ADVANCES IN LARGE GRAIN/SINGLE CRYSTAL SC RESONATORS AT DESY*

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Abstract

Several single cell and three nine-cell large grain [LG] cavities of the TESLA shape have been fabricated and tested. The best accelerating gradient of E_{acc}= 41 MV/m was measured on an electropolished single cell cavity. All three nine-cell cavities fulfil the XFEL specification already in first RF test after BCP surface treatment. A fabrication method of single crystal cavities of an ILC like shape was proposed. A single cell single crystal [SC] cavity reached an accelerating gradient of 37.5 MV/m after BCP treatment only. The developed method can be extended on fabrication of multi cell SC cavities.

INTRODUCTION

The fabrication approach of slicing discs of appropriate thickness from the ingot and to produce cavities by deep drawing and electron beam welding (large-grain [LG] cavities) was proposed in a collaboration between JLab and CBMM and may be a cost effective option. Several single cell cavities produced at JLab from large grain high purity niobium demonstrated very good performance after only buffered chemical polishing [BCP]. The main aim of the DESY R&D program is to check, whether LG cavities are an option for the fabrication of approximately 1000 nine-cell cavities for the European XFEL [1]. Two aspects have been pursued: the fabrication and preparation procedure, and the basic understanding of the difference between large grain (several or even one single crystal) and fine grain (polycrystalline) material and an analysis of large grain perspectives as a SRF material.

MATERIAL

Cost effective cutting of the discs with tight thickness tolerances, purity and high surface quality is a challenge. W.C. HERAEUS developed the cutting procedure to a point, where the discs slicing can be done now without pollution of the material. Large grain niobium discs with RRR=320-500 for several single cell and three 9 cell cavities of the TESLA shape were purchased from W.C. HERAEUS. The crystallographic structure of the main large grains was investigated. The HERAUS disc consists of a big central crystal and some smaller edge crystals. The central crystal has orientation of (100) close to ideal cube position, confirming the high quality of the single crystal (weakly pronounced mosaic structure). The remaining crystals (single crystals of high quality, too) show distinctly different orientations compared to the central crystal. It is to be expected that this disc material is less vulnerable to foreign material inclusion and other types of defects, because it is taken directly from homogeneous ingot material, which has been re-melted many times. Several sources of the material pollution like forging, rolling or annealing are not present in this case compare to fine grain sheets. The most discs used for cavity fabrication were scanned by an eddy current device available at DESY. No indications for localized defects in the crystals were observed at all. The grain boundaries have been seen distinctly, especially after BCP surface treatment, which enhanced steps at the grains of different orientation.

FABRICATION

Four single cell cavity 1AC3, 1AC4, 1AC5 and 1AC7 and three nine cell cavities AC112 - AC114 (world wide first nine cell large grain cavities) were produced at Fa. ACCEL. Deep drawing of the half cell was done in the same way as for fine grain material. All half cells were leak tight, but the grain boundaries were noticeably pronounced with steps up to 0.5 mm. It turned out that the steps on grain boundaries can be reduced by applying spinning for half cell fabrication. Half cells for the cavity 1AC5 have been produced by this means. The steps on grain boundaries were less pronounced, but nevertheless clearly visible. Optical coordinate measurement and 3D imaging was applied for estimation of the shape accuracy. Measurements were done at the Fa. DECOM with measurement accuracy of 10 µm on half cells directly after deep drawing, on dumb bells with welded stiffening rings and on end half cell units with welded connecting flanges. The variation of the large grain half cell shape is slightly bigger than for poly-crystalline material. RF frequency measurements show bigger deviations from expected frequency in large grain end cells compare to fine grain, which can be attributed to tooling problems according to ACCEL. However, the frequency deviation and standard deviation for large-grain middle half cells is smaller than for conventional material parts. With appropriate trimming the correct cavity length and the frequency of the fundamental mode in the nine cell cavities AC112-AC114 was achieved without any problems. The deep drawing behaviour for large grain is different compare to fine grain sheets (different spring back) but it is more stable and allows producing more uniform half cells. It has to be mentioned that a big central crystal in the discs is essential to avoid necking and tearing at the irises.

