How important is the surface finish/roughness in determining the performance of Nb cavities?

Introduction

Peter Kneisel

Jlab

- It is generally “believed” that appropriate surface smoothness is “key” to good/excellent cavity performance
- Therefore electropolishing has become the technology of choice not only for ILC cavity gradients (Eacc ~ 35MV/m), but also for much less demanding performance goals, e.g. cw application ~ 20 MV/m or lower
- “Buffered chemical polishing” has been more or less “outlawed” because of the resulting “rough” surface finishes , grain boundary etching and resulting “field enhancements”.
- It is also believed that smoother surfaces can be cleaned better, such limiting field emission
- Myth: “electropolishing” (+ or barrel polishing, which also gives very smooth surfaces) solves all performance problems: is it true ? And if so,why?
  - Smooth surface?
  - No field enhancements?
  - No grain boundary etching?
  - No Q-drop after baking: this is true above 100-120 mT, which can be achieved with bcp treatment also; bcp provides also some elimination of Q-drop, but less effective; why??
  - Better cleaning?
- Is this justified? Is EP the “miracle cure”?
- There have been failures with EP following BCP: Jlab large grain upgrade cavity DESY/Jlab 9-cell seamless cavity, single cell large grain at DESY…

Roughness: BCP vs EP

K.Saito et al, SRF 1997, Abano Terme

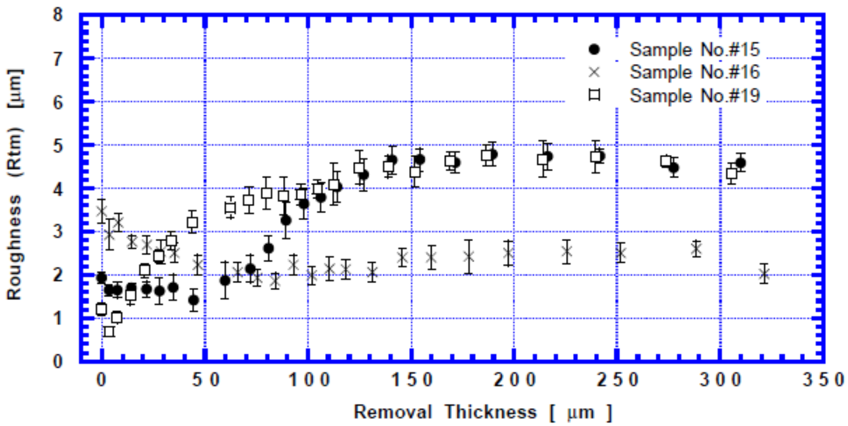


Fig.11 Relationship between material removal and surface roughness with CP.
The error bar means the variation in three points measurements.

Proceedings of the 1997 Workshop on RF Superconductivity, Abano Terme (Padova), Italy

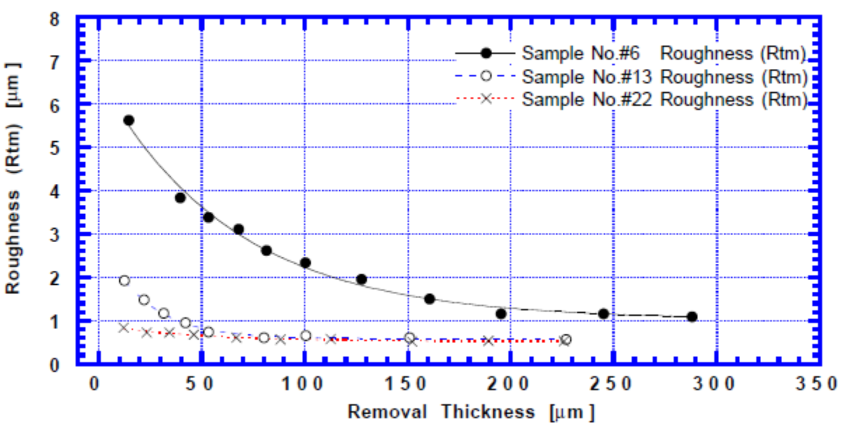


Fig. 12 Relationship between material removal and surface roughness with EP.

History (2003)

K.Saito ; Development of Electropolishing technology for Superconducting cavities

PAC 2003, 463ff

"This method can produce high gradients of 40 MV/m; a required surface smoothness is estimated to be less than 2 micron in order to prevent field enhancement problems in superconducting cavities"

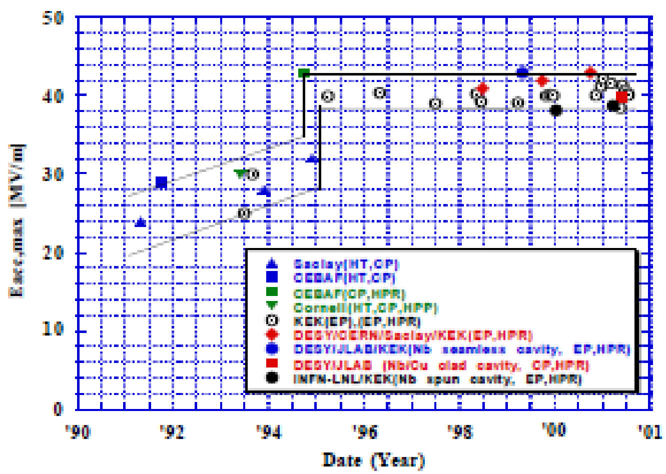


Figure 6: Review of the high gradient in last 10 years.

