Day II Summary

FE and Q-Drop

Detlef Reschke: Summary

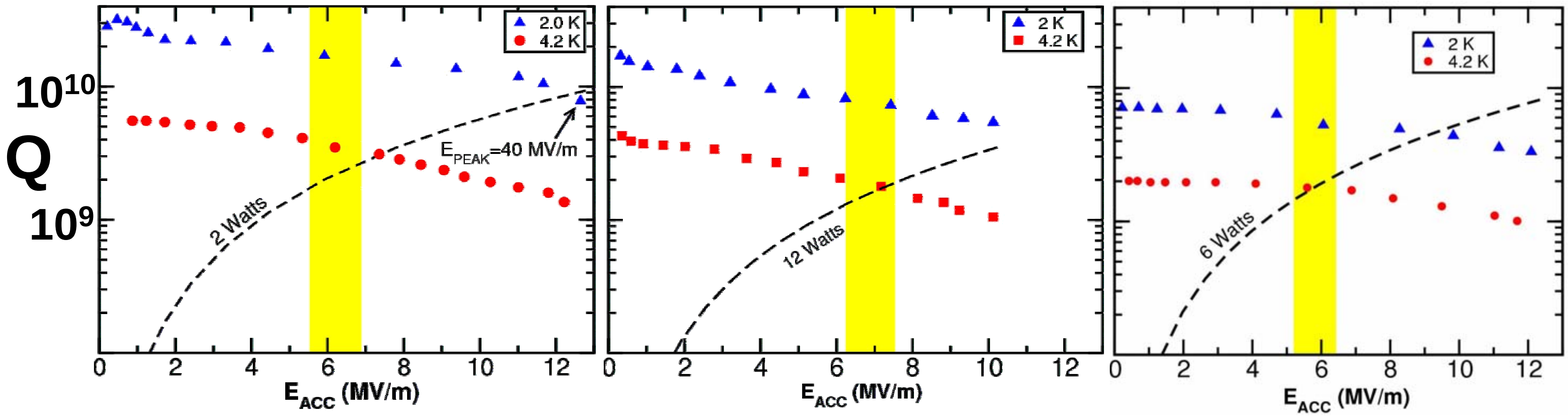
- Precent picture of field emission not complete, but well substantiated
- Standard cleaning and assembly procedures allow high quality cavity performance, but: Field emission (= dark current) is still the main limitation, if usable gradients above 20 MV/m in multi-cell accelerator cavities are required
- Further improvements of standard techniques, quality control and development of alternative approaches necessary!

Gigi Ciovati: Final remark

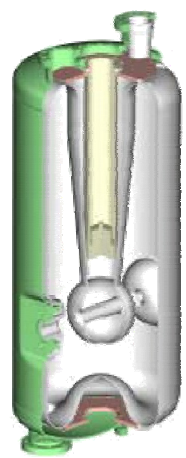
- Large scatter in medium field Q-slope values for the same cavity production

  all the sources for medium field Q-slope are not clear yet and the parameters that influence them are not under control

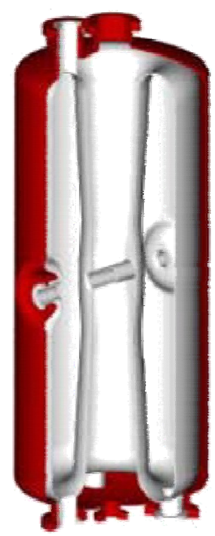
Mike Kelly: Test Performance of the RIA Mid-beta Cavities



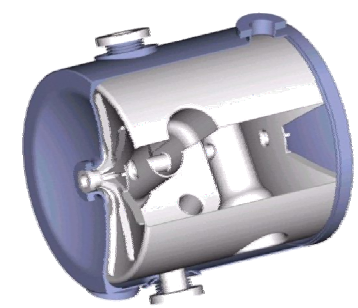
β=0.1 → β=0.5



115 MHz
β=0.15
Quarter-wave



172 MHz
β=0.25
Half-wave



345 MHz
β=0.4
Double-spoke

Lutz Lilje: Experimental Data I

- Q(E) curves show a degradation of quality factor at magnetic surface fields of ~100 mT for several surface preparations
  - BCP 1:1:2
  - BCP 1:1:1
  - EP
  - Should the bakeout parameters be different for EP and BCP?
- R_{BCS} reduces by as much a factor of 2
- Residual resistance does not change or increases slightly (a few nOhm)

