Investigation of large grain cavity surfaces

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Replicas of cavity RF surface of a large grain 1-cell cavity were made. The cavity topology and surface roughness were compared to other 1-cell cavities. Field enhancement of grain boundaries will be analyzed and discussed.

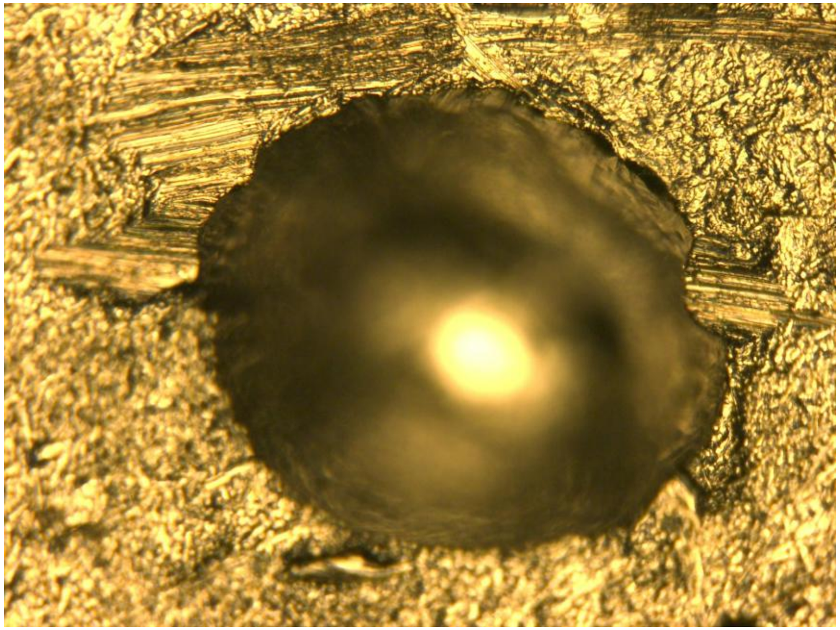
Outlines

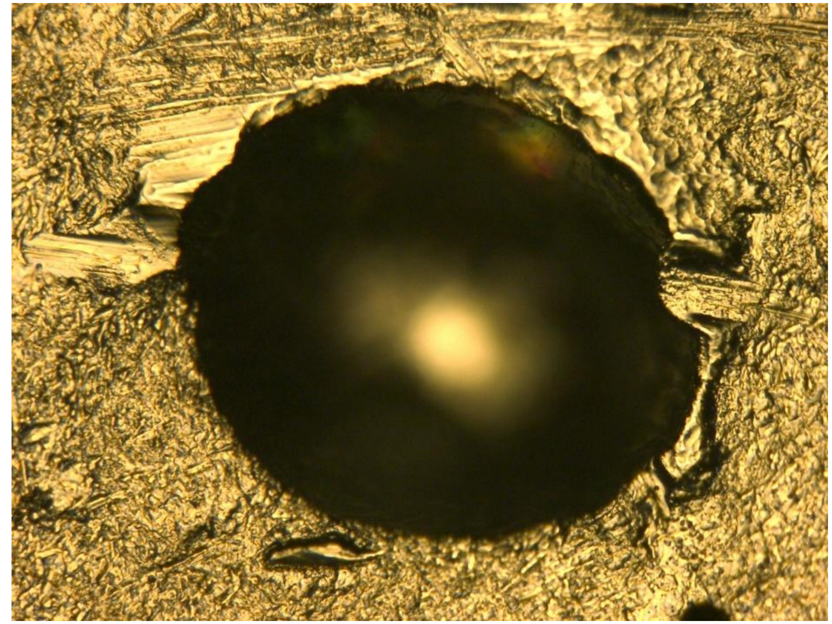
- Fermilab surface replica technique
- Large grain cavity surface optical inspection
- Cavity replica results
- Large grain cavity surface compared to other cavities
- Summary

Fermilab Cavity diagnostics – Surface replica

- To reveal the 3-D profile of geometric defects and to establish the mechanism of local quench at the defects.
- To assess surface preparation effectiveness by extracting surface roughness
- Resolution in micron detail *(to resolve features~ <100μm in diameter; <10μm in depth)*.
- Pouring silicone in and peeling it out from deep 9-cell cavity.
- No degradation for RF performance.

