

A NON - ELECTROPOLISHED NIOBIUM CAVITY REACHED 40 MV/m AT SACLAY

B. Visentin [#], J-P. Charrier, A. Aspart, Y. Gasser, J-P. Poupeau, G. Congretel
CEA-Saclay, DSM/DAPNIA/SACM, 91191Gif/Yvette Cedex - France

Abstract

A 40 MV/m accelerating gradient has been obtained in a niobium cavity after a chemical etching by using a three acids mixture. This technique is also called BCP as Buffer Chemical Polishing. This result, the third in the world, allows to hope for findings to improve systematically the thermal breakdown (quench) on BCP treated cavities. The heat treatment at higher temperature after chemistry could be an interesting way, because this means influences the quench position.

1. INTRODUCTION

The chemical treatment of niobium cavities by ElectroPolishing (EP) has already shown in the past its superiority upon the BCP in term of quench performances [1,2,3]. However, the beneficial "baking effect" through the high field Q_0 slope vanishing [4-5], and some excellent results on cavities treated by BCP [6-7] allows to hope that all has not been made yet with BCP. It is worth searching in this direction because the BCP process requires a simpler set up and it is less expensive than the EP method. A recently achieved 40 MV/m accelerator field at Saclay, in a single cell cavity (C1-15), adds force to this point of view.

2. THE C1-15 NIOBIUM CAVITY

This 1.3 GHz cavity was built using cross rolled, deep drawn and electron-beam welded niobium sheets. The cavity thickness is 2.8 mm . The Wah Chang niobium used, had a very good initial RRR (~ 400). So, without any annealing, the accelerator field in this cavity reached easily 22 MV/m (Fig.1).

To improve this performance, a high temperature annealing (1400 °C) with a Titanium getter was used: by this way, the thermal conductivity is improved through the RRR increase with the Nb purification (electron conduction) and through the grain growth (phonon conduction) [8]. After annealing the C1-15 cavity was treated several times with BCP chemical treatments to remove Titanium from the surface by using FNS ($\text{HF}/\text{HNO}_3/\text{H}_2\text{SO}_4$:1/1/1) and FNP acid mixtures ($\text{HF}/\text{HNO}_3/\text{H}_3\text{PO}_4$:1/1/2 in volume). A total thickness of 235 μm has been removed.

After such a treatment the accelerating gradient reached 31 MV/m with a limitation due to the RF power supply (the quench limit is pushed farther on). At this step, the high field slope was removed by means of the now standard "in situ" baking , and the maximum field, limited by quench, reached 40 MV/m with $Q_0 = 2.10^{10}$. Processing events with electron emission are also visible around 20 MV/m on Fig.1.

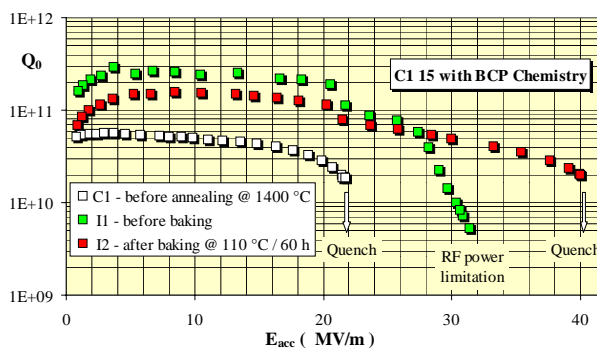


Figure 1 : $Q_0(E_{acc})$ curves for the C1-15 BCP cavity, the best result is performed after annealing and baking.

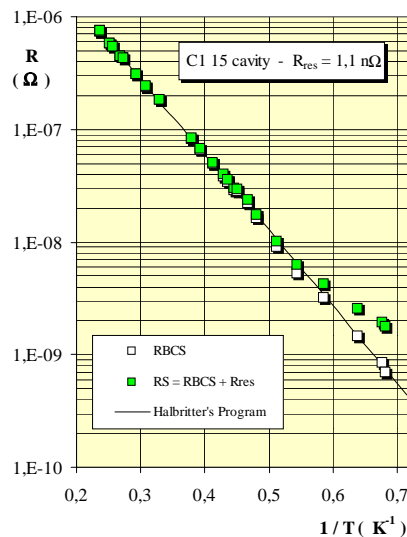


Figure 2 : R_s vs. He bath temperature (before cavity baking).

