PROGRESS OF THE TEST CAVITY PROGRAM FOR THE EUROPEAN XFEL

A.Brinkmann#, J. Iversen, D.Reschke, W.Singer, X.Singer, K.Twarowski, J.Ziegler
DESY, D-22603 Hamburg, Germany

Abstract

Two main goals of the test cavity program for the European XFEL are the qualification of alternative niobium vendors and the investigation of the capabilities of large grain niobium for large-scale nine-cell cavity production. About 25 1.3 GHz single-cell cavities of TESLA shape have been completed at Accel Instruments and DESY. Alternative vendors for high purity fine-grain niobium are ITEP Giredmet, Cabot, Ningxia and Plansee. The in-house fabricated cavities have been tested after 800C firing and final electropolishing (EP) treatment. All cavities exceed gradients of 35 MV/m at high Q-values. For the large grain cavities of high RRR Heraeus niobium gradients up to 41 MV/m have been achieved. The performance after final chemical etching (BCP) is compared to EP for several cavities.

STATUS

23 cavities at DESY have been completed (19 out of fine grain material and 4 out of large grain material):
- Machining, etching, EB-welding and mechanical/optical quality control has been done in-house.
- Deep-drawing of cups and electropolishing (EP) + etching (BCP) of cavities have been carried out at industry. 6 cavities + 1 two-cell (large grain+monocrystal) was completed at ACCEL-Instruments GmbH, Germany:
- Final mechanical/optical quality control was done at DESY; the EP at Henkel GmbH, Germany; the BCP at Accel-Instruments GmbH.

RESULTS

The motivation was to check and qualify further or alternative Niobium vendors.

1: Plansee Co., Austria, took over the sheet production from W.C.Heraeus Gmbh and has to been qualified urgently.

2: Fine and large grain niobium from the Chinese Company Ningxia has to be checked.

3: Niobium from Company Cabot, USA, has to be qualified.

4: Niobium from the Russian Company Giredmet with high RRR and low Ta content has to be qualified.

Status: PLANSEE niobium material:

Three cavities (1DE14 – 1DE16) were fabricated in-house of Heraeus/Plansee Nb with RRR ~ 300. Preparation steps were: (1) chemical etching (BCP) with more than 80µm removal. (2) 800 °C firing. (3) 100µm electropolishing (EP). (4) High pressure water rinsing (HPR). (5) Baking at 145°C for 3h under Argon atmosphere at SACLAY for Cavity 1DE14, standard baking at 130 °C for 48 h at DESY for Cavity 1DE16. Cavity 1DE15 was also measured before baking but showed unfortunately strong field emission (FE) due to a corroded waterpipe in the HPR-system and must pass a new preparation cycle. Limitation of Cavity 1DE14 and 1DE16 were breakdown at E_{ACC} = 35.9 MV/m and E_{ACC} = 37.4 MV/m. Q/E-results are shown in Fig.1.

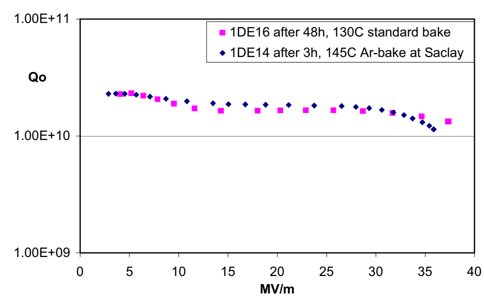

Figure 1: Q_0/E-curve of 1DE14 + 1DE16 at 2K after bake, PLANSEE

Status:NINGXIA niobium material:

Three cavities (1DE17 and 1DE18 completed) fabricated in-house of fine grain Ningxia Nb with RRR of 330. Preparation steps were: (1) chemical etching (BCP) with more than 80µm removal. (2) 800 °C firing. (3) 100µm electropolishing (EP). (4) High pressure water rinsing (HPR). (5) Standard baking at 130 °C for 48 h. 1DE18 received 2 times additional HPR after baking. Both cavities were limited by Quench at E_{ACC} = 38.3 MV/m respectively 39.5 MV/m. Q/E-results are shown in Fig.2.

