ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-TUPO059

LATEST RESULTS OF SALT BASED BIPOLAR ELECTRO-POLISHING R&D AT CORNELL*

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Abstract

Acid free electropolishing would be safer to use and friendlier to the environment. A collaboration, supported by the DOE SBIR Phase-II program, between Faraday Technology Inc. and Cornell University focused on salt-based bipolar electropolishing (BEP). In this paper, we present the latest salt-based BEP results. The superconducting performance of a single-cell 1.3GHz cavity has been carefully analyzed, showing that salt-based BEP is promising, but still has large room for improvement.

INTRODUCTION

As superconducting radio-frequency (SRF) technology is increasingly widely used in modern accelerators, the search for an eco-friendly niobium surface process has become an important topic. The objective of this work is finding an alternative to hydrofluoric (HF) and other acids used in the conventional electropolishing process. Acid free electropolishing (EP) uses a near-neutral aqueous salt solution, e.g. $NaNO_3$ or NaCl solution, as electrolyte in bipolar electropolishing [1].

It has been previously reported by Faraday Technology Inc. (Faraday) [1] that the surface roughness of niobium coupons treated with salt-based EP can achieve values as low as 0.05 um, with a material removal rate of ~42 um/hr. The transition from flat coupons to a single-cell cavity requires a more complex set-up, which is based on the bipolar electropolishing system at Faraday. In collaboration with Faraday [2], Cornell tested a 1.3GHz single-cell SRF cavity (LTE1-15) that had been treated by the salt-based bipolar EP at the Faraday EP facility. In the following, we summarize these activities and present results from the single-cell cavity test.

BIPOLAR ELECTROPOLISHING

Bipolar Electropolishing (BEP) applies forward and reverse voltage pulse waveforms on the electrodes, i.e. a cavity and cathode, alternatively, as is shown in Fig. 1. The forward pulse which is positive voltage applied on the cavity enhances mass transport in the EP processing. The reverse pulse is to depassivate the internal surface of the cavity. The off-times are generally inserted between the anodic and catholic pulses to facilitate replenishment of reacting species and removal of by-products and heat. The cathodic pulse eliminates the need for hydrofluoric acid to remove the surface oxide [1]. The bipolar system at Faraday is shown in Fig. 2 [3].

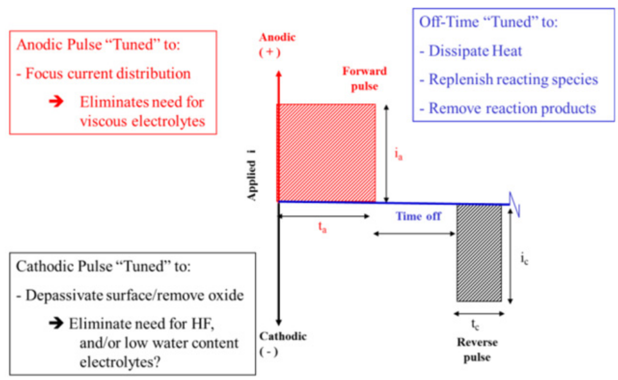

Figure 1: Illustration of the principle of Bipolar EP.

Figure 2: Bipolar EP system at Faraday [3].

SALT ELECTROPOLISHING AND TEST RESULTS

A 1.3GHz ILC-type cavity had been sent to Faraday for the salt-based EP, which was processed in 200 g/L $NaNO_3$ + 19.5 g/L Tris Acid + 1g/L Tris Base mixture. The total removal was ~30um with the polishing rate ~1.6um/hr.

Optical Inspection

After the salt electropolishing, we did optical inspection of the cavity at Cornell [4]. The inner surface of the equator region, shown in Fig. 3, is shiny and looks similar to a surface after conventional EP. However, we observed discoloration on other regions of the cavity wall, as is shown in Fig. 4. These stains are likely thick oxide layers generated in the salt EP processing.

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ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-TUP0059

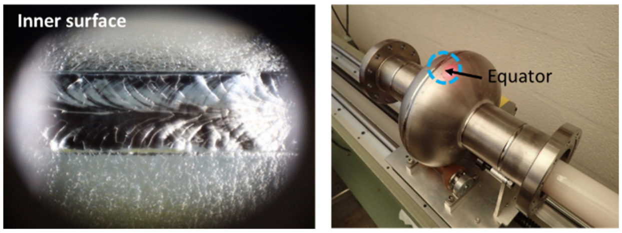

Figure 3: Optical inspection image of equator region indicating the salt EP surface looks similar to a surface after conventional electropolishing.

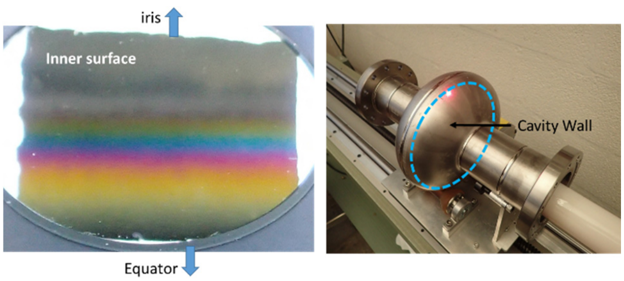

Figure 4: Optical inspection image of cavity wall showing discoloration generated during the salt EP.

Vertical Test

The cavity then was high-pressure water rinsed and cleanly assembled in class 10 clean room. The RF test showed that the cavity had a high residual-resistance R_0 of ~50 nΩ, as is shown in Fig. 5. The cavity quality factor Q_0 at 2K was low, and Q_0 versus gradient (E_{acc}) measurements at 2K were limited by RF power. Hence the Q versus E was measured again at 1.6K; see Fig. 6. The cavity quenched around 40MV/m, with a strong medium Q-slope.

