_3Sn coating. One sample was hung at the

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top close to the secondary tin source. The other sample was put at the bottom crucible. Samples, which were chemically polished with BCP before coating, were 10mm by 10mm niobium cut from 3mm high purity (RRR ≈ 300) sheet. SEM inspection showed that both samples were well coated with Nb_3Sn. Characteristic grain size for the applied coating process of about 5 μm was observed on both samples. Based on the coating process Nb_3Sn layer thickness is estimated to be about 8 μm. High-resolution SEM inspection revealed small particles (≈ 100 nm) on the surface, which are suspected to be tin, Fig.3. These particles were observed in all witness samples coated with 5-cell cavities.

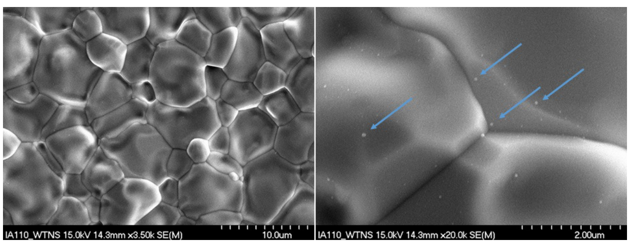

Figure 3: Images from SEM inspections of witness samples. Note nanometer-sized particles, marked with arrows, in the high resolution image [right].

RF TEST RESULTS OF Nb_3Sn-COATED 5-CELL CAVITIES

After coating, the cavities were subjected to regular cleaning procedures before vertical RF test: ultrasonic cleaning with about 1% liquinox, high pressure rinsing, cleanroom drying and assembly, and slow pump down. Niobium blanks were used to cover HOM and FPC ports. RF coupling was provided through beamline ports, where niobium blanks with brazed miniconflat feedthroughs were used to bring antennas. Once a cavity was lowered into the dewar, it was slowly

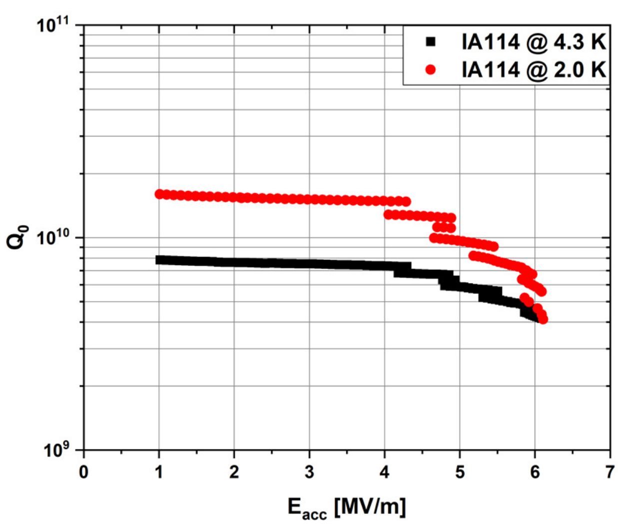

Figure 4: IA114 test results at 4K and 2K. Discontinuities in Q-curves are due to Q-switches.

cooled. The cooldown process typically involved splashing the cavity with liquid helium, then warming up to about 18.5 K. At this temperature, JT helium supply valve setting and heater power in the dewar were balanced to achieve less than 0.5 K temperature difference across the cavity length during cooldown in the temperature range between 17.5 K and 18.3 K. Once the cavity temperature was below 17.5 K, heater power was turned off and JT helium supply valve was opened to nominal dewar fill setting. Once the cavity was completely covered with liquid helium, it was tested at about 4 K. Due to the helium return pressure variation, the test temperature was between 4.3 and 4.4 K. Once 4K measurements were complete, the dewar was pumped down to about 23 Torr and the cavity was tested at 2.0 K.

