# LARGE GRAIN CAVITIES: FABRICATION, RF RESULTS AND OPTICAL INSPECTION

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*Abstract*

SRF cavities produced from large grain niobium material have been investigated as an alternative to the standard fine grain material in the past years. While many single cell cavities have been prepared and successfully tested, the number of large grain (LG) 9-cell cavities available at the laboratories worldwide is still small. The worldwide experience and results with fabrication, treatment and testing will be compared.

At DESY, a batch of eight LG 9-cell cavities has been processed and tested recently, in addition to three cavities that had been processed and tested earlier.

The surface preparation process has been closely followed by optical inspection in-between all treatment steps that include surface removal. Several of the vertical RF tests have been done with T-mapping and/or second sound measurements for determination of the quench location.

The results after a first treatment cycle with buffered chemical polishing (BCP) and a second treatment cycle with electropolishing (EP) will be presented.

## INTRODUCTION

Cavities from LG material in combination with BCP treatment promise good performance in a cost-effective production and treatment cycle. Direct cutting of discs from LG ingots is cheaper than the fabrication of sheets of fine-grain material including steps like forging, annealing and rolling. Because of the initially smoother surface within the grains, overall smoother surfaces can be reached with BCP without the need for the more expensive EP treatment.

The lower residual resistance of the material results in higher values for Q0 and therefore reduced cryogenic losses. That is especially needed in the prospect of CW operation of accelerators at medium gradient or operation at high gradient of pulsed machines.

## RESULTS

### *KEK*

Three 9-cell ICHIRO-shape cavities (I9#9, I9#10 and I9#11) from LG material have been built at KEK [1]. I9#9 and I9#10 are bare cavities without end-groups, I9#11 has been produced with full end-groups. I9#9 was tested two times already, I9#10 and I9#11 are under preparation [2].

Initial surface removal of I9#9 was done by Centrifugal Barrel Polishing (CBP) and vertical BCP. The average material removal was found to be 96 ± 28 µm at the equators with material removal in the centre cell twice as large as in the end cells due to the vertical BCP setup. The vertical test result was quench at 27 MV/m with $Q_0$=1.1E10. A horizontal BCP setup has been developed for more uniform material removal and I9#9 has been processed again. This time the material removal was 64 ± 13 µm with a more uniform distribution. The test result was the same as in the first test.

In order to improve the reliability and stability of the EBW seams, welding of all seams from the inside of the cavity has been established. All iris and equator welds of I9#10 and I9#11 have been done by inner EBW. The smoothness was improved and the number of visible defects on the equator seam after welding has been reduced by a factor of 5 from I9#9 to I9#10 [2].

### *IHEP*

At IHEP two 9-cell LG cavities of low-loss shape [3] (IHEP-1 and IHEP-2) are under preparation [4]. IHEP-1 has been built from Ningxia material without higher order mode (HOM) couplers. The initial treatment was 190 µm CBP, 110 µm BCP, 3 h firing at 750°C and another 20 µm BCP. The first vertical test was done in July 2010 at the STF at KEK. The cavity was limited at 20 MV/m by quench with field emission. A second test at Jefferson Lab is under preparation.

IHEP-2 will be built with complete end groups; the electron beam welding is to be finished in November 2011.

### *PKU*

At Peking University the cavity PKU2 (see Figure 1) was fabricated from Ningxia LG material in 2009 [5]. Processing and testing of the cavity has been done at Jefferson Lab [6]. In the first vertical test after 100 µm BCP, 10 hrs firing at 600 °C and additional 80 µm BCP the cavity was limited at 19.5 MV/m by quench. The second vertical test showed an improved performance, quenching at 22.4 MV/m after the Jefferson Lab standard ILC recipe including outgassing at 800 °C, 30 µm EP and baking at 120 °C. As reported in [7], there are a lot of pits visible next to the equator welding seam.

Figure 1: Picture of 9-cell LG cavity PKU2 [5].

