Recent Q-Slope and Related Surface Studies at Cornell

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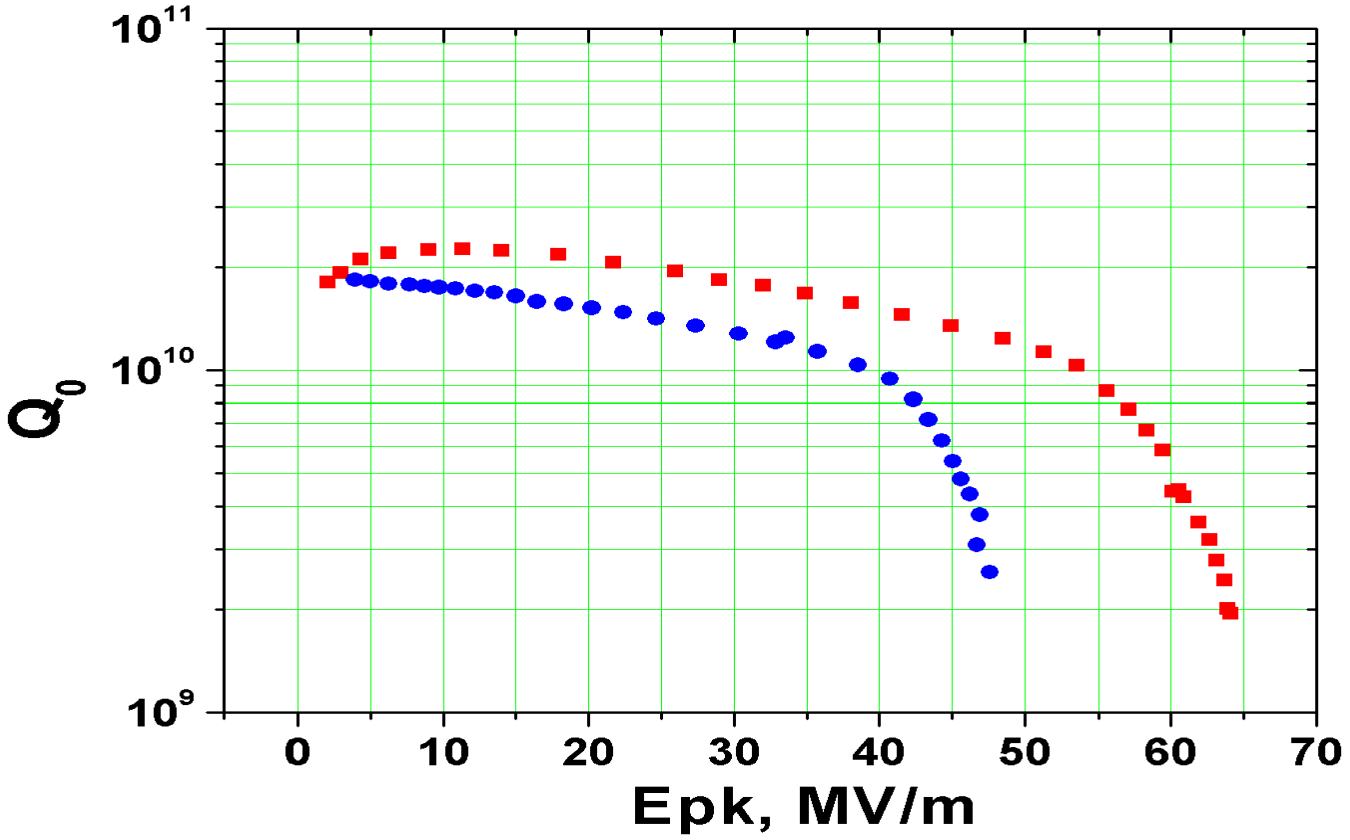
Outline

- Continue thermometry studies of Q-slope which show sudden onset of losses.
- Use anodization as a depth profile tool to determine the depth to which 100 C, 48 hour baking benefit extends
- Study effect of higher baking temperatures on Q-slope
- Using SIMS, look for oxygen related signal in the rf layer
- Re-visit the roughness model for Q-slope

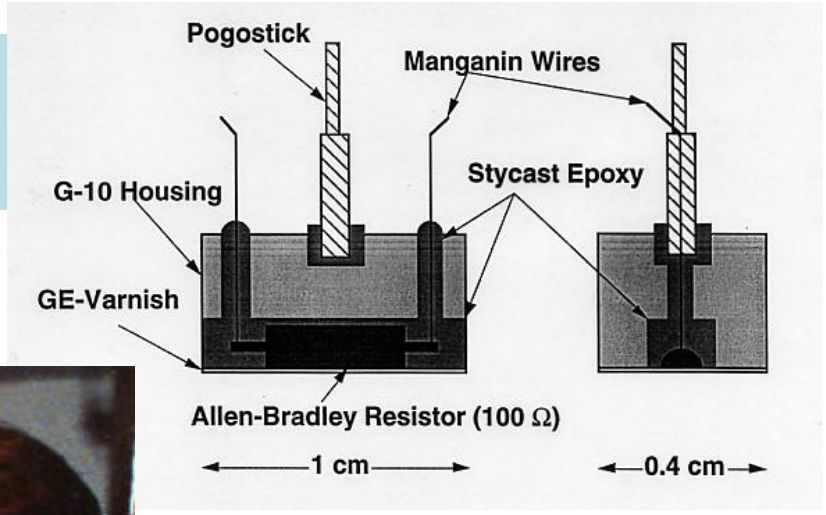
Q-Slope Improvement with 100 C bake on a BCP Cavity

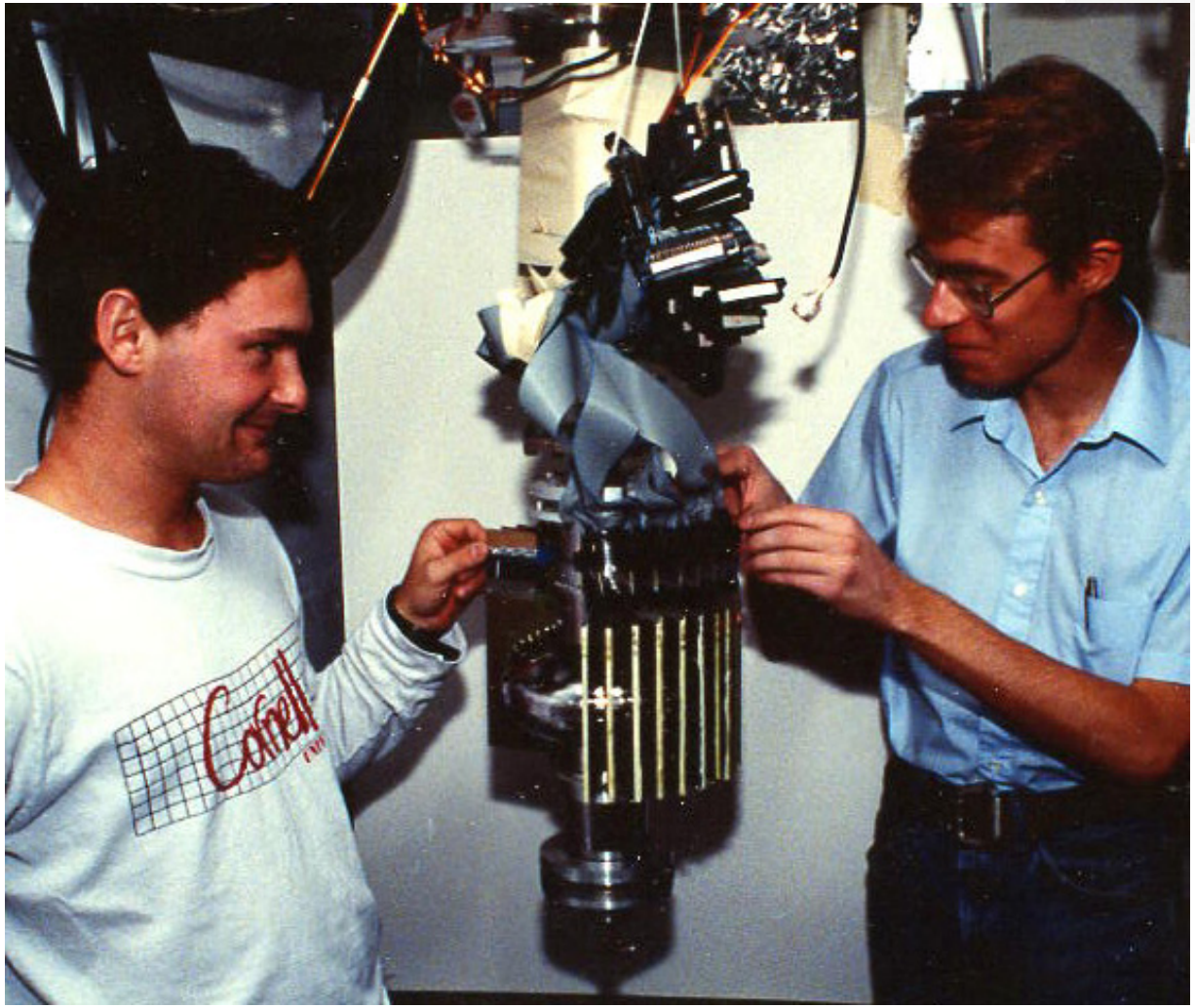
Russian Nb - 500 RRR, no HT, “smoother”