The surface resistance analysis (Fig.2) shows the superposition of the BCS resistance R_{BCS} (decreasing exponentially versus the temperature) and the residual

[#] bvisentin@cea.fr

resistance R_{res} (1.1 n Ω). The R_{BCS} data are well fitted by means of the Halbritter's computer code [9] using 600 nm as the electron mean free path value and the standard niobium parameters ($\lambda_L=31$ nm, $\xi_F=62$ nm, $\Delta=1.46$ meV).

The quality factor maximum value ($\sim 2.10^{11}$) is very high and can be explained by:

- the low helium bath temperature (1.48 K) that minimises the R_{BCS} contribution to the surface resistance,
- the FNS chemistry which is a little bit more favourable than FNP as shown on Fig.3,
- the efficient magnetic shielding of the cryostat since the residual measured magnetic field in the cavity area is lower than 1 mG that limits R_{res} .

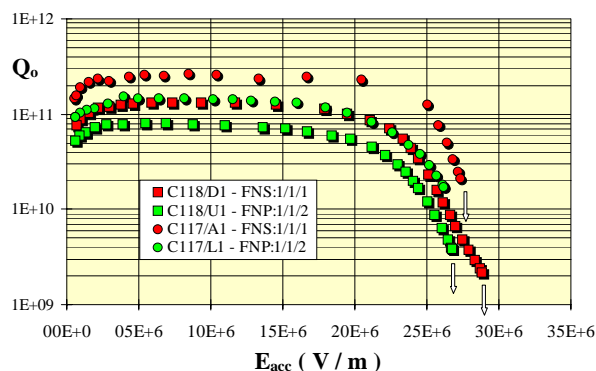


Figure 3 : Comparison between FNS and FNP chemistries for two annealed cavities. All these curves are limited by quenches and achieved without baking.

3. HIGH GRADIENTS WITH BCP CAVITIES

On table 1 we have listed the characteristics of the only three events where BCP cavities achieve 40 MV/m.

The DESY and Saclay results are similar in terms of quench value and necessity of a cavity baking. They differ by the RRR value but this is of no consequence. The DESY cavity is a Nb/Cu clad cavity, favoured by a higher thermal conductivity due to the copper material and the only 1mm of niobium. This was balanced, for the C1-15 niobium cavity, by a better initial RRR (400) and the annealing at 1400°C.

In contrast the JLab cavity has a moderated RRR value. Annealing and baking treatments are needless. Furthermore the maximum accelerator field is not limited by quench. All these facts work in the excellent quality of the cavity, well called "defect free".

We have unsuccessfully tried to reproduce the C1-15 result in using quite a similar cavity (C1-16), where half cells were spun instead of deep drawn. Even if it reached 42 MV/m previously, with an EP chemistry, this cavity could not exceed 30 MV/m with a BCP chemistry.

Summing up of these results show that some BCP cavities are able to reach high gradients. For these cavities, a high RRR is necessary but it is not sufficient and the fewest resistive defects are required. For more usual cavities, like C1-16, BCP chemistry is undeniably less efficient than EP to screen the consequences of these defects. Our purpose is to improve the quality of such cavities and to carry on using BCP chemistry.

| Laboratory Reference | Jefferson Lab. P. Kneisel [6] Gif/Yvette - 1995 | DESY W. Singer [7] Tsukuba - 2001 | Saclay This paper Paris - 2002 |
|----------------------|---|---|--------------------------------------|
| Cavity | " defect free " | 1NC2 | C1-15 |
| Frequency | 1,3 GHz | 1,3 GHz | 1,3 GHz |
| Supplier | Tokyo Denkai | Heraeus | Wah Chang |
| Material | Nb | Nb / Cu clad | Nb |
| Thickness | ? | 1 mm / 4 mm | 2,8 mm |
| Nb RRR | > 200 | 200 | 400 |
| Fabrication | deep drawing EB welding | explosive bonding hydroforming | deep drawing EB welding |
| Annealing | no | 800 °C | 1400 °C |
| Baking | no | 140 °C / 30 h | 110 °C / 60 h |
| T (He bath) | 1,6 K | 2 K | 1,5 K |
| Q_0 | 6.10^{10} | $8,7.10^9$ | 2.10^{10} |
| E_{acc} | 43 MV/m | 40 MV/m | 40 MV/m |
| Limitation | global warming | quench | quench |

Table 1 : Characteristics of the best BCP cavities.

