Basic Understanding for the Various Causes of Quench

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Acknowledgments I

1. H. Padamsee, J. Knobloch, and T. Hays, *RF Superconductivity for Accelerators*, Wiley and Sons, New York, 1998.
2. J. Knobloch, *Advanced Thermometry Studies of Superconducting Radio-Frequency Cavities*, PhD Thesis, Cornell University, Ithaca, 1997
3. H. Piel, *Superconducting Cavities, CERN Accelerator School*, May-June 1988,CERN 89-04, S. Turner (ed)(1989), p.149

Acknowledgments II

4. Wiener and Hasan Padamsee, *Thermal and Statistical Models for Quench in Superconducting Cavities*, TTC-Report 2008-08.
5. Shemelin and H. Padamsee, *Magnetic Field Enhancement at Pits and Bumps on the Surface of Superconducting Cavities*, TTC-Report 2008-07.
6. D. Reschke, *Analysis of Quenches Using Temperature Mapping in 1.3 GHz Superconducting Cavities at DESY*, Proceeding of LINAC08, Victoria, BC, Canada.

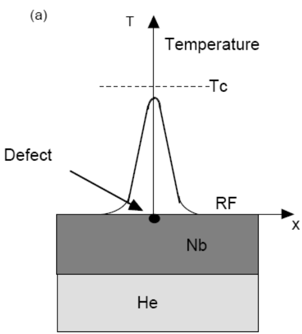
Acknowledgments III

7. Paolo Michelato, *Evolution of Surface Defect During Niobium EP*, TTC meeting, Orsay, June 16-19, 2009.
8. S. Mishra, *ILC and SRF Program*, TTC meeting, Orsay, June 16-19, 2009.
9. F. Eozenou, *EP at Saclay: Last Results*, TTC meeting, Orsay, June 16-19, 2009.
10. Y. Xie, M. Liepe, D. Meidlinger, *Thermal Modelling of Ring-Type Defects*, this conference, TUPPO048.

Acknowledgments IV

11. Y. Xie, H. Padamsee, and A. Romanenko, *Relationship Between Defects Pre-Heating and Defects Size*, this conference, TUPPO049.

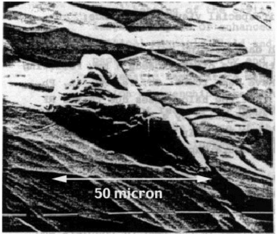
Thermal breakdown



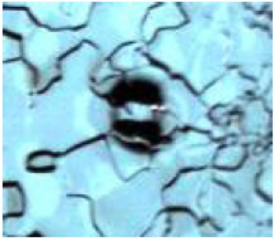
The classical model: the high power dissipation in a small, lossy defect on the RF surface causes the temperature of the surrounding superconductor to rise above T_c. At this point, the normal-conducting region grows rapidly ($\approx$ 10s of μs) until the entire stored energy has dissipated away.

Gallery of Defects[3]

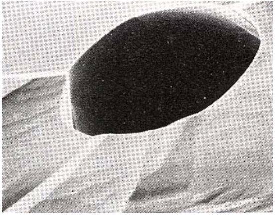
Defects can originate from the source material or the welding.



Inclusion with a 50 μm crystal containing S, Ca, Cl, and K - quench field 10.7 MV/m



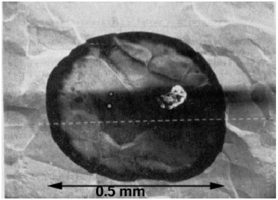
A Nb protrusion - quench at 18 MV/m



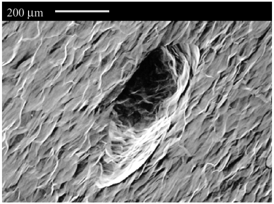
A weld hole found in a 3 GHz cavity

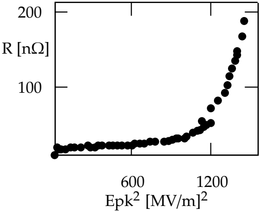
Gallery of Defects[2,3]

Defects can be introduced during chemical processing or rinsing.

