HIGH GRADIENT Q-SLOPE: NON "IN-SITU" BAKING, SURFACE TREATMENT BY PLASMA AND SIMILARITIES BETWEEN BCP & EP CAVITIES

B. Visentin #, J.P. Charrier, D. Roudier,
Y. Gasser, A. Aspart, J.P. Poupeau, B. Coadou, G. Monnereau
CEA-Saclay, DSM/DAPNIA/SACM - 91191 Gif / Yvette Cedex - France

Abstract

Ultra high vacuum conditions are not necessary in the cavities baking process to improve the Q-slope at high accelerating fields. Easier to perform, baking in the air at atmospheric pressure can be carried out with the same efficiency. Furthermore, the cavity surface treatment by oxygen plasma shows similar results as baking treatment.

These experiments show that the thickness of oxide layers is not involved in the Q-slope phenomenon, but preserve the possible role played by oxygen towards the Q-slope removal.

Analysis of experimental results obtained with buffered chemical polished (BCP) and electropolished (EP) superconducting niobium cavities, show similar behaviours before and after baking. These experiments demonstrate that surface roughness and magnetic field enhancement at grain boundaries cannot explain the origin of Q-slope.

INTRODUCTION

High gradient Q-slope and its empirical cure by baking are not well understood yet. Several theoretical models have been developed but none of them is able to account for all the observations [1]. For this reason, experiments are carried on at Saclay to improve the phenomenon understanding.

In some cases, "multipacting process" appears in the cavity during the first field rise, with a likely modification of the surface resistance. In these cases and to be able to compare comparable things, we only take into account the second "free-multipacting" RF test.

NON "IN-SITU" BAKING

"In-situ" baking, under ultra high vacuum (UHV), improves indisputably the Nb cavity performances [2]. This treatment is the last step of the cavity preparation just before the RF test itself.

Nevertheless the operating conditions for baking are not satisfactory because:

- after baking, due to thermal stress, helium leaks can appear on cavity flanges,
- cavities assembled with indium seals can not be baked.

To improve the baking procedure, we have successfully tested the possibility to operate under air, at the atmospheric pressure (see Fig.1):

- a cavity was firstly tested (green curve) after BCP, high pressure rinse (HPR) and a classical drying during three hours, under laminar flow in the clean room,
- after new BCP and HPR treatments, the wet cavity came out of the clean room and was directly baked (110°C/60h) inside a drying oven working under air at atmospheric pressure without any pumping system. Before assembly, a final HPR was performed to eliminate dusts from the surface. The RF test after baking shows a subsequent Q-slope improvement (red curve) with results similar to a classical "in-situ" UHV baking.

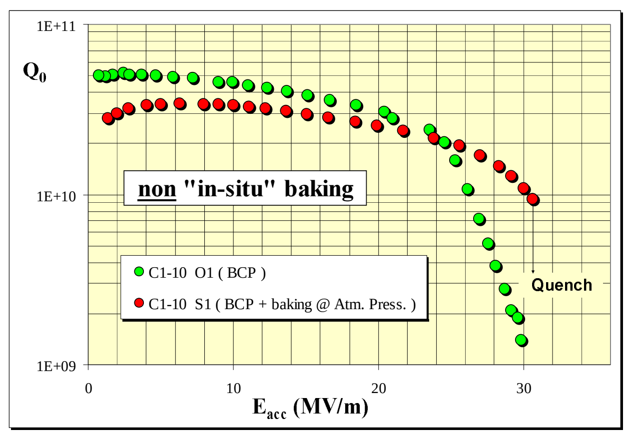


Figure 1: Q_0-slope Improvement for BCP cavity by using a non "in-situ" baking.

SURFACE TREATMENT BY PLASMA

Q-slope is not the only feature modified by cavity baking. Due to the oxygen diffusion, Nb_2O_5 and sub-oxide layers are also altered [3-4]. The "Internal Tunnel Exchange" model takes into account the decrease of the Nb_2O_5 layer thickness to explain the Q-slope improvement after baking [5].