4. HEAT TREATMENT AFTER BCP

We have started last year a research program on BCP cavities to study the quench behaviour when the cavity is thermally treated, after a BCP chemistry, in a high vacuum furnace (1.10^{-7} mbar @ 1000 °C). The idea was to purify the RF surface from a possible surface contamination, specially at the grain boundaries. So the cavity is tested just after the heat treatment followed by a high pressure rinsing.

Preliminary results [10] in C1-18 showed that:

- the quench limit is moving correlatively with the oxygen diffusion through the RF superconducting layer if $T < 800$ °C (Figures 4-5). After a first degradation until 250°C, the RF layer gets clean again and the quench limit moves up.
- Around 800 °C, a new pollution seems to appear which is not related to oxygen (T_C not affected). We have supposed a possible Nb pollution by the furnace residual gases.

To verify this hypothesis, the last experimental point (1000°C) on Fig.4-5 was achieved by using a titanium box (Fig.6), in order to shield the cavity from the furnace atmosphere, and two thin Nb sheets to close the cavity apertures and protect the internal cavity surface from any pollution.

In spite of these cares, the quench occurred at 21 MV/m. So the alleged pollution by the furnace atmosphere could not be incriminated. An additional chemistry on the

external part of the cavity excluded also a Kapitza's resistance degradation. Only an small internal BCP chemistry (5 μm removed) restored the quench at the initial value (26 MV/m) that proves an inner surface pollution and excludes a bulk contamination or a change in the thermal conductivity.

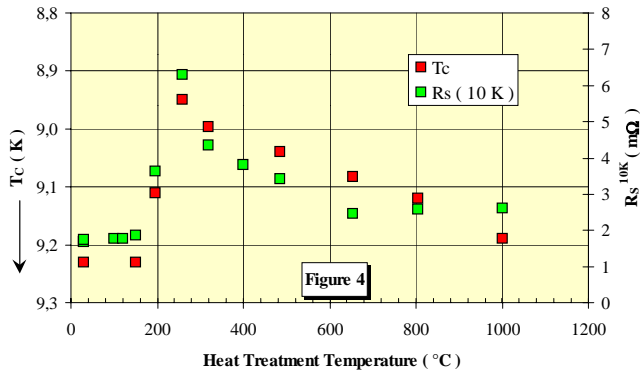


Figure 4

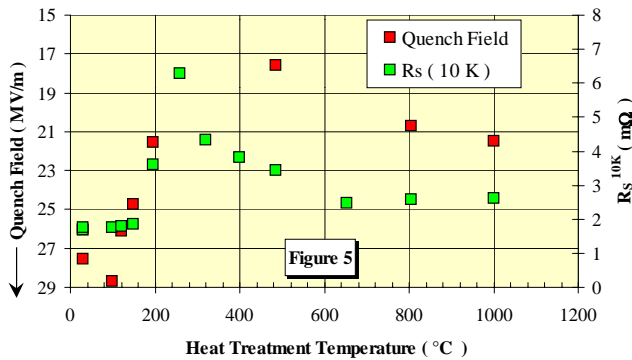


Figure 5

Figures 4-5 : T_c , $R_s^{10K}(\ell)$, E_{acc}^{quench} versus the heat treatment temperature on the BCP C1-18 cavity.

An explanation is that niobium carbide appeared on the surface due to the hydrocarbon cracking during the cavity heating [11]. So in the future, before the heat treatment, we plan a cavity cleaning by O_2 plasma to remove hydrocarbons from the inner surface. This next improvement could be allow, after the cavity heating, to restore the initial quench field, and overtake this value if our hypothesis of pollution is verified.

5. CONCLUSION

The result achieved on C1-15 cavity proves that the BCP chemistry is not an obstacle to reach high fields, when a cavity has few defects.

For other more usual cavities, we have shown that the quench limit is moving after a BCP cavity heating and

that it is connected to the RF layer cleanness. The improvement of the quench position seems possible, even if we are now limited by a phenomenon that implies a new step in the cleaning process of the cavity.



Figure 6 : The Titanium box shields the cavity from the furnace atmosphere during the heat treatment.

6. ACKNOWLEDGEMENT

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