PERFORMANCE COMPARISON OF THE SINGLE-CELL LARGE GRAIN CAVITIES TREATED BY EP AND CP*

Z. G. Zong #, J. Gao, J. Y. Zhai, Q. J. Xu, IHEP, Beijing, China
Z. G. Zong, L. Q. Liu, L. Zhang, TIPC, Beijing, China
K. Saito, F. Furuta, KEK, Tsukuba, Ibaraki-305-0801, Japan

Abstract

The 1.3 GHz single-cell large grain (LG) cavity has been studied in our research programs on superconducting RF cavity for the International Linear Collider (ILC) in the last three years. Five LG cavities were fabricated at IHEP and KEK. Three of these cavities were dealt with the surface treatments based on electro polishing (EP) and the maximum gradient of 47.90 MV/m was achieved. The other two cavities were treated based on chemical polishing (CP) and both reached the accelerating gradients higher than 35 MV/m with the maximum gradient of 40.27 MV/m. As a reference to the LG cavities a single-cell fine grain (FG) cavity was also fabricated and polished chemically. Its performance was limited by strong Q-slope. In this paper the performance of these cavities treated by CP or EP would be discussed and compared in term of surface resistance and removal thickness and so on.

INTRODUCTION

The linacs based on superconducting RF cavity accelerator technology was recommended for the ILC by the International Technology Recommendation Panel and endorsed by the International Committee for Future Accelerators [1]. The ILC design assumes an accelerating gradient of 31.5 MV/m in the SCRF cavity to achieve a center-of-mass energy of 500 GeV with two about 11-km long main linacs. As many aspects, such as the cost and linac length, would be benefited to adopt the high gradient cavity, the global R&D was launched a few years ago to achieve accelerating gradient of 35 MV/m and quality factor of 10^{10} or higher in the 9-cell cavity with a yield of 90 % during acceptance vertical testing. Although the specific requirements have been demonstrated at some labs, however, the yield is much lower than 50 % due to field emission and quench. Some parallel R&D programs have been carried out in the RF superconductivity community, two of which are the new cavity shapes and the large or single grain niobium material.

The LG and single crystal niobium have been proposed several years ago as alternative material to the polycrystalline or FG niobium for superconducting RF cavity. Since the LG niobium sheets were available from material vendors, many laboratories had developed the single-cell or multi-cell cavities made of LG niobium and resulted in the encouraging achievements [2]. The new material showed the potential to simplify the production sequence and consequently reduce the cavity cost, and addressed the present challenges of RF superconductivity.

In the framework of the ILC cooperation between IHEP and KEK, at KEK we studied the effect of electro polishing (EP) on the single-cell LG cavities (ChinaLG#1 and ChinaLG#2) with the KEK ICHIRO shape [3]. The maximum accelerating field reached 47.9 MV/m and the features of surface treatments based on EP to the large grain cavities were achieved by our research program. Encouraged by the promising results we continued the LG niobium cavity research. Two single-cell LG cavities were fabricated at IHEP [4][5]. A complete process of surface treatments based on CP (without EP) was carried out to the two LG cavities (IHEPLG#1 and IHEPLG#2) at IHEP. The two LG cavities and one Ningxia FG niobium cavity were sent to KEK for the vertical RF tests and additional treatments. In this paper the performance of the LG and FG cavities treated by EP or CP is compared.

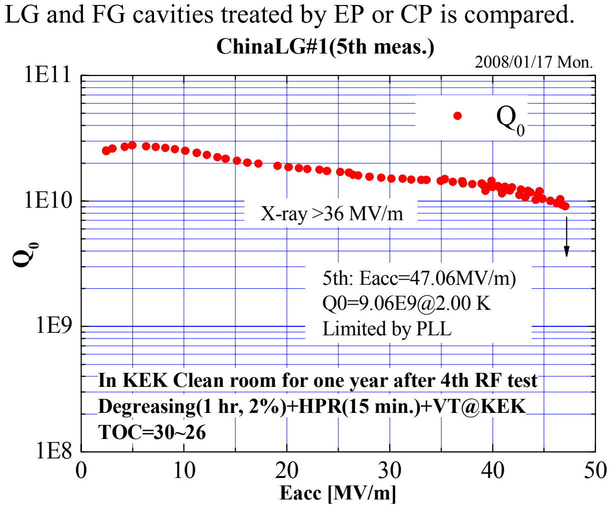

Figure 1: Excitation curve of ChinaLG#1 after one-year RF surface exposure to clean air.

STABILITY OF LG NIOBIUM RF SURFACE TREATED BY EP AND BAKING

In January 2007 ChinaLG#1 was treated by the standard surface preparation of EP and achieved the maximum accelerating gradient of 47.9 MV/m with a quality factor of 10^{10}. The cavity was kept in the clean room of KEK SRF lab and the RF surface was exposed to clean air for a year. In January 2008 the cavity was rinsed for 15 minutes by high pressure pure water and evacuated for the vertical RF test (5th). The excitation curve is shown in Figure 1. The quality factor behaviour at the accelerating field evolution did not apparently change. The observation that the LG cavity by EP and baking can be exposed to clean air for one year without loosing its

*Supported by National Natural Science Foundation of China(10525525)
#zongzg@gmail.com, *TIPC & IHEP, CAS*

good performance seems to indicate that the RF surface very stable. For the ILC this stability would be enormously significant.

