High Gradient Performance by Electropolishing with 1300 MHz Single and Multi-cell Niobium Superconducting Cavities

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Abstract

We reported the superiority of electropolishing on high gradient performance with 1300 MHz niobium bulk single cell cavities in the last SRF workshop in Abano in Italy. We are still doing the investigation. After the last workshop, we achieved the maximum field gradients of 40 MV/m in more five single cell cavities and Eacc > 30 MV/m in two 3-cell structures. For 9-cell cavities, tests are under going by a DESY/KEK collaboration. In the first test, the gradient was limited around 22 MV/m by multipacting. This contribution presents these results.

1 INTRODUCTION

In the last SRF workshop in Abano, we reported the superiority of electropolishing over chemical polishing with high gradients: Eacc > 30 MV/m [1]. This result was obtained from 1300 MHz single cell cavities fabricated out of the niobium material with RRR=200 from Tokyo Denkai. As next steps we have to make sure its niobium material dependence: firms or RRR value. In addition it has to be identified in multi-cell cavities. Investigation of the material dependence on firms was done with Heraeus material. The RRR value dependence was also checked for the Tokyo Denkai material with RRR=150. In these experiments the superiority was also identified. On the other hand, in experiments used single cell cavities on further high gradient performance by electropolishing, Eacc=40 MV/m was obtained in more 5 single cell cavities. The reliability is much more accumulated. The application of EP for multi-cell structures was started using three 3-cell cavities fabricated by companies and one 9-cell cavity from DESY. Two 3-cell cavities achieved Eacc > 30 MV/m and one was limited to 27 MV/m. The 9-cell cavity is limited to 22 MV/m presently by multipacting.

2 EXPERIMENTS

2.1 Cavity Fabrication and Preparation

One 1300 MHz single cell niobium bulk cavities: K-25 was manufactured to see the superiority in the different niobium materials from Tokyo Denkai [2]. It was fabricated at KEK out of the niobium material with RRR=300 offered from Heraeus. Another single cell cavity was manufactured with Tokyo Denkai RRR=150 niobium material to investigate the RRR value dependence of the superiority. Half cells were formed by deep drawing. After accomplishment of the cavity by electron beam welding, K-25 was removed material of 40g from the inner surface by barrel polishing (BP), which corresponds to a 30μm thickness in an average. After a light cleaning by buffered chemical polishing :BCP (10μm), it was annealed at 760^{o}C for 5 hours in a vacuum pressure ~ 1x10^{-6} torr in order to prevent the hydrogen Q-disease, then electropolished by 50μm and high pressure rinsed at 85 kg/cm^2 for one hour using filtered (0.2μm) demineralized water (10MΩcm).

K-22 was tested for the successive material removal by BCP with high gradient performance. It was removed every 40μm up to 250 μm by BCP, then switched to the same experiments with electropolishing. We never annealed this cavity during these chemistries.

Vacuum evacuation was done by a conventional system consisted of a rotary pump (200l/s) and a turbo-molecular pump (50 l/s) up to ~ 1x10^{-7} torr with 90^{o}C baking for one night, then switched to ion pump. The final vacuum pressure was about 1 x 10^{-9} torr. Then the cavity was sealed off by a metal valve, and fixed on a vertical test stand and cooled down quickly.

2.2 Vertical Test

In the vertical test, temperature dependence of the surface resistance was carefully measured from 4.2K to 1.5 K and to evaluated the residual surface resistance the data was fit by the following formula ;

$$Rs(T) = \frac{A}{T} \cdot \exp(-\frac{\Delta}{k_B T}) + Rres \qquad (1).$$

After measurement of the data, Qo-Eacc curve was measured at the lowest temperature.

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2.3 Other single cell cavities and multi-cell cavities

The other single cell cavities were tested the high gradient performance with further electropolishing succeeding to the last study [1]. These cavities : K-14, K-8, K-9, K-11, were fabricated at KEK out of RRR=200 niobium material from Tokyo Denkai by the same procedure mentioned above. JL-1 came from CEBAF by a CEBAF/KEK collaboration. It should be reminded this cavity has been achieved Eacc=43 MV/m at CEBAF before sending to KEK [3]. It was also made out of Tokyo Denkai niobium material with RRR=200.

