

OPTIMIZATION OF BAKING PARAMETERS FOR ELECTROPOLISHED NIOBIUM SUPERCONDUCTING CAVITIES*

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Abstract

High gradients, on bulk niobium cavities, can only be reached after an imperative baking at low temperature to suppress the high field Q-drop.

We demonstrate in this paper that the commonly used standard process (under ultra high vacuum at 120°C for 48 hours) could be now simplified in terms of duration (3 hours at 145°C) and requirement (argon atmosphere instead of vacuum). Some efforts to more reduce duration, down to only one hour, have been undertaken to validate hypothesis and understand baking phenomenon. The next improvement step with the open-ended treatment of cavities in oxygen free atmosphere is underway and it does not seem hard to achieve. This new “fast baking” procedure will be very useful in the XFEL and ILC projects where Nb cavities mass production is required.

INTRODUCTION

Baking is a necessary final stage in cavity preparation that allows to reach high gradients (35 MV/m) required for the International Linear Collider (ILC) project.

The standard “In-situ UHV Baking” process at 110 °C for 2 days [1] has been selected for the ILC Baseline Configuration Design (BCD). The term “In-situ UHV Baking” means that the cavity is assembled, ready to be tested on the RF test bed, full equipped with RF antennas and thermal sensors. Moreover the inner part of the cavity is under Ultra High Vacuum during baking. It is necessary to precise that duration of the “In-situ UHV Baking” at 120°C can sometimes be reduced down to 12 hours when cavities are built with large grain niobium [2]. A beneficial baking effect is even reported on a single crystal cavity after only 6 hours at 120°C [3].

Nevertheless, in most cases and especially for fine grain cavities this technique, for the large-scale cavity preparation, is too long and too restrictive because of UHV requirements. For these reasons a modified process, under the “Fast Baking” denomination, has been proposed for the ILC Alternative Configuration Design [4]. In “Fast Baking” process, a thermal treatment at higher temperature (145°C) in oxygen-free atmosphere is proposed; duration is only 3 hours and it can be achieved on an open-ended cavity inside the clean room.

WHERE DO WE STAND NOW WITH “FAST BAKING”?

All experiments described in this paragraph have been performed on single-cell fine grain niobium cavities treated by buffered chemical polishing (BCP). On such cavities baking phenomenon exits but it is more difficult to observe and less impressive compared to the one performed on electropolished (EP) cavities. Nevertheless, BCP was preferred to EP because this chemistry is a more reliable and then more desirable to clear the way.

In a first step, successfully achieved in 2003, vacuum requirement is avoided during baking: an open-ended cavity to air was baked using the standard parameters 110 °C for 2 days (Fig.1) [5].

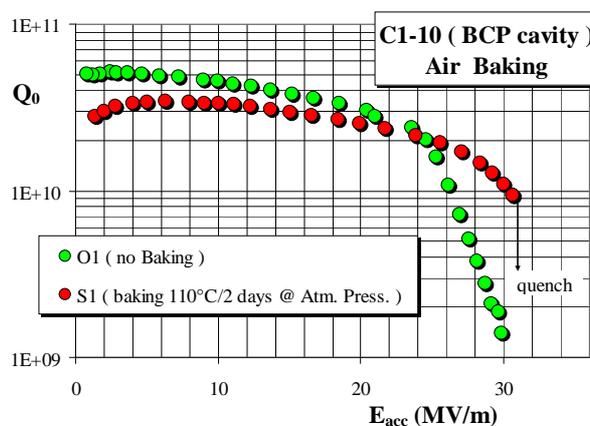


Figure 1: Baking effect (110°C for 2 days) on open-ended cavity at the room atmosphere [5].

A second step has been got over [6-7] with fast baking (3 hours at 145°C) leading to Q-drop improvement when cavity is under vacuum (red data on Fig.2) or filled with 1 atm. of argon gas (red data on Fig.3)

Nevertheless, in both cases, when cavity is open to room atmosphere, fast baking gives worsened performances (black data in Fig.2 & 3). Surface analyses by Secondary Ion Mass Spectroscopy (SIMS) achieved on Nb samples [8] explain this degradation by the diffusion of interstitial oxygen in bulk niobium (black line in Fig.4). On the contrary, no noticeable diffusion of interstitial oxygen is observed after fast baking in oxygen free atmosphere (vacuum or argon)

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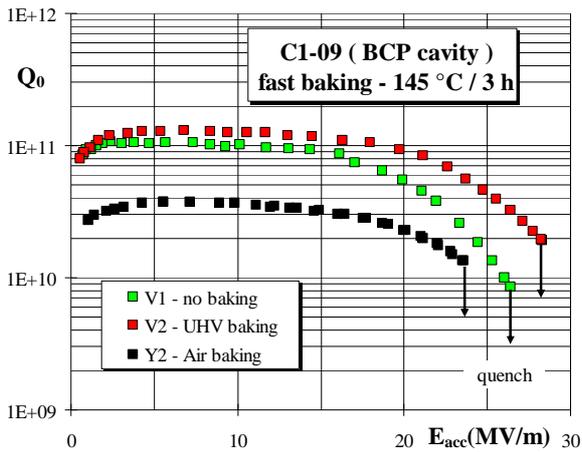


Figure 2: Baking effect (145°C for 3 hours) after BCP on cavity under vacuum (red data) and open to the room atmosphere (black data) [6].