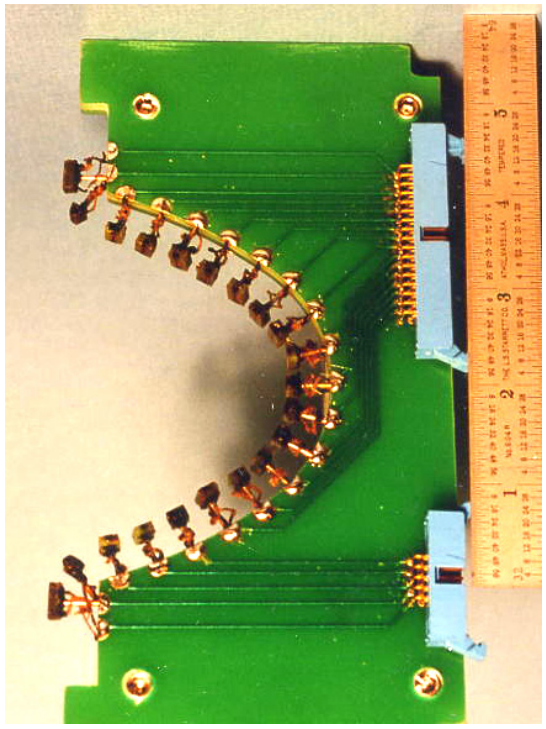


Blue circles – fresh BCP
Red squares – after additional 100 C baking

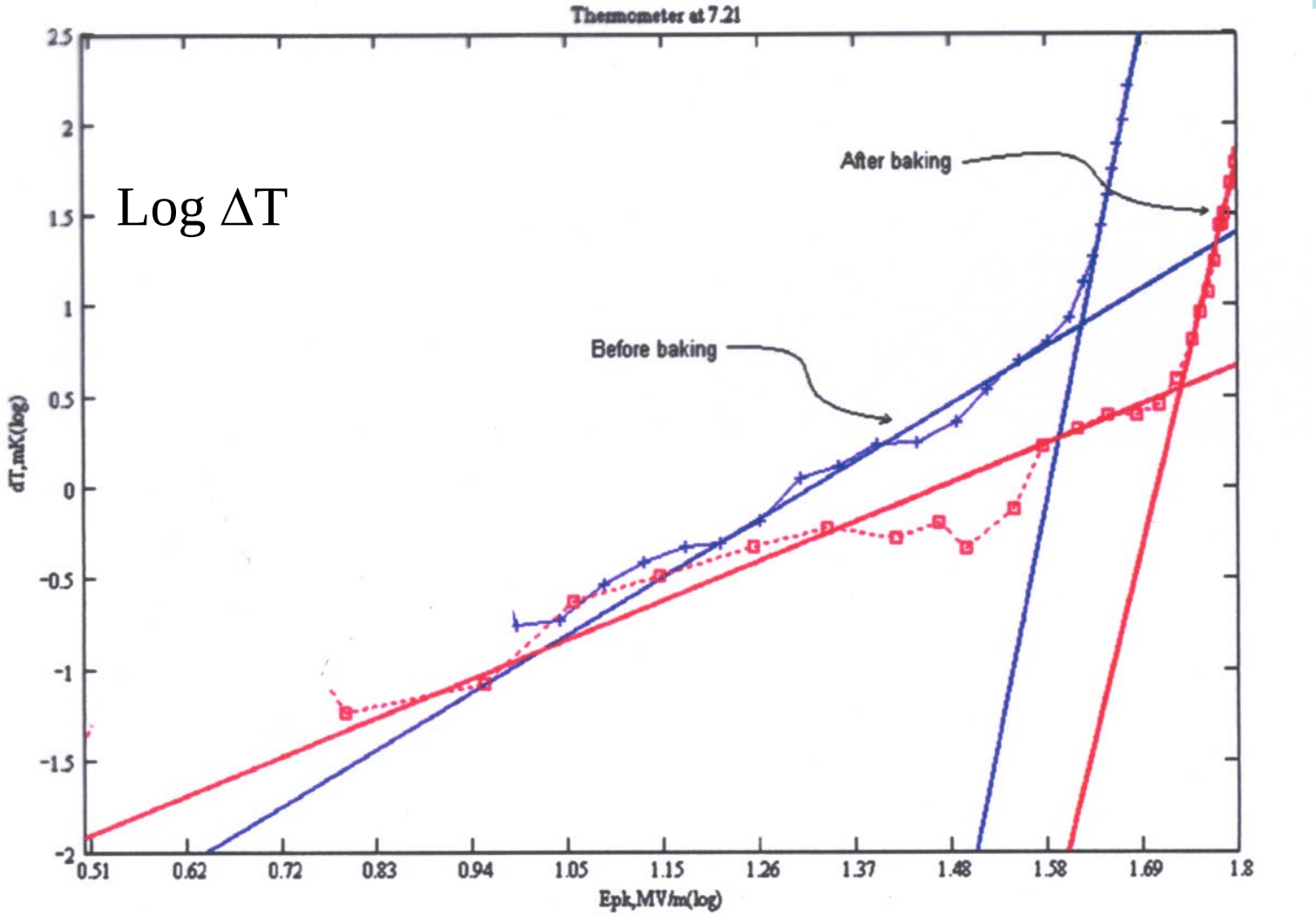
Study Q-Slope Using Thermometry







Sharp Temperature Rise Suggestive of Phase Transition
Baking Raises Transition Field



Log (Epk)

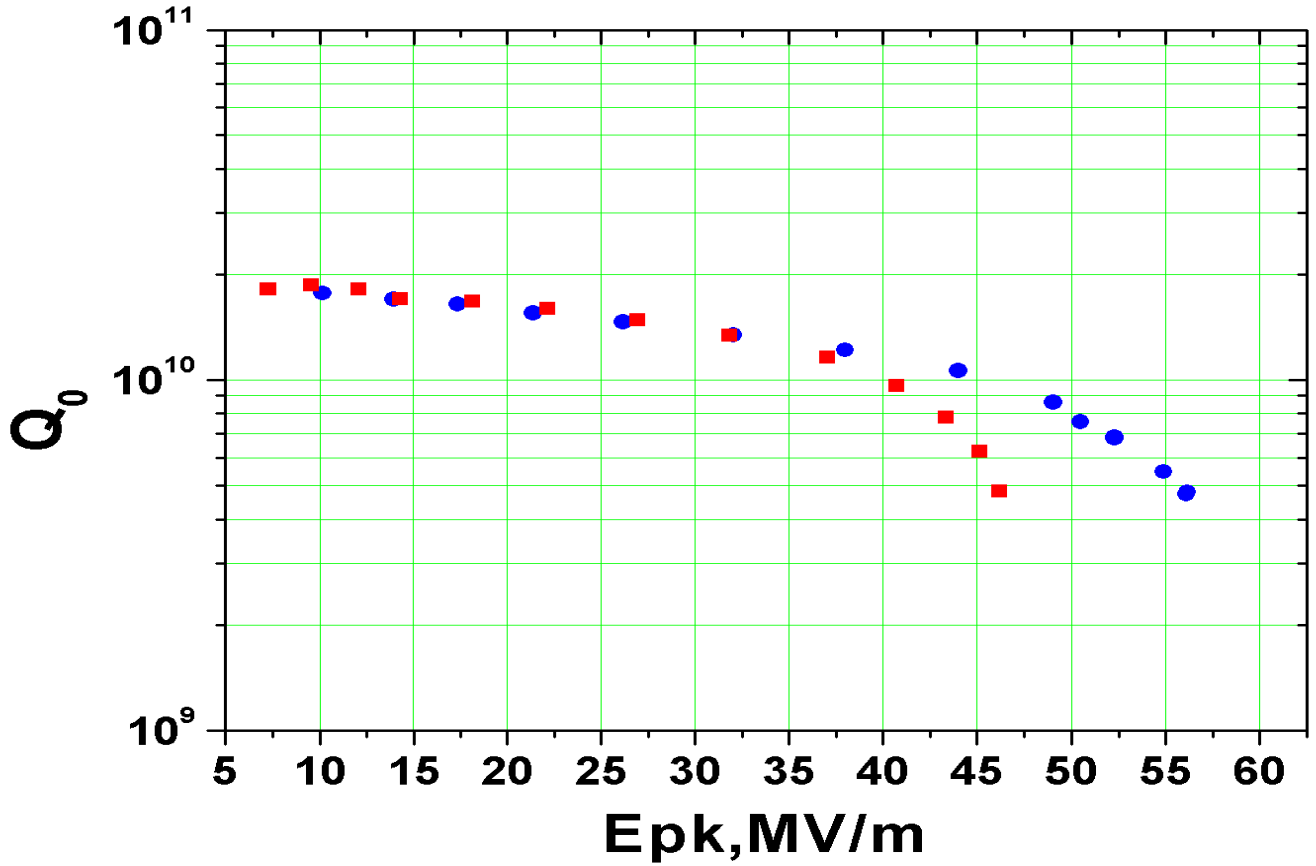
How deep is the baking benefit? Greater or smaller than penetration depth (50nm)?

Change Nb -> Nb_2O_5 gradually, by anodizing in small steps

Find out at what anodization depth the Q-slope comes back

BCP, gives Q-slope (red curve)

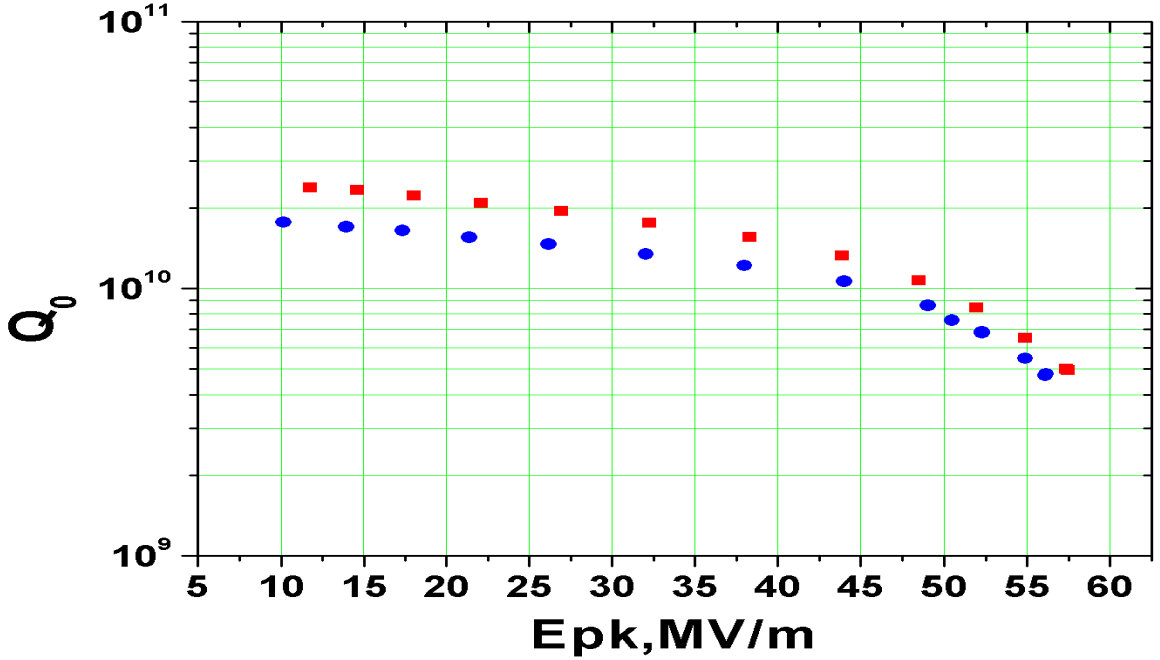
Q-slope improved by baking to 100 C, 48 hours (blue curve)



No degradation in Q-slope by anodizing to 5 V (10 nm)

2 x thicker than natural oxide (5 nm)

Conclusion: oxide layer is not responsible for high Q-slope



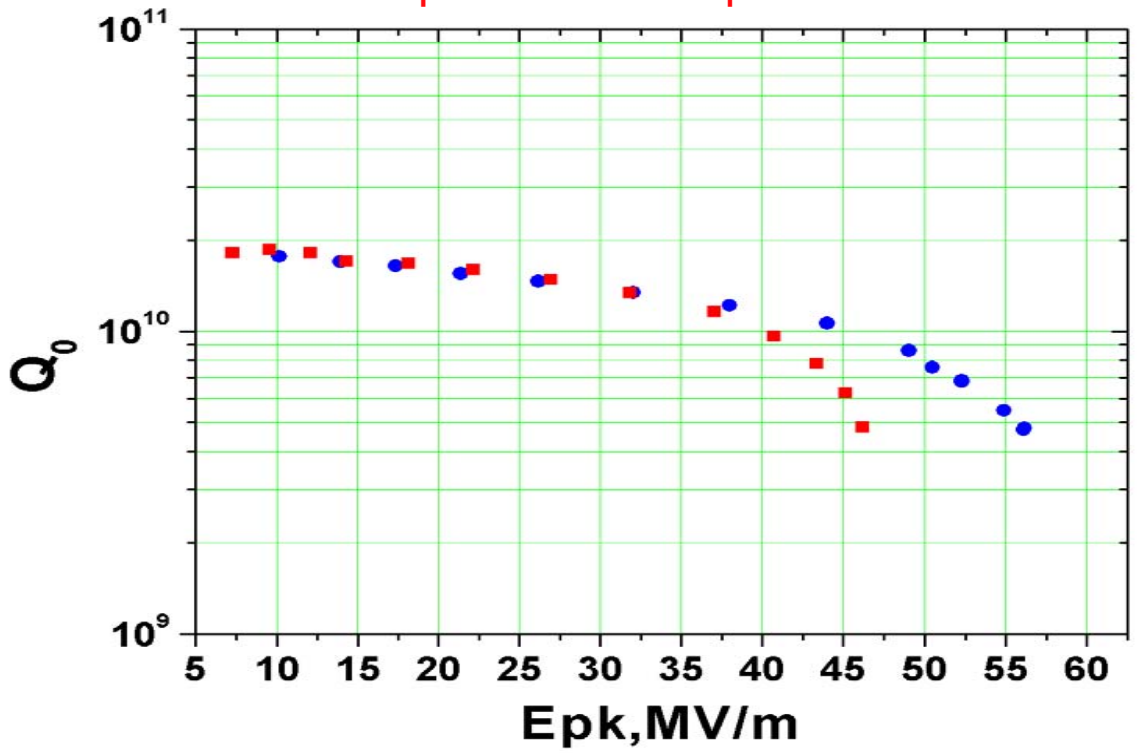
Red squares – after additional 5 V anodizing
Blue circles – BCP + 100 C baking

