IHEP 1.3 GHz LOW-LOSS LARGE GRAIN 9-CELL CAVITY R&D*

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Abstract

The combination of the low-loss shape and large grain niobium material is expected to be the possible way to achieve higher gradient and lower cost for ILC 9-cell cavities, and will be essential for the ILC 1 TeV upgrade. As the key component of the "IHEP 1.3 GHz SRF Accelerating Unit Project", a low-loss shape 9-cell cavity using Ningxia large grain niobium (IHEP-01) was fabricated and surface treated (CBP, BCP, annealing, pre-tuning, HPR) at IHEP. The cavity reached 20 MV/m in the first vertical test at KEK STF on July 2010. Second vertical test on this cavity was done at JLAB recently after 2nd pass processing at IHEP. This paper reports the latest result of the vertical tests and surface diagnostics.

INTRODUCTION

The combination of the 1.3 GHz low-loss shape [1, 2] and large grain niobium material is expected to be the possible way to achieve higher gradient and lower cost for ILC 9-cell cavities, and will be essential for the ILC 1 TeV upgrade.

Large grain niobium has several benefits: low surface resistance and high thermal conductivity around 2 K, thus higher Q and potentially higher gradient of the cavity. For example, recently the electro-polished (EP) DESY large grain TELSA cavity AC155 achieved 45 MV/m at Q_0 = 1.3×10^{10}, which has the highest gradient and surface fields and the corresponding Q value ever measured in a multi-cell cavity [4]; material production cost reduction, especially by ingot slicing technique; high Q (> 2E10) in medium field level even by buffered chemical polishing (BCP), which is very promising for CW application for XFEL, ERL and ADS.

From the excellent single-cell results (50 MV/m with very small scattering) by K. Saito and F. Furuta of KEK, there is clear physical reason and enough data to support low-loss shape for higher gradient since 2005. In 2010, the KEK low-loss shape 9-cell cavity (fine grain, electro-polished) with end groups (ICHIRO#7) reached 40 MV/m at $Q_0 = 8\times10^9$ [3].

Thus, 50 MV/m or higher gradient demonstration of the low loss shape 9-cell cavity is foreseen in the next few years, especially using large grain material.

IHEP has started R&D on the 1.3 GHz large grain cavity since 2006. Three electro-polished ICHIRO single-cell cavities were fabricated and processed in KEK with Ningxia large grain niobium material provided by IHEP. The maximum gradient achieved was 48 MV/m at Q_0 = 1×10^{10} [5-7].

Then two low-loss shape single-cell cavities using Ningxia large grain niobium were fabricated and surface treated by IHEP and tested at KEK in early 2008. We made the CBP (centrifugal barrel polishing, tumbling) machine and applied for the single cell cavity in 2007. One of the CBP + BCP treated cavities (without EP) reached the high gradient of 40 MV/m at $Q_0 = 1.6\times10^{10}$ without Q-slope [8-10]. These results showed apparent advantages of large grain over fine grain material.

As the key R&D component of the "IHEP 1.3 GHz SRF Accelerating Unit and Horizontal Test Stand Project" [11-14], a low-loss shape 9-cell cavity without HOM couplers (IHEP-01, Figure 1) using Ningxia large grain niobium was fabricated and processed at IHEP. At the same time, The CBP machine, the BCP facility, the pre-tuning machine, the large ultrasonic cleaner, the high pressure water rinsing facility (HPR) and the high resolution cavity inner surface inspection system etc. for the 9-cell cavity were constructed, commissioned and successfully operated at IHEP [11-18].

The cavity reached 20 MV/m in the first vertical test at KEK STF on July 1st 2010. After the diagnostics and 2nd pass processing, the cavity was tested in JLAB. The fabrication procedure, surface treatment recipes and the test results are summarized in this paper.

Figure 1: IHEP-01 large grain 9-cell cavity.

CAVITY FABRICATION

The large grain niobium disks were provided by OTIC, Ningxia, China. The measured RRR value was 430. Ultrasonic and eddy current scanning were performed on some of the disks.