PREPARATION AND RF TESTS

Applied treatment and some RF test results are summarized in table 1. The best accelerating gradient of

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approximately 41 MV/m was achieved with the single cell cavity 1AC3 after 150µm EP, 800°C heat treatment for 2h, 40µm EP, baking 120°C 48h, and high pressure rinsing HPR and was limited by quench at the equator. The performance of cavity 1AC5 made from half cells produced by spinning was limited by quench at a lower accelerating gradient compare to deep drawn single cells (1AC3, 1AC4). This limitation is probably related to fabrication issues.

With the three nine cell cavities AC112-AC114 only two preparation cycles and RF test each were done until now (first test after about 100 µm rough BCP, annealing at 800°C 2h followed by a fine BCP of 20 µm (table 1), second test after additional 20µm fine BCP, baking at 125°C for 48h). 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 - Mapping inspections of AC113 has detected the quench at the equator of cell 1. However, the achieved accelerating gradients up to 30 MV/m in the three large grain TESLA shape cavities can be considered as a very good result. Already in the first surface treatment all three cavities exceed the specification requirements for the XFEL, namely Eacc=23.6 MV/m with a quality factor $Q=1x10^{10}$.

An interesting comparison of these results with the performance of polycrystalline niobium cavities treated similarly during the TTF project is presented in Fig. 1. It can be seen that the average value of Eacc for these large grain cavities is almost by 5-7 MV/m higher than the average Eacc of conventional cavities. The performance of two cavities AC113 and AC114 after additional 20 µm and baking at 125°C for 48 h is shown in Fig.2. The high gradient Q-drop, which typically is present in fine grain material after bcp surface treatment and disappears after baking only in electropolished cavities, is not present in the large grain cavities (after bcp and "in-situ" baking). It deserves to be pointed out that the steps on grain boundaries were not removed by mechanical grinding. Nevertheless, the cavity performance essentially did not seems to be affected. At the moment both treatments (EP and BCP) have been applied only to a few large grain single cell cavities. It seems that the EP works more efficiently. More than 10 MV/m were gain during EP treatment on earlier BCP treated cavities 1AC3, 1AC4 (table 1). As a next step the EP will be applied to LG 9 cell cavities.

Table 1: Summary of the RF test results

Material of the company	No./Type	Treatment	Eacc, MV/m	Qo at Eacc=23.5	Limitation
Heraeus/large grain	1AC3/single cell	190µm **EP**, 800°C 2h, 120°C 48h, HPR	41.2	3.2E+10	Quench at equator
		52µm **BCP,** 133°C 48h	28.5	1.2E+10	Quench
Heraeus/large grain	1AC4/single cell	190µm **EP**, 800°C 2h, 120°C 48h, HPR	38,5	2.3E+10	Quench at equator
		41µm **BCP,** 135°C 48h,	28,2	1.2 E+10	Quench at equator
Heraeus/large grain (spinning)	1AC5/single cell	190 µm **EP**, 800°C 2h, 135°C 48h, HPR	29.7	2.0E+10	Quench, not equator
		85µm **BCP**, 127°C 110h	30.3	2.1E+10	
Heraeus/large grain	1AC7/single cell	220µm **BCP**, 800°C 2h, HPR, no baking	25.2	1.5E+10	Quench
		100µm**EP**, 120°C 48h, HPR	25.3	3.0E+10	
Heraeus/large grain	AC112/nine cell	**100 µm BCP**, 800°C, **20 µm BCP**, HPR	30,5	2.0E+10	Field Emission FE
Heraeus/large grain	AC113/nine cell	**100 µm BCP**, 800°C, **20 µm BCP**, HPR	27,4	2.0E+10	Quench at equator
Heraeus/large grain	AC114/nine cell	**100 µm BCP**, 800°C, **20 µm BCP**, HPR	28.7	2.1E+10	Quench probably FE induced

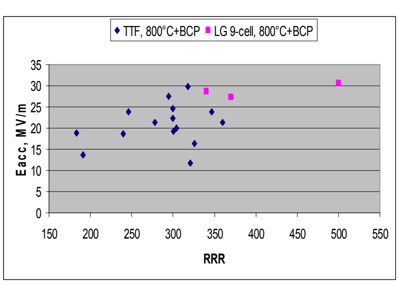

Figure 1: Comparison between large grain cavities RF results and performance of the cavities from polycrystalline niobium similarly treated during the TTF project.

