“ Pushing the Limits of RF Superconductivity ”

Workshop ~ Argonne National Laboratory ~ 22-24 September 2004

LOW, MEDIUM AND HIGH FIELD Q-SLOPES CHANGE WITH SURFACE TREATMENTS

Bernard VISENTIN

OUTLINE

Baking on Low, Medium and High Field Q-Slopes

HF Chemistry on Low and High Field Q-Slopes

Diffusion (C_S , T, t) at High Field Q-Slope

Integrated System for Cavity Baking

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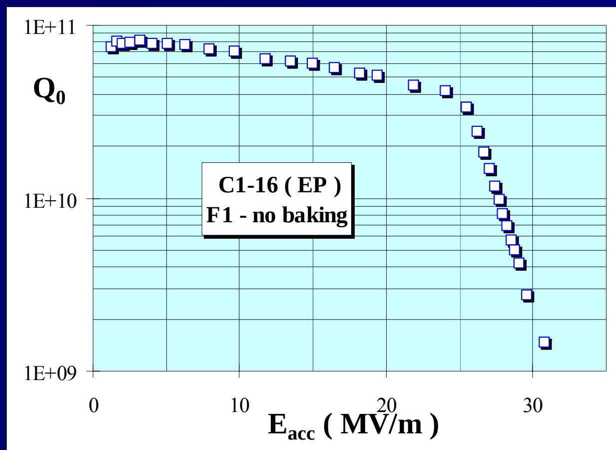
INTRODUCTION

Improve the cavity performances (higher Q, higher field, quench)

Understand the $Q_0(E_{acc})$ curve



Experiment on Nb cavities

Theory

Analysis on Nb samples

Experiments on Nb cavities → Frame for existing theories

Experiments on Nb cavities → Suggestion for new theories

Argument mainly based on Saclay experiments

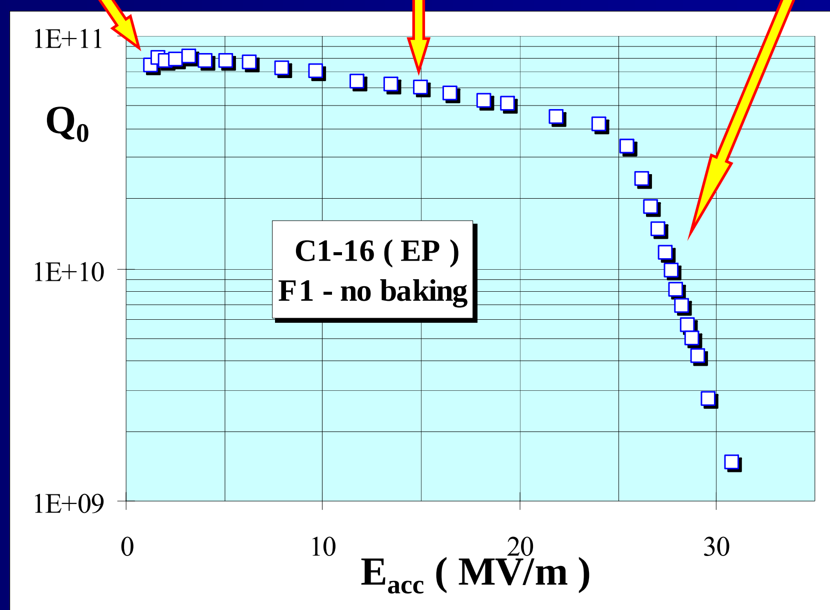
already published Reference [n] *new results* New

Q - SLOPES

Quality Factor (Q_0) versus Accelerator Field (E_{acc})