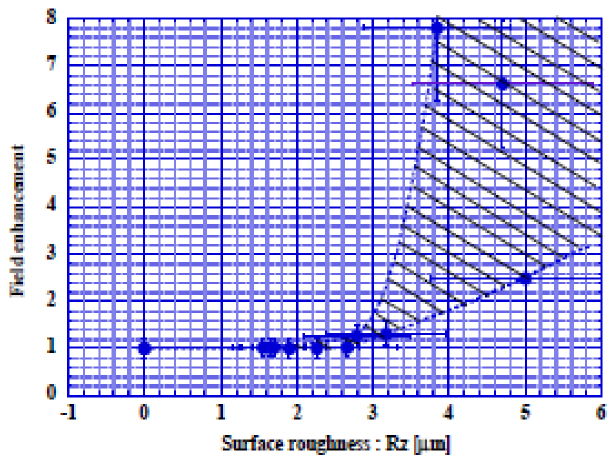
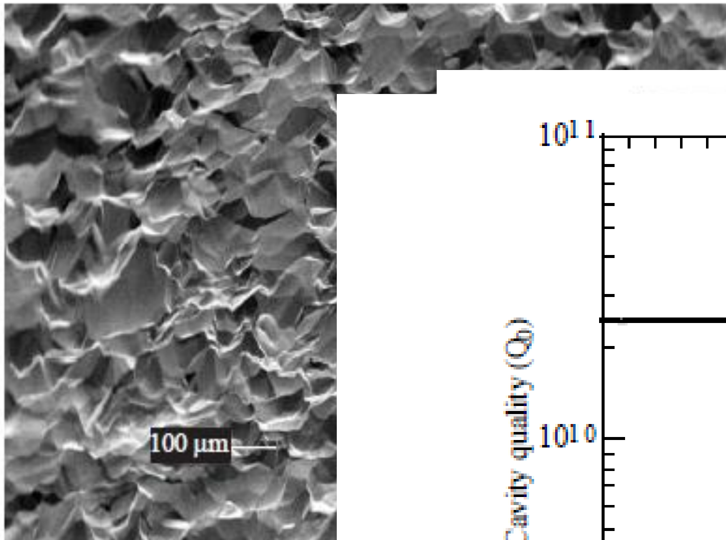
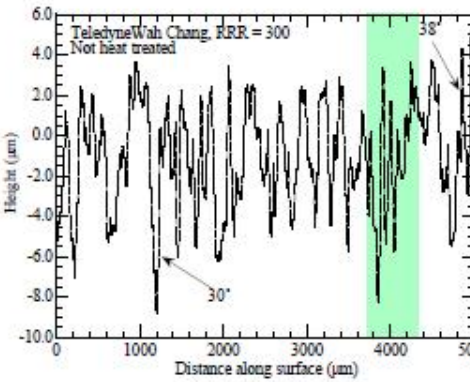


Figure12: Estimated surface roughness versus the field

Field Enhancement: J.Knobloch et al; "High Field Q-slope in sc cavities due to magnetic field enhancements at grain boundaries", SRF 1999





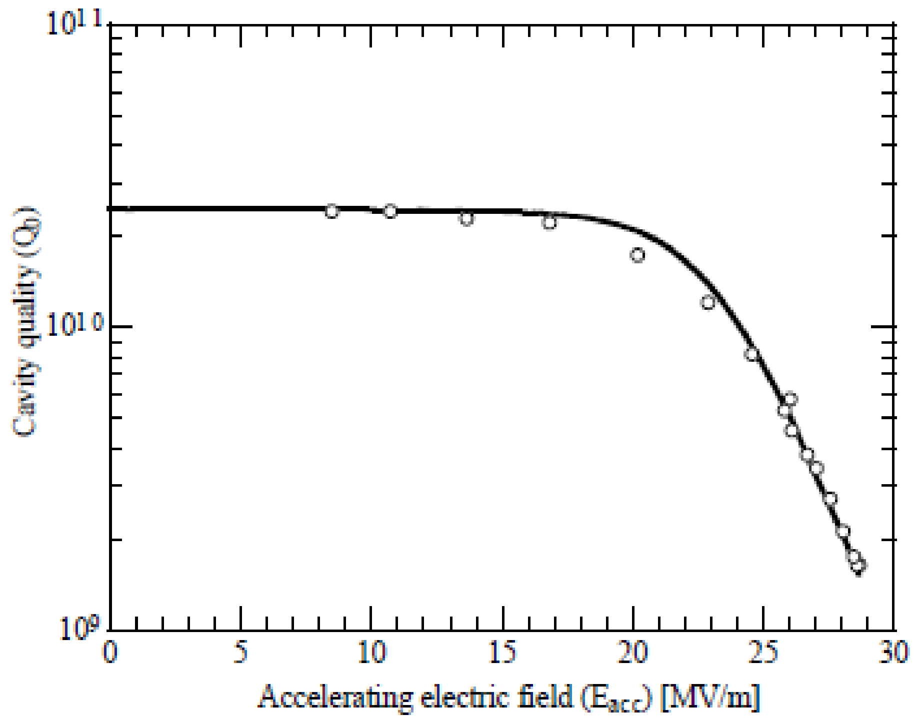
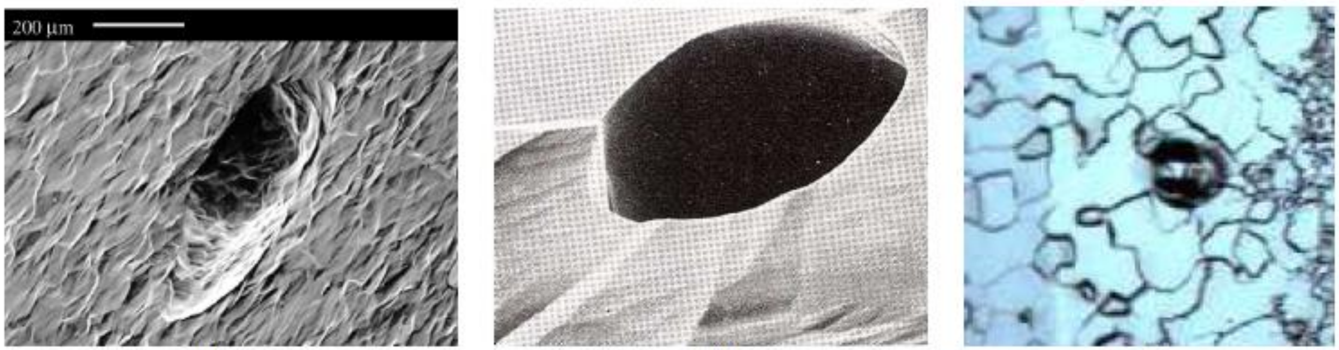