Three 3-cell structures were used to see the superiority of EP in multi-cell cavities. The cavities were manufactured at 3 companies: Toshiba [4], MHI [5], SHI [6] under the close collaboration with KEK. The manufacturing procedure was almost same as KEK but electron beam welders were different. Toshiba and MHI have been used a high voltage/low current machine but SHI used a low voltage/high current type. Toshiba cavity and SHI one were made many holes during the EBW at the iris section: 7 holes and 13 holes respectively. These holes were repaired at KEK machine shop center by patching niobium pieces. In the chemistry, for Toshiba cavity and MHI cavity HPR time was prolonged up to 3 hours but the other procedure was the same as K-25. SHI cavity was removed by 100µm by horizontally rotated chemical polishing [7], then electropolished by 50 µm. Any heat treatment was not done for this cavity. The baking time was prolonged to 3~4 days for MHI cavity and SHI one. Vertical test procedure was the same as K-25 in every 3-cell cavity.

One 9-cell cavity was sent from DESY. This cavity is a TESLA prototype and has no ports on the beam tubes. This cavity was removed by 30 µm by EP. HPR time was a 3 hours with the 0.2µm filtered demineralized water. Vertical test procedure was the same as the other cavities.

3 RESULTS

3.1 Material dependence of the EP superiority

The results of K-25 were summarized in Table 1 with other cavity results. The Qo-Eacc curve is presented in Figure 1. At the first test it achieved Eacc=33.5 MV/m without Q-degradation. The superiority of EP with Heraeus material is clear in this experiment. The more reproducibility for Heraeus material has been obtained in a Saclay/KEK collaboration, which will be reported in other paper [8].

The final result of K-22 was presented in the Table 1 and in Figure 2. The gradient of Eacc > 25 MV/m could not be achieved by BCP up to the material removal of 250µm. However, switching to electropolishing, Eacc = 40 MV/m was obtained after the material removal of 100µm. The superiority is observed in the RRR=150 niobium material. It should be reminded this cavity has never been annealed. It is so surprised that Eacc=40MV/m can be obtained even by the RRR=150 material, and without any heat treatment. The detail information is described in the reference [9].

3.2 Further high gradient performance by EP

The 40 MV/m high gradient performances by electropolishing were presented in Figure 2 including the result of K-14, which were already reported the last workshop [10]. K-8 and K-9 were investigated the additional material removal effect on electropolishing with the high gradient performance succeeding to the last experiment [1]. These cavities have achieved Eacc=40 MV/m by an additional electropolishig of 10µm - 40µm after a procedure of barrel polishing(45g) + EP(10µm) + annealing (760^{o}C, 5 hr) + EP(10µm). The result of K-11 is also the experiment succeeded to the last experiment with BCP. The high gradient of Eacc=40MV/m was obtained by 50µm EP after a procedure of the annealing + CP(280µm) + EP(30µm). JL-1 was treated by the same chemistry as K-22, which is the combination BCP and EP. This cavity also achieved 40 MV/m. It should be emphasized that this cavity did not experience any heat treatment.

3.3 High gradient with multi-cell cavities

The results on the 3-cell cavities are presented in Figure 3. Toshiba cavity and MHI one were achieved the maximum gradients of 34 MV/m and 31.5 MV/m respectively. Heavy processing levels were observed at 17

Table 1: Summary of the cavity performance

Cavity	A [ΩK]	Δ/k_B	Rres [nΩ]	Eacc,max [MV/m]	Qo at Eacc,max
K-25	1.31E-4	18.12	3.67	33.5	1.81E10
K-14	1.65E-4	19.03	4.08	40.1	7.61E09
K-9	1.35E-4	18.27	6.19	39.1	1.57E10
K-8	1.32E-4	18.27	7.85	40.3	1.13E10
JL-1	1.38E-4	19.27	10.47	39.3	1.16E10
K-11	1.11E-4	18.43	5.43	39.1	2.10E10
K-22	1.62E-4	19.03	10.82	40.0	6.71E09

