DEVELOPMENT OF LARGE GRAIN SUPERCONDUCTING RESONATORS FOR THE EUROPEAN XFEL

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Abstract

The status of the DESY test program of 1.3 GHz TESLA shape 9-cell large grain LG resonators for the European XFEL is presented. The main aim is to find out whether or not the choice of LG material could be an option for the fabrication of approximately 800 XFEL resonators.

Several aspects are under investigation. One of the aspects is the material issue: could the required amount of LG niobium be produced by industry in a cost effective and reliable manner? The second issue is the fabrication of cavities: could the series production of resonators be done on the level of required accuracy and costs? The third one is the performance issue: what is the appropriate treatment for reproducibly achieving the specified XFEL accelerating gradients?

Development of the LG disc production was done within the framework of the R&D program of DESY and W. C. HERAEUS. Eleven resonators are produced at the company ACCEL.

Up until now three resonators have been RF-tested vertically. The data and perspectives of the LG cavity application are discussed.

INTRODUCTION

The manufacturing approach of slicing discs from the melted ingot using an electron beam and producing cavities by deep drawing and electron beam welding (LG cavities) seams to be a cost effective option and presently has world wide interest [1]. Several single cell cavities produced at JLab and DESY from large grain, high purity niobium demonstrated very encouraging results [?] after buffered chemical polishing BCP or electropolishing EP [2-3]. The main aim of the DESY R&D program is to check whether the 9-cell LG cavities can be an option for series fabrication for the European XFEL.

MATERIAL

Development of LG disc production was done within the framework of the R&D program of DESY and the Co. W. C. HERAEUS.

One of the requirements was cost effective cutting of the discs with tight thickness tolerances, purity and high surface quality. W.C. HERAEUS developed the cutting procedure to the extent that the discs slicing can be done without degrading the material.

Another DESY requirement was the presence of a central crystal with a diameter >150 mm in the the disc, which is essential to avoid necking and tearing at the irises during deep drawing.

In order to achieve cost effective production, a single crystal with these dimensions has to be continuously present in the entire, approx. 2 m long ingot. The company has performed several melting runs, investigating the influence of different melting parameters on the peculiarities of solidification and crystals growth. Melting-/cooling behavior was investigated: beam figures (different numbers, position und shape); energy entry (different focusing of the beam and stay time); refrigeration parameters (bottom, crucible wall, split).

The following results have been achieved. On the one hand, LG ingots could be successfully produced to the target specifications several times. Large grain grows longitudinally (see figure 1). Material for several dozen cavities was produced. On the other hand, it turned out that production of the big central crystal specified, especially with the desired crystal orientation, is very critical. In many previous experiments, the seed crystal created had a definite downward orientation.

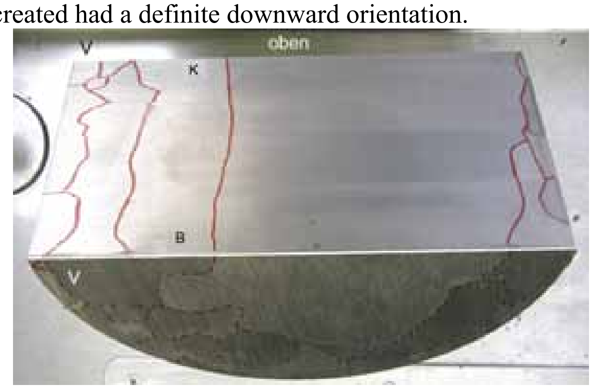

Figure 1: Example of single crystals growth in the ingot of ca. 300 mm diameter of Co. W. C. Heraeus.

The complete process is not sufficiently stable or reproducible in order to create a central crystal of 150 mm diameter along the whole ingot.

Approximately 250 large grain niobium discs with RRR=320-500 have been shipped to DESY. It can be expected that the disc material from ingots is less vulnerable to contamination with foreign material or other types of defects, because it is taken directly from homogeneous ingot material that has been re-melted many times. Several sources of the contaminants that occur with forging or rolling conventional sheets are excluded in this case. The main discs used for manufacturing the cavities AC112-AC114 were scanned with an eddy current device available at DESY. No indications of localized defects in the crystals were observed (see [2]). Therefore, it was decided not to scan the discs intended for the new 8 LG cavities.

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FABRICATION

Eight new LG cavities, AC151-AC158, with TESLA shape have been produced at Fa. ACCEL using W.C. HERAEUS material. Deep drawing of the half cells was done using the same tools as for fine grain material. The grain boundaries were noticeably pronounced with steps up to 0.5 mm. In two cavities, AC155 and AC156, the steps on grain boundaries have been grinded away with the intention to compare the performance of grinded and non-grinded cavities. Tactile 3D measurement at Co. ACCEL and optical coordinate measurement with 3D imaging at the Fa. DECOM was applied in order to estimate of the shape accuracy.