Figure 17: Comparison of the measured cavity quality (Test A) with that calculated by (25) using $H_{crit} = 2000$ Oe.

Pro’s and Con’s

- In several more recent publications it has been postulated that field limitations in niobium cavities can occur at areas of enhance magnetic fields due to pits and bumps [V.Shemelin,H.Padamsee; “**MAGNETIC FIELD ENHANCEMENT AT PITS AND BUMPS THE SURFACE OF SUPERCONDUCTING CAVITIES”,TTC Report 2008-007]**



(a) (b) (c)

- Surface smoothness is only of secondary importance

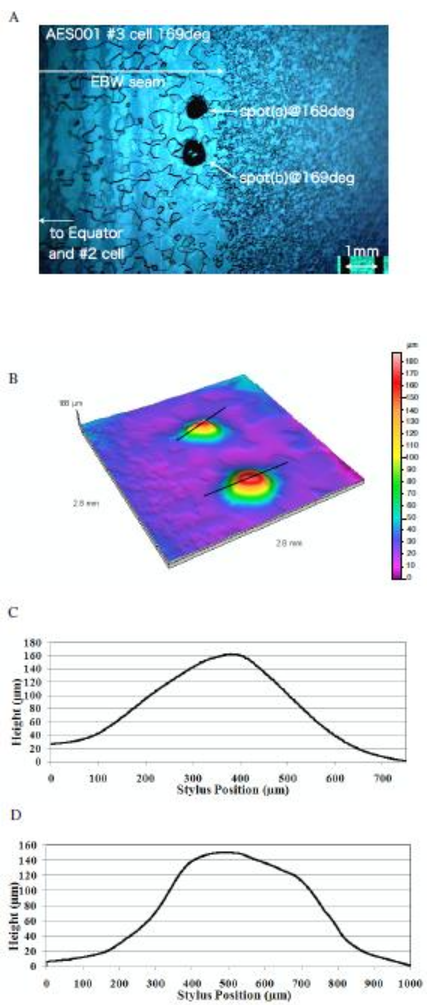
Supercond. Sci. Technol. **24** (2011) 035002 (8pp) doi:10.1088/0953-2048/24/3/035002

Routine characterization of 3D profiles of SRF cavity defects using replica techniques

M Ge, G Wu, D Burk, J Ozelis, E Harms, D Sergatskov, D Hicks and L D Cooley

Pro’s and Con’s

Example of Replica



- All the features found in this study were located at or near the equator electron beam weld, leaving open speculations about the the importance of the heating and cooling mechanisms combined with electro-chemical reactions (trapping of impurities, gas pockets, segregation of foreign materials..)
- These possible causes for limitations make the forming of seamless cavities even more attractive.
- Despite a less than “ideal” surface with many imperfections the seamless cavities perform astonishingly well (see later)

EP vs BCP

Pro's

- In a test series of alternating surface treatment between bcp and EP cavity performance always degraded after bcp [E.Kako , S. Noguchi, M. Ono, K. Saito, T. Shishido, B. Aune*, P. Charrier*, M. Juillard* and H. Safa "**IMPROVEMENT OF CAVITY PERFORMANCE BY ELECTROPOLISHING INTHE 1.3 GHZ NB SUPERCONDUCTING CAVITIES", PAC1999, p.432]**