→ **Three Slopes**

Low	Medium	High



Theories

NbO_X Clusters	Surface Heating - $R_S(T)$	I.T.E , M.F.E. etc…

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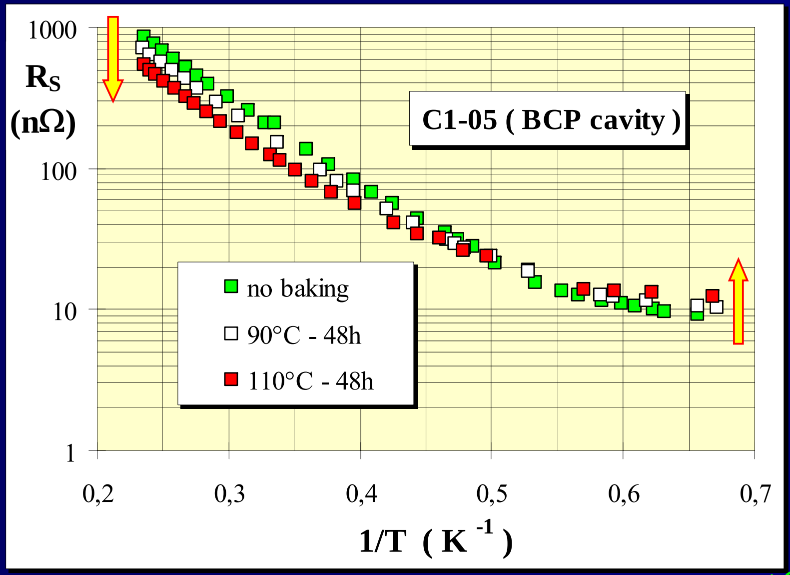
BAKING AT LOW TEMPERATURE

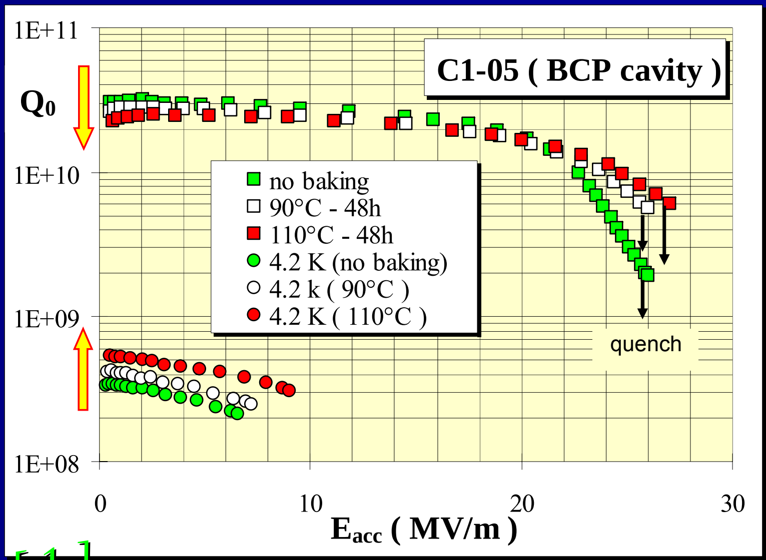
Brief Description ~ Some Features to Keep in Mind

1. Soft Heat Treatment (110 / 120 °C – 50 / 60 hours)

2. First discovered on cavity with standard chemistry (BCP)

(50 % R_{BCS} decrease – slight R_{res} increase)





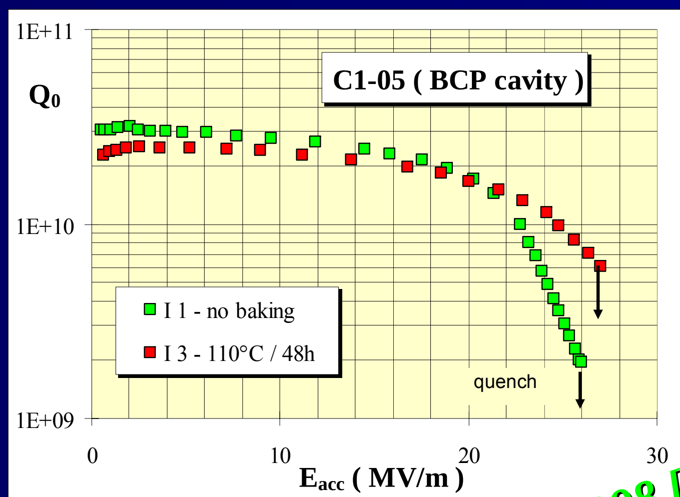
EPAC 1998 [1]