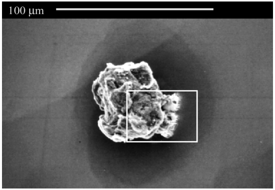


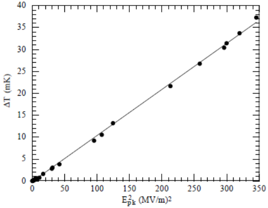
A chemical or drying stain 440 μm in diameter - quench field 3.4 MV/m





A pit with sharp eddge found in a 1.5 GHz cavity - quench field 1200 Oe





A copper particle-like defect found in a 1.5 GHz cavity - preheating only - no quench

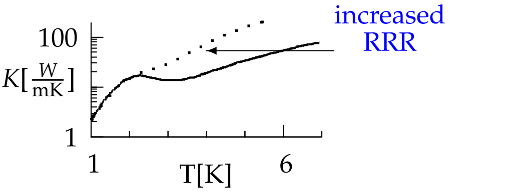
High RRR, High Quench Fields[1]

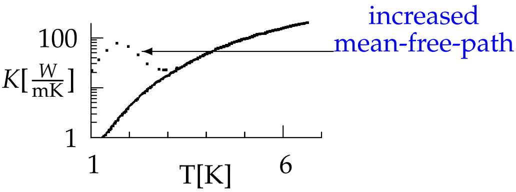
A simplified thermal model of a spherical defect predicts a quench field of

$$H_{\text{max}} = \sqrt{\frac{4\kappa(T_c - T_b)}{aR_n}}.$$

$$H_{\text{max}} \propto \sqrt{\kappa}$$

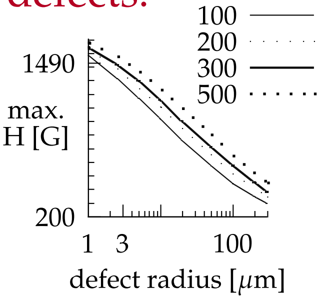
The phonon peak does not generally help since $T >> 2K$ near large defects.





Defect Size Inferred[11]

Large quench fields generally imply small NC defects.

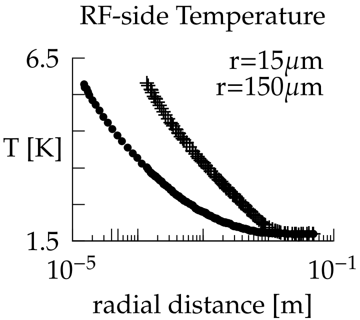


for $H_{\text{max}} > 1490$ Oe
($E_{\text{a-max}} > 35$MV/m)
defect radius<3μm
$R = 0.01\Omega$
RRR=300

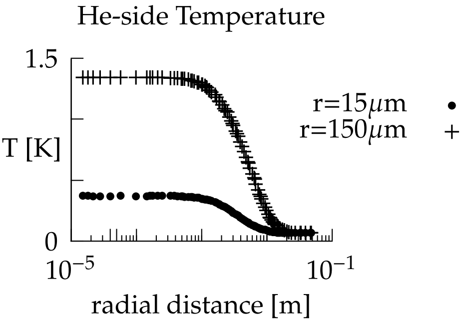
- NC defects for high gradient structures may be difficult to observe directly.
- The general model is too restrictive because resistance is too high... assumtion that all defects are NC may not be true.

Defect Size Inferred[11]

Consider a large and small defect with the same quench field:



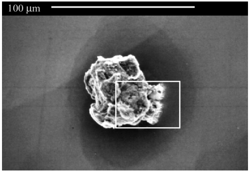
1. larger defects must have smaller resistance,

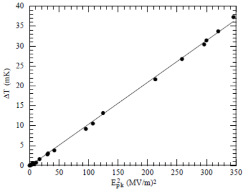


2. outer wall temperature depends on defect size.

Y. Xie, H. Padamsee, and A. Romanenko, Relationship Between Defects Pre-Heating and Defects Size, this conference, TUPPO049.

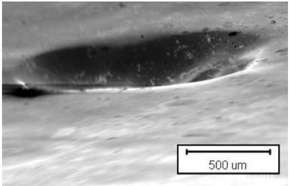
Why do large($\approx 100\mu$m) pits quench at higher fields than would be expected for NC defects of the same size?

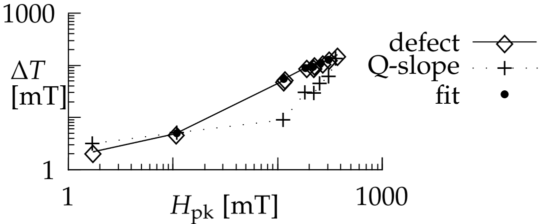




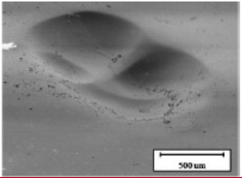
Why does a pit quench?
Part of the pit is NC.

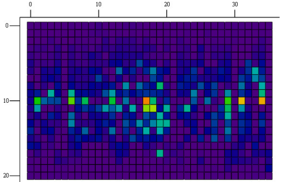
Simulations are in rough agreement with thermometric meausrements[11].