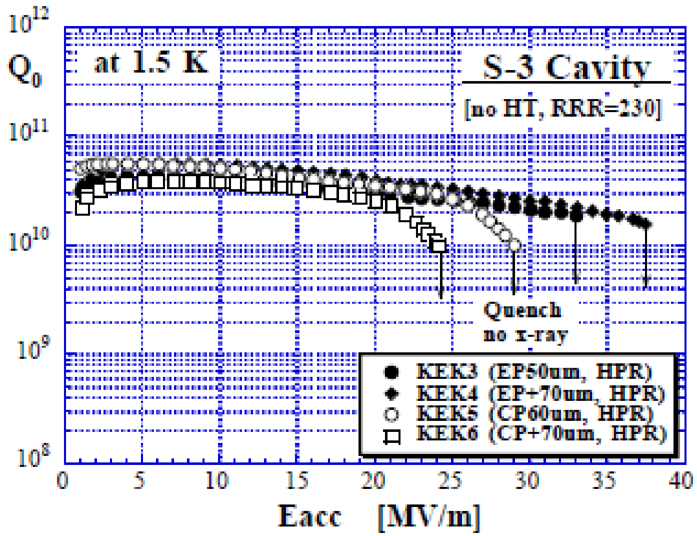
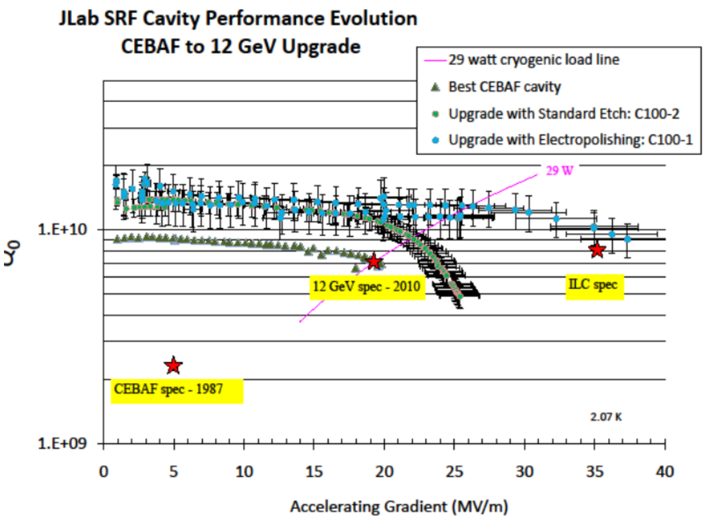


Figure 4: Cavity degradation due to CP after EP

- At Jlab, multi-cell bcp'd cavities improved significantly after light EP ($\leq$ 30 μm)

  [Data collected by C.Reece, Jlab]



Upgrade Cavity [Data from C.Reece]

BCP

- bcp- cavities improve with more material removal (rougher surface)
- BCP cavity Saclay, Jlab, DESY, KEK achieved > 40 MV/m
- PKU large grain with large grain boundary step achieved ~ 42 MV/m
- Seamless cavities achieve > 35 MV/m with bcp
- Replica studies indicate that limitation is caused by individual sites

  (M.Ge, G.Wu et al, Supercond.Science and Techn, 24, 2011)

- Bcp does not increase emitter density on samples (Uni Wuppertal) up to 200 MV/m; "Further measurements showed no significant influence of the surface roughness on the removal of particulate contamination by ultra-pure water" (N.Pupeter et al.; SRF 1995)

Material removal: e.g. P.Kneisel et al, SRF 1995, one of several

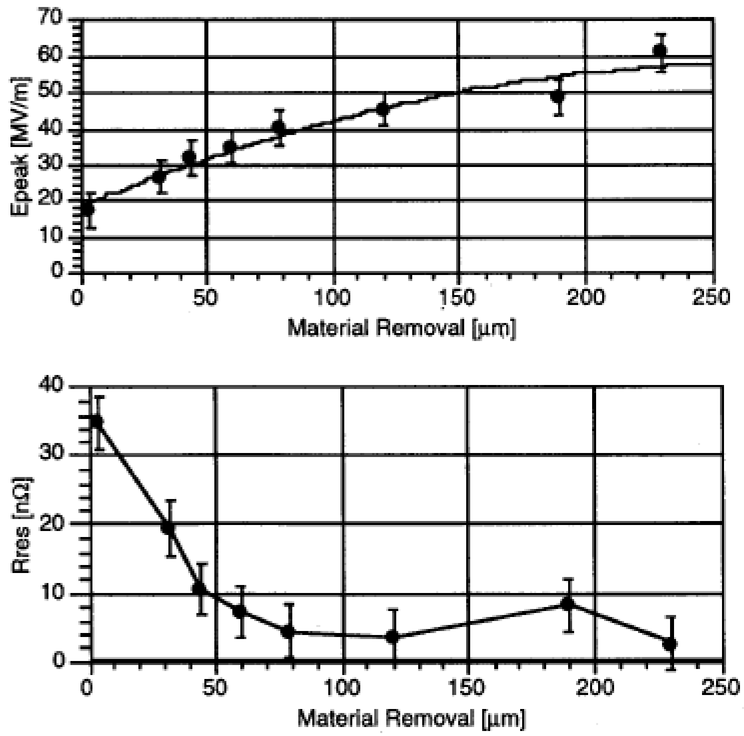
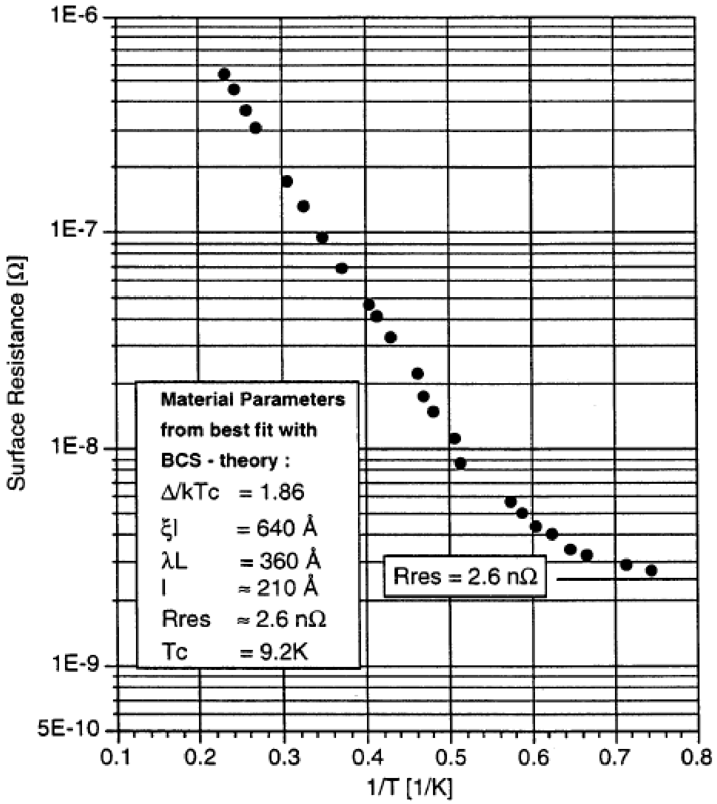