Discovery: Original BCP Q-slope returns after 30 V anodizing

Oxide layer created = 60 nm

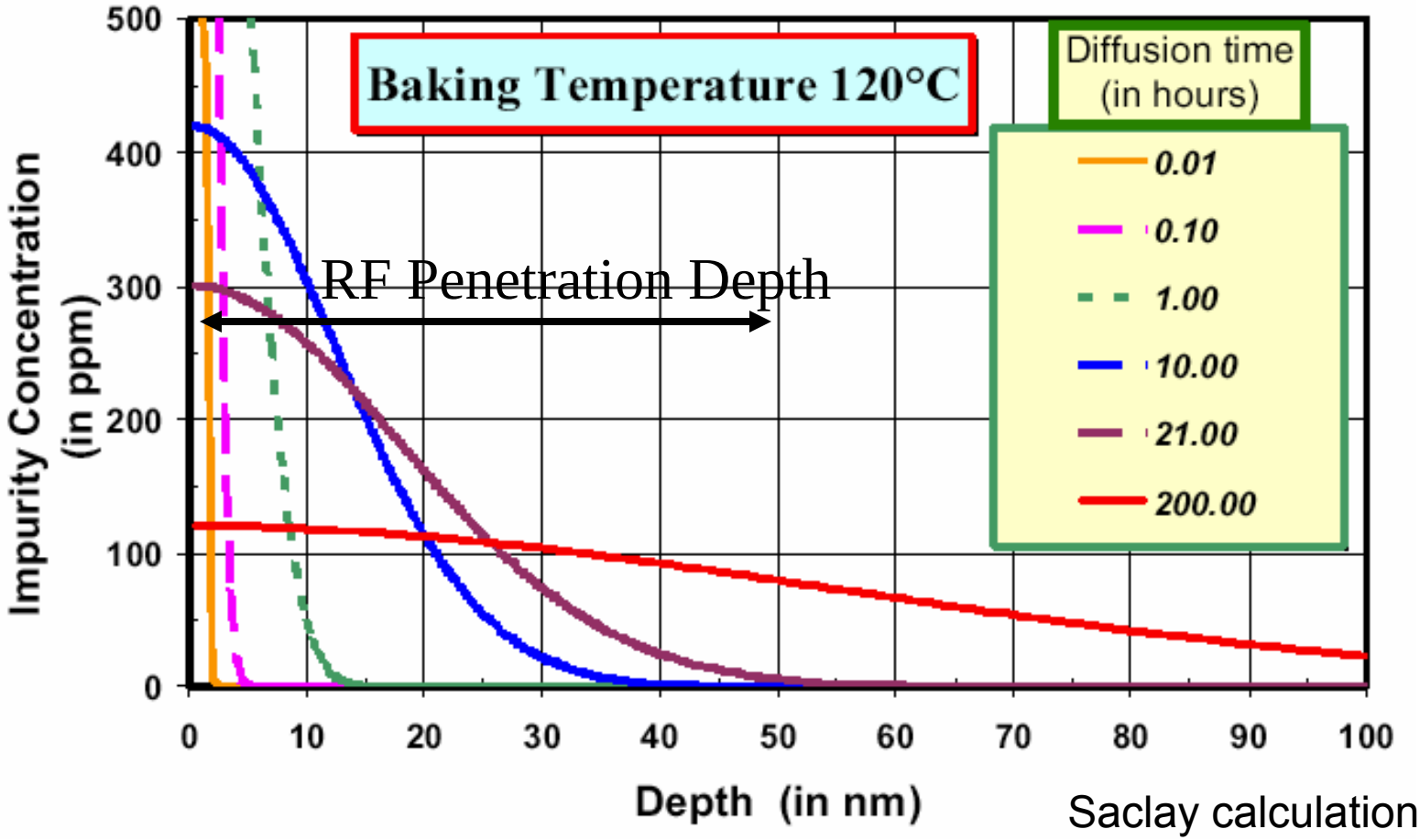
Nb thickness converted to oxide ≈ 20 nm

Tentative conclusion: baking benefit extends to 20 nm, not the full 50 nm penetration depth



Red squares – additional 30 V/60 V anodizing
Blue circles – BCP + 100 C baking

Seems consistent with large change in oxygen concentration over 20 nm, due to baking



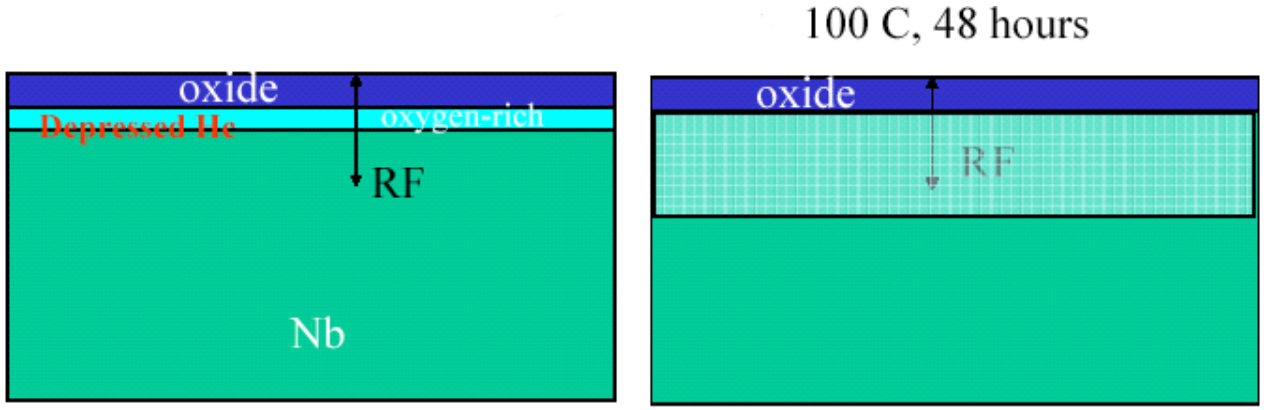
Saclay calculations

PHI 660 Scanning Auger Micrcoscope (SAM + SIMS)