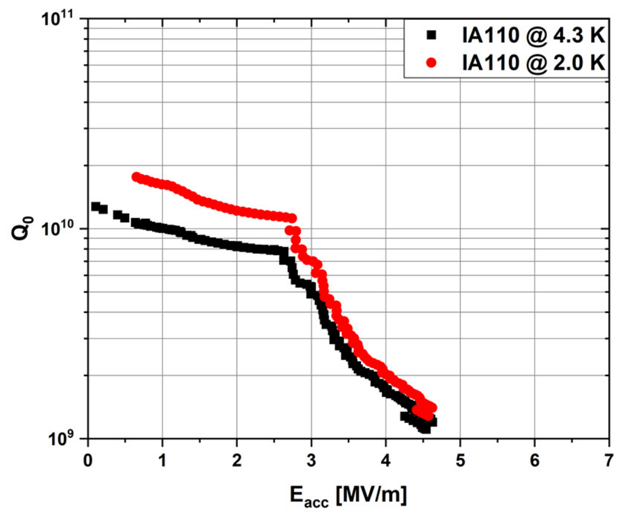

Figure 5: IA110 test results at 4K and 2K. Discontinuities in Q-curves are due to Q-switches.

IA114 test results at 4 K and 2.0 K are shown in Fig.4. The low-field Q_0 is about $8{\cdot}10^9$ at 4K and $1.5{\cdot}10^{10}$ at 2K. The quality factor was approximately constant up to about E_{acc} = 4 MV/m. Above E_{acc} = 4 MV/m, several Q-switches were observed at both 4K and 2K. The cavity was limited to E_{acc} = 6 MV/m with the quality factor of $4{\cdot}10^9$ at both temperatures.

IA110 test results at 4 K and 2.0 K are shown in Fig.5. The low-field Q_0 is about $1{\cdot}10^{10}$ at 4K and $1.8{\cdot}10^{10}$ at 2K. Above E_{acc} = 3 MV/m, several Q-switches were observed at both 4K and 2K. The cavity was limited to E_{acc} = 4.5 MV/m with the quality factor of $1.4{\cdot}10^9$ at both temperatures.

Following RF tests, both cavities were progressed towards a pair assembly. Each cavity was dimensionally checked in CMM and tuned to 1494.65 MHz. Flanges were lapped and checked for flatness. Each cavity then was degreased and brought into the cleanroom, where the cavities were HPRed and dried. After drying the cavities were assembled onto the strongback into a cavity pair with several simplifications: niobium blanks were used on the HOM elbows instead of HOM loads, tophat coupler was assembled directly to the FPC port, and end dishes were blanked with conflats without gate valves, Fig.6. The pair was then loaded into a dewar

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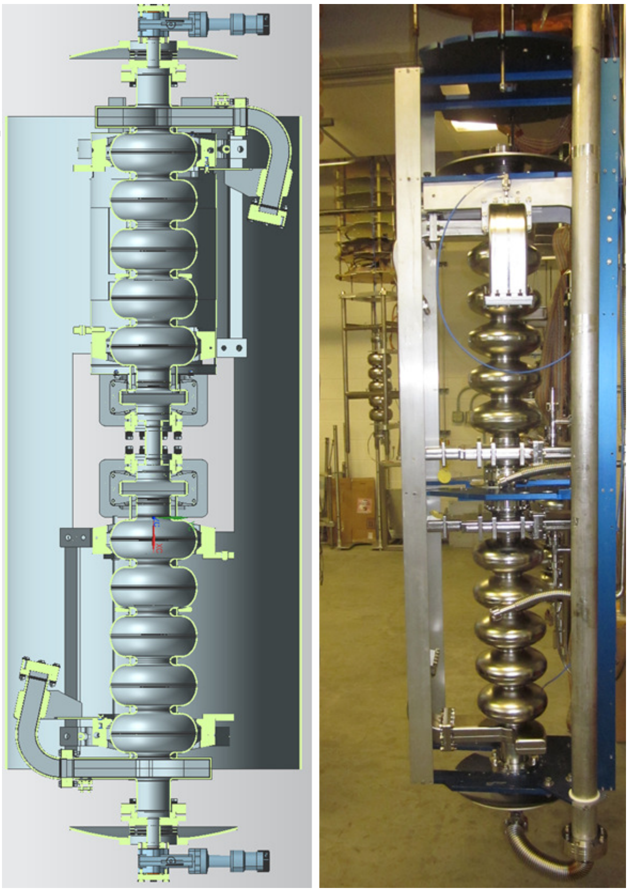

Figure 6: Cavity pair assembly pictures. C75 cavity pair in the part of the helium vessel is shown on the left. Nb_3Sn-coated IA110 and IA114 in a cavity pair are shown before RF test on the right.

and tested a both 4K and 2K. Cooldown procedure similar to that for individual cavity testing was followed.