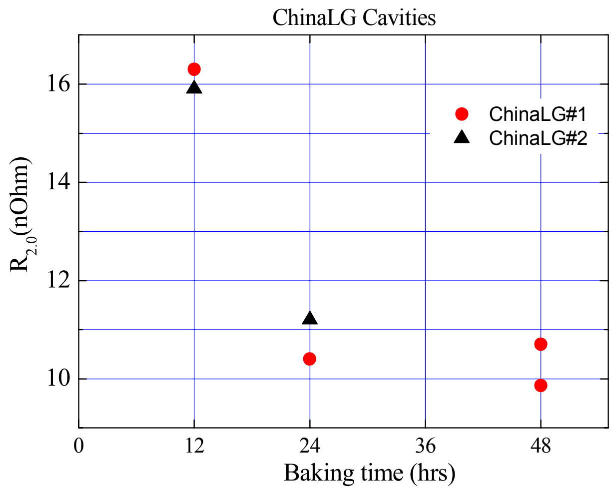

Figure 2: Reduction of surface resistance at 2.0 K of the LG cavities by EP with increasing baking time.

BAKING OF THE LG CAVITY BY EP

Baking at about 120 ℃ for 48 hours has beneficial effects on the BCS surface resistance and the high field quality factor of the cavity by both EP and CP. It is related to the oxygen diffusion into the niobium, causing changes of the structure niobium oxide interface on a nanometer scale [6]. The grain boundary is considered as "weak link" and would easily be contaminated by segregated impurities. As the LG cavity has shorter boundary in niobium surface it is believed that the baking time could be decreased, which could bring some cost reduction. During the study on the LG cavities by EP the cavity performance response to the baking time was investigated [7]. Figure 2 indicates that surface resistance at 2.0 K decreases when baking is prolonged. To remove the influence of other factors, such as the surface adsorbed gas and residual melted emitters, the tests without field emission and achieving high gradients (>35 MV/m) are adopted in the contrasts. It is suggested that 48 hours is still needed for the LG cavity.

CP ON THE LG AND FG CAVITIES

In the study of CP on the LG cavities 40.27 MV/m was achieved by the LG cavity [8]. These results demonstrated that the ILC ACD performance could be reached by chemical polishing LG cavity.

One FG cavity, IHEPFG#3 made of Ningxia FG niobium, was arranged to explore the parameters of EBW machine in the initial plan. From the subsequent X-ray checking the cavity had no defect and was qualified. At KEK the FG cavity was treated with centrifugal barrel polishing (CBP) to remove about 175 μm, CP of 150 μm, annealing, light 10 μm CP and baking as a reference for the IHEP LG cavities. In the RF test the cavity achieved 35.70 MV/m with a quality factor of 2.34×10^{9} as seen in Figure 3. The excitation curve exhibited a drop of quality factor at high gradients. Field emission could be excluded as an explanation for the performance degradation since neither X-ray nor secondary electron was observed. The Q-slope limited the achievable gradients but also would greatly increase cryogenic load.

In contrast to the electro polished cavity the remedy to overcome the Q-slope, baking at 120 ℃, could not always improve quality factor of the FG cavity chemically polished. However, Q-slope in the tests of the LG cavities treated by CP had not been observed in our study. The difference reveals the advantages of the LG niobium.

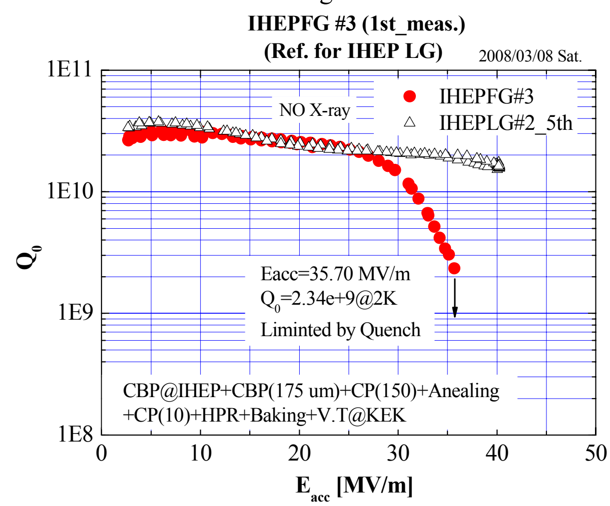

Figure 3: Comparison of quality factor behaviours at high gradients between the LG and FG cavities by CP.

