ELECTRO-POLISHED CAVITIES USING CHINA NINGXIA LARGE GRAIN NIOBIUM MATERIAL*

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Abstract

For the International Linear Collider (ILC), superconducting RF cavity technology was chosen. The superconducting cavity is made of polycrystalline niobium material so far. However, the material cost is high and the cavity performance has a rather scatter now. Large grain (LG) niobium cavity has the potential of simplifying the production and reducing the cost of the superconducting RF cavities for ILC. To investigate the feasibility of fabrication and the possibility to achieve high gradient by large grain cavities, three single-cell cavities were made of China Ningxia large grain niobium. A series of vertical tests has been carried out on several different surfaces treatment procedures by electro polishing. One cavity has reached the high gradient of more than 43 MV/m repeatedly. The maximum accelerating field of 47.9 MV/m has been achieved. This paper describes the features of electro polishing on China Ningxia LG niobium and presents the preliminary results of the research.

INTRODUCTION

The baseline material of SC RF cavities for ILC is the polycrystalline high purity niobium [1]. The complex processes to produce these sheets increase the cost and also the risk of foreign material inclusions. On the other hand, for many years it has been observed that the performance of SC RF cavities made of fine grain high purity niobium and treated by electro polishing has a rather scatter although the average gradient is increased by electro polishing [2,3]. The reasons are not well understood and a prime candidate for causing the scatter is the "weak" grain boundaries in a niobium surface since the boundaries can easily be contaminated by segregated impurities and form "weak links" which lead to magnetic field enhancement. Also, till now it has been believed that uniform and fine grain material is needed for deep drawing of cavity half cells, and the standard recipes of the fabrication and surface treatments of the polycrystalline niobium cavities have come into being. Dedicated to investigating the possibility of fabricating the 1.3 GHz superconducting RF cavity using large grain niobium and achieving high gradient, three single-cell cavities in Figure 1 made of China Ningxia large grain niobium have been fabricated. After some surface treatments a series of vertically cryogenic tests have been carried out in the framework of ILC cooperation between IHEP and KEK.

Figure 1: Three 1.3 GHz cavities by using China large grain niobium.

LARGE GRAIN NIOBIUM SHEETS

The large grain niobium sheets were produced by OTIC, Ningxia, China. Sheets of 2.88 mm thickness were sliced from the ingots by saw machine. RRR, the most important value for SC RF cavities, was more than 300. Tantalum with a concentration of 50 ppm was the maximum metallic impurity. Among the interstitially dissolved impurities, oxygen whose content was 28 ppm in these sheets was dominant due to the high affinity of niobium for oxygen above 200 °C. The size of the large grains in the sheets was not uniform. The average maximum grain radius in one sheet was about 85 mm and the minimum was 1.38 mm.

CAVITY FABRICATION

To investigate the maximum accelerating field that large grain cavities can achieve, KEK ICHIRO shape was adopted, which has a lower H_{peak}/E_{acc}. From the test results on the existing single-cell cavities, this shape promises higher accelerating gradients. The half-cells were produced by one-step deep drawing. As the grain sizes of the large grain sheets were not uniform, tearing at the iris, and strong earing and grain steps at equator region occurred as shown in Figure 2. Precise 3D geometrical measurements on the inner contour of all the half-cells， height, roundness at equator and iris region, were performed and the deviation values were one order

Figure 2: Half-cell after deep-drawing and trimming.

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of magnitude larger than those of the half-cells from polycrystalline niobium. To avoid making a hole or non-fusion caking at the region of high surface current, 40 % welding from the inside (equator RF-side) was adopted firstly and then from outside with 10 % overlap.

SURFACE TREATMENT

The cavities were subjected to the surface treatments which consisted of centrifugal barrel polishing (CBP), light chemical polishing (CP), annealing, electro polishing (EP), high pressure rinsing (HPR) and baking. The brief introductions of each process are the following.

After electron beam welding, the roughness and defects were very large especially at the region of equator and not uniform and it was necessary to apply mechanical polishing as pre-treatment before chemical or electro polishing. Two of the cavities, #1 and #2, were totally removed about 90 µm averagely by using the CBP machine in Reference [4]. To confirm the effect, Cavity #3 was treated by the procedures without CBP. The removal thickness of light chemical polishing for all three cavities was 10 µm by the acid mixture of HF (48%), HNO_3 (60%), and H_3PO_4 (85%) in the volume ratio 1:1:1. Annealing was performed at 750 °C for 3 hours in the vacuum furnace at a pressure of 10^{-3}~10^{-4} Pa.

