HIGH GRADIENT STUDIES FOR ILC WITH SINGLE-CELL RE-ENTRANT SHAPE AND ELLIPTICAL SHAPE CAVITIES MADE OF FINE-GRAIN AND LARGE-GRAIN NIOBIUM*

R.L. Geng† ‡, G.V. Eremeev, H. Padamsee, V.D. Shemelin, CLASSE, Ithaca, NY 14853, USA

Abstract

Based on the encouraging results of the first 1300 MHz 70 mm aperture single-cell re-entrant cavities, we continue the high gradient studies for ILC with new re-entrant cavities made of fine-grain as well as large-grain niobium. These new cavities have smaller apertures of 60 mm, providing a further reduced H_{pk}/E_{acc} or a further improved ultimate gradient. Four 1300 MHz 60 mm aperture re-entrant cavities are made, two out of fine grain niobium and the other two out of large-grain niobium. In addition, two elliptical shape 1500 MHz cavities are also made out of large-grain niobium. A new record gradient of 59 MV/m was achieved in a 60 mm aperture 1300 MHz single-cell fine-grain niobium cavity.

INTRODUCTION

High-gradient cavities are the core components for the International Linear Collider (ILC). The ILC reference design report (RDR) calls for a goal gradient of 35 MV/m for accepting a 9-cell TESLA-style cavity.

Despite several demonstrations of this goal gradient in the recent years, it remains a major challenge to reliably achieve 35 MV/m in a 9-cell cavity. The world SRF community is addressing this challenge with two parallel approaches. The base line approach focuses on the TESLA-style cavity made of fine-grain polycrystal niobium. The alternative approaches include exploring cavities of new shapes and cavities made of large/single crystal niobium.

The advantages of new cavity shapes are two fold: (a) an increased ultimate gradient due to a reduced ratio of H_{pk}/E_{acc}; (2) a reduced liquid helium consumption due to an increased $G \cdot R/Q$. Two leading new shapes include the "low-loss" shape and the re-entrant shape. A summary of RF parameters of the "low-loss" and re-entrant cavities can be found in Ref. [1]. Several advantages of large/single-crystal niobium cavities are identified following the encouraging results at JLAB [2]. Our interests in large/single-crystal niobium are two fold: (1) to study the role of grain boundaries in the limiting quench field and in the residual surface resistance; (2) to compare the performance of electropolished large-grain niobium cavities with that of electropolished fine-grain niobium cavities of the same cavity shape.

The first two 1300 MHz single-cell re-entrant cavities (LR1-1 and LR1-2), designed and built at Cornell, have a 70 mm aperture. The ratio of H_{pk}/E_{acc} is 10% lower than that of the TESLA-shape [3]. LR1-2, processed and tested at Cornell, achieved a record gradient of 47 MV/m in 2004 [4]. LR1-1 was sent to KEK for processing and testing and achieved again a record gradient of 52 MV/m in 2005 [5]. Encouraged by these single-cell cavity results, a 9-cell 70 mm aperture re-entrant cavity has been built and is under preparation of its first cold test.

NEW 60 mm APERTURE RE-ENTRANT CAVITIES

The new re-entrant shape has a 60 mm aperture [6]. The ratio of H_{pk}/E_{acc} is 15% lower than that of the TESLA shape. We built two 60 mm aperture cavities (LR1-3 and LR1-4) with regular fine-grain RRR 250-300 sheet niobium. A comparison of a 60 mm re-entrant single-cell cavity with a TESLA-shape single-cell cavity is shown in Fig. 1.

LR1-4

Processing of LR1-4 includes the following: (1) inner surface removal of 120 μm by using the vertical electropolishing method; (2) high-pressure water rinsing for 4 hours; (3) bake-out at 120 °C for 48 hours. An accelerating gradient of 38 MV/m was reached during the first RF test at 2 K. Additional electropolishing did not improve the limit-

Figure 1: Left: 60 mm aperture re-entrant cavity; Right: 70 mm aperture TESLA cavity.

* Work supported by NSF and DOE
† rg58@cornell.edu
‡ Current address: Jefferson Lab, 12000 Jefferson Ave, Newport News, VA 23606. E-mail: geng@jlab.org

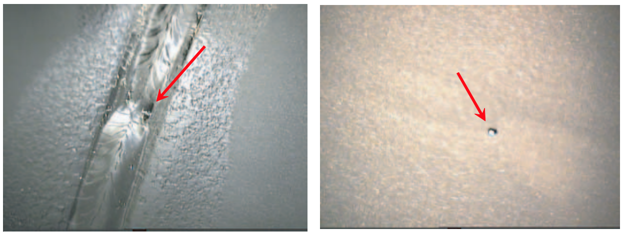

Figure 2: Defect at the EBW overlap of the equator joint of LR1-4. Left: before repair; Right: during repair with CBP after 50 μm surface removal. Photo credit: T. Saeki.