Sensitive to first
10 - 100 nm

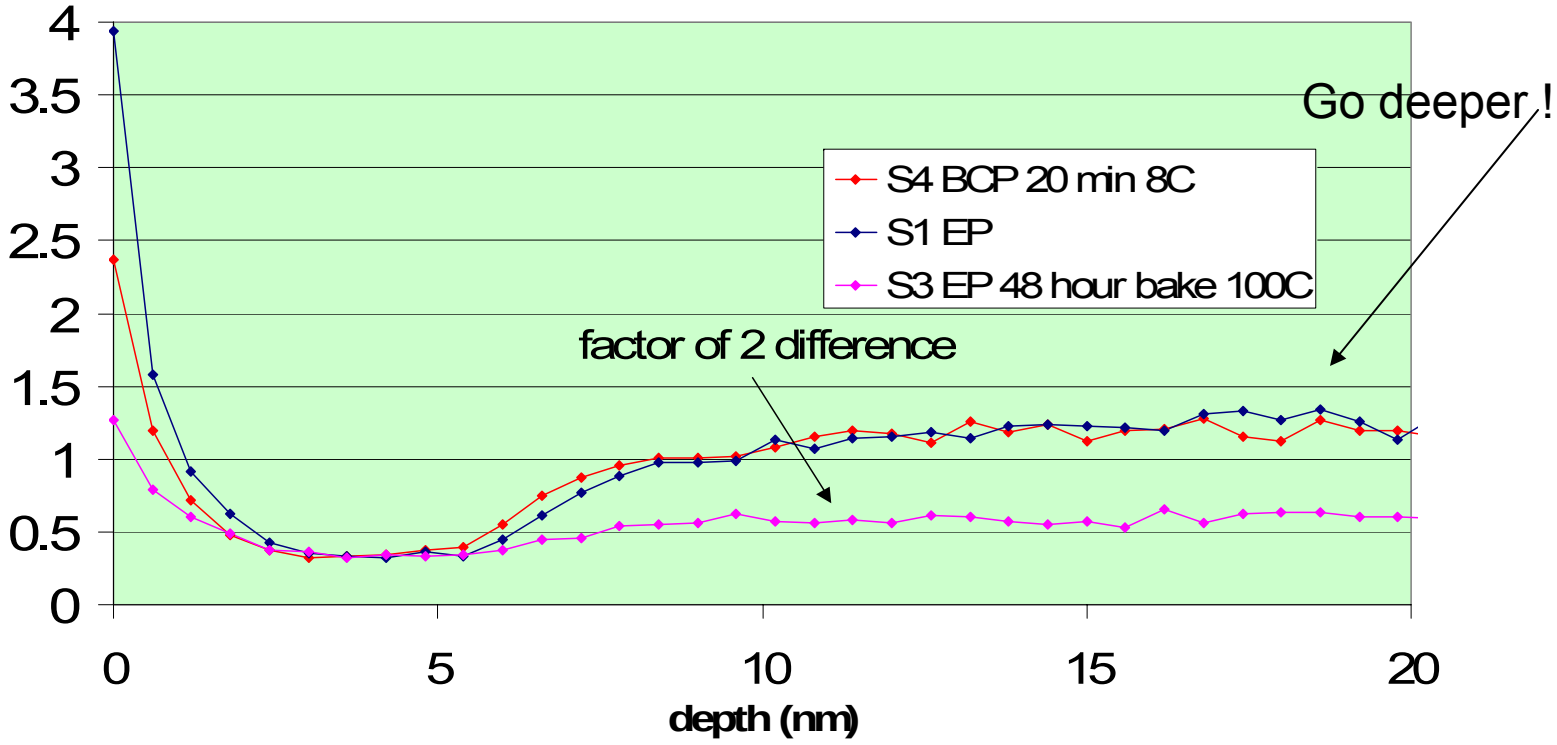
Oxygen Pollution Model

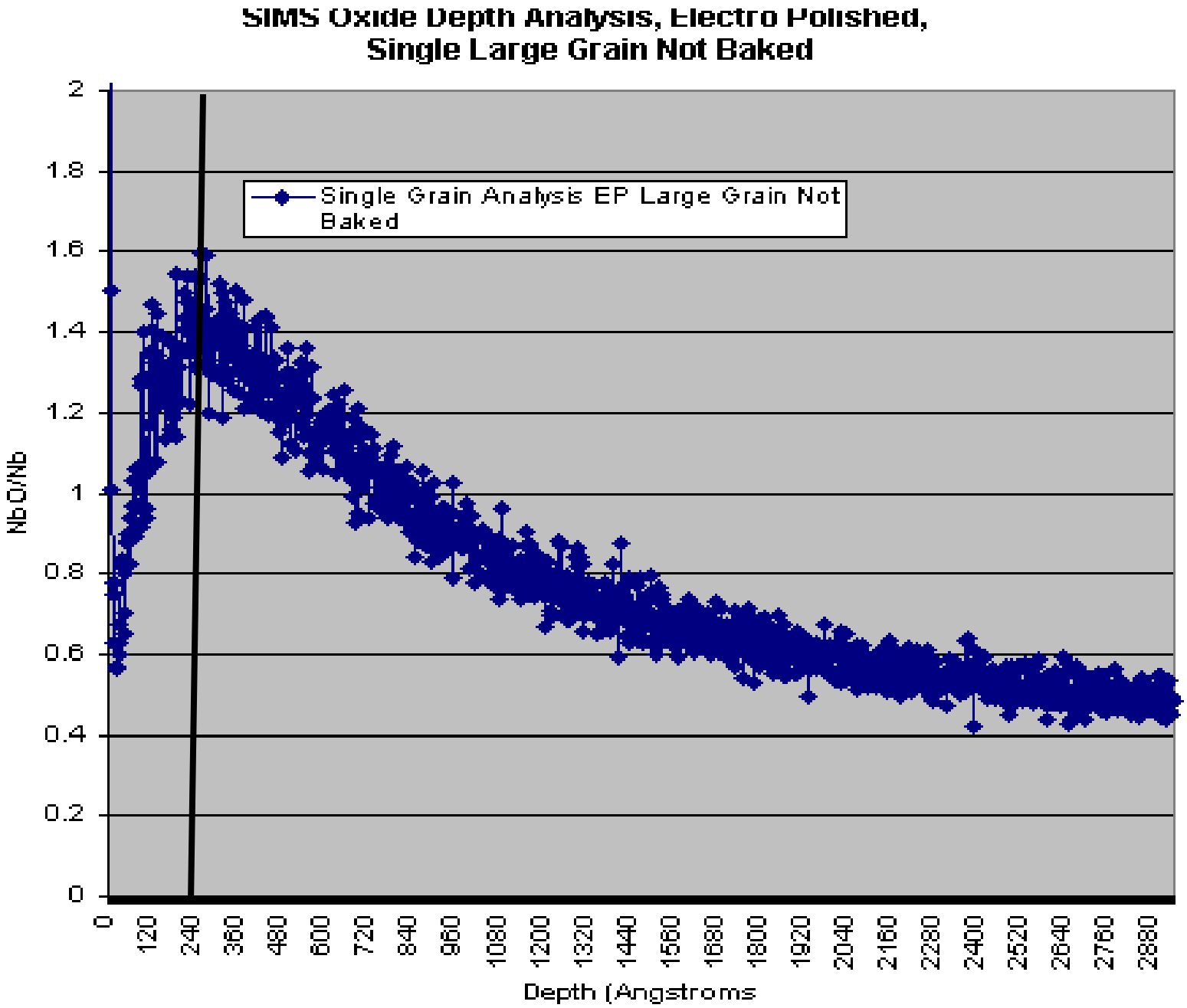
BCP leaves natural oxide + oxygen rich layer



Baking dilutes oxygen rich layer

SIMS Analysis

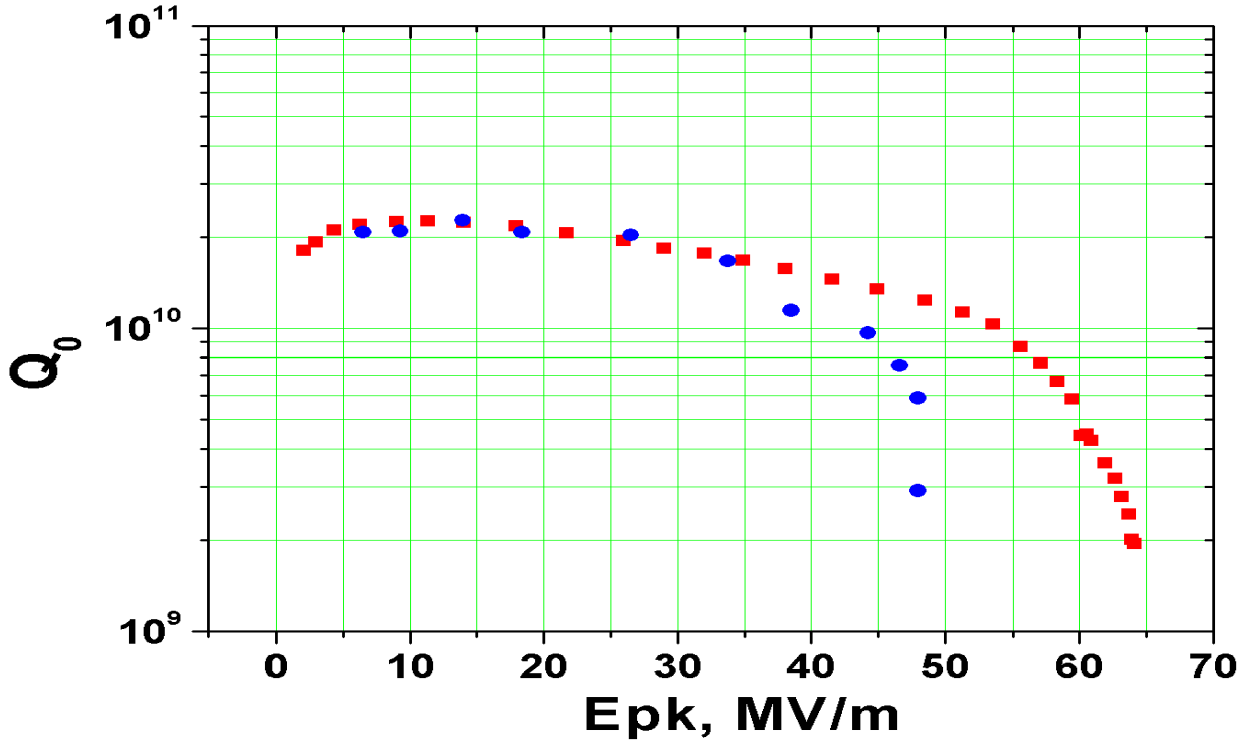



SIMS Oxide Depth Analysis, Electro Polished,
Single Large Grain Not Baked
Single Grain Analysis EP Large Grain Not Baked
NbO/Nb
Depth (Angstroms
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
1680
1800
1920
2040
2160
2280
2400
2520
2640
2760
2880

Baking at 150 C

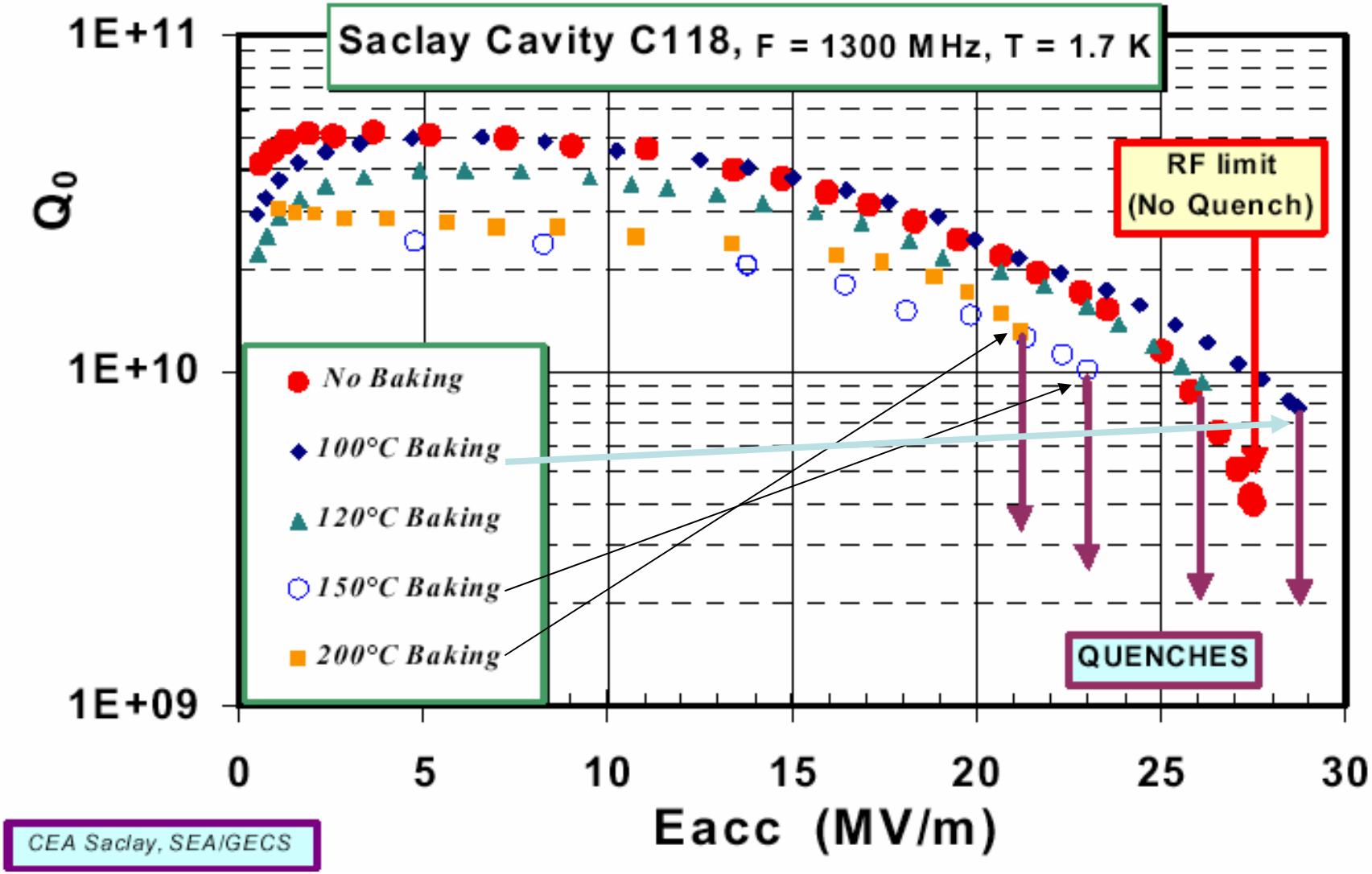
- INCREASES the Q slope
- Increases residual resistance
- Decreases quench field

T = 150 C baking makes Q-Slope stronger

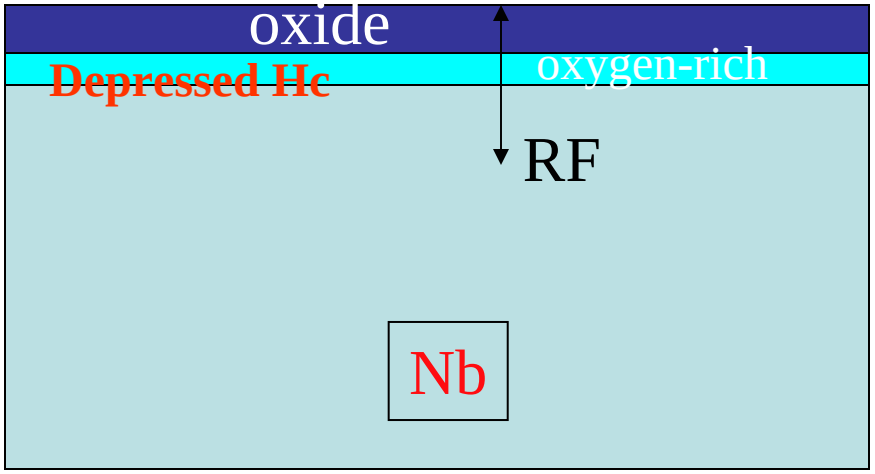


Red squares – after 100 C baking
Blue circles – after 150 C baking

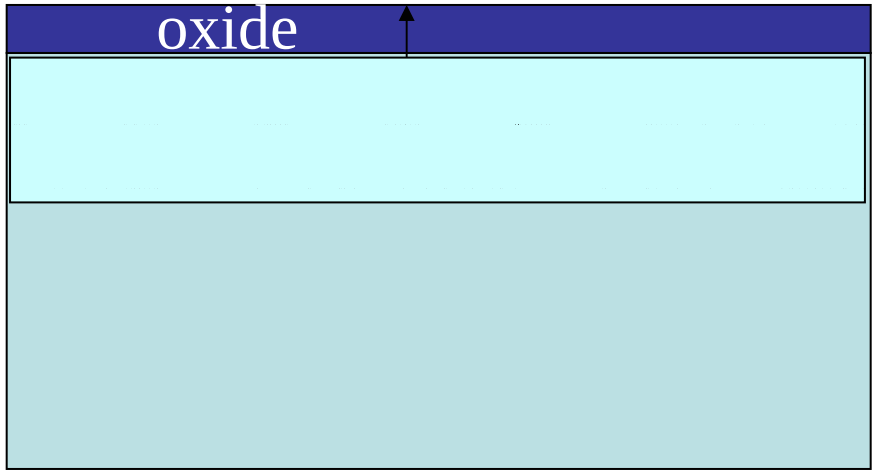
Similar Results by Saclay (KEK workshop, 2001)