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### *Jefferson Lab*

Built from CBMM large-grain material the cavity JLAB LG#1 was fabricated, processed and tested at Jefferson Lab. The result of the first test (~20 MV/m at Q0=8E9) after BCP treatment was improved to 30 MV/m with Q0>1E10 in the second test by an EP surface treatment. Temperature mapping and optical inspection identified a repaired section in the equatorial welding seam of cell #5 as the quench location [8]. Local grinding of the defective spot and subsequent 85 µm EP were carried out at KEK. The next test at Jefferson Lab showed an improved performance of the repaired cell (obtained by mode-measurement) but overall degradation of the cavity. Before the latest test hydrogen outgassing, another 30 µm EP, and 120 °C baking were done. Now the cavity is limited at 24 MV/m with Q0>1E10 [6].

### *FNAL*

The surface of the single-cell TESLA-shape cavity [9] PKU-LG1 has been investigated in detail by means of optical inspection and surface replica techniques [10], [11]. The cavity had reached 43 MV/m after BCP processing at Jefferson Lab. One grain-boundary next to the equator weld was of particular interest. It is shown in Figure 2.

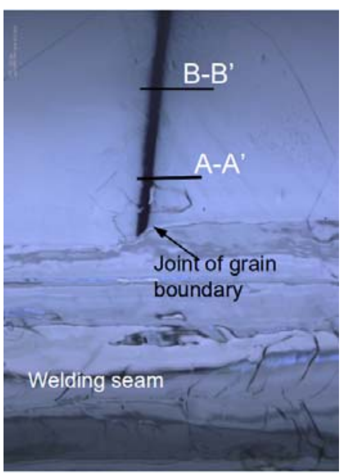


Figure 2: Optical inspection picture of PKU-LG1. B-B' indicates the location of the profile scan in Figure 3 [10].

After taking a surface replica, profile scans of the grain boundary were done. The scan by confocal scanning laser microscope along the line B-B' is shown in Figure 3.

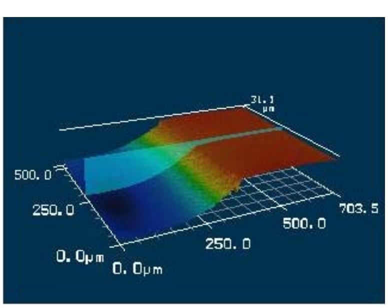


Figure 3: Scan along the line B-B' indicated in Figure 2 by confocal laser scanning microscope [10].

### *DESY*

At DESY a batch of 8 LG TESLA-shape cavities (AC151-AC158) is under preparation and testing since 2009. The fabrication of the cavities was done at the company Research Instruments GmbH. The production of the LG material was part of a R&D program of DESY and the company W. C. Heraeus aimed towards the European XFEL. Each disc had a single crystal of diameter > 150 mm in its centre. For the 8 cavities different orientations of the central crystal were used [12]. AC151-AC153 had a central crystal of orientation (100), AC154 and AC158 orientation (211) and AC155-AC157 orientation (221). After deep-drawing, the averaged deviation from the ideal shape of the half-cell has been determined depending on the orientation of the central crystal. The results are depicted in Figure 4. Orientation (100) where the crystallographic plane is parallel to the sheet surface yields higher deviations than the other two.

As a speciality the grain boundaries in the cavities AC155 and AC156 were ground after the deep-drawing step in order to check if that influences the performance.

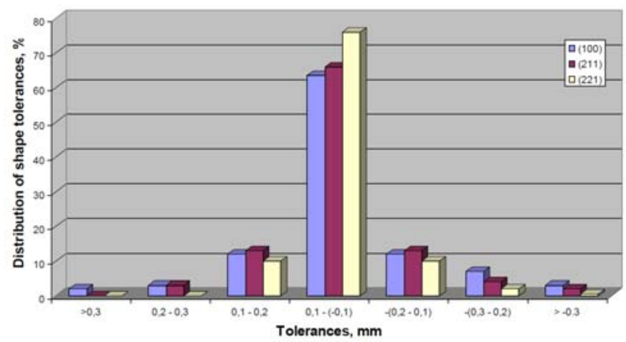


Figure 4: Averaged deviation from the ideal half-cell shape after deep-drawing for different crystal orientations [12].