To experimentally find such a correlation, a BCP cavity has been tested before and after a surface treatment by oxygen plasma (Fig.2). An electron cyclotron resonance (ECR) discharge (f = 2.45 GHz, P_{RF} = 1.5 kW) is performed inside a 5 m^3 reactor [6] filled with O_2 gas

bvisentin@cea.fr

(5.10^{-3} mbar). Sm-Co permanent magnets (875 G) are put inside the cavity, on the beam axis, to ensure the resonance condition (Fig.3). During the cold RF discharge, oxygen ions are created and impinge the inner cavity surface at low energy (~50eV) causing no surface modification by sputtering. The discharge is sustained during half an hour while the temperature on the cavity surface does not exceed 80 °C, in such a way that no baking effect can be suspected. After this surface treatment the cavity is rinsed by HPR and tested once again (red data on Fig.2). The results are similar to those achieved after baking treatment, with the R_{res} increase and the slight improvement of Q-slope.

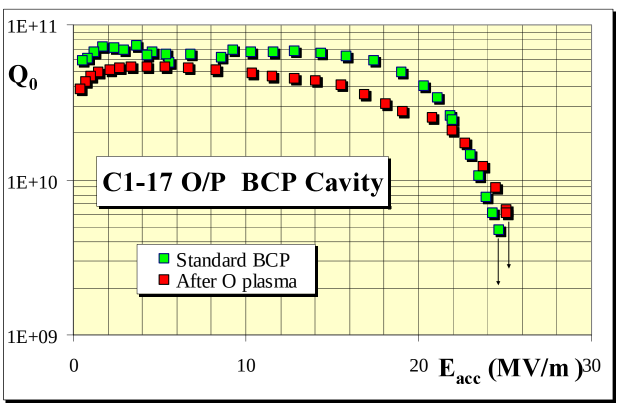


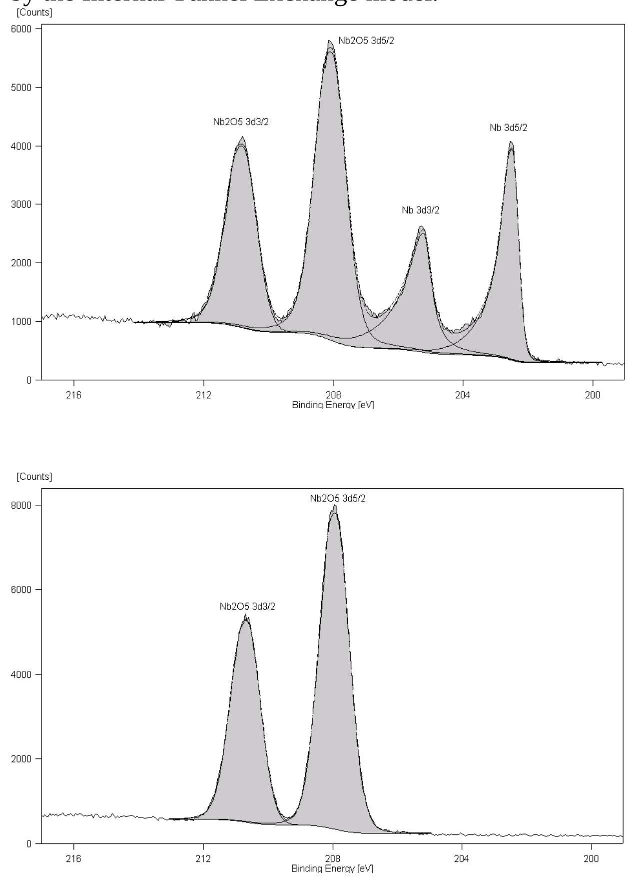
Figure 2: Q_0 (E_{acc}) before and after O^+ plasma treatment.

Figure 3: Internal view of plasma reactor with cavity, permanent magnets and gas inlet system.

Moreover, samples are simultaneously treated with the cavity, submitted to an XPS analysis, performed by Biophy Research [7]. It shows the pentoxide layer increase after the plasma treatment (Fig.4). These observations can be explained by O^+ ionic implantation on the surface followed by oxygen diffusion.

Some efficiency of this treatment can be noted because no difference is observed on BCP cavity after a classical baking in the same conditions (80 °C / 30 mn). These preliminary tests should be continued with the goal to optimise the plasma parameters (time, P_{RF}).