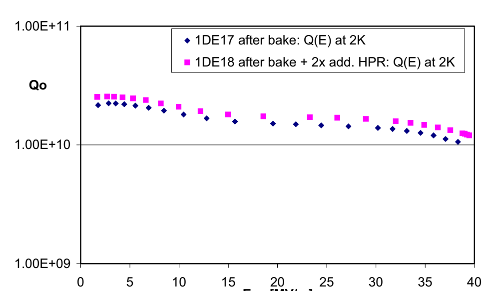

Figure 2: Q_0/E-curve of 1DE17 and 1DE18 at 2K after bake (and additional 2x HPR), NINGXIA

#arne.brinkmann@desy.de

Status: GIREDMET niobium material:

Three cavities of Russian Giredmet Niobium with RRR > 600 were fabricated at DESY. Tests for 2 Cavities are completed. The preparation steps were in detail: (1) EP with 150µm removal, (2) 800°C firing, (3) EP with 40µm removal, (4) HPR, (5) standard baking procedure at 130°C for 48 h. After all the qualification was successful but field emission could not be removed completely. Q/E behavior is shown in Fig. 3 and 4.

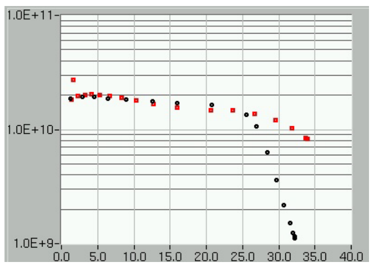

Figure 3: Q(E)-curves of 1DE4 before and after bake (some FE present before and after bake),GIREDMET

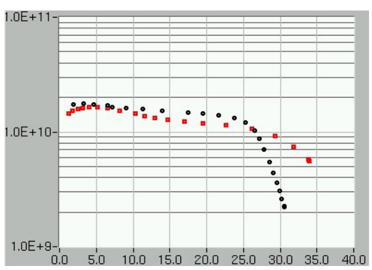

Figure 4: Q(E)-curves of 1DE5 before and after bake (some FE present before and after bake),GIREDMET

Status: CABOT niobium material:

Two cavities, 1DE12 and 1DE13 were fabricated at DESY of Cabot Niobium with RRR ~ 230 (XFEL Specification about RRR: 300)

Preparation steps were in detail: (1) More than 100µm removal with BCP at Accel Instruments, (2) 800 °C firing, (3) more than 100µm EP at Henkel GmbH, (4) HPR, (5) 130 °C bake for 48 h. Even if the RRR-value is lower than required the qualification was successful. Since some field emission was present the Q-value was somewhat lower. Q/E-curves shown in Fig.5.

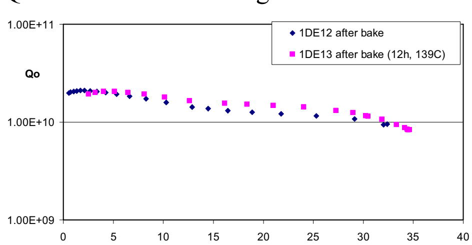

Figure 5: Q/E-curves of 1DE12 and 1DE13,CABOT

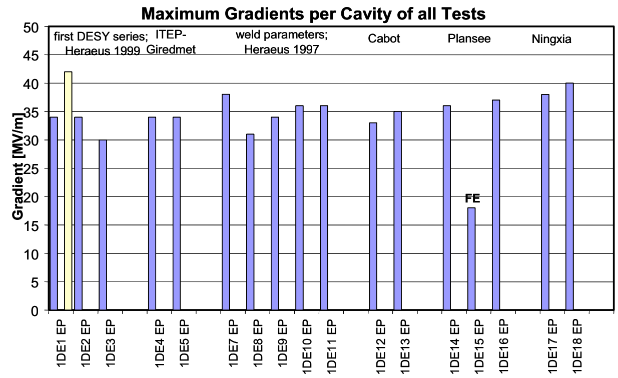

Figure 6: Maximum Gradients of all single-cell, fine grain Cavities

Fig. 6 shows the maximum Gradient from all single-cell, fine grain Cavities. This figure also includes gradients from Cavities out of former productions (1997 and 1999).