The first series of vertical tests of all eight cavities was done after a pure BCP treatment of 100-110 µm bulk surface removal, hydrogen outgassing at 800 °C for 2 hrs and a final BCP of 20-30 µm. The $Q_0$(E)-curves of the final tests – some cavities were retested after additional HPR, due to field emission (FE) – are shown in Figure 5. All eight cavities achieve a gradient of 24.5 – 28.5 MV/m. The $Q_0$ at the breakdown field lies in the range of 1.4-2.1E10 for seven cavities. Only AC158 still showed strong FE in the "final" test and thus had a $Q_0$ of 4.5E9.

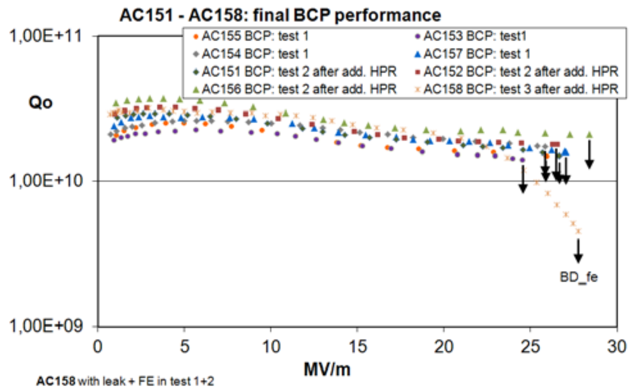


Figure 5: $Q_0$(E)-performance after BCP treatment, measured at 2K. All cavities limited by thermal-breakdown; AC158 with strong FE [13].

After the initial BCP treatment all eight cavities were treated by EP. For six cavities a full EP cycle including 60-70 µm EP, 2 hrs at 800 °C and final 48 µm EP was done. For AC151 and AC155 only the final 48 µm EP step was applied [13]. Figure 6 shows the $Q_0$(E)-curves for the vertical tests after EP. Up to now five cavities have been measured with gradients of 31-45.5 MV/m and $Q_0$ > 1.2E10 at breakdown. AC155 and AC158 exceeded 45 MV/m.

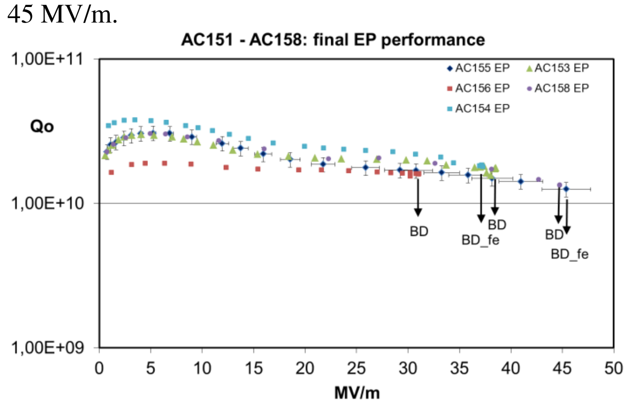


Figure 6: $Q_0$(E) performance after EP-treatment, measured at 2K [13].

A detailed description of the preparation and testing of the cavities is given in [13].

Optical inspection of locations that have been identified as the quenching spot by T-mapping and 2nd sound measurement so far showed no "obvious defects" but grain-boundaries and "etching-pits" that showed up all over the cavities after the BCP-treatment. A typical grain-boundary is depicted in Figure 7; after BCP (sharp) and after EP (smoothened).