Both cavities had similar quality factors and quality factor field dependence, see Fig.7. Low-field Q_0 was about $5{\cdot}10^9$ and had a strong field dependence at both 4K and 2K. Initially, a pair component common to both cavities, e.g., the inner adapter, was suspected to be the cause of degradation from the previous tests. The pair was taken apart, and IA114 was re-HPRed and dried in the cleanroom. IA114 was then assembled to be tested individually with hardware used in the initial tests after Nb_3Sn coating. However, cavity performance was unchanged from the pair test. Lower quality factors and strong Q-slope were observed again, Fig.8. Further test indicated that performance degradation was likely caused by the cavity tuning during pair preparation process.

SUMMARY

Nb_3Sn deposition system has been used to coat two CEBAF 5-cell cavities with Nb_3Sn using vapor diffusion-based process. Both cavities had high low-field quality factors, but were limited to about E_{acc} = 5 MV/m after Nb_3Sn coating. To check for potential degradation during cavity integration into cryomodule, these Nb_3Sn-coated 5-cell cavities were tested before and after pair assembly. Following pair assembly, both cavities added about 30 nΩ of surface resistance at low fields and were limited by a strong Q-slope to $E_{acc} \approx 3$ MV/m. The degradation was linked to cavity tuning step during cavity preparation step for pair assembly.

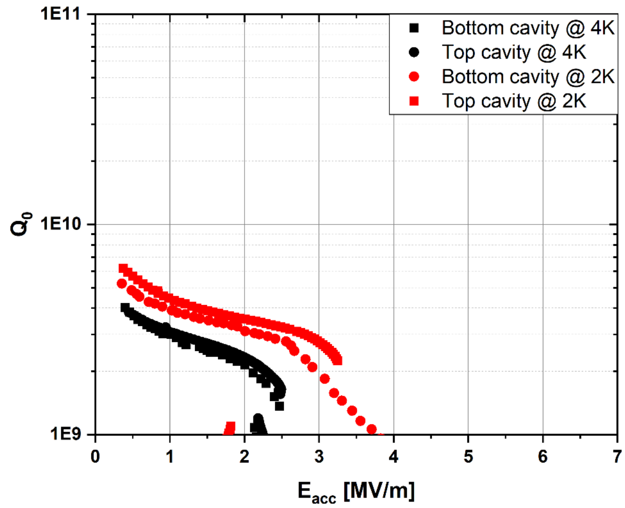

Figure 7: Cavity pair test results. Note lower quality factors and a strong Q-slope compared to previous tests, cf. Fig.4 and Fig.5.

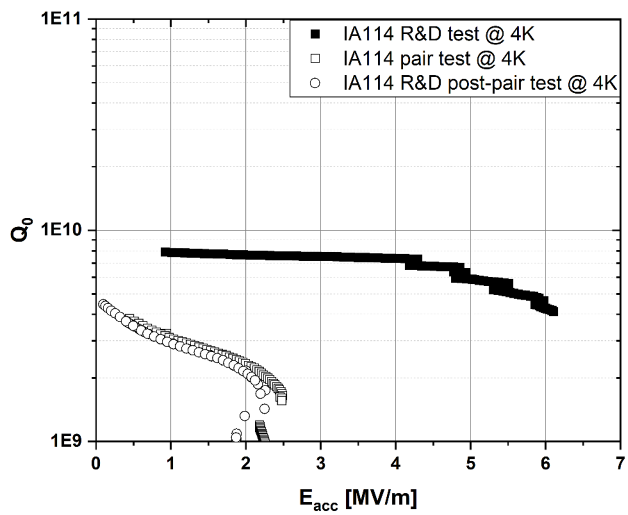

Figure 8: IA114 test results after Nb_3Sn coating [full squares], after pair assembly [open squares], and after re-assembly with R&D hardware[open circles].

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