Status and results of large grain niobium:

Large grain niobium sheets can be cut directly from the ingot, without forging and rolling. Expecting less impurities due to less grain boundaries, eddy current scanning could be needless.

Following cavities are produced or are under construction:

Made from Heraeus ingot I25 (RRR=500): 1AC3,1AC4,1AC5 and 1DE20 and 1DE21.

Heraeus ingot I28 (RRR=505): 1AC7 and three 9-cell cavities: AC112, AC113 and AC114.

From CBMM, Brasil, two 1-cell cavities, 1DE25 and 1DE26 are under construction.

One 2-cell cavity, 2IP1, was made from ingot I30 coming from Ningxia, China.

The Cavities 1AC3 and 1AC4 showed an increased gradient about 10MV/m respectively 13 MV/m after EP-treatment compared to BCP. Q/E-curves are shown in Fig.7.

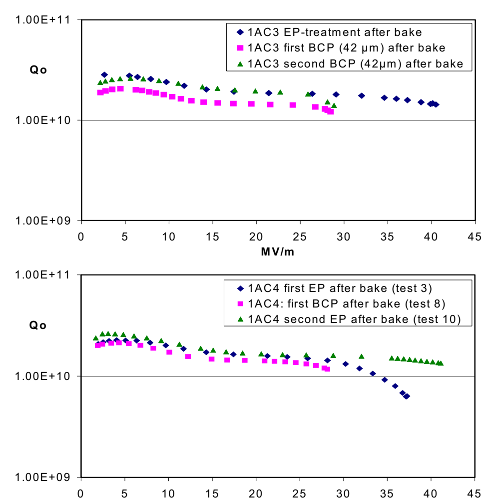

Figure 7: EP versus BCP by means of Q/E-measurement (1AC3 and 1AC4)

General RF-performance of large grain cavities features all characteristic parameters identic to cavities made out of fine grain material.

Other results belonging to large grain cavities:

1AC5 gained no increasing of the gradient after EP compared to BCP (E_{ACC} = 30MV/m at $Q_0 = 1.5 \times 10^{10}$).

1AC7 made from a different Heraeus ingot reached 25 MV/m with strong field emission after EP and baking. A new EP preparation is under way.

1DE21 and 1DE22 are not measured yet; a final EP treatment is in process.

9-cell cavities AC112 – AC114 showed gradients about 27 – 30 MV/m after BCP. RF-tests after EP will follow.

Status and results of single crystal niobium[1]:

Up to now two 1-cell cavities were fabricated out of single crystal material. Cavity 1AC8 made of niobium cut out of the rolled core of Heraeus ingot I28 and 1AC6 made out of CBMM ingot I26. The cups for this cavity were made by spinning. The advantage of single crystal material is to obtain the RF-performance out of pure niobium without grain boundaries. At Jefferson Lab, USA, several RF-tests were done with Cavity 1AC8. The best result was achieved after BCP and bake with E_{ACC} = 38,9 MV/m at $Q_0 = 1{,}8 \times 10^{10}$. Limitation was thermal breakdown.

Cavity 1AC6 achieved after BCP 21 MV/m, limited by quench, and after additional EP with 120µm removal plus bake a gradient about E_{ACC} = 41MV/m at $Q_0 = 1{,}2 \times 10^{10}$. Q/E-curves are shown in Fig.8.