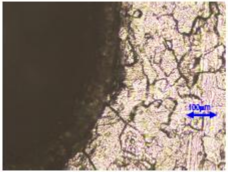
For the measured H_{quench} and T_{wall}, simulations predict defect size ≈ 40 to 150 μm and R ≈0.5 to 2 mΩ.





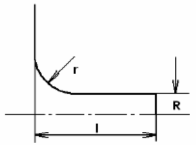
Why is only a small region of the pit involved[5,7]?

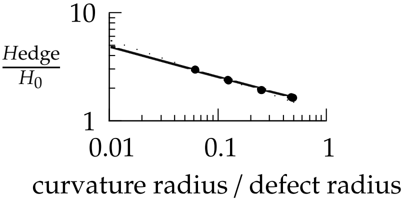
BEFORE EP



AFTER EP

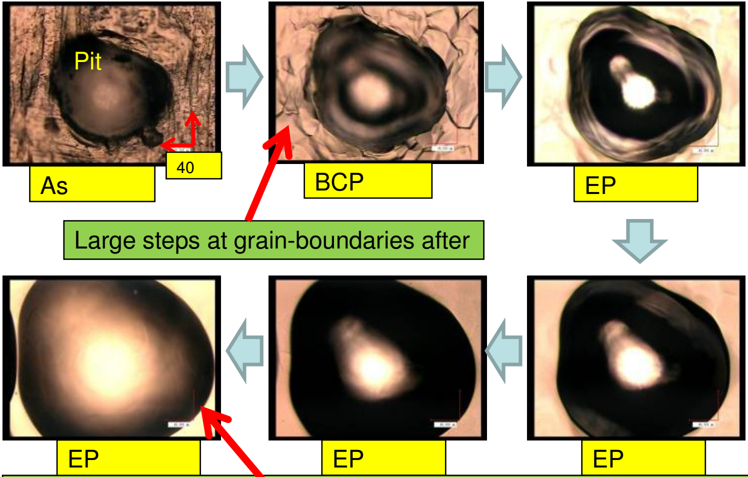
Experiments shows EP sharpened the edges,





possibly field-enhancement at sharp edges.

Heavy Polish Increases Pit Size[9].

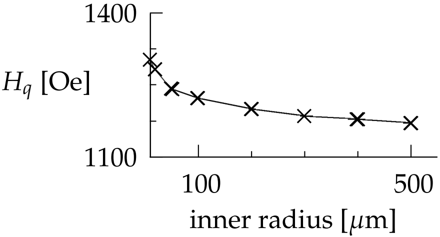


After BCP(30um)+EP(120um), still the edge of pit is

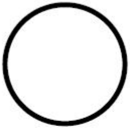
T. Saeki, H. Hayano (KEK), R.L. Geng(JLab),Study on the Electro-Polishing of Nb Sample with Artificial Pits, this conference, THPPO086.

EP Gets You Two Ways[10]:

1. sharper pits and
2. larger pits.



New Simulations for Ring-like Defects



ring-shape defect modelling a pit

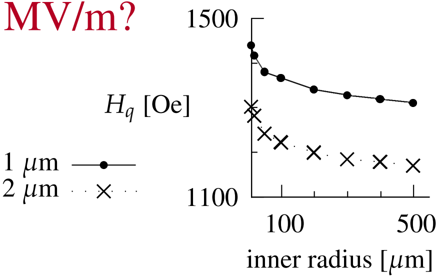
disc-shape defect used in previous simulations

Larger ring diameters increase the NC area and lower the quench field. The quench field increases rapidly for ring sizes $< 50\ \mu$m.

Y. Xie, M. Liepe, D. Meidlinger, Thermal Modelling of Ring-Type Defects, this conference, TUPPO048.

Some Open Questions[10]

- Which is more important: the diameter or the edge?
- Why is the max. field for pits $E_a \approx 30$ MV/m?

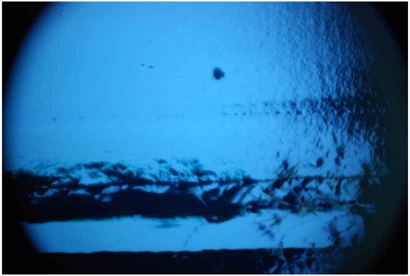


$H_{pk} = 1235$ Oe for the TESLA shape. Simulations predict quench at this approximate field level for typical pit properties

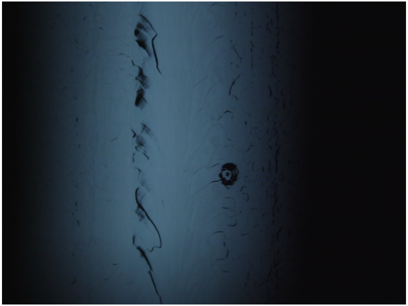
— Increasing the ring radius can cause a big drop in quench field for initial radii < 100 μm.