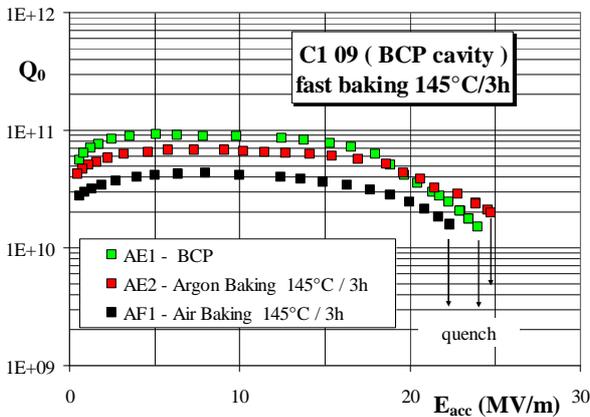


Figure 3: Baking effect (145°C for 3 hours) after BCP on cavity filled with argon (red data) and open to the room atmosphere (black data) [7].

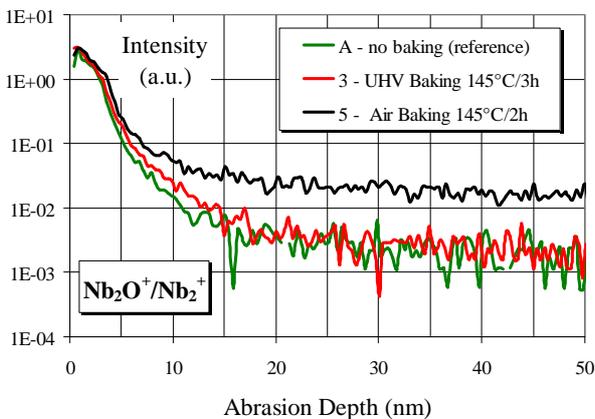


Figure 4: Interstitial oxygen profiles by SIMS analyses on niobium samples before and after fast baking (under vacuum and air atmosphere) [8].

FAST BAKING ON ELECTROPOLISHED CAVITIES

After the first “fast-baking” tests on BCP cavities, the process has been performed on EP cavities where the observation of Q-drop improvement is in general more impressive. Comparison between “fast” and “standard” bakings is made using 1DE14 and 1DE16 twin cavities. Both cavities were built in DESY house with fine grain Heraeus-Plansee niobium sheets (RRR 300) and annealed at 800°C to prevent Q-disease. All RF tests were performed at DESY.

To perform this experiment, 1DE14 cavity is sealed with flanges, evacuated by a turbomolecular pump and filled with argon gas (N50 - 1 atm.). Two infrared heaters are used to perform a very fast temperature rise time (~ 3 mn) up to 145 °C and an accurate temperature regulation (~ 1 °C) over 3 hours by a remote thermal IR sensor (Fig.5). RF tests at 1.8 K are shown in Fig.6. After baking, Q-drop is removed and performances are limited by quench at 36 MV/m with field emission.

Comparison with the standard UHV baking achieved on 1DE16 twin cavity is shown in Fig.7. Results are equivalents; the difference at high gradients is due to the field emission on 1DE14.



Figure 5: Fast Baking set-up in Saclay clean room

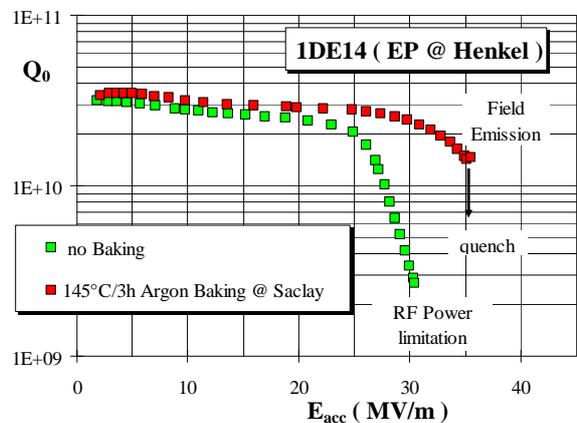


Figure 6: Fast Baking (145°C / 3 hours) on EP cavity filled with of Argon gas (1 atm.).