The phenomenon exists also on electropolished (EP) cavities

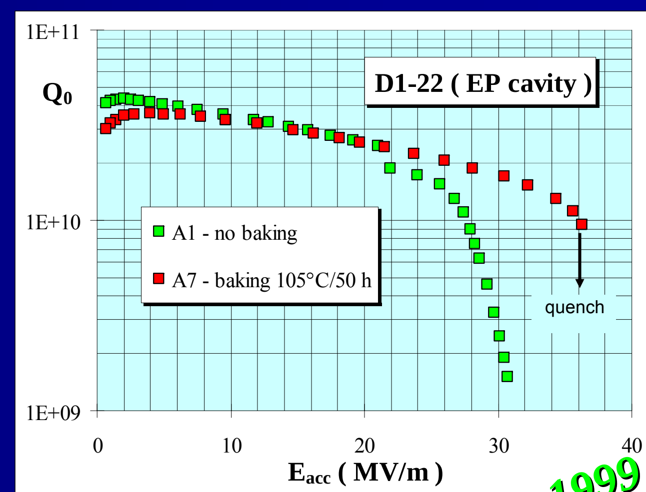
BAKING AND Q-SLOPES

Baking has an effect on the three Q-slopes (BCP and EP cavities):

** enhancement at low field*
** slight flattening at medium field*
** strong improvement at high field*



EPAC 1998 [1]



SRF Workshop 1999 [2]

Without Baking : Electropolished Cavity Can Not Reach 40 MV/m

Q-SLOPE AT LOW FIELD

SRF Workshop 2001 [3]
(J. Halbritter)

~~*Theory : NbO_x Clusters in Niobium*~~ Q-Slope

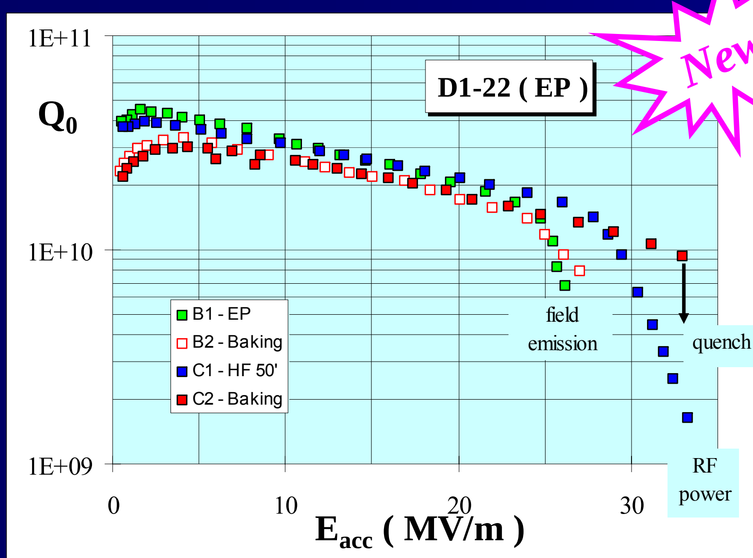
~~*Baking : Additional Clusters (O Diffusion)*~~ Q-Slope enhancement

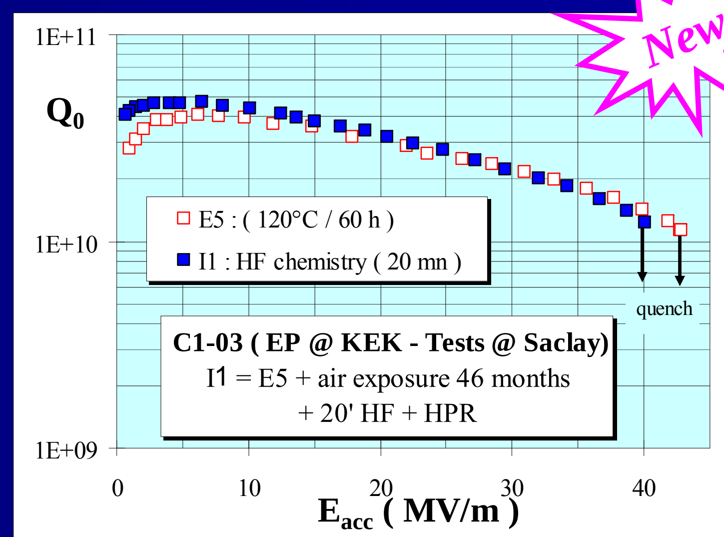
Other Surface Treatment : HF Chemistry (10%) **Initial Q-Slope is restored**

$$Nb_2O_5 + 10\ HF \rightarrow 2\ H_2NbOF_5 + 3\ H_2O$$

→ if we consider clusters in Nb are removed : **why a residual slope ?**

→ if we consider clusters are not removed : **not consistent with 2nd hypoth.**





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Q-SLOPE AT HIGH FIELD

SRF Workshop 2001 [3]
(J. Halbritter)

