# IMPROVING GRADIENT AND Q PERFORMANCE OF BCP ETCHED MULTI-CELL CAVITIES BY APPLYING A LIGHT EP*

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## *Abstract*

We have electropolishing (EP) processed several multi-cell cavities previously heavy buffered chemical polishing (BCP) etched. With a surprisingly light EP removal of less than 50 micron, all cavities have shown significant gradient and Q improvement. So far three cavities including two fine-grain niobium 7-cell CEBAF upgrade prototype cavities and one large-grain niobium 9-cell ILC cavities have been treated and tested. The two 7-cell cavities reached a quench limit (without field emission) of 35 MV/m and 25 MV/m, respectively. Another 7-cell cavity has been treated and is under RF test. We give a summary of the test results.

## INTRODUCTION

It is well known that EP processing improves the gradient performance of previously BCP etched niobium cavities. More than a decade ago, in single-cell cavity studies at KEK, a light EP removal of 10-50 μm following heavy BCP etching of 200-250 μm was found already sufficient for improving the gradient performance [1, 2]. Shortly after these single-cell cavity demonstration, in the year of 2001, the benefit of EP for improving gradient performance of previously heavy BCP etched multi-cell cavities were also shown in 9-cell as well as in 7-cell cavities [3, 4, 5]. With the discovery of the low temperature bake effect [6], a recipe for high performance cavity treatment has been established, namely EP followed by low temperature bake. It was commonly believed that, for a previously BCP etched multi-cell cavity, at least 65 μm of EP removal would be required for full advantage.

An EP facility became available at Jefferson Lab in 2003 [7]. In the past three years, extensive EP processing capability and expertise for ILC 9-cell cavities have been established for relatively reliable 9-cell processing up to 42 MV/m [8]. This allowed us to re-examine the benefit of a light EP in a previously heavy BCP etched multi-cell cavity. A strong motivation is to explore the potential benefit of improving the Q value at an intermediate gradient (15-25 MV/m) by the high gradient recipe, namely a light EP followed by low temperature bake.

7-cell CEBAF upgrade prototype cavities were chosen initially as some available cavities had been previously BCP etched and RF tested already. Another reason for choosing these cavities is that, for a CW SRF machine such as the 12 GeV CEBAF, a higher $Q_0$ value at ~ 20 MV/m reduces the cryogenic load and hence operation cost. In fact, EP processing was favorably considered in the year of 2002 as a "key" to meet the 12 GeV upgrade $Q_0$ specification of $8\times10^9$ at 19.2 MV/m [9]. However, for some reason, in-house evaluation of EP processed 7-cell cavities with favorable results did not happen until the work in the last two years as reported here. In the mean time, JLab has built two large grain 9-cell ILC cavities [10]. Both were previously tested following BCP etching. One of them was chosen for light EP processing to assess its effect on the performance of large grain material.

## PROCESSING PROCEDURES

Three previously BCP etched 7-cell fine-grain cavities (HG006, HG007 & HG008) were light EP processed. They were built as CEBAF upgrade prototype. The detailed cavity RF parameters and processing history can be found in [11, 12]. The processing resembles that for ILC 9-cell cavities and is consisted of the following steps:

1. Tune field flatness.
2. Ultrasonic cleaning.
3. Light EP (30-50 μm removal at equator).
4. Ultrasonic cleaning (2% Liquinox).
5. HPR.
6. Class-10 area drying.
7. Class-10 assembly.
8. Second HPR.
9. Final class-10 area assembly.
10. Slow pump down and leak check.
11. Low-temperature bake out (120ºC 48 hours).
12. RF test at 2 Kelvin.

Some cavities were tested additionally before the low temperature bake treatment. Fig. 1 gives the process parameters of a typical 7-cell cavity light EP process.

Figure 1: A typical light EP process of a 7-cell cavity.