FIGURE 5: Effect of material removal on peak surface electric fields and on residual surface resistance.

History (1995)

P.Kneisel,R.W.Roeth,H.-G.Kuerschner; “Results from a nearly “Defect-free” Niobium cavity”, 5th SRF Workshop (1995)

Q = 1 x 10^{11} at 1.3K; E $_{acc}$ ~ 42 MV/m, app. 160 micron bcp



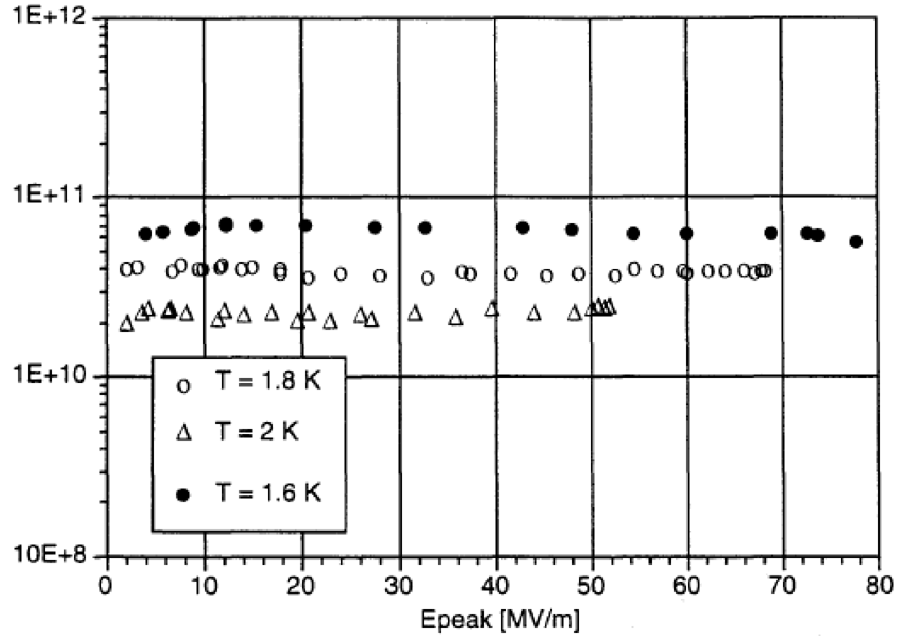
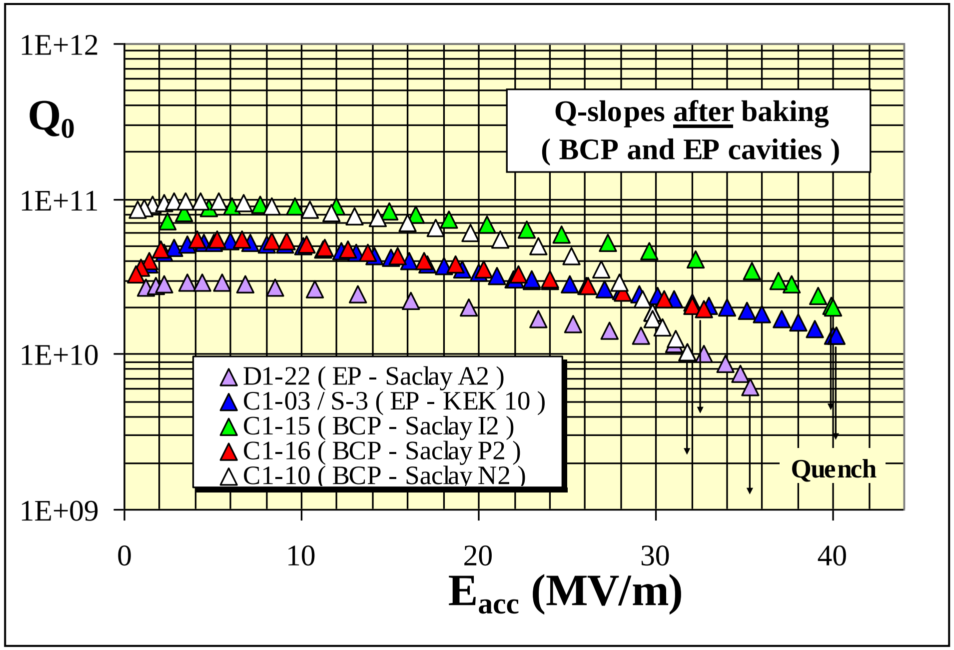