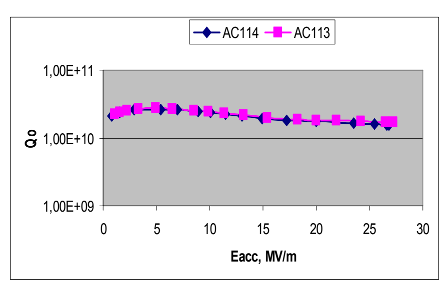

Figure 2: Q(Eacc) curve of the nine cell cavities AC113 and AC114 after second test (additional 20 µm fine BCP and baking at 125°C for 48 h)

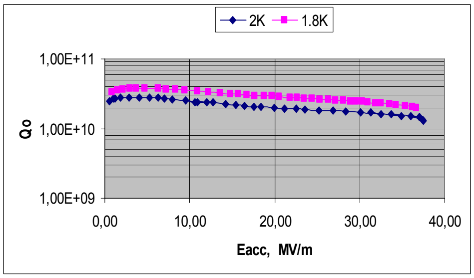

Figure 3: Q(Eacc) curve for the single crystal single cell cavity after 112 µm BCP and in situ baking 120°C for 6 hrs.

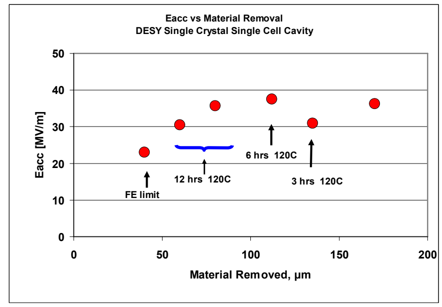

Figure 4: Eacc vs. material removal on single crystal single cell cavity.

SINGLE CRYSTAL CAVITY

The high potential of single crystal material SC was recently demonstrated on small single crystal cavities at JLab [2]. A fabrication method for a ILC like single crystal cavity was proposed at DESY. The following aspects are verified on samples and taken into consideration for the fabrication proposal. Definite enlargement of the single crystal disc diameter is possible without destroying the single crystal structure. The single crystals keep the crystallographic structure and after forming of the cavity half cell from a disc by deep drawing the orientation perpendicular to the surface remains. Appropriate heat treatment will not destroy the deformed single crystal. Two single crystals will grow together by EB welding, if the orientation of the crystals is matched. Based on these investigations a prototype single crystal cavity of the TESLA shape was produced. A niobium ingot supplied by W.C. HERAEUS with a single crystal of approximately 150 mm in diameter in its centre was used. Surface treatment and a series of RF tests after successive material removal with BCP were done at JLab. A best accelerating gradient of E_{acc} = 37.5 MV/m was reached after only 112 µm of material removal by BCP and in situ baking at 120°C for 6 hrs with the quality factor of $2x10^{10}$ at 1.8K (Fig. 3). The limitation was caused by a quench. Fig. 4 shows the quench field as a function of the removed surface layer after each material removal step. It is known from experiments on fine grain material that heat treatment around 800°C provides for hydrogen outgassing and stress relaxation and in many cases an increased accelerating gradient could be obtained. Therefore, as a next step it is planned to anneal the cavity at an appropriate temperature, guided by annealing procedures developed on samples.

OUTLOOK

Cavities produced from LG niobium deserve attention as potentially cost effective option with comparable to fine grain performance potential. Accelerating gradients similar to the best fine grain cavities can be achieved in LG cavities especially after EP treatment. Very reasonable performance up to E_{acc}= 30 MV/m was achieved on the single cell and nine cell cavities after BCP treatment only.

A fabrication method for a ILC like SC cavity was proposed. The first RF test results obtained with the SC single cell cavity are very encouraging. The single crystal option opens the possibility to achieve mirror like inner surfaces of a complete cavity cell by applying standard chemical treatment BCP (1:1:2). This may potentially lead to better cavity performance in terms of achievable accelerating field, quality factor and reproducibility of performance.

The developed method can be extended to fabrication of multi cell single crystal cavities by using the above described assembly method not only for equators but also for the iris welds. A single crystal applied for cavity fabrication has a crystal orientation close to (100). Whether or not the cavity performance can be influenced by the crystal orientation is an open question and may deserve to be investigated.

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