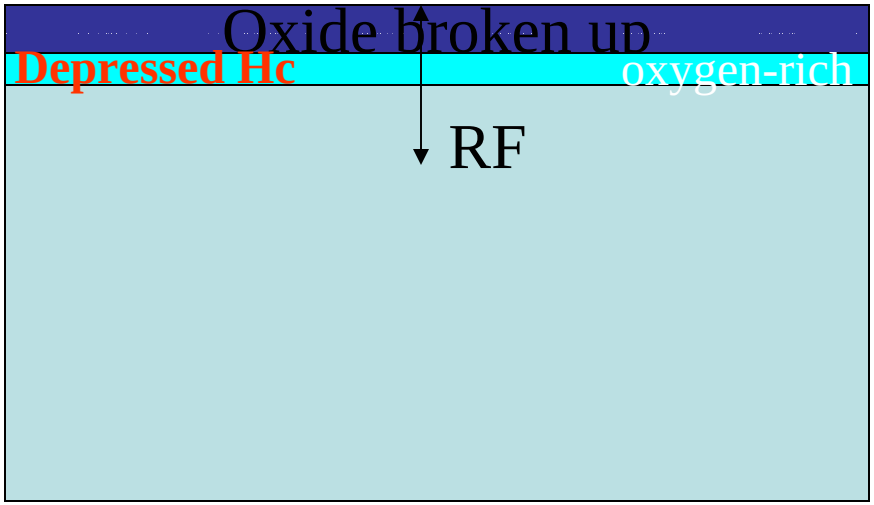
- Is it again the influence of oxygen in the RF layer?
- Or is it the break up of the oxide layer?



100 C, 48 hours

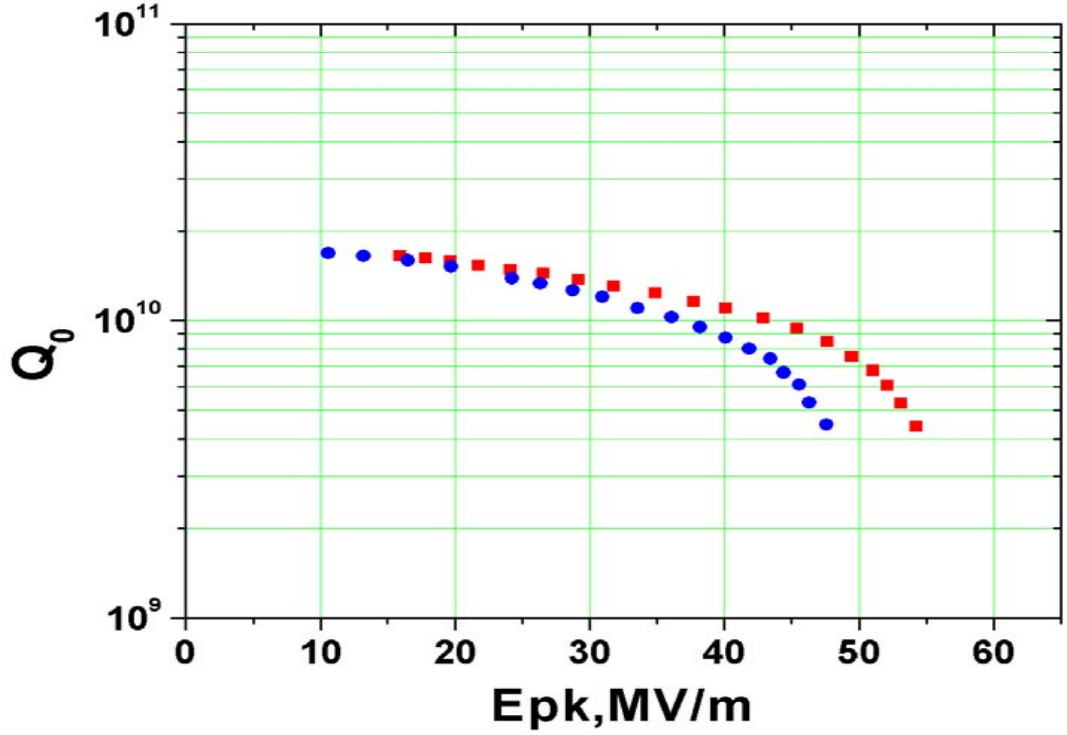


150 C,
48 hours



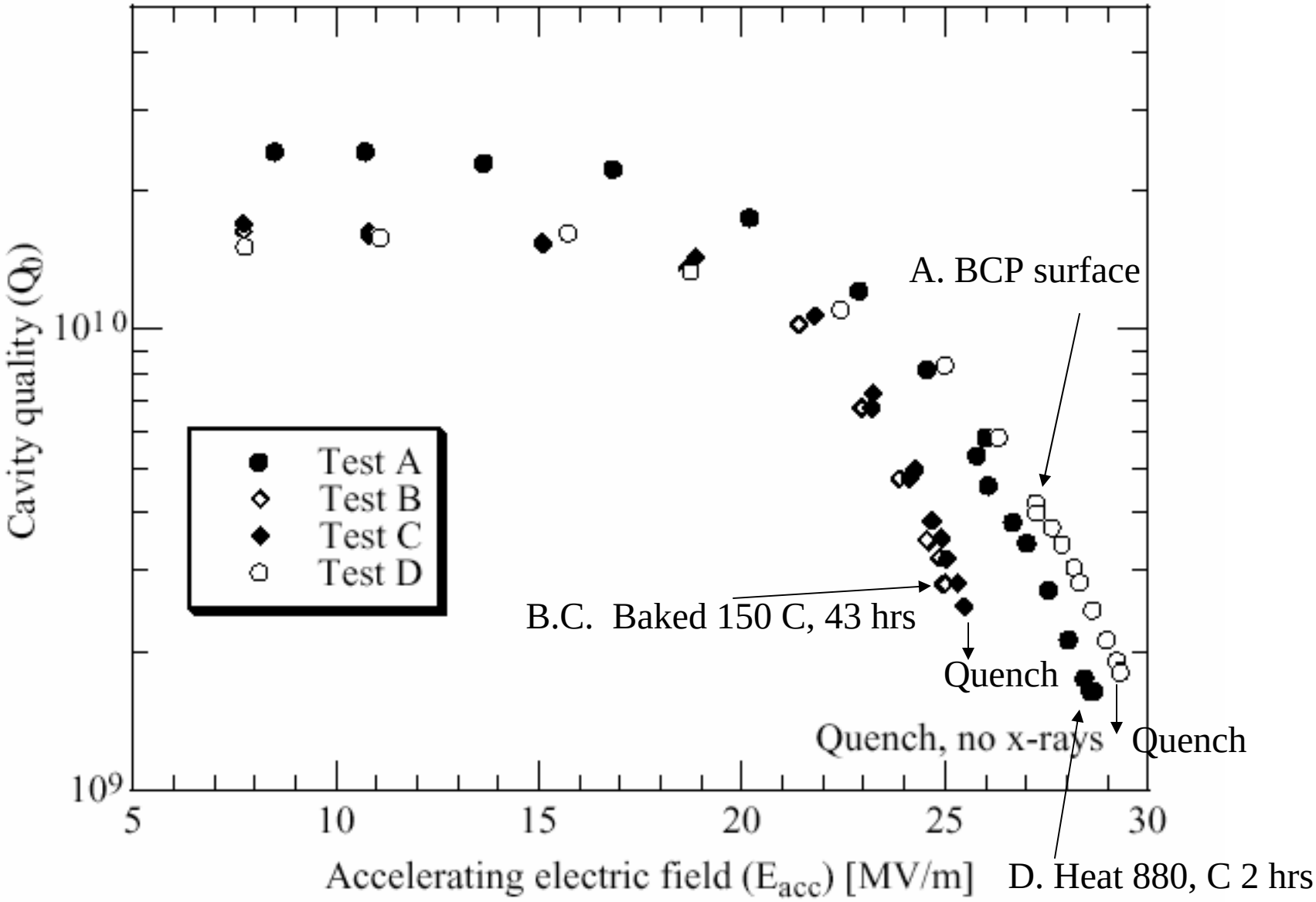
130 C bake -> deteriorated Q-slope

which does not recover with another 100 C bake



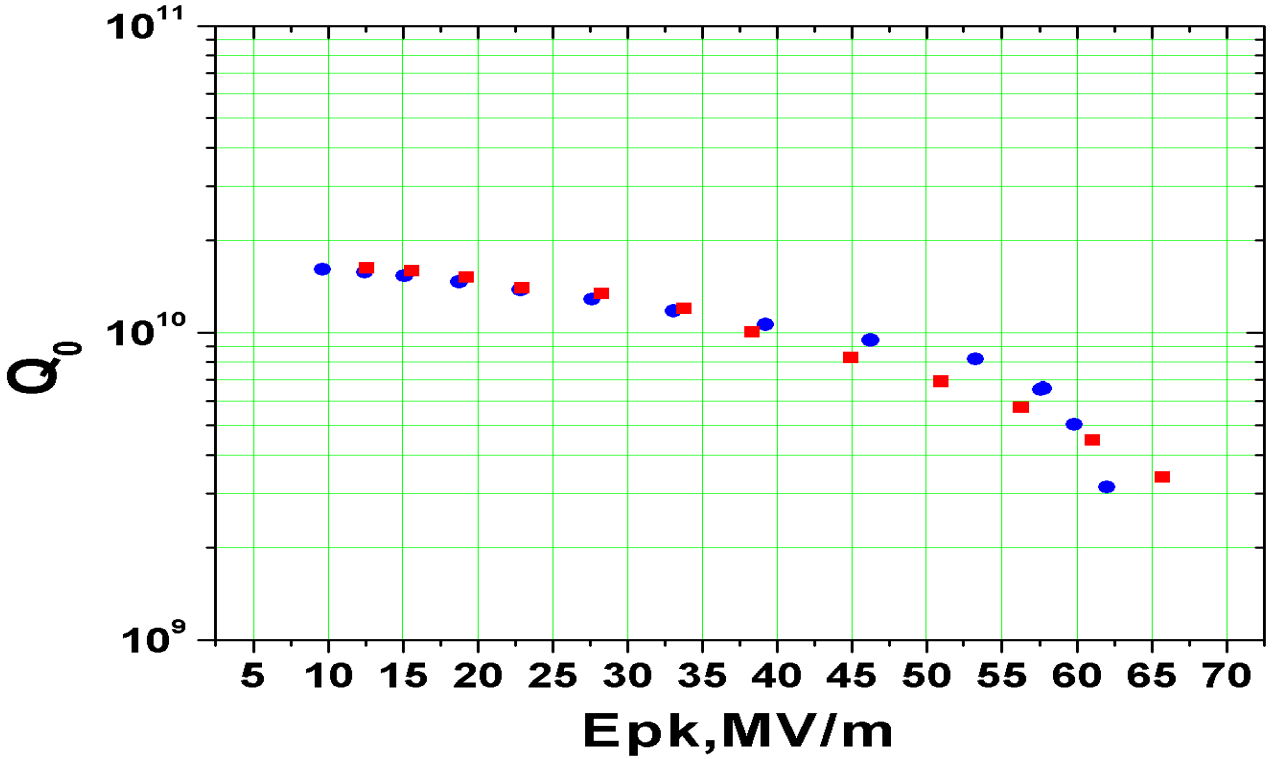
Red squares – 130 C baking
Blue circles – additional 100 C baking