Fig. 2: Q_0 vs. E_{peak} at 3 different temperatures for a nearly "defect - free" niobium cavity

History (2003)

B.Visentin,

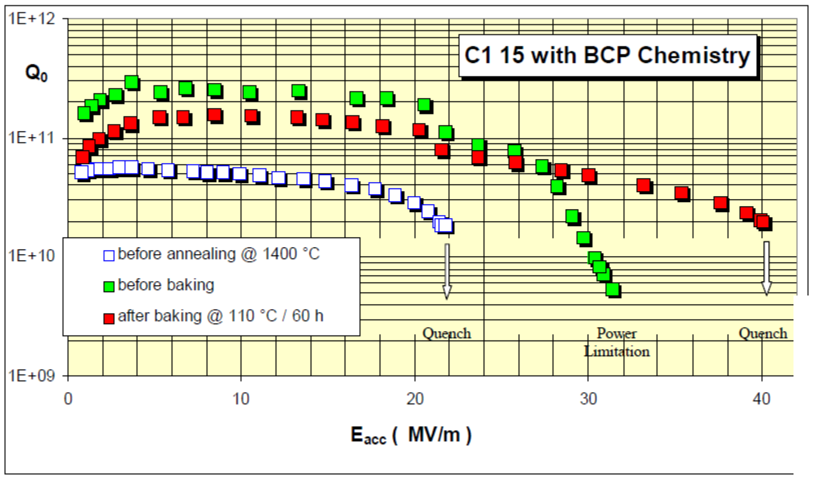
SRF2003, MO-P19



History: B.Visentin, TTF Meeting Saclay, April 2002

LAST RESULTS ON A B.C.P. NIOBIUM CAVITY

E_{acc} = 40 MV/m - $Q_0 = 2 . 10^{10}$



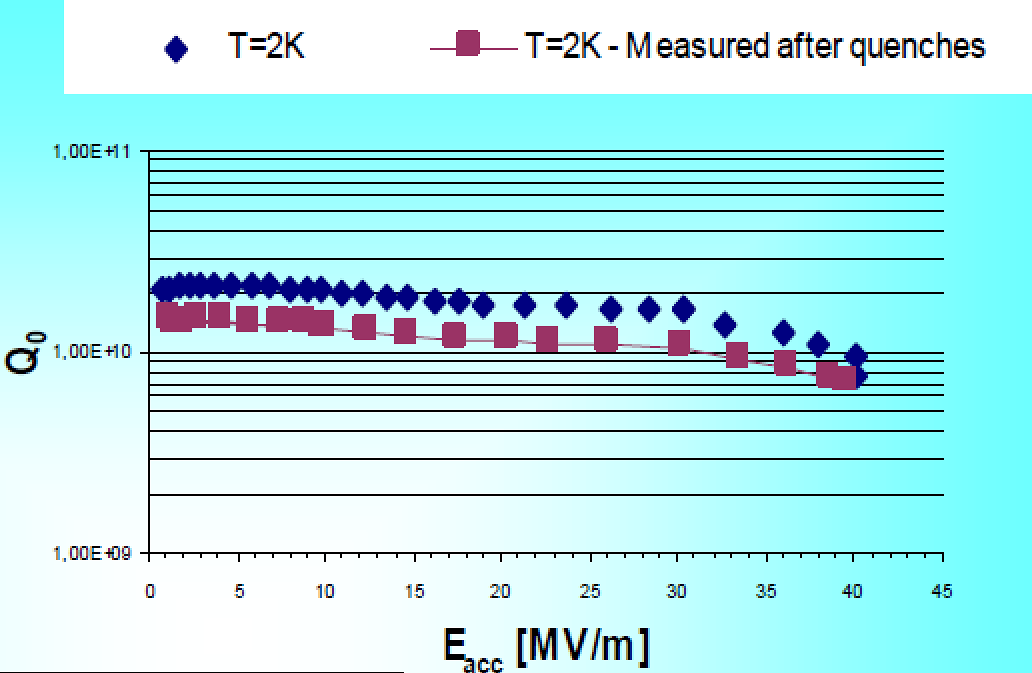
TTF Meeting - April 3/5, 2002 - Saclay *Bernard VISENTIN - CEA S*