EP has been identified as an excellent technology for high gradient SC RF cavities by smooth surface finishing. The horizontally rotating continuous electro polishing method (HRC-EP) in Reference [4] was used for the large grain cavities. The acid pumping speed into cavity was 3.8 L/min for the large grain cavities. The voltage was 25.0 volts and the solution temperature in the cavity was between 25 and 35 °C. The thickness of removed niobium was estimated from the total current and was cross-checked by the content of niobium in the electrolyte. In the series of the tests, the removal thickness varied from 20 µm to 80 µm according to the programs proposed on the research. 3 µm of thickness was usually removed with fresh electrolyte after a heavy removal more than 20 µm by EP. The additional light EP of 3 µm was effective to improve the cavity performance.

Immediately after EP process, the cavity was placed in a closed loop of ultra pure water system for 1 hour. The specification of the water included the resistance of more than 18 MΩ/cm, the total organic carbon (TOC) of 10~20 ppb and the bacterial count of less than 4 per liter. With ultra pure water inside the cavity, the valve attached to the cavity was closed and the cavity was brought into the dust-free clean room (Class 10) where the water was drained. In the clean room, the wet cavity was assembled with an RF input-coupler and pick-up antenna on ends of cavity, respectively. In the vacuum stand, the cavity was dried via heating while pumping by the turbo molecular and mechanical pumping system. The vacuum leaking of flange connections was strictly checked before in-situ low-temperature baking. During baking, the optimum temperature ranged from 115 to 135 °C and the vacuum of 10^{-5}~10^{-6} Pa was obtained by ion pump. The baking time of these tests differed from 12 hours to 48 hours.

RF TESTS

RF tests consisted of measuring the surface resistance from 4.2 K to 2.0 K and the dependence of the Q-value on the accelerating gradient (Q_0 vs E_{acc}) at 2 K.

Residual Resistance

Cooling down to 2 K was achieved via pumping down to the pressure of 3.0×10^3 Pa. During pumping down, the temperature dependence of the surface resistance in the range from 4.2 K down to 2.0 K was measured. The curve fitting according to the experimentally obtained R(T) dependence resulted in the residual resistance R_0. Figure 3 was the distribution of the residual resistance values of 8 tests of three cavities. Compared with the cavities made of the polycrystalline niobium, the large grain cavities have a lower residual surface resistance which is attributed to less impurities and smoother surface of the large grain material.

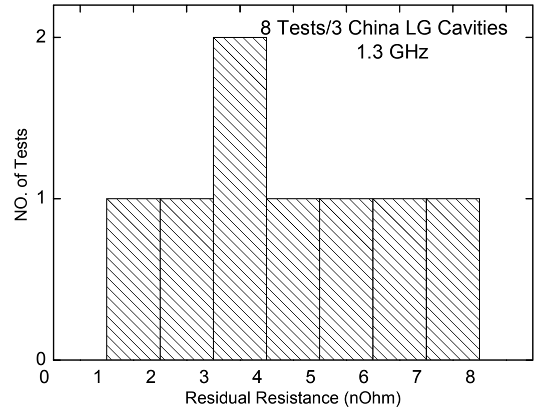

Figure 3: Statistical distribution of residual resistance for 8 tests on three single-cell cavities, 1.3 GHz, large grain cavities prepared by electro polishing.

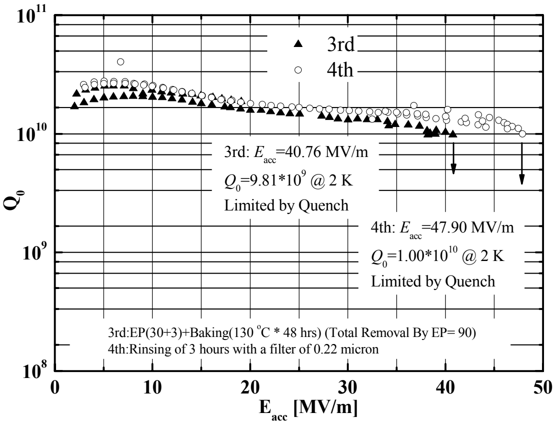

Figure 4: Excitation curves of the third and fourth tests of China LG #1.