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## RESULTS

### *HG006*

Figure 2 shows the baseline performance as well as its performance after a light EP of 30 µm before and after a 120 °C 48 hours bake at 2.0 & 1.8 °K. It should be noted that HG006 reached a maximum $E_{acc}$ of 24 MV/m at $Q_0$ of $6\times10^9$ after initial BCP etching. Somehow its performance degraded with additional etching afterwards. In contrast, after 30 µm EP, the $Q_0$ was already significantly improved even before low temperature bake. After baking at 120 °C for 48 hours, both the gradient and $Q_0$ were further improved. The maximum gradient was limited by available RF power. Finally, at 1.8 K, the low field $Q_0$ was raised to > $2\times10^{10}$ and the maximum gradient reached 35 MV/m limited by hard quench. No X-ray was detected in any of these tests.

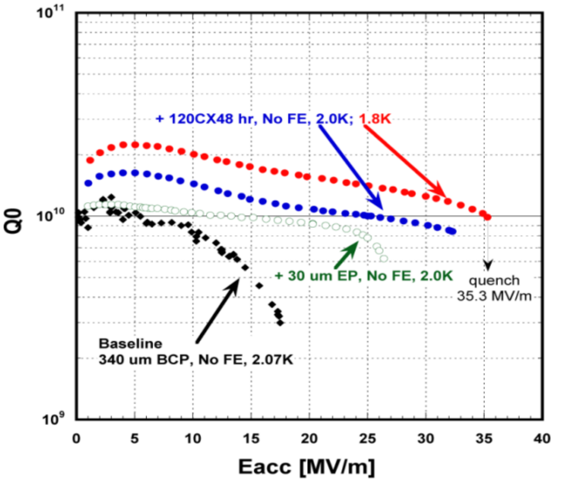

Figure 2: Gradient and $Q_0$ improvement of HG006 by a light EP processing of 30 µm removal and bake.

### *HG007*

Figure 3 shows the baseline performance as well as the improvement of HG007 by a light EP of 35 µm and bake.

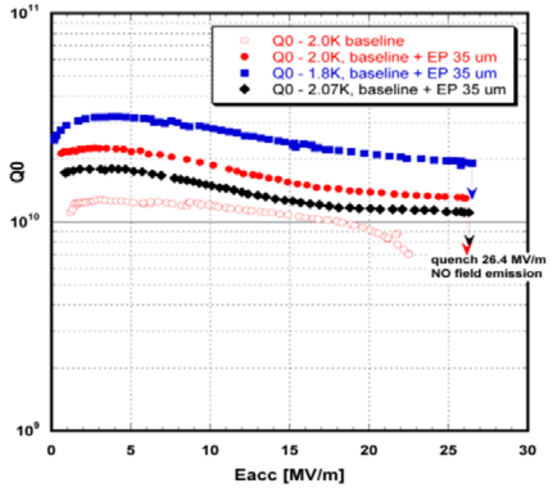

Figure 3: Gradient and $Q_0$ improvement of HG007 by a light EP processing of 35 µm removal and bake.

Pass-band measurements suggested the end cells were responsible for the quench limit. High resolution optical inspection revealed an equator EBW weld defect (Fig. 4) in the end cell near the rectangular waveguide RF power coupler. This weld irregularity turned out to be caused by filament blown-off during fabrication. It is a strong candidate defect responsible for the quench limit at the highest gradient of 26 MV/m.

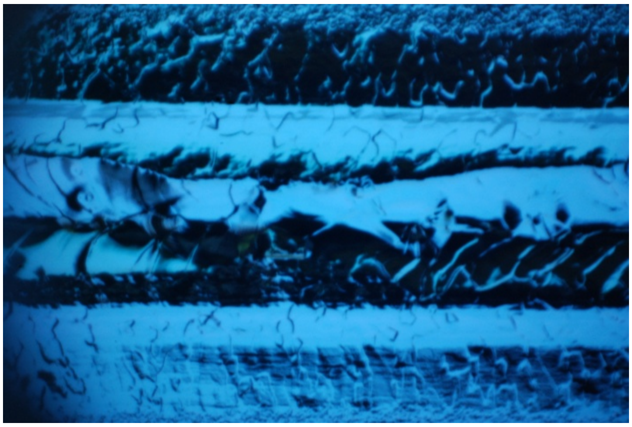

Figure 4: Equator weld irregularity in end cell near the rectangular waveguide RF coupler in HG007.

