High Field Q-Slope & Oxygen Diffusion
High Field

Q-slope

Baking → O Diffusion
**Baking** ≡ **Recipe for high gradients**

**in-situ (UHV)**  \( T = 110 - 120\, ^\circ\text{C} \)  \( t = 1 - 2 \) days

**TTF 1.3 GHz - Saclay / KEK**
- Polycrystalline
- No Thermal Treatment
- Electropolishing

**LL 2.2 GHz - JLab**
- Single crystal
- 800°C - 1250°C / Ti
- Chemical Etching 1:1:1

**Whatever the niobium structure...** (Single or Poly-crystal,)
**Whatever the fabrication method...** (EB Welding or Hydroforming, bulk Nb or clad Nb/Cu)
**Whatever the thermal treatment...** (nothing, 800°C, 1300°C/Ti)
**Whatever the chemical treatment...** (Electropolishing or BCP)
**Baking => O Diffusion**

Nb superconductivity is modified
surface resistance $R_s$ is trough $R_{BCS}(\ell)$ & $R_{res}$

$$R_s = R_{res} + A(\lambda_L, \xi_F, \ell) \frac{\omega^2}{T} e^{-\Delta/kT}$$

High Field Q-slope improvement : O diffusion is it involved too ?

110 °C
60 hours
in-situ
(UHV)

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**Figure:**

- **Graph 1:**
  - $R_s$ vs. $1/T$ for C1-05 (BCP cavity)
  - RS vs. 1/T
  - Data points for no baking and 110°C - 48h

- **Graph 2:**
  - $Q_0$ vs. $E_{acc}$ for C1-05 (BCP cavity)
  - Data points for different conditions:
    - no baking
    - 110°C - 48h
    - 4.2 K (no baking)
    - 4.2 K (110°C)
  - Quench
**Baking Parameters** $(T, t)$

with **Unchanged Oxygen Penetration**

$2^{nd}$ Fick's law

\[
\frac{\partial C}{\partial t} = D_0 e^{E_A/RT} \frac{\partial^2 C}{\partial x^2}
\]

\[\rightarrow \text{analytic solutions}\]

110 °C / 60 hours

145 °C / 3 hours

High Field Q-Slope?

thin oxide layer: $C(x,0) = Q \delta(x)$

semi infinite solid: $C(0,t) = C_S$
« Fast » Baking ( UHV )

- Infra-Red emitters (short T rise time)
- Cavity pumped out ( Ultra High Vacuum )

Similarities with Standard Baking
O diffusion → HF Q-slope improvement

145 °C - 3 hours
« UHV » → « Air - Baking »

Atmosphere - Nb Surface Interaction

Cavity open-ended in Stove
( room atmosphere - atmospheric pressure )

110 °C
60 hours
+ HPR

no significant modification due to the atmosphere, but...
**Fast Air-Baking**

**145°C / 3 hours + HPR**

**Bad Results after baking (R_s, quench)**

Active interaction between atmosphere and Nb surface (≠ Fast UHV-Baking)

**Oven Wet Cavity from HPR**

**IR heaters**

**Dry Cavity**

CR hygrometry 60%

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Similarities with standard in-situ baking (UHV) 
150 °C / 60h

Fast Air-Baking @ 145°C / 3h

O concentration in excess

going from surface
due to wet atmosphere H₂O

3 hours is too long

XPS analysis on Nb Samples:
- to confirm this hypothesis
- to fix the right time for fast air-baking @145°C
From H$_2$O on surface

<table>
<thead>
<tr>
<th></th>
<th>110 °C 3 h</th>
<th>110 °C 60 h</th>
<th>145 °C 3 h</th>
<th>145 °C 60 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>UHV</td>
<td>=</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Air</td>
<td>+</td>
<td>-</td>
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</tbody>
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O % from NbO$_x$, NbO$_5$
optimum value for O concentration is needed in the Nb RF layer to suppress the HF Q-Slope...

High Field Q-slope

Baking ➔ O Diffusion

Nb doping by O

A key to understand the High Field Q-slope Origin ...

But not only ...
Practical Consequence:

Fast Baking well adapted to Cavity Mass Production

- Clean Room (Class 100)
- Test Stand (Vertical Cryostat)

- High Pressure Rinse - 85 bars (FE)
- Air-Drying: RT - 3 hours
- Assembly + Helium Test
- «in-situ» Baking: 110 °C - 2 days
- RF Test

- Save time:
  - Decrease Baking Duration
  - Risk of helium leaks (∝ T)
  - Baking before Assembly

- Save step:
  - Drying with Baking
Combination of Air-Drying and Baking

- Clean Room (Class 100)
  - High Pressure Rinse - 85 bars (FE)
  - Hot Air-Drying: 145°C, t < 3 hours
  - Assembly + Helium Test

RF Test

Fast Air-Baking on Wet cavity under Laminar Flow (FE)

OK, t < 3 hours

turbulences
Thank you for your attention ...