THERMAL BOUNDARY RESISTANCE for SRF cavities

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My Talk consists in 20 questions to the Audience
For the work I am presenting

2 main ingredients needed
6 GHz
In a small, but active, Research Group

6 GHz Cavities

The Ideal Tool For Self-motivation:
Common sentences you can daily hear in the lab:

- «Bye, I go to spin some other 60 cavities!»

- «This week we have tested 12 cavities»

- We just did the EP, I go now to anneal the cavity, tonight we do the rf test

- Is Cavity #148 or cavity #134 that has the highest field?
Second Ingredient: 
a Great Team

- Mattia G.
- Martina M.
- Antonio Rossi
- Ruggero Vaglio
Question 1:

Suppose to have an ideal cavity
(a perfectly homogeneous monocrystal, no trapped flux,)

$$R_{RES} = 0 ?$$

(or will you have still a contribution due to a bad thermal exchange with the Helium bath?)
This quantity has a strong $T^n$ temperature dependence with $n$ varying between 2 and 4
\( R_s \) Nb 122 After ATM Annealing

\[ f(T) @ 2\text{MV/m} \]

FitRs1 (User) Fit of Sheet1 Rs

\( R_s [\Omega] \)

\( 1/T [\text{K}^{-1}] \)

<table>
<thead>
<tr>
<th>Model</th>
<th>FitRs1 (User)</th>
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<tbody>
<tr>
<td>Equation</td>
<td>( C + (x^A \exp(-B \cdot x)) / ((1 + \exp(-B \cdot x))^2) )</td>
</tr>
<tr>
<td>Reduced Chi-Sqr</td>
<td>3.55369E-13</td>
</tr>
<tr>
<td>Adj. R-Square</td>
<td>0.99425</td>
</tr>
</tbody>
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<th>Value</th>
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<tr>
<td>Rs A</td>
<td>0.00367</td>
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<tr>
<td>Rs B</td>
<td>14.47994</td>
</tr>
<tr>
<td>Rs C</td>
<td>1.22522E-6</td>
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</table>
EFFECT OF LOW TEMPERATURE BAKING ON NIOBIUM CAVITIES

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Department of Physics, SUNY Albany, Albany, NY 12222

Figure 15: Surface resistance vs. \(1/\text{temperature}\) before and after 120°C, 48h baking.
Effect of high temperature heat treatments on the quality factor of a large-grain superconducting radio-frequency niobium cavity


![Graph showing the temperature dependence of the quality factor](image)

FIG. 9. \( R_s \) vs \( 1/T \) measured after BCP and after HT at 1400°C. Solid lines are least-square fits with \( R_s(T) = R_{BCS}(T) + R_{res} \). The values of the fit parameters are \( \Delta/kT_c = 1.87 \pm 0.02, \ell = (303 \pm 85) \text{ nm}, \), \( R_{res} = (2.0 \pm 0.3) \text{ n}\Omega \) after BCP and \( \Delta/kT_c = 1.90 \pm 0.01, \ell = (76 \pm 17) \text{ nm}, \), \( R_{res} = (1.0 \pm 0.2) \text{ n}\Omega \) after HT at 1400°C.
$R_s$ Nb 122 After 3$^{rd}$ UHV Annealing

\[
\frac{1}{T} = \frac{1}{K} + \frac{1}{R_s} \\
R_s = \frac{C}{1+e^{-Bx}} + A
\]

- Reduced Chi-Sqr: 7.85399E-15
- Adj. R-Square: 0.99727

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<tr>
<td>A</td>
<td>0.00265</td>
<td>2.52241E-4</td>
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<tr>
<td>B</td>
<td>17.57752</td>
<td>0.36563</td>
</tr>
<tr>
<td>C</td>
<td>7.37002E-8</td>
<td>3.96425E-8</td>
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</table>
$R_s \text{ Nb 126 @ 2MV/m}$