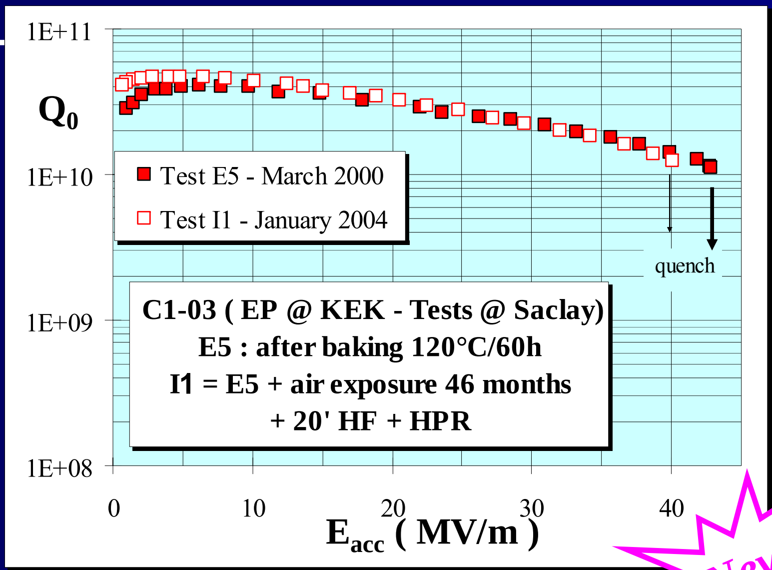
Theory (1): Tunnel exchange @ Nb-Nb_2O_5 interface — Q-Slope

Baking : ~~Nb_2O_5 (localized states) reduction~~ — Q-Slope improvement

Surface Treatment by **HF** during 20' (**last baking : 4 years ago**)

Nb_2O_5 removed ~ Growing of a new pentoxide layer

high field Q-Slope is unaltered → Q-slope improvement not linked to Nb_2O_5 reduction



New

HF chemistry preserves the baking benefit at high field (F.E.)

Additional comment

Life expectancy of the baking effect : (4 years) cavity open on shelves

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Q-SLOPE AT HIGH FIELD (cont.)

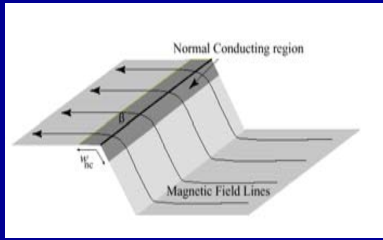
for "Magnetic Field Enhancement" theory (2)

correlations exist between:

* ~~Q-Slope origin and surface roughness ($\beta_m H$)~~

* Q-Slope improvement (after baking) and H_C increase

SRF Workshop' 99 [4]
(J. Knobloch)



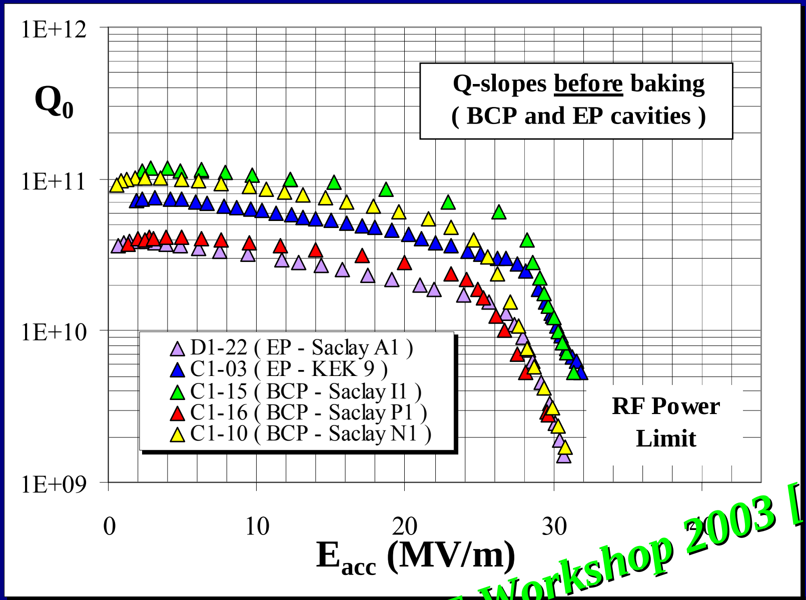
but (before baking)