Figure 2: Discs of the single crystal with crystallografic orientation (100) after deep drawing.

The deep drawn half cells have, in some cases, a quadrangular or oval shape and do not meet the required tolerance of +/- 0.2 mm. The half cells' shape deviation for cavities AC151-AC154 was very prononced compared to cavities AC155-AC158. It turned out that the reason lay in the difference of the orientation of central crystals in the discs. Analysis of the crystal orientation done with the Lauer technique showed that in discs AC151-AC154, the main orientation of the central crystal is (100), and for discs of AC155-AC158, it was mainly (211) or (221). It is well known that the main atom planes slipping for BCC metals takes place in the (110) planes in the [111] direction; therefore, for the dics with (100) orientation, a more prononced anisotropy and quadrangular shape after deep drawing should be expected. This can easily seen in figure 2, where the deep drawn single crystal disc of (100) orientation is shown. The (211) or (221) planes tend to be oval shaped and represent smaller anisotropy.

The pronounced shape deviation in the half cells generated some difficulties for assembling half cells and especially for dumb-bells for welding. These difficulties have been overcome by using a special tool that ensured precise assembly of the male and female half cells together. Applying the DESY length ajustement procedure helps achieve the correct cavity length and the frequency of the fundamental mode in the cavities AC151-AC158.

PREPARATION AND RF TESTS

The investigations on single cell cavities [2] have shown that relatively good performance can be achieved by rather simple BCP treatment available in most laboratories. Therefore, as a first step, a BCP treatment has been applied to 9-cell cavities (about 100 μm rough BCP, annealing at 800°C for 2h followed by fine BCP of 20 μm). The Q(Eacc) excitation curve can be seen in Fig. 3. During the first test, the performance of AC112 and AC114 was restricted by some field emission. The performance of AC113 was limited by quench. T - Map inspections of AC113 detected the quench at the equator of cell 1. The achieved accelerating gradients up to 30 MV/m in the π-mode measurement and up to 35 MV/m in the pass band measurement in all three large grain TESLA shaped cavities can be considered as a very good result for XFEL. Already in the first surface treatment, the specification requirements for the XFEL, namely Eacc=23.6 MV/m with a quality factor $Q=1x10^{10}$, was exceeded. The same BCP treatment is being applied to the recently fabricated 8 LG cavities AC151-AC158. The rough BCP treatment (removal of 100 μm inside and 20 μm outside) is currently in process at Fa. ACCEL.

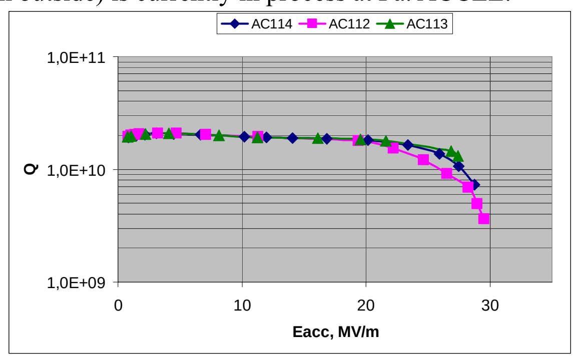

Figure 3: Q(Eacc) of the cavities AC112- AC114; first test after about 100 μm rough BCP, annealing at 800°C for 2h followed by a fine BCP of 20 μm.

The second test was done on two cavities (AC113 and AC114) after additional 20μm fine BCP, baking at 125°C for 48h [3]. After in-situ baking, the Q-drop almost disappeared, but the accelerating gradient was not increased, in contradiction to most observed behavior on single cell BCP-treated and baked LG cavities [4].

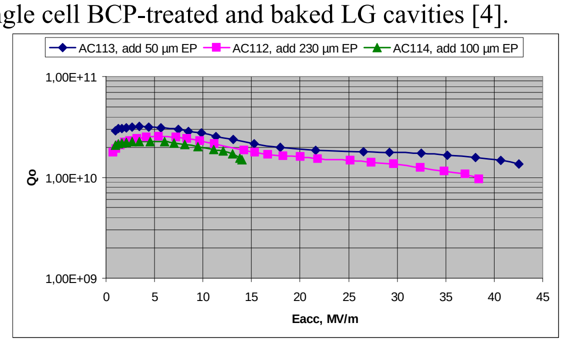

Figure 4: Q(Eacc) of the cavities AC112- AC114 after additional EP treatment.

Comparision of EP and BCP treatment done on a few large grain single cell cavities has shown that the EP works more efficiently. About 10 MV/m was achieved during EP treatment on some previously BCP treated cavities [3]. As a next step, additional EP of approx. 50-100 μm, combined with additional "in situ" baking, was applied to three LG 9-cell cavities. For the AC112 cavity, more EP in steps of 40-50μm were applied few times because of the field emission load that appeared in between. The Q(Eacc) excitation curves are represented in Fig. 4. Enhancing the acceleration gradient by approx. 10 MV/m can be seen on two cavities (AC112 and AC113). Surprisingly, significant degradation of Eacc from 28 to 14 MV/m was observed for the cavity AC114. The acceleration gradient of the individual cells was dramatically reduced too. After BCP treatment the Eacc was 28-35 MV/m, but after EP the values were between 15 and 22 MV/m. In order to check the quench position, an additional RF test (test 5) was done on this cavity with rotating T-map after 6 times HPR.