Lutz Lilje: Experimental Data II

- T-mapping shows heating of a large region (high magnetic field region)
- Temperature for baking
  - Relatively large variety of data available (each lab has a special flavour)
  - Temperatures above 120° C and below 140° C seem favourable
- Surface RRR goes down (G. Ciovati)
- XPS measurements show a change of the chemical surface composition
- Air exposure of the baked surface does not change the cavity performance
- Depth of the bake affected zone
  - 300 nm: R_{BCS} is back to value before bakeout (P. Kneisel)
  - 60 nm: Q-slope re-appears, but not fully back pre-bake state (D. Reschke)

Lutz Lilje: Experimental Data III

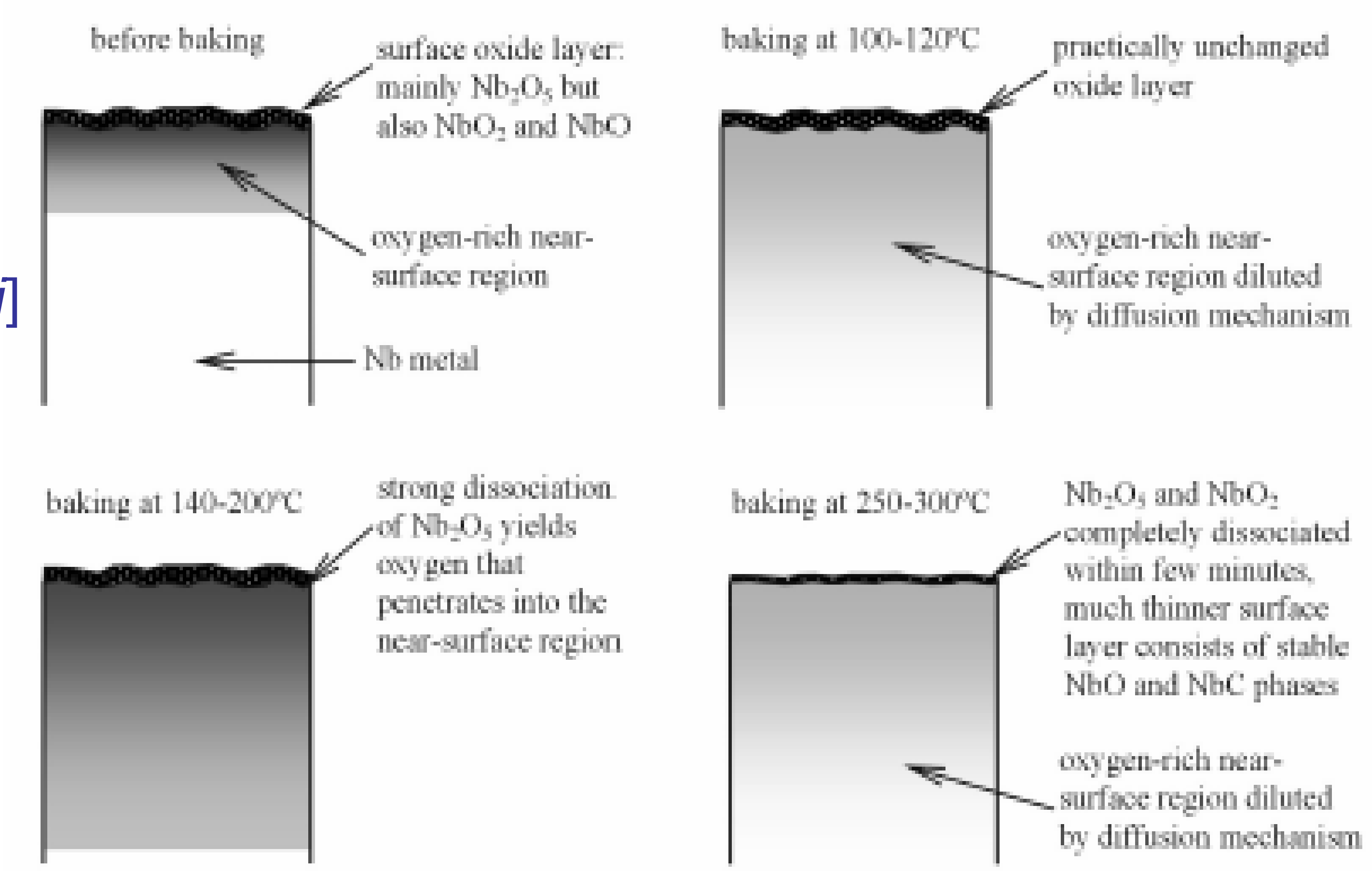
- Sample measurements
  - Bulk properties are not changed
  - Surface properties (B_{c3}, critical current) strongly depend on the surface preparation
  - Critical fields and critical currents
  - Power law analysis of the phase transition hints to the surface topology
    - EP is ‘two-dimensional’, current patterns are more simple
    - BCP has higher dimensionality, more complex current patterns
  - Paramagnetism cannot be explained by oxygen deficiencies alone
- ‘In-situ’ baking is not the only means to change of the slope (B. Visentin et al. – SRF2003 MoP19)
  - Baking under air is effective
  - Plasma discharge
  - ….