Q-Slopes of EP and BCP cavities are similar

in spite of different

surface roughness ($\neq \beta_m$)

SRF Workshop 2003 [5]



SRF Workshop 2003 [6]

Theory still valid to give explanation related to the quench origin

DIFFUSION PROCESS

Baking treatment : R_{BCS} (ℓ) decreases

decrease linked to baking time

→ *diffusion*

SRF Workshop 1999 [7] (P. Kneisel)

The Element ? Oxygen is good candidate

- Nb_2O_5 , NbO , sub-oxides , O interstitials at the interface with Nb
- diffusion at low temperature (Palmer's Thesis 1988) and more recently on sample analysis by XPS
- diffusion depth @ 120°C / 60 h compatible with RF layer (50 nm, 2K)

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DIFFUSION PROCESS (cont.)

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2}$$

Diffusion Equation (Fick's 2nd law)

$$D = D_0 \, e^{-E_a/RT}$$

Diffusion Coefficient (Arrhenius equation)

Where : C(x,t) is the concentration,

E_a the activation energy,

R the universal gas constant,

T the temperature.

Analytic solution in few cases, specially for a semi-infinite solid :

with the initial condition (bulk) $C(x,0)=C_0$

and the boundary condition (surface) $C(0,t)=C_S$

$$\frac{C - C_S}{C_0 - C_S} = erf \frac{x}{2\sqrt{Dt}}$$

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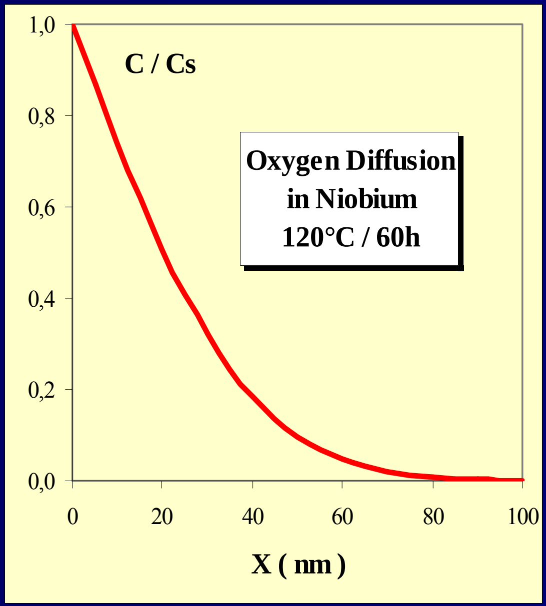
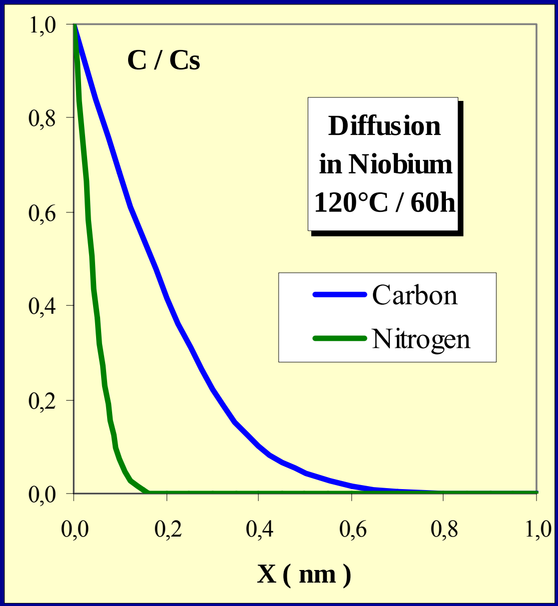
DIFFUSION PROCESS (cont.)



if $C_0=0$

$$\frac{C}{C_S} = erfc\frac{x}{2\sqrt{Dt}}$$



We can assume an oxygen diffusion during baking

One fundamental question about diffusion:

Is just a **consequence** of the thermal process

or the **real origin** of Q-Slope improvement ?