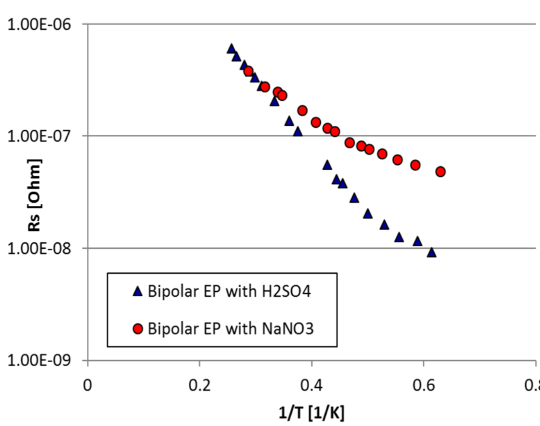

Figure 5: R_s vs. 1/T curves of salt EP compared to regular BEP.

Post Surface Processing

Following the first RF test, the cavity was baked at 120°C for 48 hours in a UHV furnace [5] to reduce surface resistance and improve cavity Q_0. After the baking, the 2K Q_0 at low-field had been dramatically increased from 3.6×10^9 to 6.2×10^9, as is shown in Fig. 7. The gradient was limited by a low helium level in the test dewar, and no cavity quench was observed.

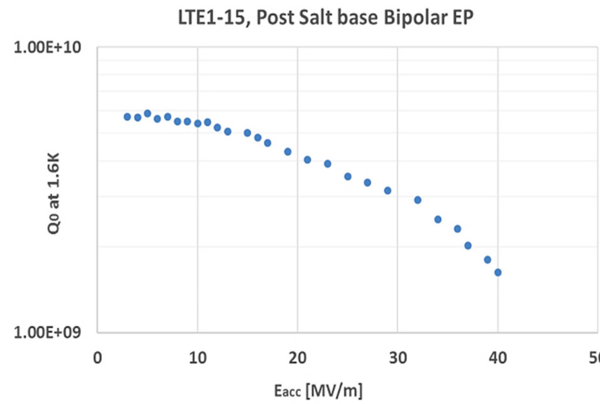

Figure 6: 1.6K Q_0 vs. E_{acc} curve after salt-based EP.

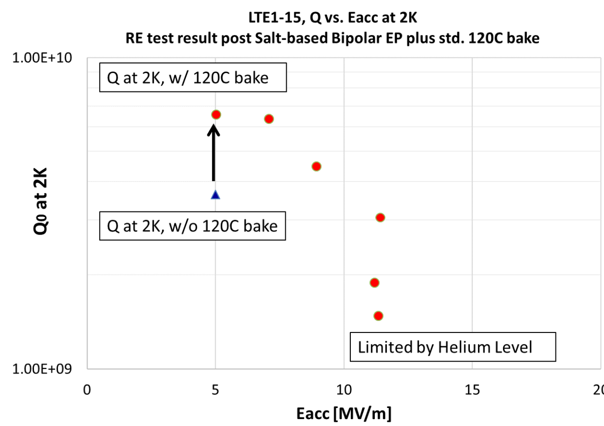

Figure 7: 2K Q_0 vs. E_{acc} curves after 120°C baking showing that Q_0 at low field was improved.

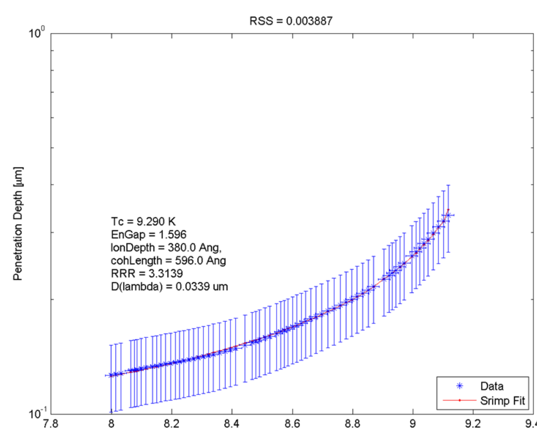

Figure 8: Frequency versus temperature curve fitting indicating that the mean-free-path of the cavity is around 18nm.

The frequency versus temperature data was taken during the cavity warm-up. From the curve shown in Fig. 8, the mean-free-path of the cavity after 120ºC baking was determined to be ~18 nm.

CONCLUSION

A salt-based electropolished single-cell cavity was measured at Cornell University. The results showed that

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the cavity had high residual resistance of ~50nΩ, which is likely due to the discoloration found on the cavity wall indicating a thick oxide layer. The cavity quenched around 40MV/m at 1.6K. This results manifest that salt-based EP can produce high-gradient performance, which is close to the theoretical limits of niobium. A subsequent 120ºC bake reduced the surface resistance and improved the low-field Q_0 from 3.6×10^9 to 6.2×10^9 at 2K. Frequency versus temperature measurements indicates that the mean free path of the cavity was ~18 nm, which is shorter than a conventionally electropolished cavity.

The test result suggests that salt-based EP with post surface treatment, e.g. 120 ºC baking and HF rinsing, has the potential of producing a high-gradient cavity. The mean-free-path of the surface after salt-based EP is short, indicating that some impurities are present in the RF penetration layer. The salt-based EP parameters need to be optimized further, which will be the focus of future work.

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