Due to the special properties of the large grain material, several mechanical and RF problems were found and successfully solved during the fabrication and EBW of half cells and dumbbells. Earrings and steps were found in the equator area. Large cracks and unsmoothness were found between adjacent grains in the iris area. Iris wall thickness was not uniform after trimming [15].

The dumbbell equators were reshaped and trimmed to have the right length and frequency [15]. We inspected

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and carefully grinded most of the defects on the inner surface of the dumbbells, especially on the irises.

For the equator EBW, we matched the dumbbells with similar equator inner diameters and also to make the combined cell frequencies similar.

We used the laser tracking instrument to check the key dimensions of the cavity. The total length (flange to flange) is 1252.85 mm and the concentricity of the 9 cells is 0.86 mm. The designed value is 1247.4 mm and 0.8 mm respectively. During pretuning, we will only squeeze the cells to make the cavity frequency down and the cavity shorter as planned.

SURFACE PROCESSING

Processing Procedures

To explore the BCP limitation of the large grain cavity, the baseline processing of the first two passes is CBP and BCP at IHEP. We will apply EP on this cavity at JLAB for further higher gradient study.

The processing procedures of the two passes are shown in Figure 2 and Figure 3 respectively. The temperature of the BCP acid in the cavity was kept below 15°C and the cavity was reversed during the mid of bulk BCP to make uniform etching [16]. The annealing temperature was 750 °C, 3 hours at the vacuum of 10^{-3} to 10^{-5} Pa. The ultrasonic cleaning was done with 2 % Micro-90® or Liquinox® at 50 °C for 1~3 hour. HPR water pressure was about 80 bar. Baking temperature was 120 °C for 48 hours.

For the 2nd pass HPR at JLAB, we made the first HPR without flanges and the second HPR with the top flange (for the field probe) and the input coupler port transition part (for cavity evacuation) installed to avoid dust contamination. Slow pumping down was also applied.

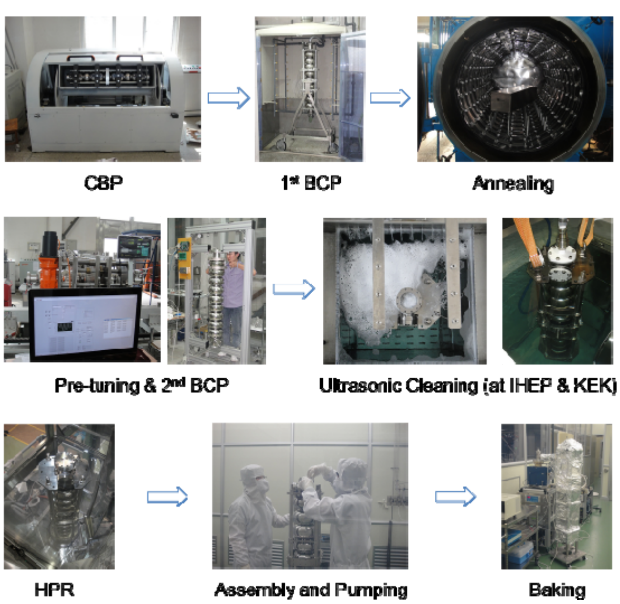

Figure 2: 1st pass processing at IHEP and KEK.

Figure 3: 2nd pass processing at IHEP and JLAB

Defects Removed by CBP

Due to possible hydrogen absorption or other unknown reasons, many EBW sputtering spots appeared in the 2nd to 7th equator as the cavity delivered, except the two equators at the end. 1st pass CBP (190 µm) removed most of the sputtering spots and defects near the equators [16]. 2nd pass CBP (150 µm) removed all the remained detects seen by the IHEP high resolution inspection camera. Some example is shown in Figure 4 and Figure 5.