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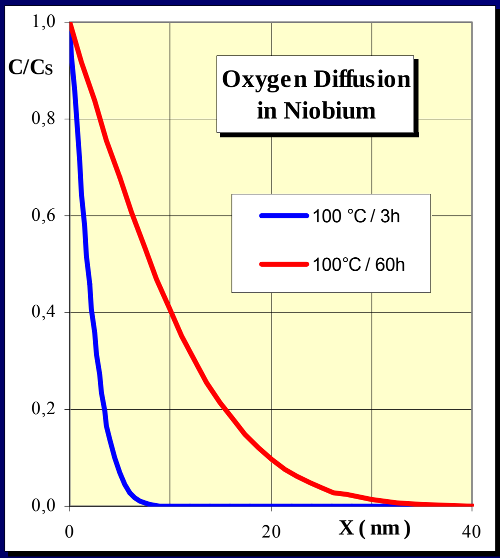
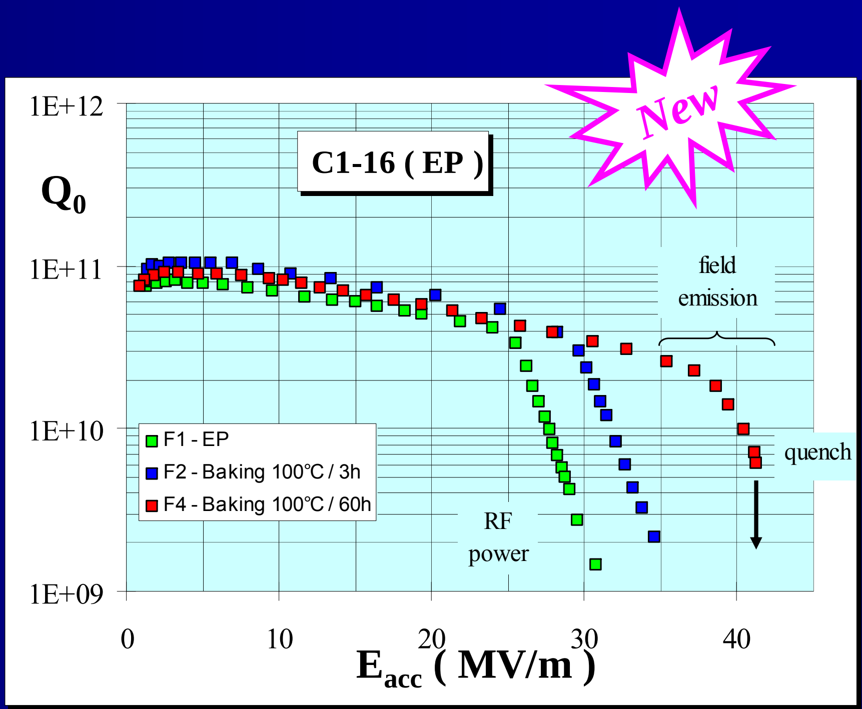
DIFFUSION AND Q-SLOPE

First Element :

E_{acc} onset for Q-Slope is linked to the diffusion parameters

$$\left.\begin{aligned} C &= C_S \; erfc \frac{x}{2\sqrt{Dt}} \\ D &= D_0 \; e^{-E_a / RT} \end{aligned}\right\} \quad (C_S \, , T \, , t \,)$$





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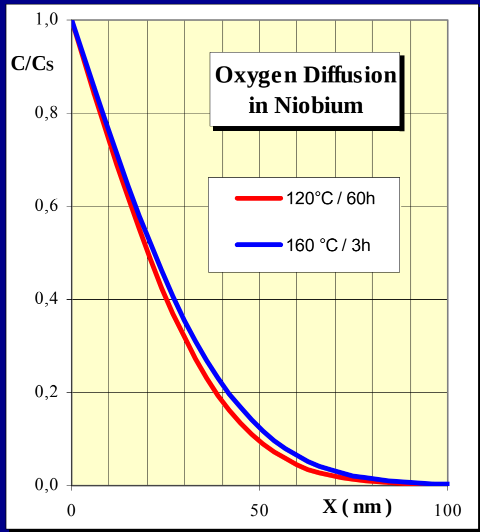
DIFFUSION AND Q-SLOPE (cont.)