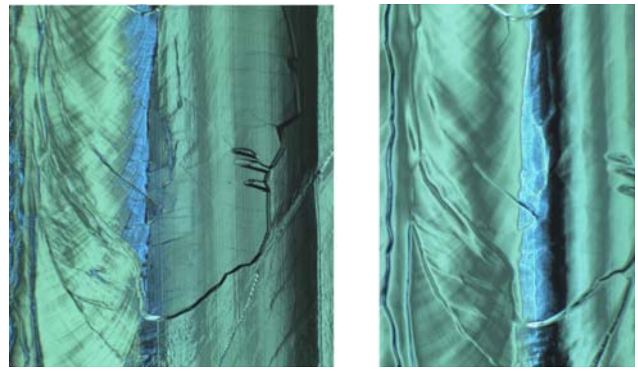

Figure 7: Typical sharp grain-boundary in AC158 after BCP treatment (left), same location after EP with smoothed grain boundary (right).

## COMPARISON OF $Q_0$-VALUES

For the large grain cavities tested at Jefferson Lab, PKU2 and JLAB LG#1, high values for $Q_0$ were reached after EP treatment. Both cavities exceeded $Q_0$=2E10 at Eacc=15 MV/m and 2 K and $Q_0$=3E10 at 1.8 K. At Eacc=15 MV/m and at 20 MV/m the $Q_0$-values lie above the values that were achieved in a sample of 15 fine-grain cavities processed with a similar surface treatment and tested at Jefferson Lab as well [6].

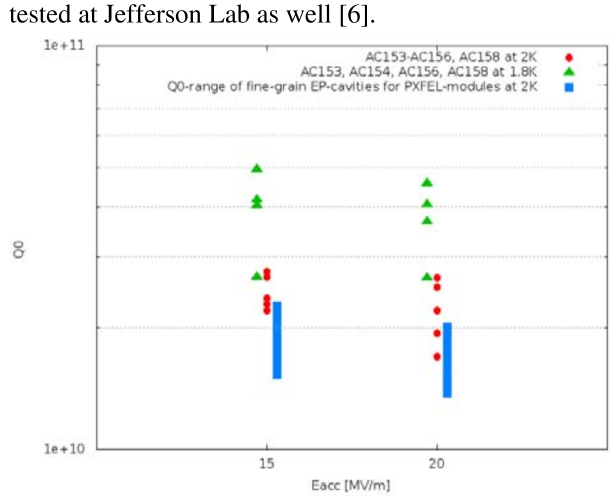


Figure 8: Comparison of $Q_0$ values for selected LG and fine-grain cavities at DESY, all $Q_0$ values taken at 15 and 20 MV/m.

Figure 8 shows a similar analysis for LG and fine-grain cavities processed and tested at DESY recently. The LG cavities are those of the batch AC151-AC158, where the second treatment cycle with final EP has been done and a vertical test was carried out already.

The basis for the fine-grain data set are the cavities for the modules PXFEL1, PXFEL2 and PXFEL3_1. Only cavities with EP surface treatment are considered. Z100 has been excluded, since the limitation was not quench but a parasitic excitation of the 7/9-pi-mode, what leads to a lower value of Q0. In the end 10 fine-grain cavities are taken into account and the Q0-data was taken from the last vertical test before the module assembly.

At 15 MV/m and 2 K all 5 LG cavities exceed $Q_0$=2E10, at 1.8 K all but one (AC156) lie in the range of 4-5E10. The fine-grain cavities are scattered at lower $Q_0$-values of 1.6-2.3E10.

At 20 MV/m and 2 K the LG cavities reach $Q_0$=1.7-2.5E10 with the fine-grain cavities below that with $Q_0$=1.4-2.0E10. At the temperature of 1.8 K the LG cavities exceed $Q_0$=3E10 with the exception of AC156 at $Q_0$=2.7E10.

## SUMMARY

A growing number of 9-cell LG cavities has been produced, processed and tested at the laboratories worldwide. Cavities are produced at different locations with material from several different vendors.

Electropolishing of LG cavities after the initial BCP treatment at Jefferson Lab and DESY has yielded cavities with very good $Q_0$ values, exceeding those of similar fine-grain cavities, and in the case of AC155 and AC158 excellent gradients above 45 MV/m.

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