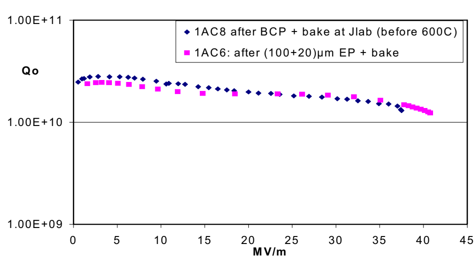

Figure 8: Q/E-curves of 1AC6 and 1AC8

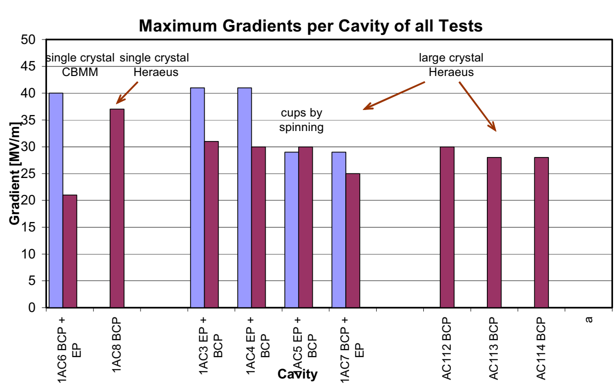

Figure 9: Maximum Gradients of all large grain and single crystal Cavities.

Fig.9 shows a chart of achieved maximum gradients of cavities made out of large grain and single crystal material. The blue bars indicate gained gradients after EP-treatment.

Summary:Large grain niobium:

After EP-treatment large grain cavities obtain a comparable performance (up to 40MV/m) to the best fine grain niobium cavities. A complete comparison EP versus BCP is on the way. Up to now 1 cavity (1AC3) lost 12 MV/m after BCP treatment, and 1AC4 increased the gradient about 13 MV/m after EP. Otherwise 1AC5 did not change the gradient after BCP and EP. The three 9-cell large grain cavities are tested after BCP with a gradient between 28 and 30 MV/m, EP treatment is in process.

Single crystal cavity: Cavity 1AC6 increased from 21 to 41 MV/M from BCP to EP, cavity 1AC8 reached 38 MV/m after BCP only.

Investigation on treatment parameters:

EP-treatment: Cavity 1DE1 was used to compare the EP-System at SACLAY, France with the EP at Henkel. After EP at Henkel a gradient at 35MV/m could be achieved, after EP at SACLAY the gradient was 43 MV/m. Only one test could be done up to now, so we have to check the reproducibility. On to 1-cell cavities a comparison between two different electrolytes were done. We observed no change in E_{ACC}.

Bake parameters: baking at 120 – 135°C for 48 h is a well established procedure for EP treated cavities. Increasing the temperature to 135 – 140°C and reducing the baking time to 12 h provides good RF-test results. This procedure is now the standard bake-procedure for 1-cell cavities.

The first test of an open bake procedure under Ar atmosphere (collaboration with Saclay) was successful, see Cavity 1DE14. Open bake procedure with N_2-atmosphere was done with 1DE3. The Q_0 value could be improved, but the maximum E-field degraded.

Dry-Ice cleaning[2]: By now the results are comparable to HPR, but still more statistic is necessary.

SUMMARY

A successful and reproducable cavity in-house production at DESY could be achieved. Plansee and Ningxia Niobium are qualified for 9-cell cavity production. Cabot material showed good results in face of lower RRR-values. To qualify Giredmet material more statistics is needed.

Large grain material shows excellent results after EP-treatment and stable results after BCP. This has to be demonstrated on 9-cell cavities next.

Single crystal Niobium shows excellent results after EP and BCP. Experiments with single crystal cavities will continue.

Studies on electropolishing: EP-system at SACLAY started operation successfully, more tests will follow.

Comparison between different electrolytes gives comparable results.
New bake procedure with shorter baking time is established. Tests with open baking under Ar or N_2 will continue.
RF results after Dry Ice cleaning are comparable to HPR. The cleaning device will be upgraded to handle 9-cell cavities.

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REFERENCES

[1] W.Singer et al., "Fabrication of single crystal Niobium cavities", presented at this Workshop.
[2] D.Reschke et al., "Dry-Ice cleaning: The most effective cleaning process for srf cavities ?", presented at this Workshop.