Q_0 IMPROVEMENT OF LARGE-GRAIN MULTI-CELL NIOBIUM CAVITIES BY USING JLAB'S STANDARD ILC PROCESSING*

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Abstract

As reported previously at the Berlin SRF conference, applying the JLab standard ILC electropolishing (EP) recipe on initially buffered chemical polishing (BCP) etched fine-grain multi-cell niobium cavities results in improvement both in gradient and Q_0. We recently had the opportunity to further experiment with two 1300 MHz 9-cell large-gain niobium cavities, one manufacture by JLab and the other by Peking University. Both cavities were initially BCP etched and further processed by using JLab's standard ILC EP recipe. Due to fabrication defects, these two cavities only reached a gradient in the range of 20-30 MV/m. Interestingly, both cavities exhibited significant Q_0 improvement in the gradient range of 15-20 MV/m. At 2K, a Q_0 value of 2E10 is achieved at 20 MV/m. At a reduced temperature of 1.8K, a Q_0 value of 3E10 is achieved at 20 MV/m. These results suggest that a possible path toward raising Q_0 in the medium gradient range is to use the large-grain material for cavity fabrication and ILC-style recipe, namely furnace heat treatment, light EP and low temperature bake for final processing.

INTRODUCTION

Pushing the unloaded quality factor (Q_0) of SRF cavities has received lot of attention in recent years. This development is driven by two classes of SRF cavity applications:

- CW machine operated at a medium gradient, such as CEBAF 12 GeV upgrade, Cornell ERL, FNAL Project X.
- Pulsed machine operated at very high gradient, such as ILC 1 TeV upgrade.

For a CW machine at GeV energy range, high Q_0 is needed to keep both the size of the cryo plant and the cryogenic operation cost at reasonable levels. For a pulsed machine at TeV energy range, pushing gradient is important to keep the machine length at a reasonable level; however, to make the higher gradient economically attractive, the cavity Q_0 value must be further pushed beyond the state-of-the-art.

Although there are candidate alternative materials that offer the perspective of lower surface resistance and hence a higher Q_0, it is still premature to plan a future SRF project based on a material other than niobium. In fact, Cornell ERL, Project X and ILC are all based on niobium technology at frequencies in the range from 650 MHz to 1300 MHz. It is therefore of interest to explore methods of improving Q_0 of niobium cavities.

As reported in Ref. [1], applying JLab's standard ILC processing recipe [2] onto an initially BCP etched multi-cell fine-grain niobium cavity resulted in improvements both in gradient and Q_0. Besides the two 7-cell 1497 MHz cavities HG006 and HG007 reported in Ref. [1], a third 7-cell 1497 MHz cavity HG008 was also successfully processed and tested, re-confirming the benefit (Fig. 1).

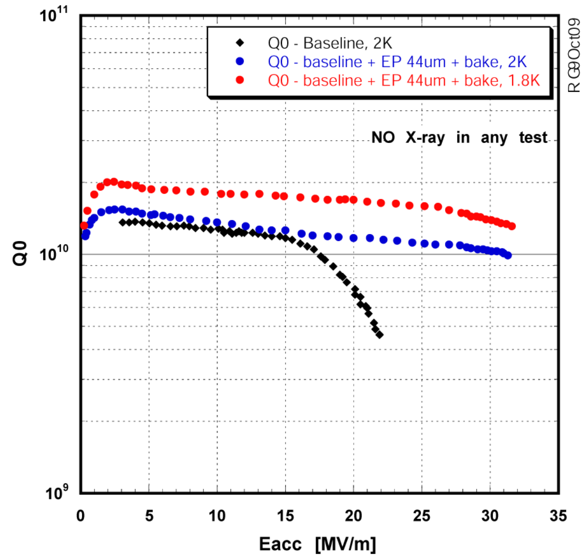

Figure 1: Test results of 1497 MHz 7-cell fine-grain niobium cavity HG008.

These encouraging results with fine-grain multi-cell niobium cavities were followed by further experiments with large-grain multi-cell niobium cavities. In this paper, we will report on the results of two 1300 MHz 9-cell large-grain niobium cavities. We will also analyze the new and previous data in an attempt to understand the physics behind the Q_0 improvement.

CAVITIES AND RESULTS

JLAB LG#1

This cavity was fabricated at JLab using CBMM large-grain material [3]. It was initially tested after BCP etching with a quench limit at ~ 20 MV/m at Q_0 8E9. Following a light EP with 35 μm removal and 120 °C 48 hour bake, the cavity quench gradient was improved to 30 MV/m at Q_0 of > 1E10 [1]. Through T-mapping measurements and optical inspection, a weld repair at the equator EBW of the center cell was found to be responsible for the quench limit. The cavity JLAB LG#1 was then sent to KEK for

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defect removal by local grinding. At KEK, the defective weld repair region of the center cell was successfully smoothened by local grinding [4]. A total removal of 85 μm was accumulated by post-grinding EP at KEK prior to shipping the cavity back to JLab. At JLab, the cavity was RF tested after tuning for field flatness, high pressure water rinsing and 48 hour baking at 120 °C. Pass-band measurements show significant improvement in the center cell performance, confirming the successful removal of the weld repair defect. However, the π mode gradient was degraded due to another weld repair in cell #6 [5].