Lutz Lilje: Summary on High field Q-slope and Baking

- Experimentally:
  - Baking is effective to cure the Q-degradation at high field
    - Especially EP cavities allow very high gradients
    - Etched cavities usually show breakdowns at lower fields
      - But there are exceptions from this!
      - Is there a difference in BCP 1:1:1 and 1:1:2?
  - Sample measurements show a change of the surface layer
    - Baking effect is clearly observed
    - Clear difference between etched and electropolished samples
    - Indications that the surface topology can play a role
- Theoretically…
  - … we are still looking for the 'experimentum crucis'

Clair Antoine: The "right" scenario: as inferred from XPS

[Kowalski]
[Antoine, Chincarini, Ma, ….]



Clair Antoine: Conclusions about the Q-slope

- Surface studies allow to rule out several hypothesis : adsorbed layer, modification of the oxide layer, hydrogen…and possibly ITE, morphology.
- Interstitial oxygen is the best suspect.
- Possible influence of Carbon (source = interstitial rather than hydrocarbon).
- There are (difficult) ways to check the variation of the oxygen distribution and/or to measure locally the superconducting gap.
- Morphology seems to better explain quench than slope

Further theoretical developments are needed

Gigi Ciovati: Conclusion

- The same dependence R_s vs. B_p as seen in TM_{010} mode above 90mT was observed in TE_{011} mode at higher field, once the thermal conduc. was decreased by HT

- Q-drop is more probable to be a magnetic field effect
- None of the present models explain all the experimental results

Peter Lee: Summary

- Magneto-Optical Imaging shows that non-uniform flux penetration can occur along some grain boundaries
  - Is this topological or chemical or both?
- Considerable variation in surface topology observed
  - Local inhomogeneity: Orientation of facet surfaces
  - Grain size variation across weld region
  - Grooved grain boundaries in weld region and grain-growth heat treatment.
- Software tools enable quantification of surface topology over large areas.

Hasan Padamsee: 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 Nb2O5 into lower oxides.
- Surface roughness still plays a role in Q-slope..

Bernard Visentin: CONCLUSIONS

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

Q-Slope at High Field (cont.)

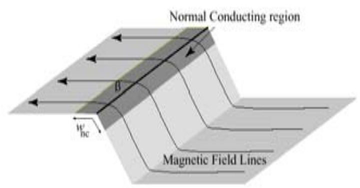
for "Magnetic Field Enhancement" theory (2)

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 ($\neq \beta_m$)

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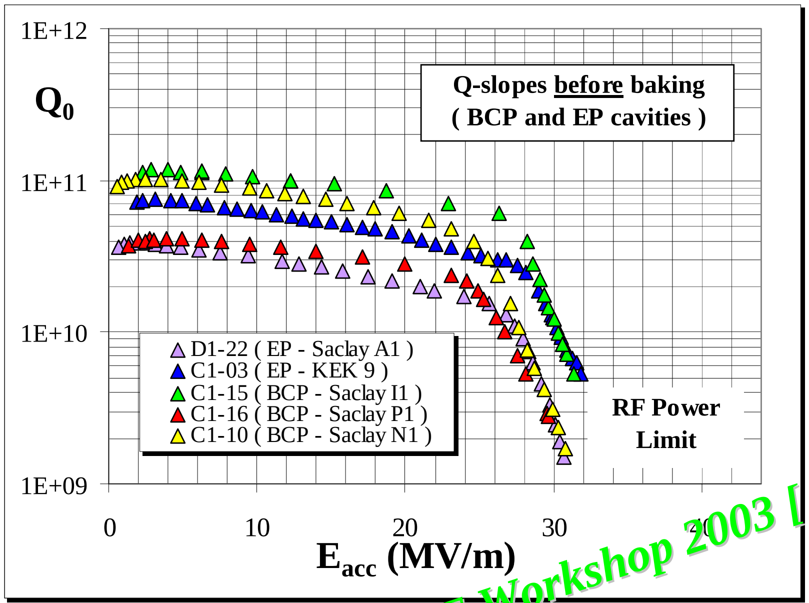

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Theory still valid to give explanation related to the quench origin

Table 1: Summary statement of comparison between experiments and theoretical models
(**Y**es or **N**o: theory **can** or **can't** explain experimental result).