In summary, plasma treatment and non "in-situ" baking suggest that oxygen is really involved in Q-slope improvement but not the Nb_2O_5 decrease as put forward by the Internal Tunnel Exchange model.



Figures 4: XPS analysis of the Nb3d doublet on sample before (above) and after (below) oxygen plasma.

SIMILARITIES BETWEEN EP AND BCP CAVITIES

The "Magnetic Field Enhancement" theory [8] finds the Q-slope origin in the surface roughness. Unfortunately electropolished and chemically polished cavities, which have different surface roughness, show similar Q-slope behaviors before baking (see Fig.5).

After "in-situ" baking (110 °C / 60 hours) the EP and BCP curves show also similarities (Fig.6). But in most cases, residual Q-slope remains for BCP cavities as for C1-10 (white curve): the C-15 and C-16 cavity results (red and green data) are exceptional and it is difficult to redo them. For these results, after baking, roughness cannot either be an explanation of Q-slope, if we compare:

- C1-10 with a residual Q-slope and a smoother surface (Fig.7a) than
- C1-15 (Fig.7b), with no residual Q-slope, large grains (2 to 3 mm^2) and high steps (8 μm).

A comparison between the curves of C1-10 and C1-16 cavities (Fig.6 - white and red) show that Q-slopes and quench limits cannot be correlated: residual Q-slope absence does not imply systematically a high field value for the quench.

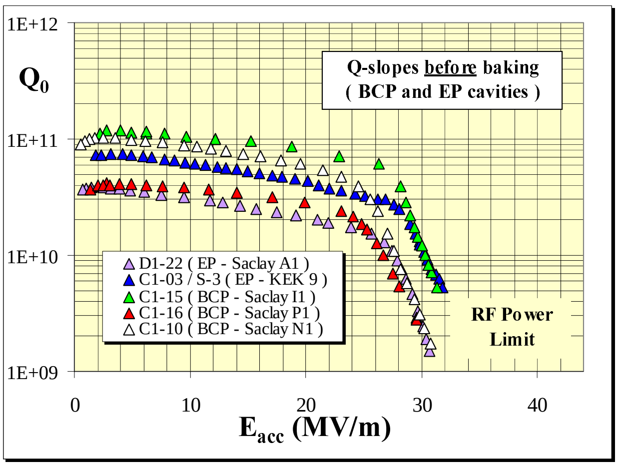


Figure 5: Q_0-slope similarities before "in-situ" baking between EP and BCP cavities.

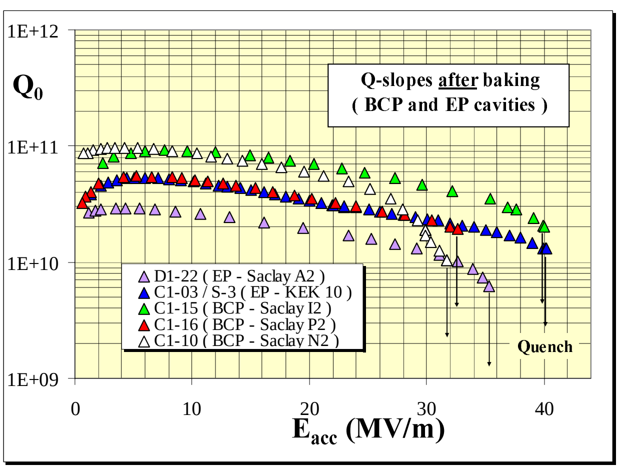


Figure 6: Q_0-slope Improvement after baking.