### *LG1*

Figure 5 shows the baseline performance as well as the improvement of LG1 by a light EP of 35 µm followed by a low temperature bake.

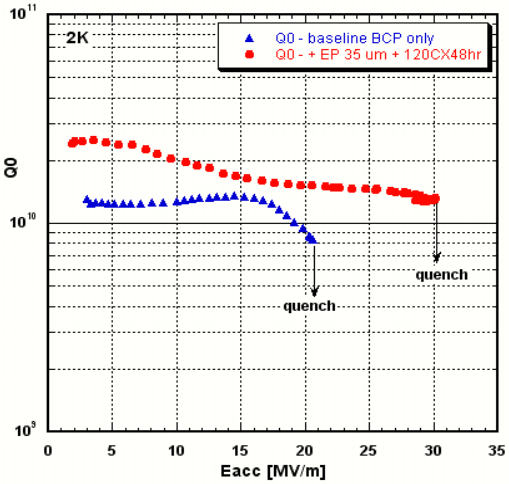

Figure 5: Gradient and $Q_0$ improvement of LG1 by a light EP processing of 35 µm removal and bake.

Pass-band measurements suggested the center cell was responsible for the quench limit. All other cells already reached a peak surface magnetic field of 130-150 mT (corresponding to a gradient of 31 – 35 MV/m). T-mapping test found the quench location to be at the equator weld. Optical inspection revealed weld irregularity (Fig. 6) at the quench location predicted by T-mapping. This weld defect coincides with a weld repair done during fabrication. Weld repair was also necessary for one of the two end cells. Nevertheless that end cell already reached a peak surface magnetic field of 150 mT.

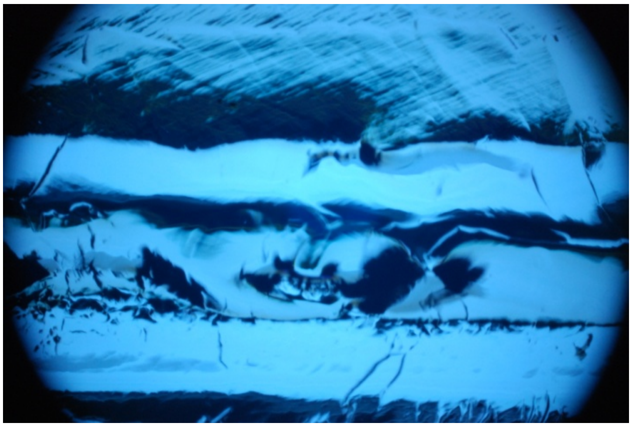

Figure 6: Center cell equator weld irregularity correlated to quench in LG1 at 30 MV/m.

## CONCLUSION

A light EP of 30-50 μm removal at the equator region followed by low temperature bake significantly improved the gradient as well as $Q_0$ performance of two 7-cell fine-grain CEBAF upgrade prototype and one ILC 9-cell large-grain niobium cavities, in-house fabricated, previously BCP etched and RF tested at JLab. All cavities are pushed to their quench limit. The limit in 2 out 3 cavities is attributable to equator weld repairs. In all cases, for the gradient range of 20-25 MV/m, the $Q_0$ value is raised to $1\text{-}2\times10^{10}$ at 2K, without presence of field emission. Further improvement in $Q_0$ to $> 2\times10^{10}$ was demonstrated at a reduced temperature of 1.8 K in a 7-cell cavity. These improved results open up new space in the ($E_{acc}$, $Q_0$) diagram and are expected to impact the optimal cavity working point through optimization algorithms such as the one in [13] published a decade ago. As a "key" for meeting CEBAF 12 GeV $Q_0$ specification at 19.2 MV/m identified seven years ago [9], EP is now finally available in-house and ready to be used to open a door leading to improved SRF cavity operations.

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