Only heat treatment at 880 C recovers original Q-slope



Repeat anodization depth profiling for EP

First experiment done

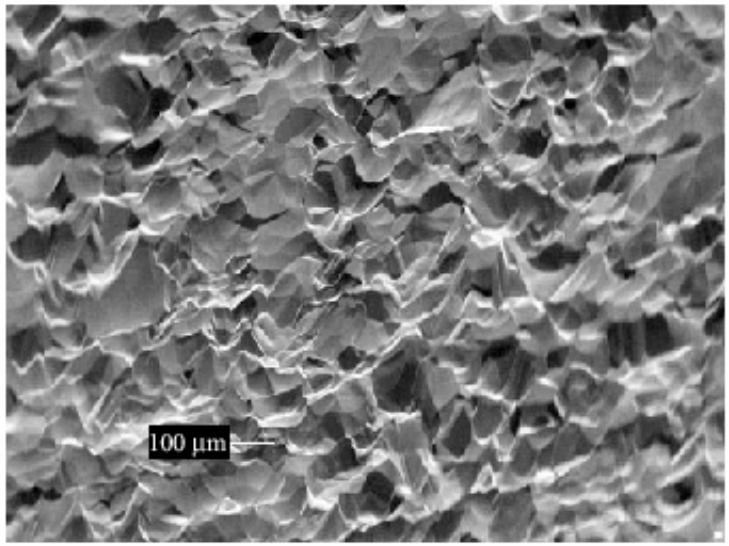


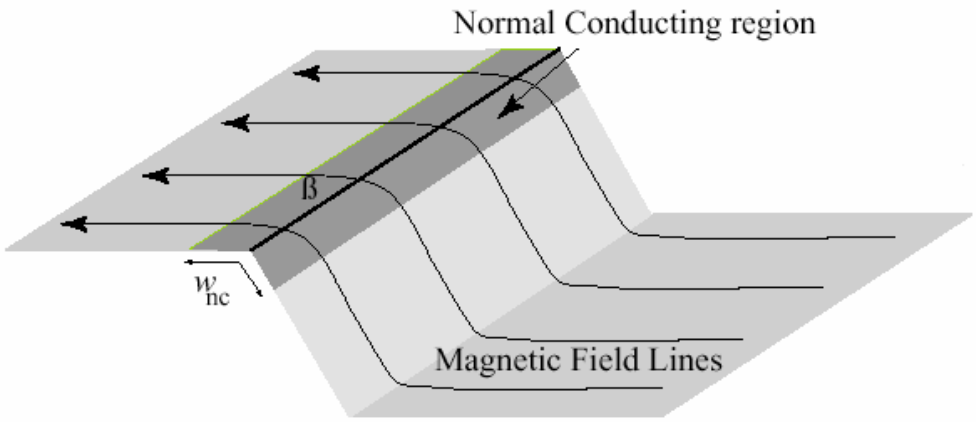
Red squares – fresh EP

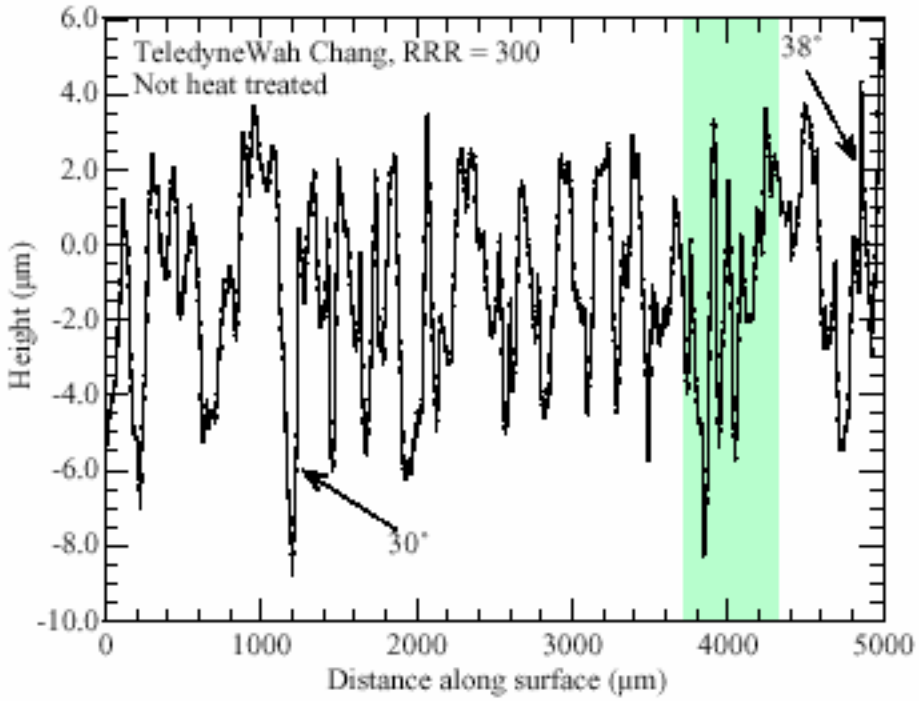
Blue circles – after 10 V anodizing

Does Roughness Play Any Role in Q-slope (BCP) ?

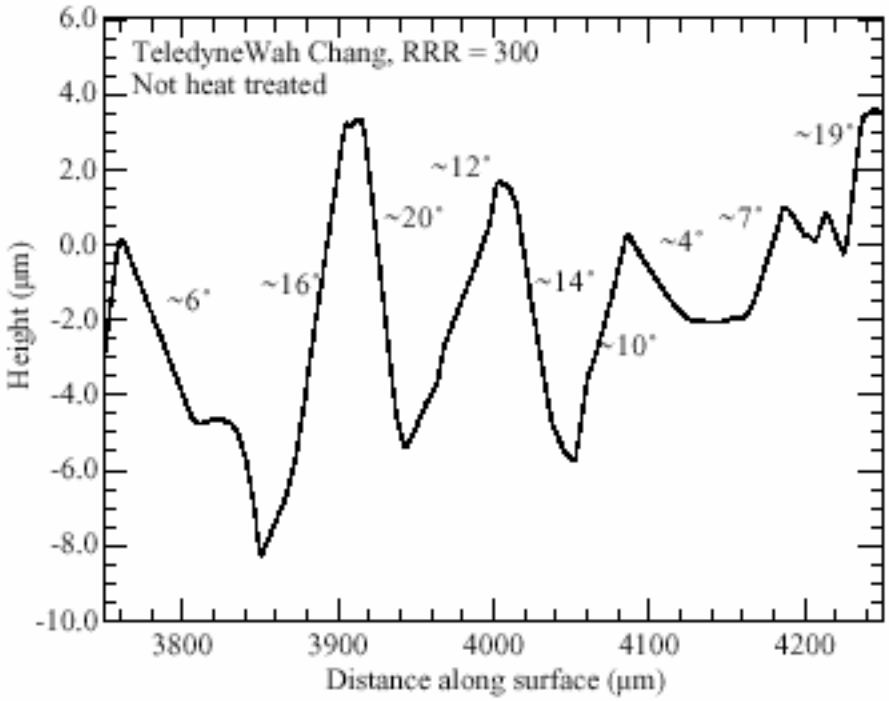
Recall Knobloch model


100 µm

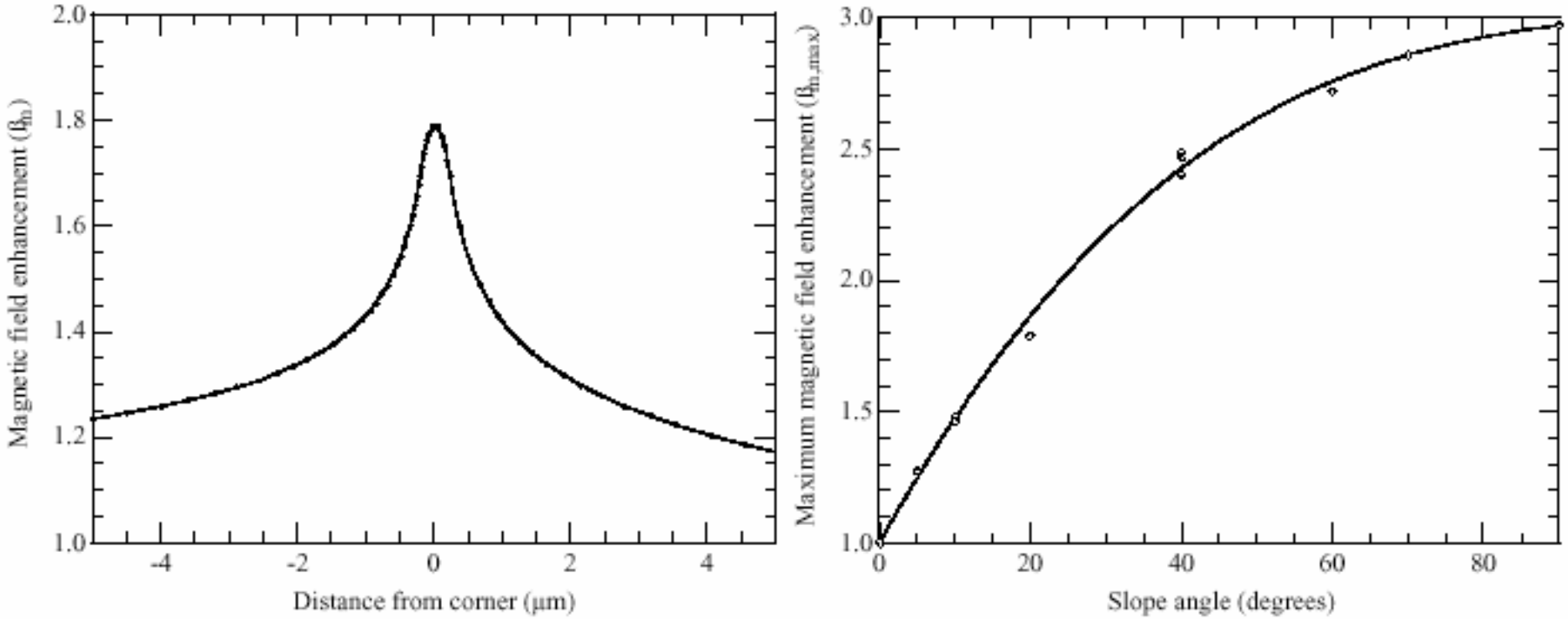

Normal Conducting region
B
w_{nc}
Magnetic Field Lines


TeledyneWah Chang, RRR = 300
Not heat treated
38°
30°
Height (µm)
Distance along surface (µm)

(b)


TeledyneWah Chang, RRR = 300
Not heat treated
~6°
~16°
~20°
~12°
~14°
~10°
~4°
~7°
~19°
Height (µm)
Distance along surface (µm)

(c)