As the cavity accumulated 120 μm removal due to EP since the baseline test, we decided to perform vacuum furnace heat treatment for hydrogen outgassing. Due to a facility glitch, the actual furnace cycle ended up with 1000 °C for 3 hours (as compared to our standard recipe of 800 °C for 2 hours). Then a light EP with 30 μm removal was applied, followed by our standard post-EP cleaning and assembly procedures including high pressure water rinsing. After a 48 hour bake at 120 °C, the cavity was RF tested at 2 K as well as 1.8 K. The results are shown in Fig. 2. At an accelerating gradient of 15 MV/m, Q_0 reached a value of 2E10 at 2 K and 3E10 at 1.8 K, respectively. For reference, the baseline test result (after BCP only and prior to any EP) is also given in the same figure.

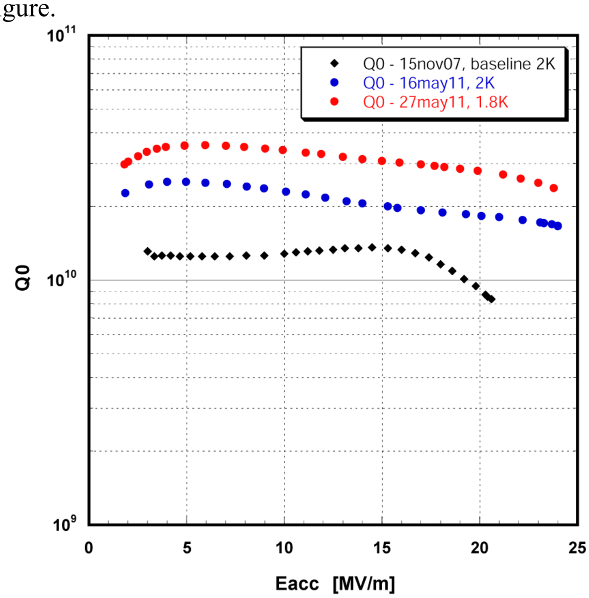

Figure 2: $Q(E_{acc})$ curves of 9-cell large-grain niobium cavity JLAB LG#1 following an ILC-style final treatment including vacuum furnace high temperature heat treatment, light EP and in-situ low temperature bake. Test results at 2 K and 1.8 K are shown, along the baseline result at 2 K after BCP only and prior to any EP.

PKU2

The cavity PKU2 was fabricated by Peking University using Ningxia large-grain material. Fig. 3 shows a photo of the cavity ready for RF testing.

Figure 3: 9-cell large-grain niobium cavity PKU2.

After initial preparation at Peking University, PKU2 was sent to JLab for further processing and testing. At JLab, the cavity was initially BCP etched for 100 μm removal, vacuum furnace heat treated at 600 °C for 10 hours. Another 80 μm BCP etching was applied before the first RF test. The cavity reached a gradient of 19.5 MV/m at Q_0 of 9E9, limited by quench. Pass-band measurements suggest that all cells are more or less equally limited. High-resolution optical inspection of the RF surface revealed a large number of pits near the equator electron beam welding [6]. Fig. 4 shows an example.

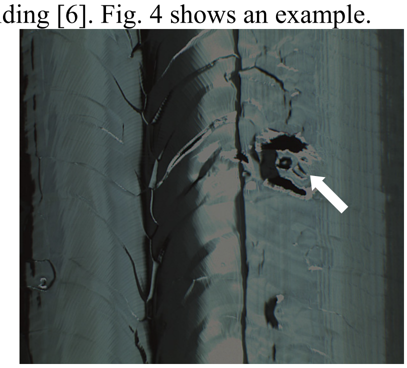

Figure 4: A pit of ~ 2mm in diameter (arrow) near the equator electron beam welding joint of the cell#1. Similar defects are observable in equator weld regions of all cells.

The cavity PKU2 was later on processed by using our standard ILC final processing recipe: first vacuum furnace heat treatment at 800 °C for 2 hours for hydrogen outgassing, then a light EP for 30 μm removal, and finally in-situ bake at 120 °C for 48 hours. The test results at 2K and 1.8 K are given in Fig. 5. The maximum gradient reached 22.4 MV/m both at 2 K and 1.8 K, limited by quench. At an accelerating gradient of 20 MV/m, Q_0 reached a value of 2E10 at 2 K and 3E10 at 1.8 K, respectively. For reference, the baseline test result (after BCP only and prior to any EP and baking) is also given in the same figure.