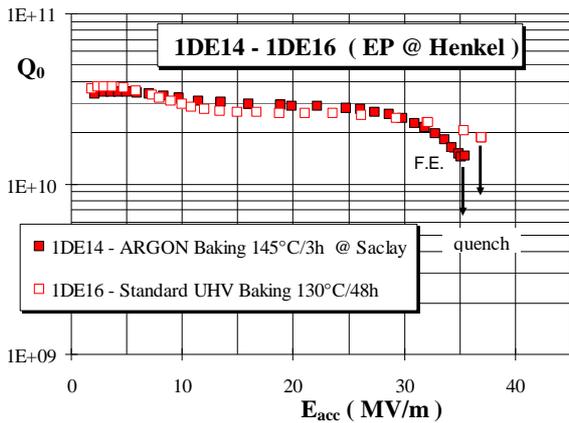


Figure 7: Comparison between “Standard UHV” and “Fast Argon” Baking.

“ONE-HOUR” BAKING

According to the experimental observations on fine grain cavities “temperature / duration” parameters seem to be correlated. SIMS analyses on Nb samples show that oxygen diffusion is a physical process to be avoided: it is harmful to reach good RF performances. So optimized values for an efficient baking (120 °C / 48 h; 145 °C / 3 h) have to be considered as the upper limits before an effective interstitial oxygen diffusion in the RF layer.

To verify such a claim we decided to bake the electropolished C103 cavity at 160°C during only one hour. According to the theoretical simulation described in [6], the couple of parameters 160 °C / 1 hour is equivalent in term of oxygen diffusion to 120°C / 48 h and 145°C / 3 h. Red square data in Fig.8 show an improvement after baking but without comparison to standard baking (white data). Additional baking for half an hour at 160°C (red round data) does not improve the results more.

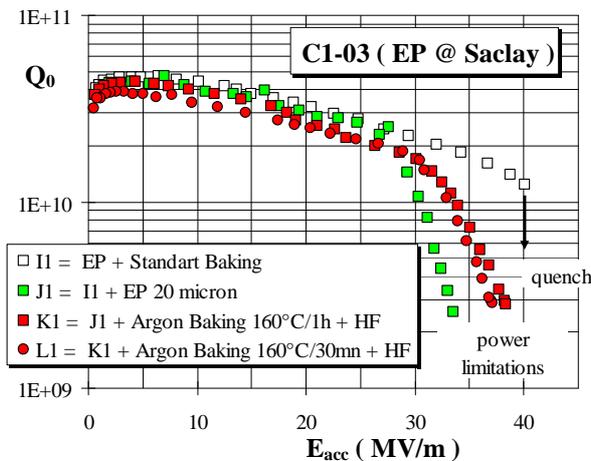


Figure 8: Baking effect at 160°C for 1 hour on EP cavity filled with argon (red data); comparison with standard UHV baking (white data).

This limited effect of baking could be explained by the fact that at such a high temperature, dissociation of suboxides begins with an undesired increase of oxygen amount under the Nb surface.

Moreover, during this experiment at 160°C, we observed an unusual and important field emission. Hydrofluoric rinsing was then necessary to suppress field emitters and to get red curves in Fig.8. This increase of field emitters could be linked to the observation reported in [9] where more emitter sites are revealed at the grain boundaries after baking (150°C for 14 hours) of a large grain Nb sample. Other possibility to explain such a drawback can be held with a surface pollution by particles during the cavity filling with argon. Due to an inadequate filtering, particles could be efficiently stuck to the surface after baking at 160°C, resisting to the high pressure rinsing.

SET-UP IMPROVEMENT

A more efficient gas filtering will be installed to prevent a possible contamination of inner cavity wall during argon filling,

A new baking box (Fig.9) equipped with 6 vertical IR heaters is quite ready to be tested. That will allow to perform a real oxygen-free baking on an open-ended cavity. Oxygen diffusion through external wall will be avoided, preserving both RRR and thermal conductivity of niobium.



Figure 9: New apparatus for fast baking in oxygen-free atmosphere on open-ended cavity.

CONCLUSION

We have demonstrated the equivalence, in terms of high gradient performances, between the “Standard Baking” (120°C for 48 h in vacuum) and a faster process (145°C for 3 hours in oxygen-free atmosphere). We will try to adapt this alternative process to bake XFEL cavities and to demonstrate its usefulness for ILC project.

Efficient baking at 160°C seems not easy to carry out, a too high temperature probably leads to a side-effect. Nevertheless, in our quest to understand the baking phenomenon and to verify if “temperature / duration” parameters are really correlated, we plan to explore the efficiency of fast baking at 145°C for 1 and 2 hours.

Experiments will be performed on fine grain, large grain, and single crystal cavities. Correlations with SIMS analyses on samples will be considered too.

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