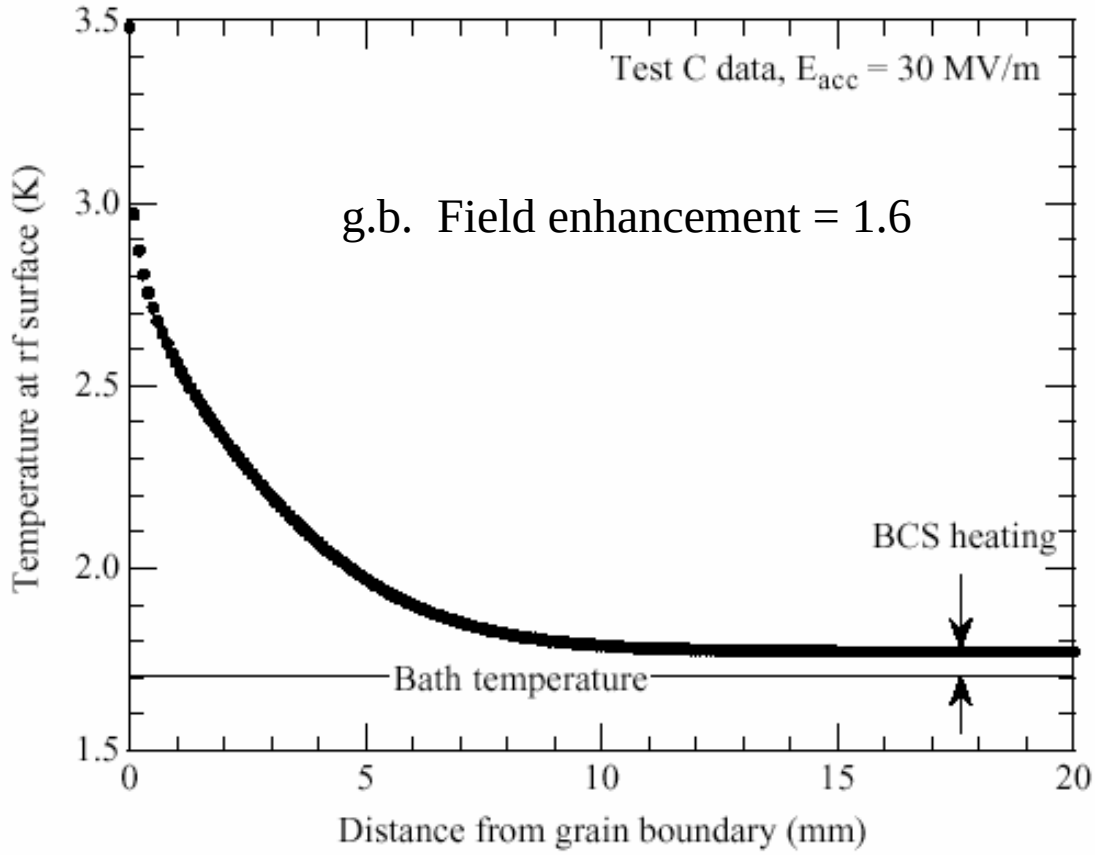


(a) (b)

Figure 11: Magnetic field enhancement due a 100 μm $\times$ 10 μm step. (a) Field enhancement along the rf surface near the corner (slope angle = 20°). (b) Maximum field enhancement versus slope angle.


Temperature (K)
1.738
1.932
2.126
2.32
2.513
2.707
2.901
3.095
3.289
3.483

(a)


Test C data, E_{acc} = 30 MV/m
g.b. Field enhancement = 1.6
BCS heating
Bath temperature
Temperature at rf surface (K)
Distance from grain boundary (mm)
3.5
3.0
2.5
2.0
1.5
0
5
10
15
20

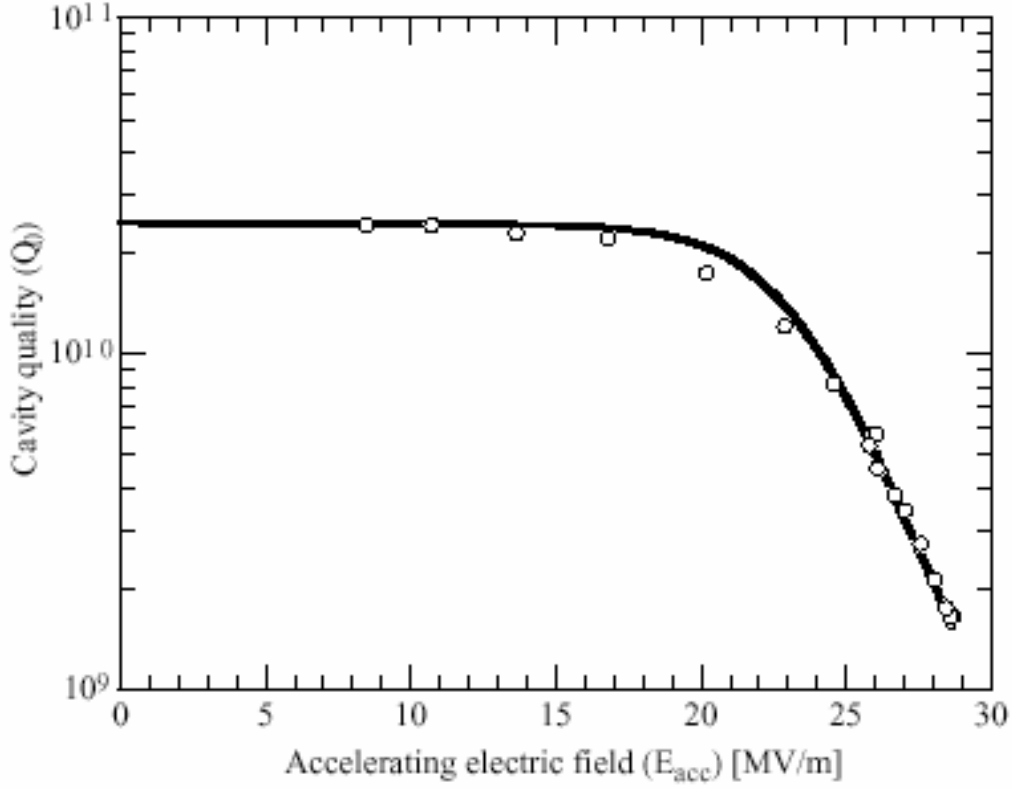
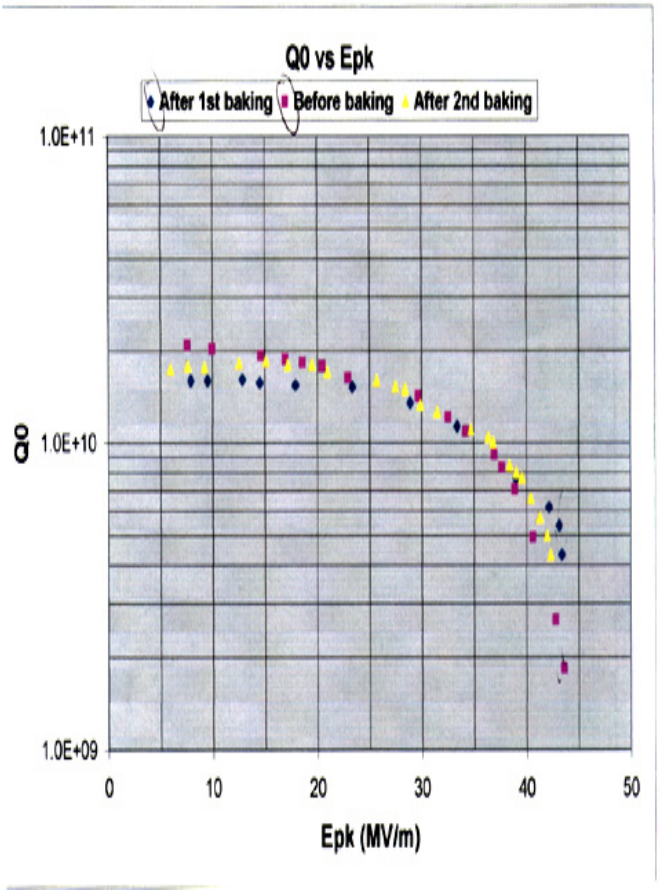
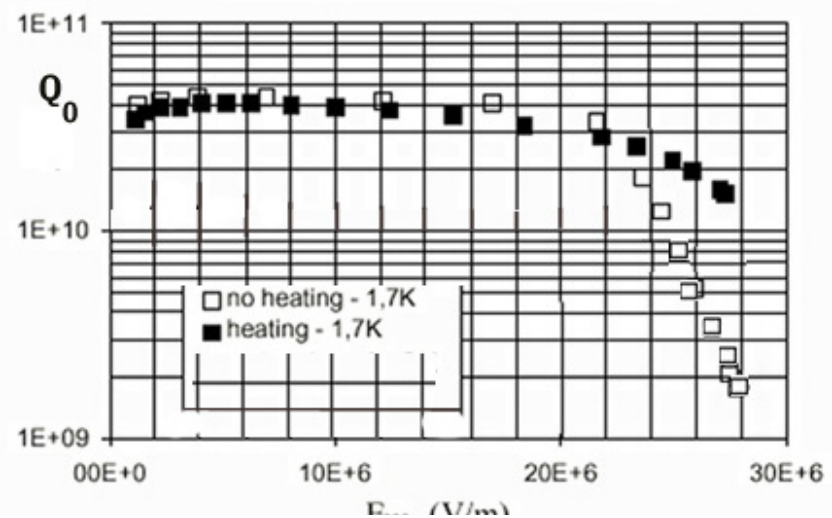


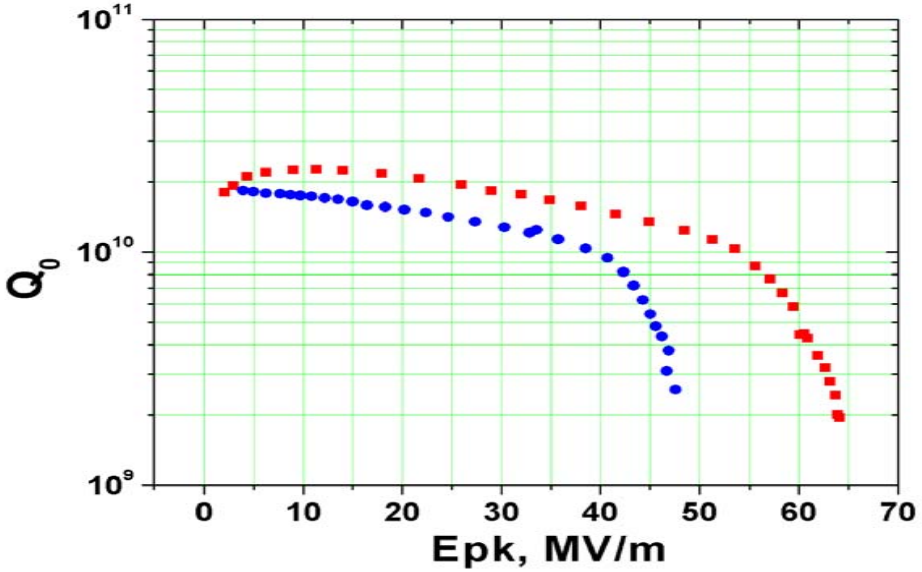
Figure 17: Comparison of the measured cavity quality (Test A) with that calculated by (25) using $H_{\rm crit} = 2000$ Oe.