**FitRs1 (User) Fit of Sheet1 Rs**

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<td>Equation</td>
<td>$C + (A \times \exp(-B \times 1) + 1 + \exp(-B \times Y^Z))$</td>
</tr>
<tr>
<td>Reduced Chi-Sqr</td>
<td>$1.14352E-1$ +</td>
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<tr>
<td>Adj. R-Square</td>
<td>$0.96679$</td>
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<th>Rs</th>
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<tbody>
<tr>
<td>A</td>
<td>$0.00000$</td>
<td>$3.15275E-4$</td>
</tr>
<tr>
<td>B</td>
<td>$19.7631$</td>
<td>$0.30078$</td>
</tr>
<tr>
<td>C</td>
<td>$1.86164E-7$</td>
<td>$3.29175E-8$</td>
</tr>
</tbody>
</table>
Question 2:
If we cooled the cavity in $^3$He instead then in $^4$He, should we wait a different $R_{RES}$?
Question 3:

Are we saying, in other words, that $R_{\text{RES}}$ depends on Liquid He instead than on Nb material?
$Q_o$ vs. $E_{acc}$ [MV/m] for different temperatures:
- $T = 4.2$ K (red curve)
- $T = 1.8$ K (blue curve)

- Constant field
- Constant power (120 mW)

The graph shows the behavior of $Q_o$ under varying $E_{acc}$ at two different temperatures.
Constant $E_{\text{acc}}$ means that both $T$ and $W$ are changing. Constant $W$ means that, apart $E_{\text{acc}}$ only $T$ is changing.
Rs vs 1/T (termometro Ge)

1/T [K⁻¹]

Rs [Ω]

25 mW
50 mW
75 mW
100 mW
125 mW
150 mW
175 mW
200 mW
400 mW
600 mW
1000 mW
Thermodinamically, shouldn’t we prefer the family of $R_s(T)$ at constant $W$ rather than the $R_s(T)$ at constant $E_{\text{acc}}$? Especially then if the curves are mixed.
Rs vs $1/T$ [P=100mW]

At $\lambda$-point:

$\Delta R_s = 1.3508 \cdot 10^{-7} \Omega$

$\Delta T = 0.039K$
Question 5:

Whenever we neglect the jump at $T_\lambda$, don’t we extract a false value of the strong coupling factor $S$?
\[ R_{BCS}(T_0) = \frac{A \omega^2}{T_0} \exp \left[ - \frac{sT_C}{2T_0} \right] \]

\[ R_{BCS}(T_0 + \Delta T) \approx \frac{A \omega^2}{T_0} \exp \left[ - \frac{sT_C}{2(T_0 + \Delta T)} \right] \]

\[ R_{BCS}(T_0 + \Delta T) \approx \frac{A \omega^2}{T_0} \exp \left[ - \frac{sT_C}{2T_0} \left( 1 - \frac{\Delta T}{T_0} \right) \right] \]

\[ s^{\text{meas}} = s \left( 1 - \frac{\Delta T}{T_0} \right) \]
Question 6:

Since $R = R_s(T)$ and $Q = Q(E_{acc})$, could we join the 2 curves into 1 graph?
Rs vs 1/T vs P (Cernox X63398)

Thermal sensor:
X63398

- @ 1.8K
- 25mW
- 50mW
- 75mW
- 100mW
- 125mW
- 150mW
- 175mW
- 200mW
Question 7:

Which strange dissipation mechanism makes the Q-factor decreasing linearly with \( W \), but at a certain point it becomes almost constant?
Question 8:

The critical power where the losses change slope do correspond to the He boiling nucleation?
Q-SLOPE ANALYSIS OF NIOBIUM SC RF CAVITIES

K. Saito #, KEK, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, Japan

Figure 20: Qo-Eacc excitation curve fitting by the combined model for the 1500MHz niobium film coated cavity at CERN.
Nb 122 After ATM Annealing

\( f(T) \)

\( 4,2K \)

\( 1,8K \)