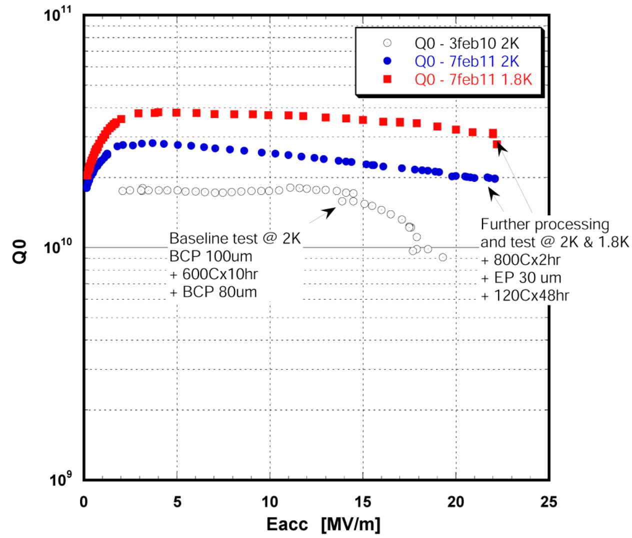

Figure 5: Q(E_{acc}) curves of 9-cell large-grain niobium cavity PKU2 following an ILC-style final treatment including vacuum furnace high temperature heat treatment, light EP and in-situ low temperature bake. Test results at 2 K and 1.8 K are shown, along the baseline result at 2 K after BCP only and prior to any EP.

DISCUSSIONS

The achieved 2 K Q_0 values of JLAB LG#1 and PKU2 exceed 2E10 at E_{acc} 15 MV/m. At 1.8 K, Q_0 values exceed 3E10 at E_{acc} 15 MV/m. These results suggest that the large-grain material has an advantage in getting higher Q_0 values as compared to the fine-grain material. In Fig. 6, Q_0 values of these two large-grain 9-cell niobium cavities are compared to that of fifteen fine-grain 9-cell niobium cavities processed by using JLab's standard ILC recipe and tested in the same dewar.

By using the same data analysis method published in [7], a residual resistance in the range of 3-4 nΩ is derived for JLAB LG#1 and PKU2. This is an improvement of more than a factor of two, as compared to the average value of 8 nΩ derived from fine-grain 9-cell niobium cavities [7]. It should be noted that both JLAB LG#1 and PKU2 are quench limited due to known fabrication defects. Nonetheless, both cavities exceed E_{acc} 20 MV/m, corresponding to a peak surface magnetic field of 85 mT.

Our results suggest that a promising recipe for achieving high Q_0 1300 MHz niobium cavities is the following:

- Cavity fabrication by EBW large-grain niobium.
- Initial BCP etching for 100 μm removal.
- Furnace heat treatment at 800 °C for 2 hours.
- Light EP 30 μm removal.
- Post-EP cleaning, HPR & clean room assembly.
- In-situ baking at 120 °C for 48 hours.

As the residual resistance becomes increasingly dominant in the total surface resistance, this recipe is expected to provide further assurance for getting high Q_0 at lower frequencies [8], such as 650 MHz for the proposed Project X project.

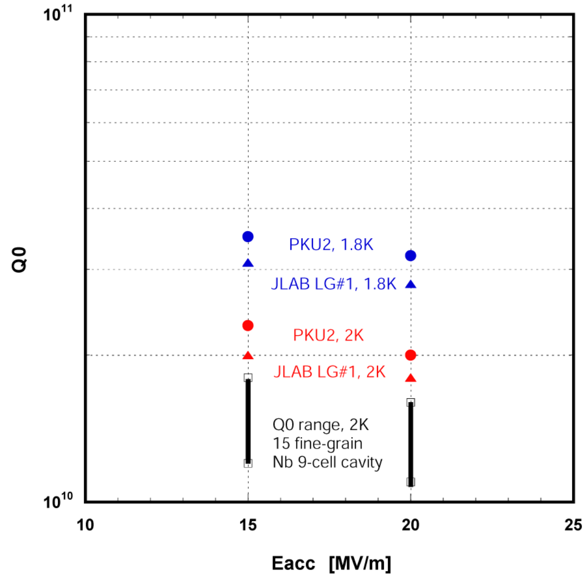

Figure 6: Comparison of Q_0 values of 1300 MHz large-grain 9-cell niobium cavities to those of 1300 MHz fine grain 9-cell niobium cavities similarly processed.

CONCLUSION

Two 1300 MHz large-grain 9-cell niobium cavities achieved a Q_0 of > 2E10 at 2 K and > 3E10 at 1.8 K at E_{acc} 15 MV/m, after processing by using JLab's ILC-style final treatment recipe. By using the large-grain niobium material, there is a prospect of high Q_0 at high gradient of > 35 MV/m required by ILC. A promising recipe for getting high Q_0 at medium gradients with technologies that are becoming increasingly available is suggested. Further processing and testing of more large-grain 9-cell niobium cavities are being planned to increase the statistics of the results.

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