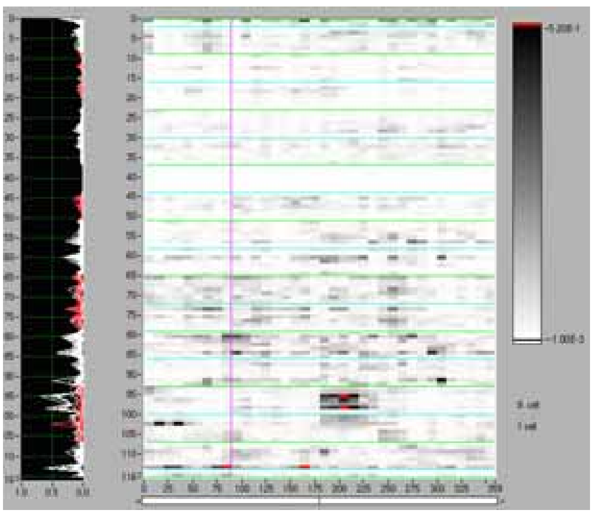

Figure 5: T-map for π-mode, full measurement,E > 14 MV/m, all cells seen (equator is marked by light blue color).

Local heating distribution registered by T-map is illustrated in Fig. 5. The same accelerating gradient Eacc=14.1 MV/m, limited by thermal breakdown without field emission FE or multipacting as in previous tests (test 3, 4), has been observed. T-maps were received for all modes; for π-mode, the quench was found in cell 2 above and near equator. In other modes, quench was also found in cell 1 and 9. In addition, many other smaller hot spots were found with the T-mapping (Fig. 5).

The T-map results were compared with optical inspection data using the high resolution camera developed at KEK in collaboration with Kyoto University. Unfortunately, the main hot spot in cell 2 found in π -mode and 1/9 π mode is located in an area, where no clear picture could be obtained, due to the difficult lighting situation. Only several leftover hotspots? from grinding were detected, which can hardly be a relevant for quench of approx. 14.1 MV/m (the cavity has previously shown much better performance).

Large groups of small craters on the entire inner and outer surface of all cells have been found (see Fig. 6 for example). It appears that the craters may be responsible for the performance degradation of in all cells. Similar craters were discovered in the fine grain cavity Z110 (with similar Eacc) that correlated with the quench location detected with the T map.

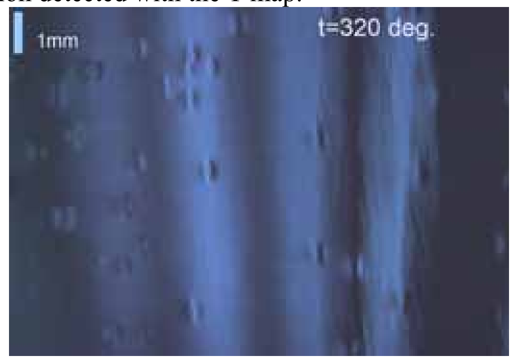

Figure 6: Example of craters seen on optical inspection image of the inner cavity AC114.

The cause of such craters is now being discussed, not only at DESY, but worldwide. It is difficult to say whether or not the LG grain surface behaves in an unusual manner during EP treatment compared to fine grain. It is possible that some imperfections (roots) were already present before EP and became larger with EP, if EP does not work properly. In any case, it is well known that EP works much better when starting with a previously prepared surface (the smoother the better). In light of this, large steps on grain boundaries of LG cavities can cause trouble for EP.

SUMMARY AND OUTLOOK

DESY experiences have shown that cavities can be built from LG material without significant difficulties; no special problems compared to fine grain cavities have been observed during work with the LG cavities. The helium tank was welded onto the cavity AC112, which then passed the horizontal RF-test. The cavity is intended for installation in one of the next accelerating cryo modules. Performance at the level of approx. 30 MV/m can be stably achieved with BCP treatment. Better performance at the level of 40 MV/m can be achieved with EP treatment.

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REFERENCES

[1] AIP Conference Proceedings, 927, 2007. Editors G. Myneni, T. Carneiro and A. Hutton.

[2] W. Singer et al. International Niobium Workshop, October 30 - November 1, 2006, Araxa, Brazil. AIP Proceedings, New York, 2007 p.123-132.

[3] W. Singer et al. PAC'07, Albuquerque, USA, June 25-29, 2007, Paper THOAKI01

[4] P. Kneisel, "Progress on Large Grain and Single Grain Niobium", SRF07, Beijing, Oct. 2007, TH102.