	Q-Slope Fit	Slope before baking (EP = BCP)	Slope Improvement after baking	Slope after baking (EP < BCP)	No change after 2 m. air exposure	Exceptional Results (BCP)	Quench (EP > BCP)	BCP Quench unchanged after baking	Validity
Magnetic Field Enhancement	Y	N (β_m et $H_c \neq$)	Y ($H_c \uparrow$)	Y ($\beta_m <$; $H_c >$)	-	N (high β_m)	Y ($\beta_m <$; $H_c >$)	N ($H_c \uparrow$)	Y
Interface Tunnel Exchange	Y (E^8)	N ($\beta* \neq$)	Y ($Nb_2O_{5-x} \downarrow$)	Y (low $\beta*$)	N ($Nb_2O_{5-x} \uparrow$)	N (high $\beta*$)	-	-	Y
Thermal Feedback	Y (parab.)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	N (coeff. C)
Magnetic Field Dependence of Δ	Y (expon.)	N ($H_c \neq$)	Y ($H_c \uparrow$)	Y ($H_c >$)	-	N	-	-	N (thin film)
Segregation of Impurities	?	N (≠ segreg.)	N (only O)	-	-	Y (cleaning)	-	-	Y
Bad SC Layer	N	Y (n.c. layer)	Y (dilution)	N	N (bad layer ↑)	-	N	N ($H_{c2}' \downarrow$)	N (unrealistic)

Update from Bernard

	Q-Slope Fit	Q-Slope before baking (EP ≡ BCP)	Q-Slope Improvemt after baking	Q-Slope after baking (EP < BCP)	No change after 4 y. air exposure	Exceptional Results (BCP)	Q-Slope unchanged after HF chemistry	Q-slope TE_{011} (B) after baking	New Exp.	Quench EP > BCP	BCP Quench unchanged after baking	Argumt Validity	Fundal Disagreemt Exper. ? Theory
Magnetic Field Enhancemt	Y	~~N β_m and $H_C \neq$~~	Y $H_C \uparrow$	Y $\beta_m <$ $H_C >$	-	N high β_m	-	-		Y $\beta_m <$ $H_C >$	N $H_C \uparrow$	Y	D_1
Interface Tunnel Exchange	Y E^8	N $\beta* \neq$	Y $Nb_2O_{5-y} \downarrow$	Y Low $\beta*$	N $Nb_2O_{5-y} \uparrow$	N high $\beta*$	~~N new Nb_2O_{5-y}~~	~~N improvt~~		-	-	Y	D_2
Thermal Feedback	Y parabolic	Y	Y $R_{BCS}\downarrow$ $R_{res}\uparrow$	N	-	N	-	-		-	-	N C coeff.t	-
Magnetic Field Dependence of Δ	Y exponentl	N $H_C \neq$	Y $H_C \uparrow$	Y $H_C >$	-	N	-	-		-	-	N thin film	-
Segregation of Impurities	?	N segreg. ≠	N only O diffusion	-	-	Y good cleaning	-	-		-	-	Y	-
Bad S.C. Layer	~~N Far from real Q-profile~~	Y n.c. layer	Y dilution	N	N bad layer↑	-	~~N new bad layer~~	-		N	N $H_{C2}' \downarrow$	Y	D_2
Next Theory													

My View

- I.T.E. model is probably not working
- Hydrogen is probably not a player in the Q-drop game
- Magnetic field enhancement should be real, but can not explain all observations ⇒ quench field
- Baking and oxygen diffusion ⇒ promising, test this model!
- Are all Q-drops the same?? (BCP, EP before bake; EP after bake)
- Combination of Oxygen-M.F.E. model?
- Need to work harder:
  - communicate, correlate our work better (SRF web-page?)
  - exchange all test results, all important information
  - get help from experts