\( E_{\text{Acc}} \) [MV/m]
EXPERIMENTAL COMPARISON AT KEK OF HIGH GRADIENT PERFORMANCE OF DIFFERENT SINGLE CELL SUPERCONDUCTING CAVITY DESIGNS

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\textsuperscript{a}KEK High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba 305-0801, Japan
\textsuperscript{b}DESY Deutsches Elektronen-Synchrotron, Notkestrasse 85, 22603 Hamburg, Germany

\textbf{Figure 5: The reproducibility of high gradient.}
Question 9:

Is it possible that He-II will have memory of the boiling nucleation of He-I?
QUESTION 10:

Can be the reason that 1.8 K is very close to $T_\lambda$, so at 1.8K $\rho_n$ is $\sim 34\%$?

\[ \rho = \rho_s + \rho_n \]

\[ \frac{\rho_n}{\rho} = \left( \frac{T}{T_\lambda} \right)^{5.6} \quad \text{for} \quad T \leq T_\lambda \]
Measured twice

1st RF Test:
- @4.2K
- @1.8K
- P=200mW

2nd RF Test:
- @4.2K
- @1.8K
- P=200mW
Termometro:
Cernox X62101

- $R_s$ Before anodization
- $R_s$ After anodization

$1/T$ [K$^{-1}$]
Before Anodization
After Anodization
After De-Anodization

$E_{\text{acc}}$ [MV/m]

$Q_0$

$T=1.8K$

- Before Anodization
- After Anodization
- After De-Anodization

Q-switch
Q-slope
quench
field emission
Question 11:

Why the anodization is responsible of the Q increase?

• because of the lower $\theta_D$ ?

• because of the boiling nucleation on the external surface ?

• because the oxide does not reflect thermal phonons ?

• because of both ?
Question 12:

If we **mirror finish** the cavity exterior surface, will this behave as a Mirror for thermal phonons?
La figura mostra la dipendenza della 
pressione di ritardo 
$\sigma_\phi$ 
rispetto alla 
pressione di accensione 
$E_{acc}$ 
per due diversi campioni:

- Senza EP esterno Nb129
- Con EP esterno Nb127

I dati sono presentingi per diverse temperature:
- @ 4.2 K
- @ 1.8 K

La curva per Nb129 è rappresentata da punti rossi, mentre quella per Nb127 è rappresentata da punti verdi.
Question 13:

A mirror-like external surface will decrease the nucleation sites for Helium boiling nucleation, promoting then the Liquid He Super-heating.
Question 14:

If liquid He Super-heating is detrimental for $Q(E_{acc})$, should we worry more about that type of superheating rather than to the Nb $H_{Sh}$?
Question 15:

If the hypothesis that the external surface of a cavity is important, is the 24 hours 120°C baking effective because it changes the external surface?
Question 16:

If the hypothesis that the external surface of a cavity is important, are the High Q factors got by Anna at FERMILAB due to a change of it?
Question 17:

Since the $\theta_D$ of the Cu is higher than the one of Nb and in Kapitza it plays as $\left(\frac{T}{\theta_D}\right)^3$, does this contribute to the fact that, at 1.8K, sputtered Nb shows lower performances?
Outer Lead coating of a sputtered Nb/Cu
Lead however did not remain attached to CU
Question 18:

Can water micro-cristallites on the external surface of Nb promote film boiling and then positively affect cavity performances?
Question 19:

For years we have considered a cavity as an adiabatic system made by the RF fields + Nb, because the He bath has been considered as a stable and infinite reservoir at fixed temperature.

Is it not the time now to consider instead the adiabatic system composed by RF fields + Nb + Liquid Helium?
RS Nb 122 After ATM Annealing

\[ f(T) @ 2\text{MV/m} \]

Fit Rs1 (User) Fit of Sheet1 Rs

\[ \frac{1}{T} \text{[K}^{-1}] \]

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Question 20:

THE END

(But is it really the end? Or just the beginning?)