Other Elements :

Change diffusion parameters

time ↓ 60 → 3 hours

T ↑ { 110 → 145 °C
120 → 160 °C

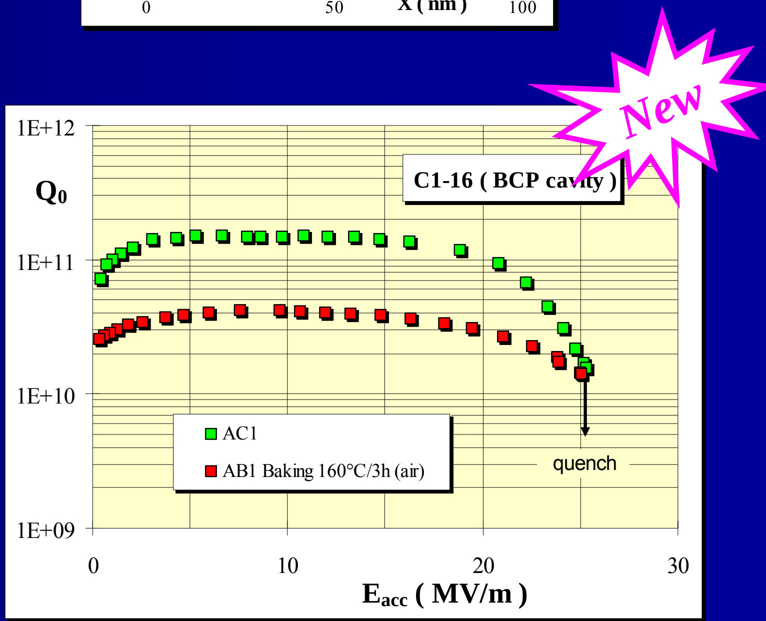


Baking (atmospheric air)

Q-Slope change

but 160 °C / 3 h is too much

Adjustment : 145 °C / 3h



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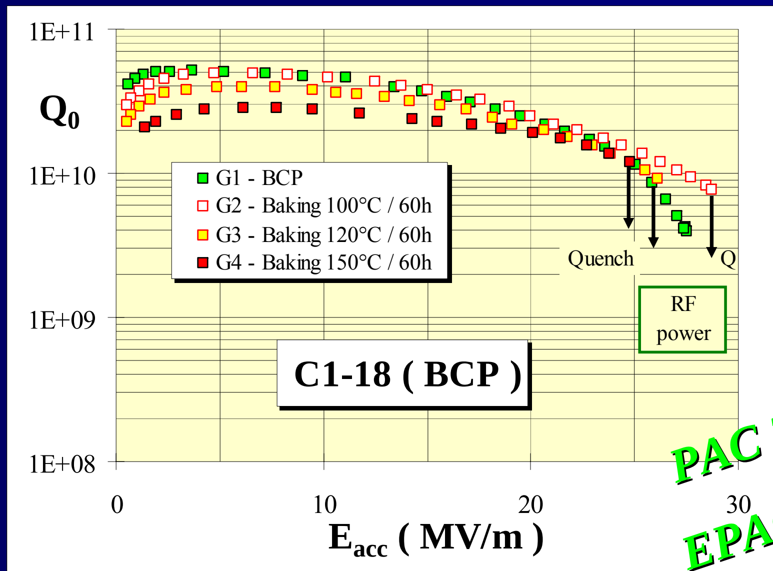
DIFFUSION AND Q-SLOPE (cont.)



PAC 2001 [8]
EPAC 2002 [9]

Cumulative UHV Bakings

(110 → 120 → 150 °C/60 h)

Degradation (Q_0 , quench)

T > 110 °C / 60 h

Strong Correlations between O Concentration and High Field Performances

Usual Baking (110°C / 60 h) : right parameter values (T, t , C_S(T))

moderate O concentration ↔ Nb “doping”

For higher values (T > 110 °C / 60 h) ↔ Nb “pollution”