China Large Grain Cavity #1

China LG #1 was polished 30 µm of thickness per step by EP and then was vertically tested to figure out the influence of EP removal thickness on the accelerating gradient. In the test when EP removal thickness was only

30 μm, after a processing of 4 minutes from 20 to 24 MV/m, the maximum accelerating gradient reached 24.02 MV/m with a drop of Q-value and a sharp rise of X-signal. The Q-drop demonstrated that the baking of 12 hours was presumably insufficient. For the second test the baking of 48 hours was conducted after EP of 30 μm. The Q-value was higher than the previous test. But multipacting could not be surmounted by processing. When the removal thickness by EP reached 90 μm, the performance of the cavity was evidently improved. Between 20 MV/m and 27 MV/m a processing of 9 minutes worked well to overcome the soft barriers of multipacting. The maximum accelerating gradient reached 40.76 MV/m at Q_0 of 9.81×10^9 and was limited by quench with high X-signal. As some particles or defects on the surface were suspected to answer for field emission, the cavity was rinsed for 3 hours after the replacement of a filter of 0.22 μm. In the fourth test the power could be increased to the gradient of 47.90 MV/m at Q_0 of 1.0×10^{10} as shown in Figure 4.

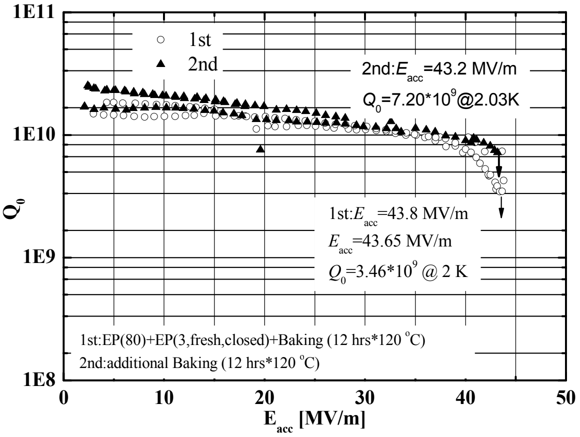

Figure 5: Excitation curves of the first and second tests of China LG #2.

China Large Grain Cavity #2

China LG #2 was dedicated to demonstrating the high gradient of China large grain niobium material by a removal thickness of 80 μm once and the thickness was identified to be enough for polycrystalline cavity to reach a high gradient of 40~45 MV/m. After baking at 120 □ for a short time of 12 hours, the cavity reached a gradient of 43.8 MV/m, limited by *Q*-drop with a weak signal of X-ray. The frequency over the accelerating gradient shifted at the high field level so quickly that the resonance was easy to lose. The degradation of the quality factor at high gradient was cured by an additional baking of 12 hours. The second test achieved a high Q-value of 7.2×10^9 at 43.2 MV/m as shown in Figure 5.

China Large Grain Cavity #3

As China LG #3 was prepared without CBP, after a removal thickness of 30 μm by EP, the maximum accelerating gradient only reached 13.09 MV/m with Q_0 of 1.0×10^{10} and was limited by quench.

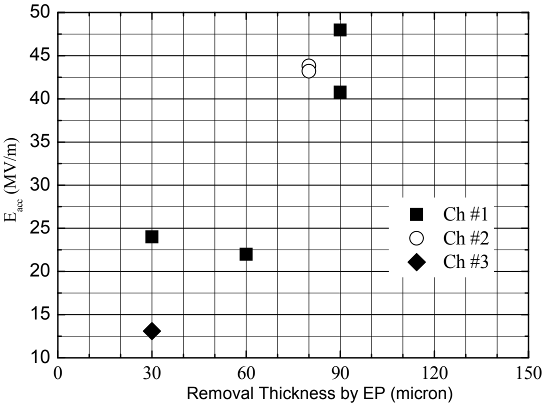

Figure 6: Thickness removed by EP versus the maximum accelerating fields.

SUMMARY

Large grain niobium is a promising prospect for SC RF cavities of ILC. Although the non-uniform characteristics of mechanics brought some complexities to the fabrication, such as deep-drawing and electron beam welding, the manufacture was completed successfully. The standard surface treatments which are effective for polycrystalline material are still suitable for the large grain material. When 90 μm by CBP, 10 μm by CP and more than 80 μm by EP for the two cavities were removed, the cavities both reached the high gradient of above 43 MV/m and the maximum was 47.9 MV/m with a quality factor of 1.0×10^{10} as shown in Figure 6. A baking of 48 hours for large grain niobium is still needed.

More surface treatments and vertical tests on three cavities will be continued in the near future.

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