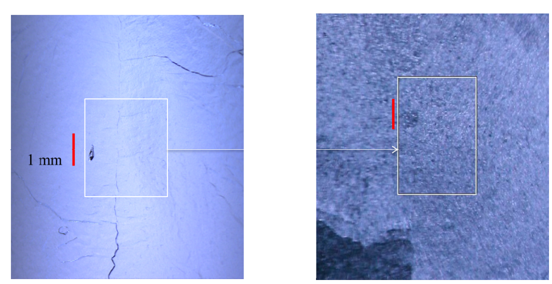

Figure 4: (Left) bump at 340 deg near cell #2 equator (32 MV/m quench location of the 1st vertical) with Kyoto camera after 1st vertical test. (Right) same location after 2nd pass CBP and bulk BCP with IHEP camera.

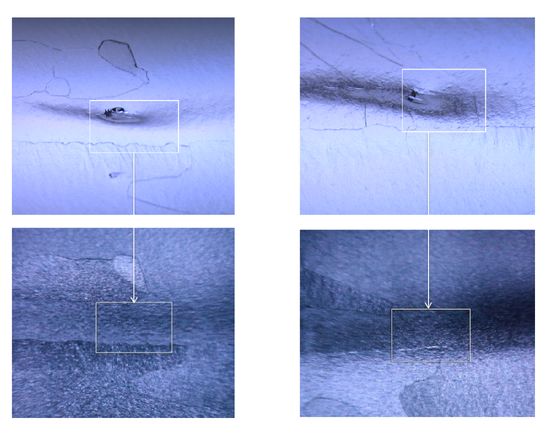

Figure 5: Bump removed at 85 deg (left) and 90 deg (right) near cell # 3 equator after the 2nd pass CBP and bulk BCP.

Field Flatness Change

In the 1st pass, we vertically pre-tuned the cavity field flatness to 97.6 % without the cavity jig and 94 % after jig fitting. After vertical test, the horizontal field flatness was 90 % with jig. In the 2nd pass, the cavity horizontal field flatness was 98.5 % without jig by holding the beam pipes. The vertical field flatness was 92 % by holding the beam pipe and the end plate. After vertical test, the field flatness is 90 %. The 6% difference of the vertical field flatness from the horizontal by the gravity is due to the low loss shape, thin cavity wall (reduced from 2.8 mm to about 2 mm after two processing passes), and the relatively soft large grain material.

VERTICAL TEST RESULTS

Test results are shown in Figure 6.

In the first test (VT1), the initial gradient was 6 MV/m with severe field emission, after passband processing the gradient was limited by hard quench at 20 MV/m with strong field emission.

In the second test (VT2), the initial gradient was 17 MV/m. Then field emission turned on, the π mode gradient decreased to 13 MV/m with field emission.

Passband modes test (Table 1) of the two tests shows that the gradient of five cells is near or higher than 30 MV/m. Two cells were better than 25 MV/m.

T-mapping in the 1st test showed that the quench locations were on the equator of cell #9 270-300 deg (20 MV/m) and cell #2 340 deg (32 MV/m), where the defects were found by the optical inspection (Figure 4 & 7). Although the defects of cell#2 were removed by CBP in the 2nd pass processing, the max gradient was limited by other cells in the 2nd test (Table 1).

The 270-300° area on the equator of cell #9 was suspected to be problematic (incomplete penetration at the end of the equator EBW seam) as delivered (Figure 8 top). After CBP, all the defects seemed to be removed (Figure 7 middle). After the 1st vertical test, two small slits (about 1 mm long) were found in this area by optical inspection with Kyoto Camera, which may be the reason for the hard quench. After the 2nd pass CBP and bulk BCP, the slits couldn't be seen by the IHEP camera.

OST (Oscillating Superleak Transducer) in the 2nd test shows that the quench locations of π, 4π / 9, 5π / 9 modes are around the iris area between cell #7 and 8 (90-120 deg) with field emission. Although the final π mode gradient is 13 MV/m for the 2nd test, the passband test of 6π / 9 showed the gradient is 20.2 MV/m for cell #9. Thermometry attached to the quench area of cell#9 of the first vertical test didn't heat up at 20 MV/m. Field emission induced quench is the possible reason.