ing gradient. Visual inspection of the inner cavity surface revealed a mechanical defect in the high electric field region and another mechanical defect at the EBW overlap of the equator joint. With our "guided-repair" apparatus, the defect in the high electric field region was successfully eliminated. However, the defect at the EBW overlap of the equator joint can not be accessed by the same apparatus. We then decided to send LR1-4 to KEK to remove this defect by tumbling. It was finally eliminated after a surface removal of about 300 μm by using CBP (centrifugal barrel polishing) at KEK. It also turns out that this overlap defect goes 150 μm into the bulk. Figure 2 shows the defect before tumbling and after 50 μm surface removal. LR1-4 was then annealed (750 °C 3 hours) for out-gassing hydrogen after tumbling and further electropolishing has been carried out. It is to be RF tested in the future.

LR1-3

Following the completion of fabrication, LR1-3 was purified with titanium in our vacuum furnace. The cavity temperature was held at 1300 °C for 2 hours followed by another 4 hours at 1200 °C. This improves the RRR to about 500. The cavity was then sent to KEK for processing and testing.

At KEK, the cavity inner surface was first removed for about 300 μm by using CBP. This procedure effectively modified the initial rough under-bead of the equator EBW joint and produced a smooth inner surface. After furnace heat treatment for out-gassing hydrogen, the cavity was electropolished (110 μm), high-pressure water rinsed and low-temperature baked. An accelerating gradient of 46 MV/m was reached limited by strong field emission. LR1-3 was then sent back from KEK to Cornell.

At Cornell, the cavity was first ultrasonic rinsed in warm soapy water, then high-pressure rinsed for 2 hours. Unlike previous drying and pumping of re-entrant cavities, this time we started pumping down the cavity just after overnight drying in the clean room while there was still trapped water in the re-entrant pocket. Consequentially, it took much longer time to reach the desired cavity vacuum. To assist water vapor evacuation, we warmed up the cavity to 35-40 °C during the final pumping down by using an IR lamp. This cavity achieved a remarkable result, as

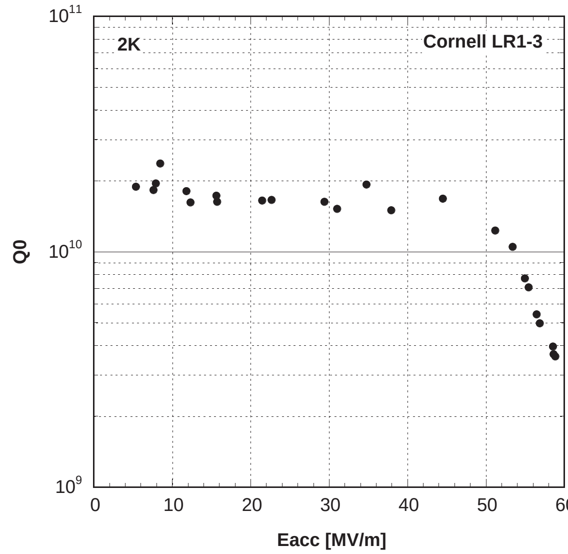

Figure 3: $Q(E_{acc})$ of the 60 mm aperture single-cell cavity LR1-3.

shown in Fig. 3. A few quench events were observed near 30 MV/m. The first X-ray was observed at 51 MV/m. Finally a gradient of 59 MV/m was achieved with a Q_0 of 4×10^9. This corresponds to a peak surface magnetic field of 2065 Oe and a peak surface electric field of 125 MV/m. The gradient was limited by a hard quench.

LARGE-GRAIN NIOBIUM CAVITIES

LE1-37

The first large-grain 1500 MHz niobium cavity built at Cornell (LE1-37) has a Cornell/CEBAF shape. A picture of this cavity is shown in Fig. 4.

The two large-grain niobium disks, manufactured by OTIC (Ningxia, China), have a RRR value of 340 and 420 respectively. Standard manufacturing method was used (deep-drawing and EBW). The completed cavity was electropolished with our vertical EP apparatus for an inner sur-

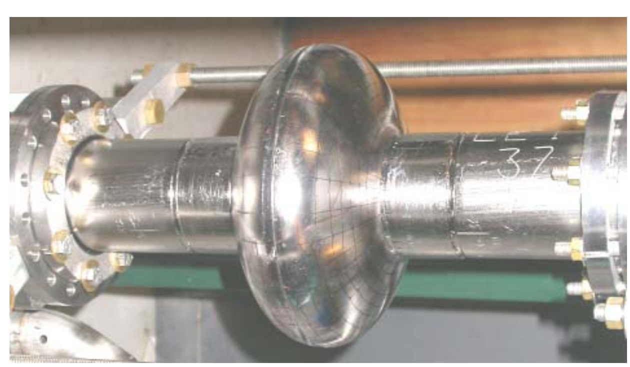

Figure 4: First large-grain niobium single-cell cavity at Cornell. It has Cornell/CEBAF shape. Large-grain disks manufactured by OTIC (Ningxia, China).