— The quench field is very dependent on the width of the NC region.

Large pits don't always quench at low fields[8].

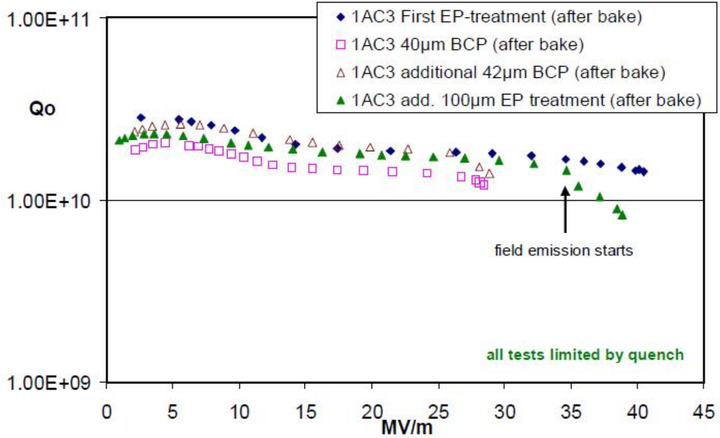


700 μm defect, $E_a < 20$ MV/m at quench

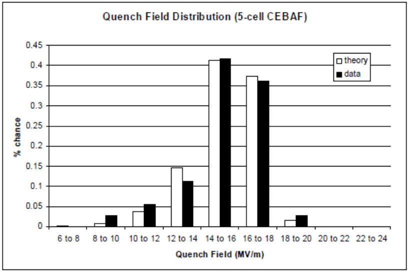


1 mm defect, Maximum $E_a = 39$ MV/m

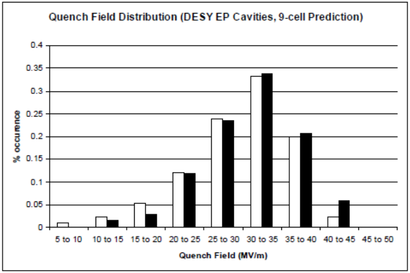
BCP quench field < EP quench field[6]



CEBAF BCP quench field < DESY EP quench field[4].

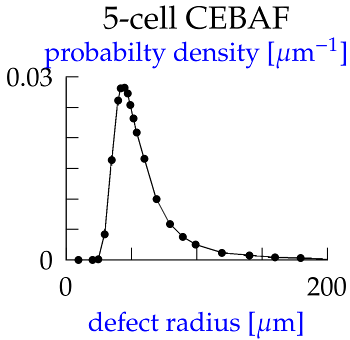


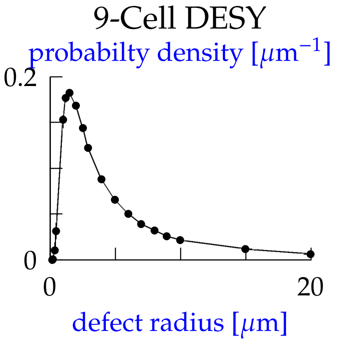
peaks at 14-15 MV/m



peaks at 30-35 MV/m

Statistical Analysis of Defects[4]





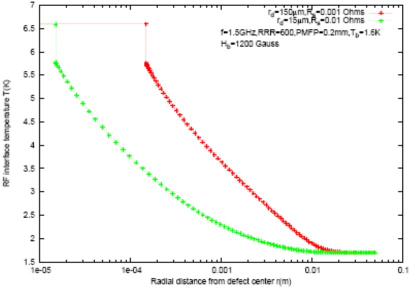
- chemical treatment affects the defect size?
- combination of segregation of impurities at grain boundaries with field enhancement produces lower quench fields for BCP cavities?

Concluding Remarks

- The thermal model is reasonable.
- The thermal model with ring-shape defects explains why some pits quench and others do not.
- Thermometry is still key to understanding defects with quench fields at 35 MV/m and beyond.
  - The size of the heating region can be determined by thermometric measurements of preheating.
  - Defects smaller than the resolution of optical inspection may be studied.

Thank You!

Side-heating dominates:



(a) r.f. surface temperature distribution

the heat transfer rate through the sides of a cylinder extending down from the defect to the wall is the same for both defects.

The defect temperature and quench field are the same.