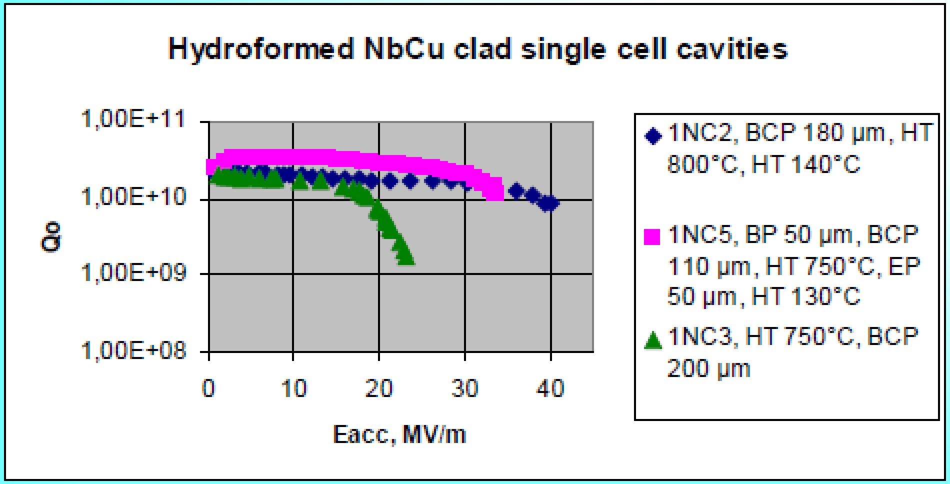
SOME COMMENTS

- **Classical BCP compared to Electropolishing :**
  - High gradients are also achieved by BCP chemistry
  - Cavity baking is so efficient to remove high field slope
- **Small processing around 20 MV/m**
- **This result is the third event by the world :**
  - Nb defect-free cavity (P. Kneisel - 7th RFSC Workshop - Gif/Yvette - 1995)
  - NbCu clad-cavity (W. Singer - 10th RFSC Workshop - Tsukuba - 2001)

NbCu single cell cavity 1NC2 produced at DESY by hydroforming from explosively bonded tube. Preparation and HF tests at Jeff. Lab: 180 µm BCP, annealing at 800°C, baking at 140°C for 30 hours, HPR.

Defect free cavity (talk of B.Visentin SRF 2003)





Summary of HF tests on NbCu explosively bonded cavities. Preparation and RF tests at JLab, KEK, DESY

Seamless cavities [P.Kneisel, G.Ciovati, X.Singer,W.Singer,I.Jelezov, SRF2009, THPPO058]

Surface Finish

Figure 3: Examples of interior cavity surfaces.

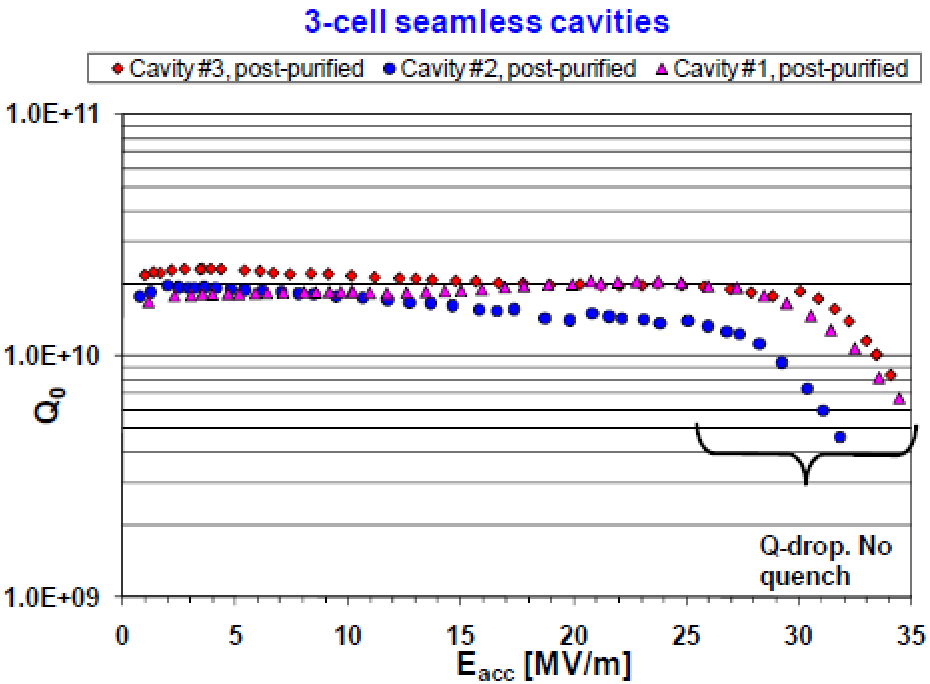
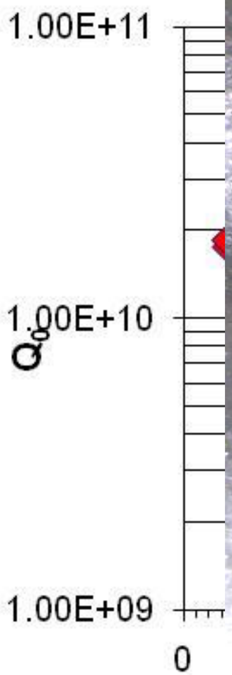
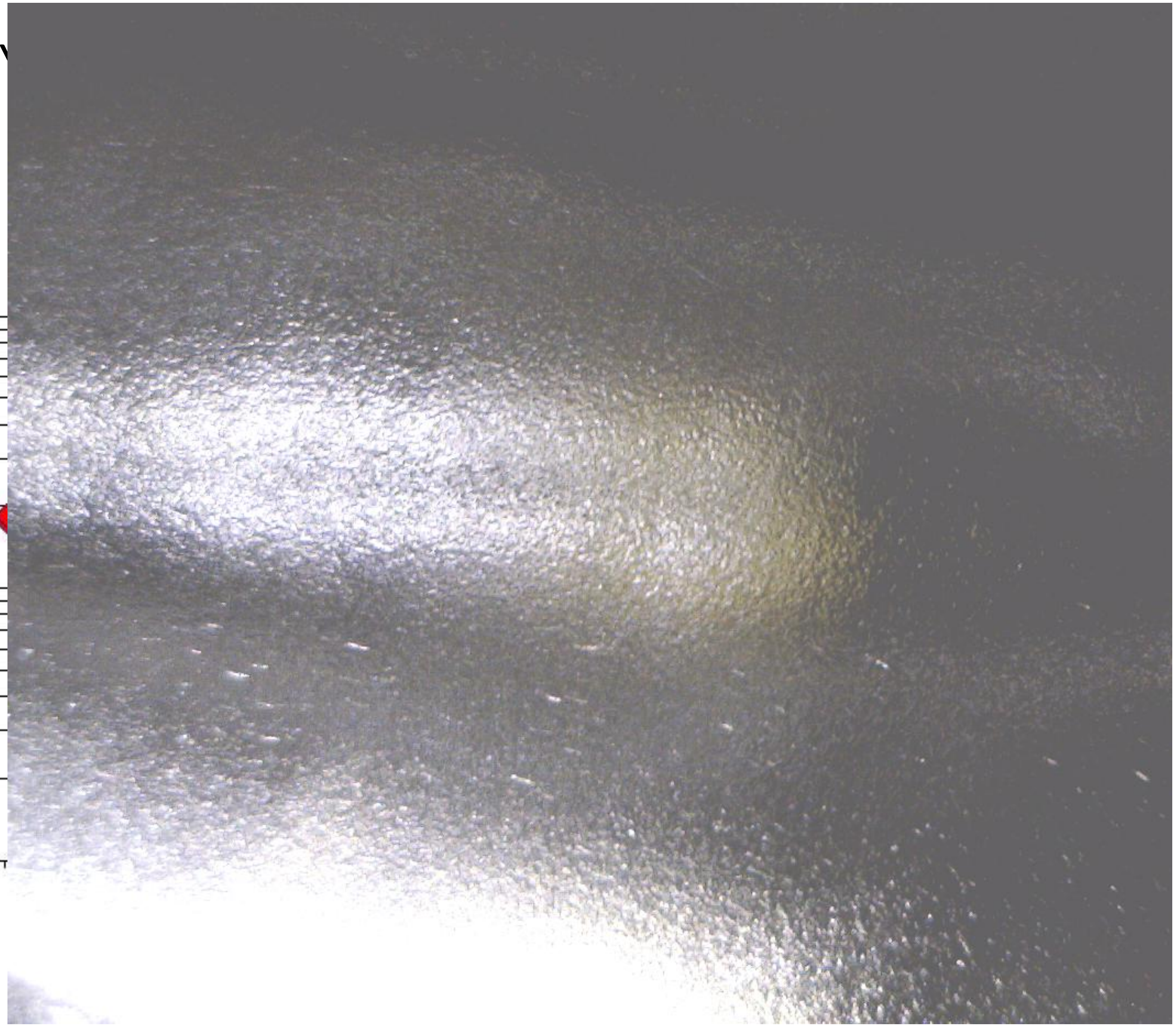