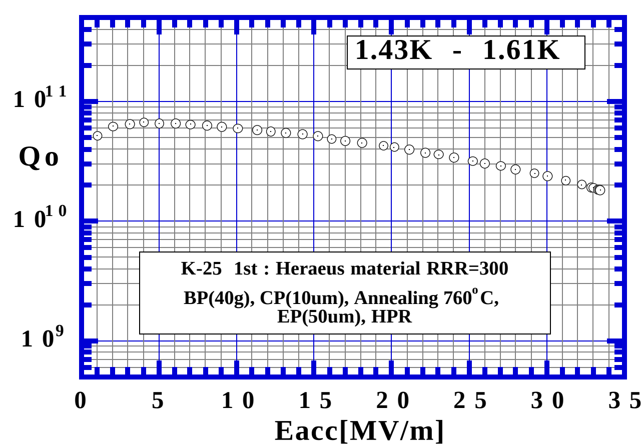

Figure 1: Qo- Eacc curve with a 1300 MHz niobium cavity fabricated with Heraeus material RRR=300

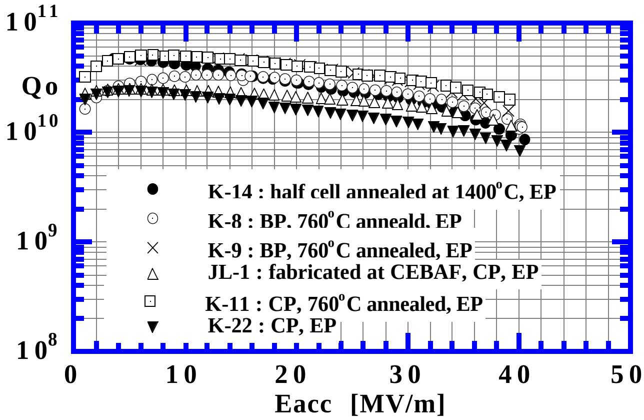

Figure 2: Best performance at KEK with 1300 MHz niobium cavities by electropolishing