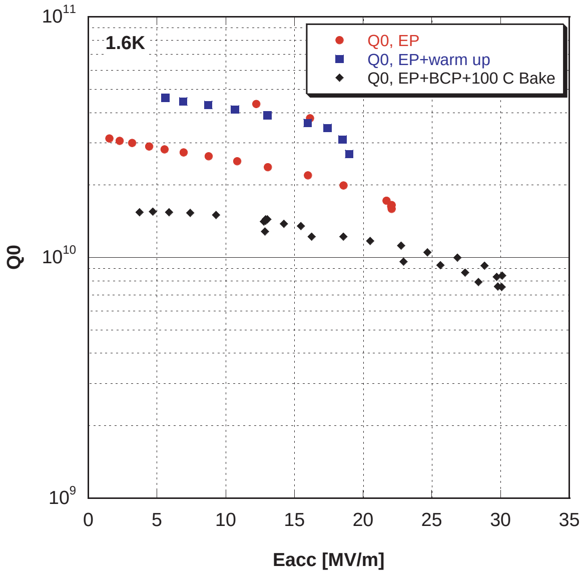

Figure 5: Test results of LE1-37.

face removal of about 150 μm. After high-pressure water rinsing, we performed the first RF test without low-temperature bake. The unloaded Q at low fields was $> 4 \times 10^{10}$. After a few quench events at the highest gradient of 22 MV/m, the low-field Q was degraded appreciably. Nevertheless, the initial high Q was completely recovered after a partial warm-up above 10 K. The accompanying temperature map showed that quench was caused by some point defects not related to grain boundaries.

Post-test visual inspection indeed revealed some pitted spots on the inner surface corresponding to the locations determined by the thermometry. Heavy BCP etching (>200 μm) successfully eliminated the pitting. In the following RF test, the cavity showed high-field Q-slope. After baking at 100 °C, the high-field Q-slope disappeared. The low-field Q was 1.6×10^{10}, typical for many other BCP etched LE cavities tested in the same dewar. The highest gradient reached 30 MV/m. A summary of the above test results is given in Fig. 5.

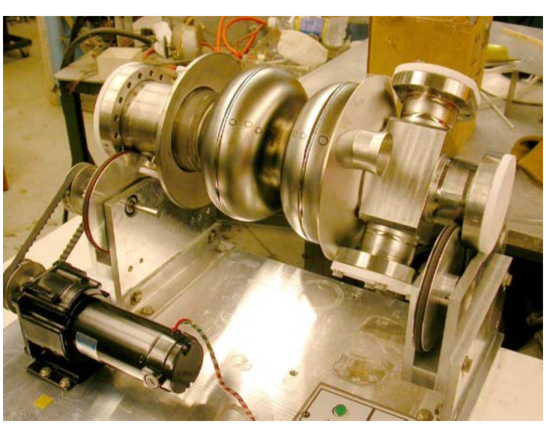

Figure 6: 1-cell/2-cell cavity tumbling apparatus.

Other large-grain niobium cavities

Two more 60 mm aperture re-entrant and one more LE large-grain niobium single-cell cavities are under fabrication. The deep-drawn cups of 60 mm aperture cavities all experienced severe thinning of wall thickness at the iris, which resulted in holes after weld prep trimming. The plan is to patch the iris holes with EBW and smooth the inner surface of the completed cavity by tumbling (see Fig. 6).

SUMMARY

The high-gradient studies with single-cell cavities for ILC continue at Cornell. A new record gradient of 59 MV/m was achieved in a new 60 mm aperture re-entrant cavity. The peak surface magnetic field reached also a record value of 2065 Oe. It has been demonstrated that the re-entrant cavity can be pumped down in the presence of trapped water and does not show field emission at a peak surface electric field of over 100 MV/m.

To achieve high gradients, it seems to be necessary to eliminate the inner surface mechanical defects that may cause field enhancement. Examples of such mechanical defects include the pin hole at the overlap of the electron beam weld and the rough under-bead of the equator weld. Tumbling removes these defects effectively.

The first Cornell large-grain niobium cavity shows comparable gradient performance as fine-grain niobium cavities. It is demonstrated that an electropolished large-grain niobium cavity can have a much lower surface resistance than a BCP etched fine-grain cavity. More large-grain niobium cavities are under preparation to examine their performance after surface processing by electropolish.

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