Figure 2: Performance of all 3-cell seamless cavities after post-purification at 1250C for 3 hrs.

Seamless Cavities(2)

2-cell DESY





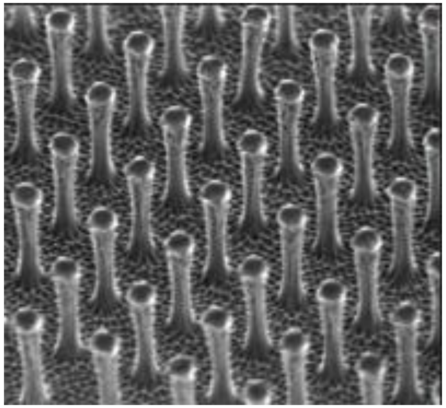
Smooth Surfaces can be cleaned better?

- One of the arguments for applying EP in cases of “mediocre” performance goals is that a smooth surface can be cleaned better, therefore reducing the chances of Field emission

- Even if this would be true, it neglects the possibility of re-contamination

- Particles stick to surfaces because of adhesion. The interactions include molecular interaction, electrostatic interaction, liquid bridges, double layer repulsion, and chemical bonds. The most dominant forces are van der Waal’s forces . They increase with surface area and are inversely proportional to distance^2 (Why can a gecko climb a glas wall? Why does a dusty car not get cleaned when it drives 100 mph?)

Gecko foot:millions of sub-micron hairs: large surface area, small distance



My Conclusion

- Surface roughness is of secondary importance

  Generally field enhancements due to grain boundary etching are over emphasized: important is the “alignment “ to the field lines and that is usually “random”
- Field limitations are caused by individual spots

  Those are most often detected near the equator weld/heat affected zone
- No such areas have been seen yet in seamless cavities, which perform quite well even with less than “ideal” surface finishes
- More attention should be paid to this technology
- There is no need for EP for gradients corresponding to peak magnetic fields of ~ 100 to 120 mT (“Is it overkill, if one is concerned with budgets?”)
- It is a “myth” that smoother surfaces can be cleaned better: the procedure and the configuration of the HPR system matters.