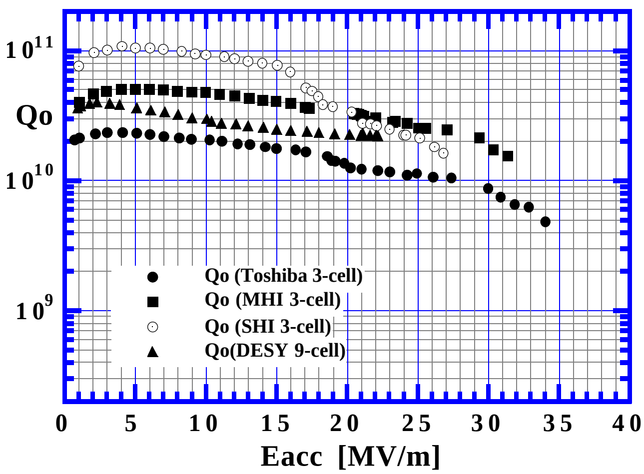

Figure 3: Performance with electropolished multi-cell cavities

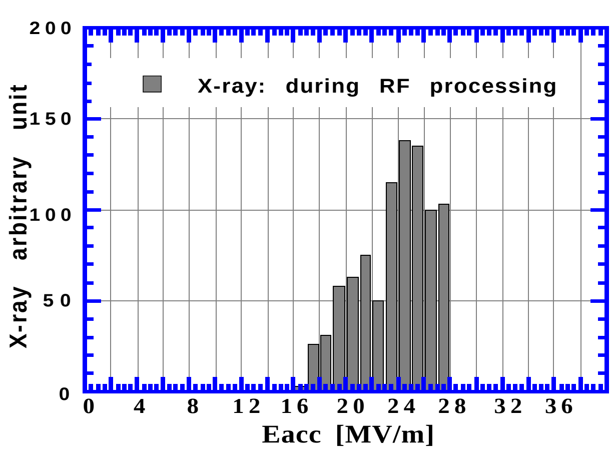

Figure 4: X-ray observation drying RF processing with SHI 3-cell cavity

- 25 MV/m and at 27 - 30 MV/m in Toshiba cavity. Two hour RF processing was needed to go through these levels. MIH cavity has also processing levels at 17 - 20 MV/m and at 25 - 29 MV/m. It needed one hour to process out these levels. This cavity was baked for four days at 90°C. That might be good to shorten the processing time. SHI cavity was limited to Eacc,max=27 MV/m by the heavy processing level started from 16 MV/m. The x-ray during RF processing is presented in Figure 4. The x-ray dose not exponentially go up with increasing filed. This x-ray occurrence suggests these are multipacting levels. This cavity has no experience the annealing. Behind the heavy multipacting, hydrogen effect might be there.

This problem is much serious in the 9-cell structure. The maximum gradient was limited around 22 MV/m. We observed a possibility of upgrading field by further RF processing but too much liquid helium was needed to continue the processing, e.g. 6 hours. So we gave up to continue the measurement.

4 DISCUSSION

For the single cell cavities, experimental evidences, which electropolishing can offer the high gradient of Eacc > 30 MV/m, are accumulated. It is independent on firms in high RRR material : RRR > 200. The superiority is observed in the RRR=150 material of Tokyo Denkai. The other verification test of the superiority is going by L.Julje independently at DESY by a DESY/CERN/ Saclay collaboration. In spit of the poor electropolishing only around beam tube, they had a good result [11].

The highest gradient in the world : Eacc=40 MV/m is collected in 6 single cell cavities by electropolishing. Such a high gradient is achieved independently on the residual surface resistance between 3nΩ and 11nΩ. Even in RRR=150 it is possible. In addition, it is attainable without any heat treatments by a simple chemistry combined BCP and EP. This procedure has no hydrogen Q-disease[12].

However, for multi-cell cavities multipacting is a serious limitation. This problem in round shaped clean cavities seems to be much pronounced in electropolished cavities. Two problems can be considered. One is that electropolished surface has a much porous oxide layer on the surface compared with chemically polished surface. Multipacting is pronounced by surface gas adsorption [13]. A primary electron source as field emission hits the surface, then evaporates adsorbed gas around there. This gas is ionized by electromagnetic field and a burst occurs (processing). To solve this problem the high temperature baking should be effective [14]. As the other method, a hydrofluoric acid rinsing after electropolishing could be effective to remove such a porous oxide layer.

The other problem might be KEK's own. At KEK we observe the multipacting in chemically polished cavities too. On the other hand, when our cavities are tested at CEBAF, multipacting is not observed at least up to 27 MV/m by CEBAF chemistry : BCP. It was seen in only the case intentionally oil contaminated [15]. However, when we measured electropolished cavities at CEBAF, which were sent from KEK under vacuum after electropolishing, light multipacting was observed but easily processed out in a few minutes [14]. These experimental facts suggest KEK has a problem in the rinsing water. We have not yet find out what is the problem in the water but SiO_2 is suspected.

5 SUMMARY

1) The high gradient : Eacc >30 MV/m was achieved with Heraeus material as same as Tokyo Denkai material.
2) The superiority of EP seems to be firm independent for high RRR niobium material.
3) Eacc=40 MV/m high gradient performance was collected by electropolishing up to 6 cavities. Such a high gradient is possible with RRR=150 Tokyo Denkai material. The combined chemistry of BCP and EP can achieve such a high gradient without any heat treatment.
4) The superiority of EP with high gradient became more clear. This superiority was also identified in two 3-cell cavities.
5) However, specially for 9-cell cavity, multipacting is a serious problem which limits the gradient around 20 MV/m. We need a further study to overcome this problem.

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