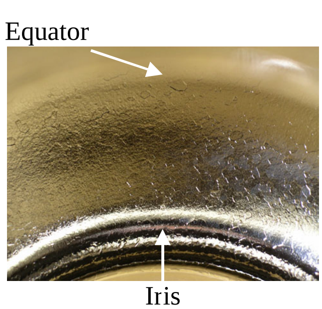
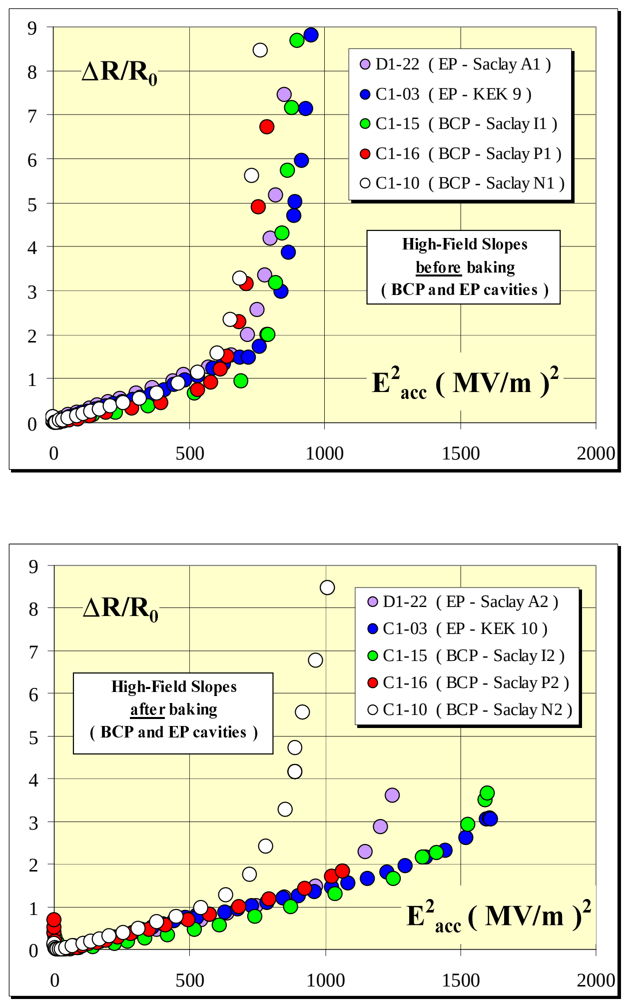


Figure 7a: Picture of the inner surface of C1-10 (residual Q-slope after baking).

Figure 7b: Picture of the inner surface of C1-15 (no residual Q-slope after baking).

In fact, it is not correct to say that high gradients Q-slope is removed after baking. The onset value E° is only pushed away towards higher values, because a residual slope still exists above 40 MV/m, even for EP cavities (Fig.8).



Figures 8: Residual Q_0-slopes before and after baking (EP and BCP cavities).

CONCLUSION

Unlike UHV baking, the new procedure of baking under air at the atmospheric pressure allows to actually integrate this treatment into the preparation process of cavities.

Built from differences between EP and BCP cavities, theories are not able to explain yet their similarities, probably because no big differences are found between these two types. Nevertheless best results are more easily achieved with EP cavities. So, perhaps, after all, surface roughness plays a role, but should not be fundamental: it is more efficient to clean a smooth surface than a rough one...Using the fact that UHV is not necessary for baking, we plan to bake a cavity in the clean room, directly after high pressure rinse: a fast drying could be necessary to suppress Q-slope...

REFERENCES

[1]- B. Visentin "Q-Slope at High Gradients: Review of Experiments and Theories", 11th Workshop on RF Superconductivity, Travemünde GERMANY (2003) - SRF2003: TuO01.

[2]- B. Visentin et al., "Improvement of Superconducting Cavity Performances", 6th EPAC, Vol. III p. 1885, Stockholm - SWEDEN (1998) EPAC1998: TUP07B.

[3]- P. Kneisel, "Preliminary Experience with “in-situ” Baking of Nb Cavities", 9th Workshop on RF Superconductivity, Santa Fe - USA (1999), Vol. I, p.328, SRF1999: TUP044.

[4]- F. L. Palmer, "Influence of Oxide Layers on the Microwave Surface Resistance of Nb", IEEE Trans. Magn. 23, n°2, p. 1617 (1987).

[5]- J. Halbritter, "Material Science of Nb RF Accelerator Cavities: where do we stand 2001?", 10th Workshop on RF Superconductivity, Tsukuba - JAPAN (2001), SRF2001: MA006.

[6]- SNLS Vide Cryo Plasma: http://www.snls.fr

[7]- Biophy Research: http://www.biophyresearch.com

[8]- J. Knobloch et al., "High Field Q Slope in SC Cavities due to Magnetic Field Enhancement at Grain Boundaries", 9th Workshop on RF Superconductivity, Santa Fe - USA (1999), Vol. I, p.77, SRF1999: TUA004