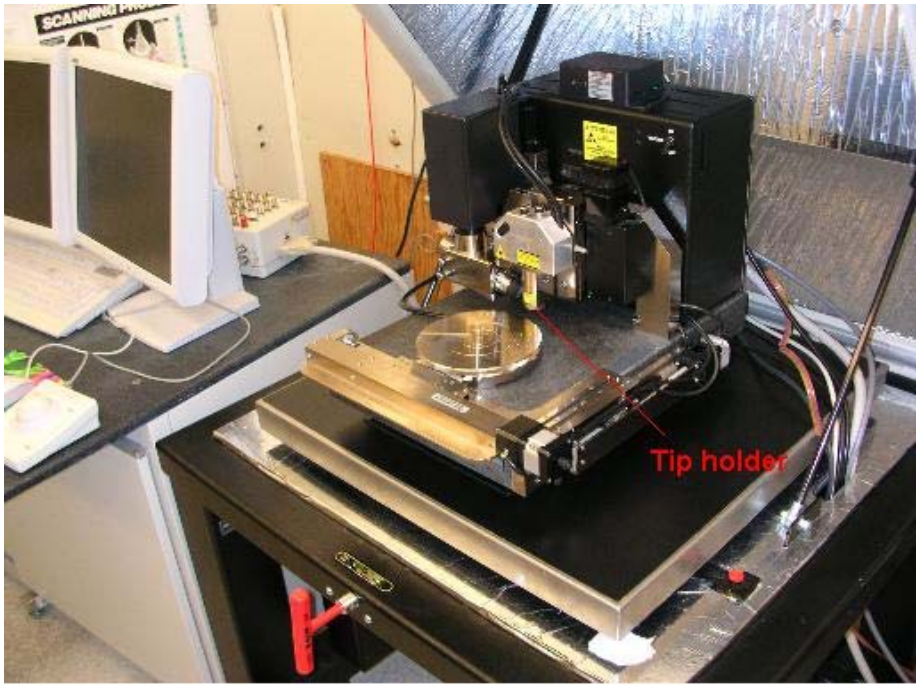
Most BCP cavities don't show very strong improvement of Q slope on 100 C baking

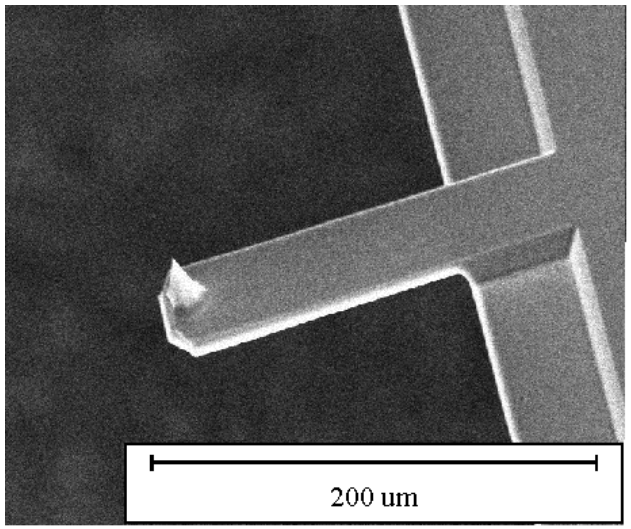
There are some exceptions…our 500 RRR cavity is one of them…why? Look at the grain boundary steps using AFM and profilometer

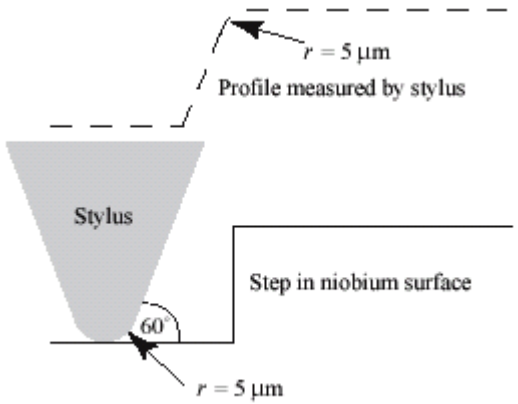




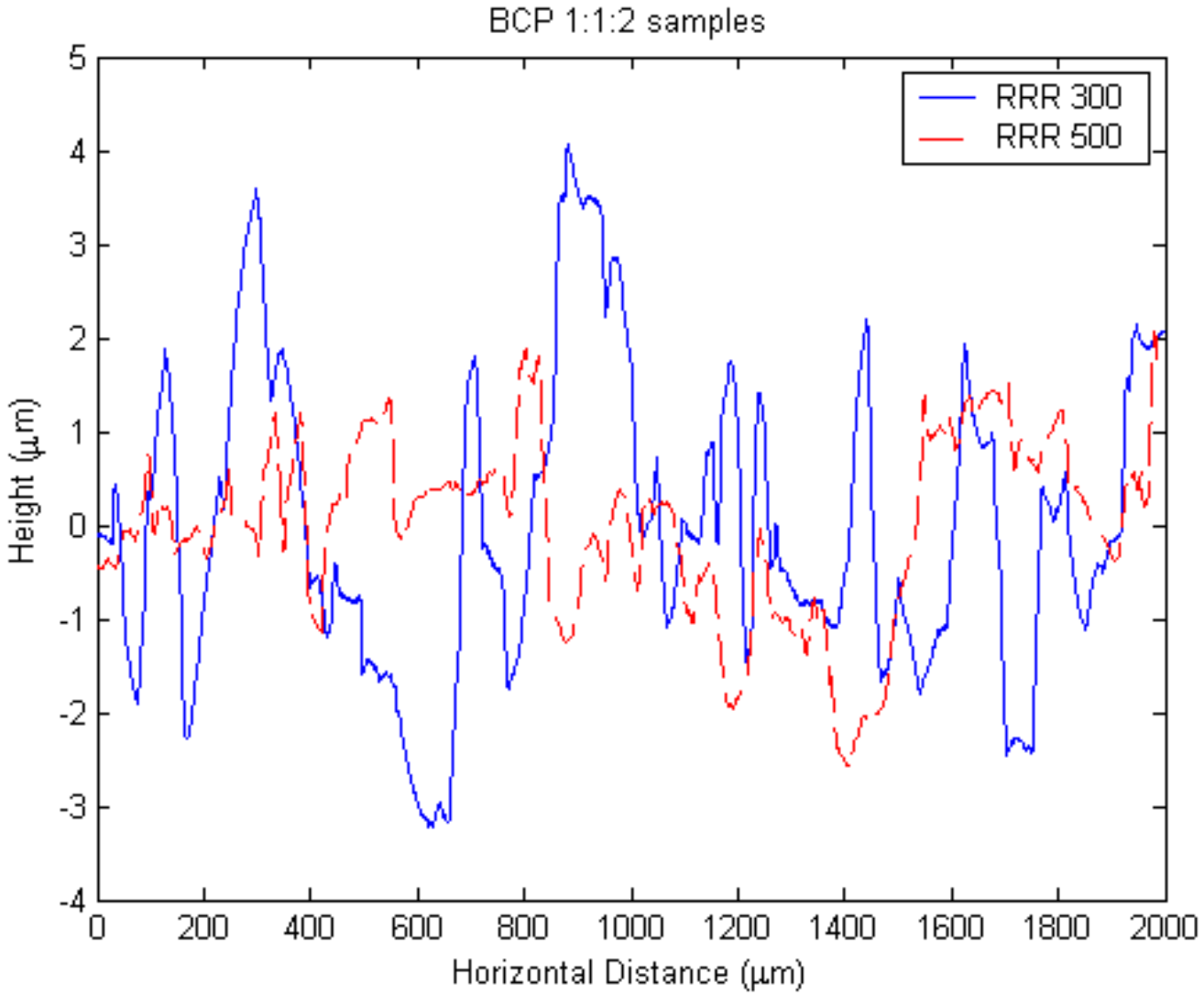


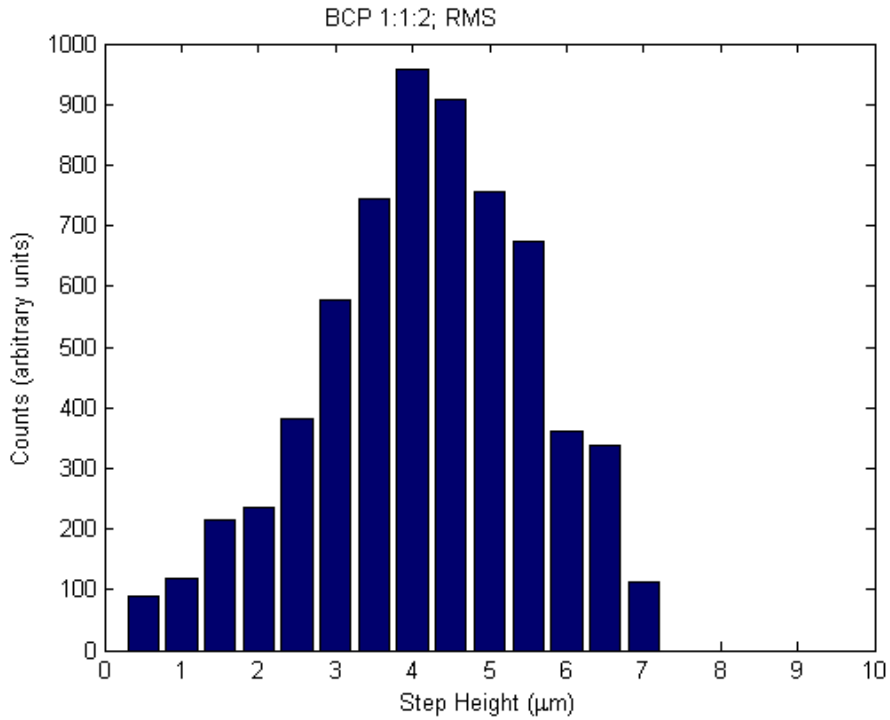

Tip holder

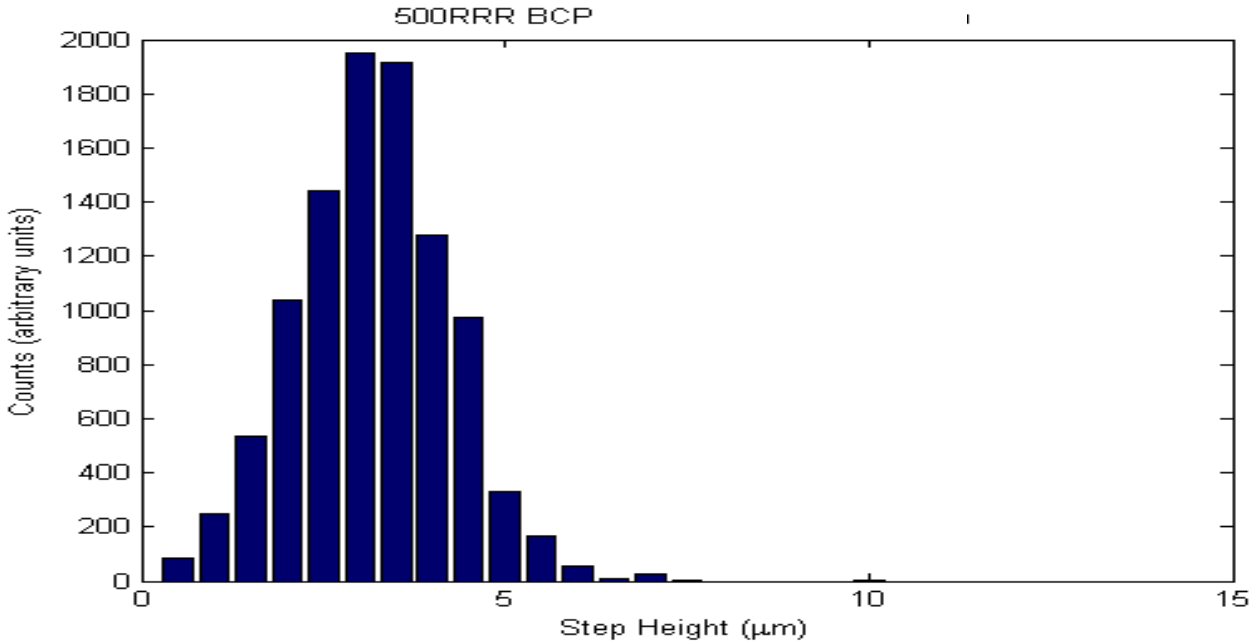

200 um


r = 5 μm
Profile measured by stylus
Stylus
Step in niobium surface
60°
r = 5 μm

500 RRR Russian Nb cavity is smoother than standard Nb, but not as smooth as EP…




BCP 1:1:2; RMS
Counts (arbitrary units)
Step Height (μm)
0
100
200
300
400
500
600
700
800
900
1000
0
1
2
3
4
5
6
7
8
9
10


500RRR BCP
Counts (arbitrary units)
Step Height (μm)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
5
10
15

Conclusions

- Baking benefit takes place within the first 20 nm of rf layer
- There is a large accumulation of oxygen below the oxide layer, with a maximum at about 20 nm
- Baking eliminates the oxygen related peak
- Mystery: Why does repeated anodization bring back the Q-slope?
- 150 C baking causes irreversible increase in Q-slope..perhaps due to break up of Nb_2O_5 into lower oxides.
- Surface roughness still plays a role Q-slope..