The possible field emitters are the pits found in the center of the iris EBW seam between cell #7 and 8 after the 2nd pass CBP and bulk BCP (Figure 8). The pits are the underneath EBW induced gas porosities and appeared after intensive grinding, CBP and BCP. We will apply EP to this cavity to reduce the field emission or local grinding the defect if EP doesn't work.

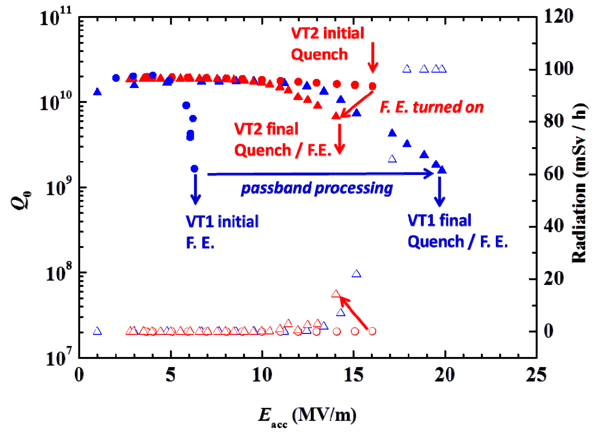

Figure 6: Test results of the IHEP-01 9-cell cavity.

Table 1: Max Gradient (MV/m) of Each cell

Cell	1st Test#	2nd Test
1	> 19.8 (π / 9)	> 20.2 (6π / 9)
2	= 32.2 (3π / 9)	> 29.4 (3π / 9)
3	> 20.7 (5π / 9)	> 32.3 (2π / 9)
4	> 25.4 (4π / 9)	> 22.7 (π / 9)
5	> 32.2 (3π / 9)	= 29.4 (3π / 9)
6	> 25.4 (4π / 9)	> 22.7 (π / 9)
7	> 20.7 (5π / 9)	= 32.3 (2π / 9)
8	> 32.2 (3π / 9)	> 29.4 (3π / 9)
9	= 19.8 (π)	= 20.2 (6π / 9)

π / 9 and 2π / 9 not tested

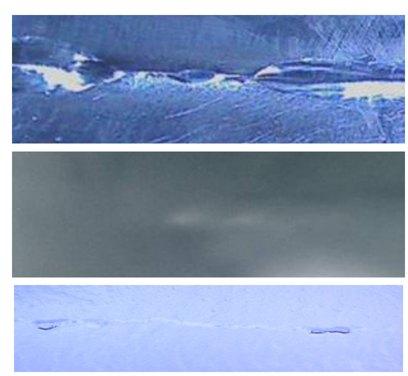

Figure 7: Cell #9 equator 270-300 deg as delivered, after 1st pass final CBP, the 1st test and the 2nd test (not to scale).

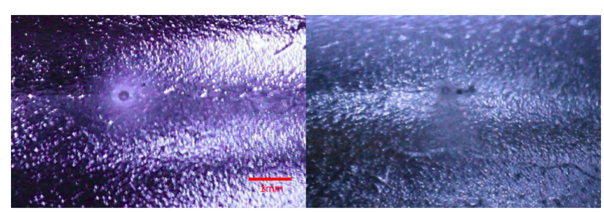

Figure 8: Pits on the iris of IHEP-01 cavity after bulk BCP of the 2nd pass (Picture taken by IHEP camera; Left: ~ 200 µm diameter pit, 120 deg @ cell # 3 & 4, Right: ~ 90 deg @ cell # 8 & 9) [18].

SUMMARY

IHEP has made a low-loss shape large grain niobium 9-cell cavity. The cavity was fabricated, welded and successfully processed (CBP and BCP) with the SRF facilities developed in IHEP. We will apply EP to this cavity and test it again.

The low-loss shape large grain 9-cell cavity with full end groups (IHEP-02) is under fabrication. We will test it at FNAL in early 2012. This cavity will be installed into the cryomodule to make horizontal test at IHEP.

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