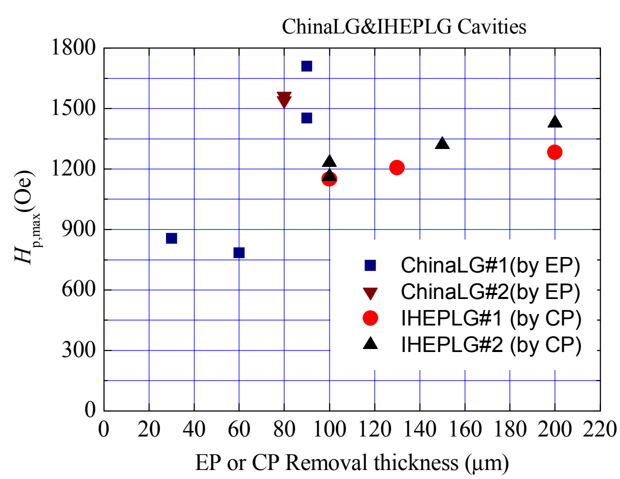

Figure 4: Peak magnetic field on RF surface achieved by the LG cavities when difference material thickness was polished by EP or CP.

REMOVAL THICKNESS FOR HIGH GRADIENTS

After fabrication by EBW, the LG cavities were all treated with CBP, annealing and light CP. The equator welding seams were inspected by the CCD camera and free of defect. Before CP or EP, RF surface of these LG

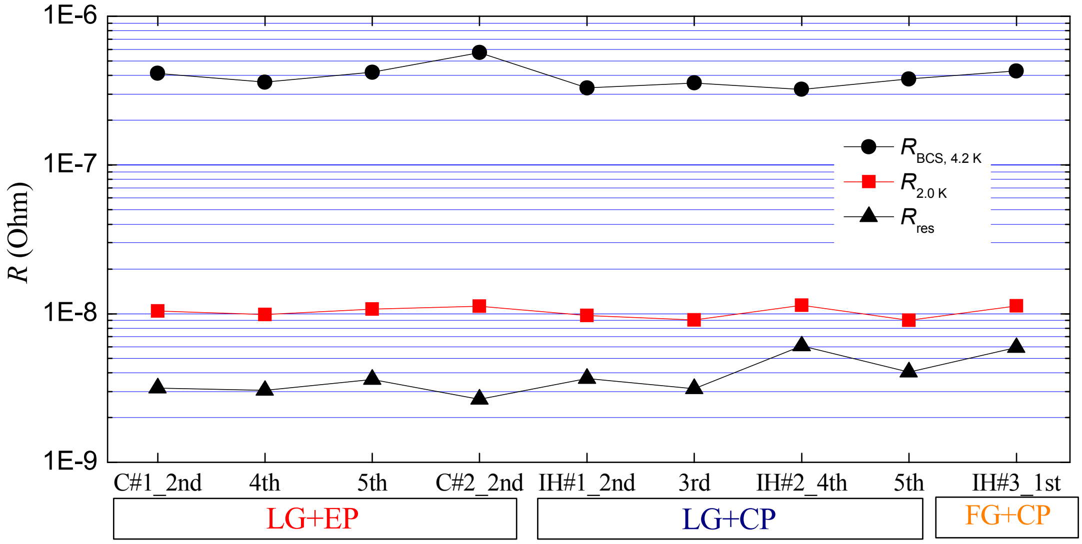

Figure 5: Surface resistance of the LG and FG cavities treated by EP or CP.

cavities was almost similar. In the study the cavities were polished by EP or CP step by step. When additional thickness was removed the quench peak magnetic fields on RF surface were improved as shown in Figure 4. In the EP process the sharp edges and burrs were firstly smoothed out and a very glossy surface could quickly be obtained. When only 90 micron was removed the peak surface field almost reached its fundamental limitation of the niobium material. However, about 200 micron was not enough for the chemical polishing LG cavities to achieve the intrinsic RF critical magnetic field.

Table 1: Comparison of LG and FG cavity treated by EP and CP.

Items		LG	FG
High gradients (~40 MV/m)	EP	Yes	Yes
	CP	Yes	No
Cost		Lower	High
Defect		Lower	High
Fabrication by ST		Yes	Yes
Baking		No different	
Surface resistance		No different	
Mechanics for tuning		No different	

SURFACE RESISTANCE

Surface resistance consists of the BCS theory and residual surface resistance. The BCS surface resistance has a minimum at mean free path of about 20 nm. As mean free path in the LG niobium are longer and should deviate more from the minimum than FG niobium. The BCS resistance would be larger and this is perhaps a disadvantage of LG niobium. Figure 5 shows some kinds of resistance of the LG and FG cavities by EP or CP. As the CP LG surface is rougher and its mean free path is a litter shorter, R_{res} is larger and $R_{BCS,\ 4.2\ K}$ (at 4.2 K R_{BCS} is dominant) is smaller than EP surface. Considering the comprehensive influence of these factors $R_{2.0\ K}$ of LG and FG niobium by EP or CP is almost in the same range.

CONCLUSION

The comparison of LG and FG cavity treated by EP and CP is summarized in Table 1. The LG niobium for superconducting RF cavity is comparable with FG material in the high gradient application. The ILC ACD performance was achieved in the single-cell LG cavity treated by CP. The performance should be demonstrated by the 9-cell LG cavity in the near future. The LG niobium would be a good solution to the ILC huge quantity and high quality requirements on superconducting RF cavity.

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