INTEGRATED BAKING SYSTEM

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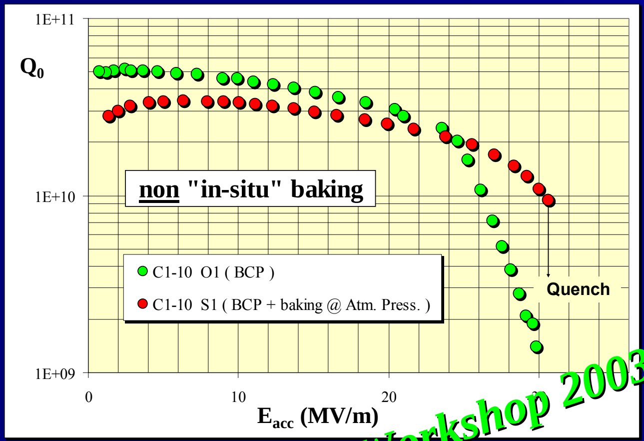
make easier baking process

Baking under
Atmospheric Air
(no under UHV)

+

Fast Baking
150°C / 3h

Baking with IR heaters
and remote thermal sensor
3 hours in Clean Room
(instead of usual air-drying)



SRF Workshop 2003 [6]

Short time – Higher temperature

No risks for He leak compare to the UHV baking

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dapnia sacm cea saclay

CONCLUSIONS

Pushing the Limits of RF Superconductivity

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1 - HF chemical treatment on baked cavities :

Clusters and I.T.E. theories are probably not involved
to explain the Low and High Field Q-slope modifications by baking.

2 - High field Q-slope and diffusion parameters :

Diffusion process as the explanation for the Q-slope improvement ?

3 – Integrated Baking to improve the process

Baking (air – 3 hours) during
the cavity preparation in clean room

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REFERENCES

J. Halbritter

[3] SRF'2001 Workshop – Tsukuba (J) – MA006

P. Kneisel

[7] SRF'1999 Workshop – Santa Fe (USA) – TUP044

J. Knobloch

[4] SRF'1999 Workshop – Santa Fe (USA) – TUA004

B. Visentin et al.

[1] EPAC'1998 – Stockholm (S) - TUP07B

[2] SRF'1999 Workshop – Santa Fe (USA) – TUP015

[8] PAC'2001 – Chicago (USA) – MPPH122

[9] EPAC'2002 – Paris (F) – THPDO013

[5] SRF'2003 Workshop – Travemünde (G) – TuO01

[6] SRF'2003 Workshop – Travemünde (G) – MoP19

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Q-SLOPE AT MEDIUM FIELD

Theory : Thermal dependence of R_S Q-Slope

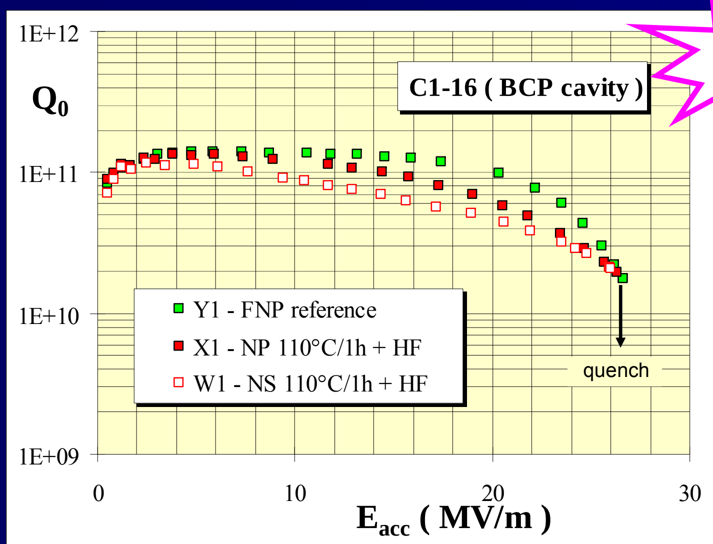
Surface Treatment by **NP** or **NS** Chemistry (1:10) @ **110°C / 1 hour** + **HF** (45')

Enhancement of the medium Q-slope

(not well analyzed at this moment : surface pollution)

Differences less marked between M and HF Q-Slopes

New



$$6\,Nb + 10\,HNO_3 \rightarrow 3\,Nb_2O_5 + 10\,NO + 5\,H_2O$$

$$Nb_2O_5 + 2\,H_3PO_4 \rightarrow Nb_2O_2(PO_4)_2 + 3\,H_2O$$

$$Nb_2O_5 + n\,H_2SO_4 \rightarrow Nb_2O_{5-n}(SO_4)_2 + n\,H_2O$$

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