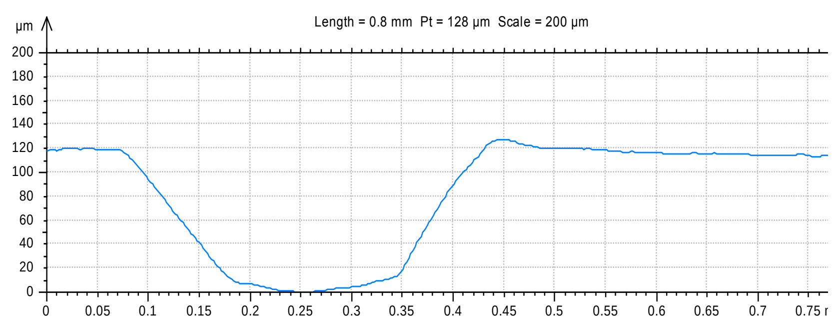
M Ge, G Wu, D Burk, J Ozelis, E Harms, D Sergatskov, D Hicks, and L D Cooley, Routine characterization of 3-D profiles of SRF cavity defects using replica techniques, Manuscript to be submitted to *Journal of Superconducting Science and Technology.*



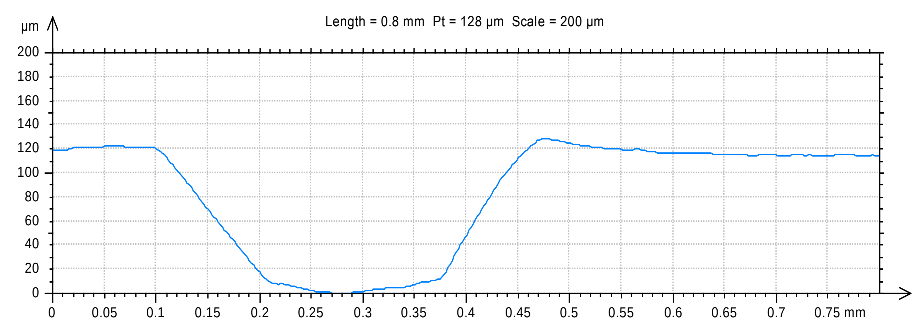


A man-made pit 125µm deep, 300µm in diameter

Pit replica



profile of a pit on the Nb coupon

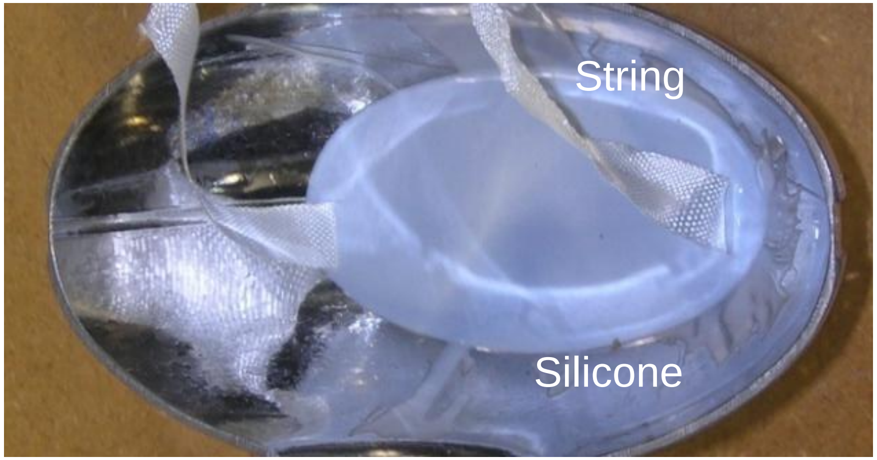


profile of pit's replica

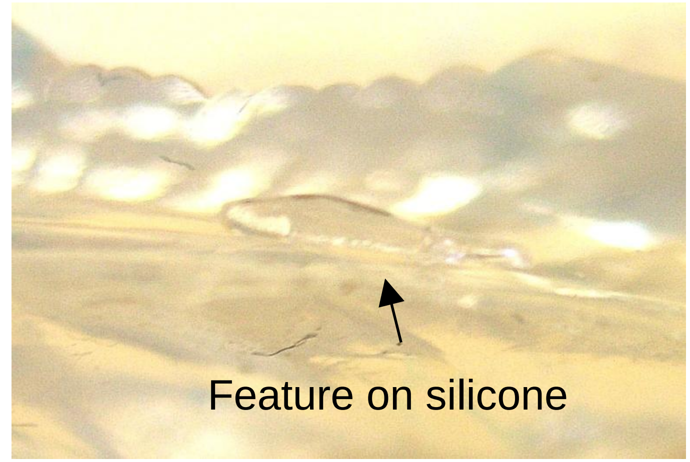
Overall, 1 µm detail can be replicated

M Ge, G Wu, D Burk, J Ozelis, E Harms, D Sergatskov, D Hicks, and L D Cooley, Routine characterization of 3-D profiles of SRF cavity defects using replica techniques. Manuscript to be submitted to Journal of Super. Sci. and Tech.

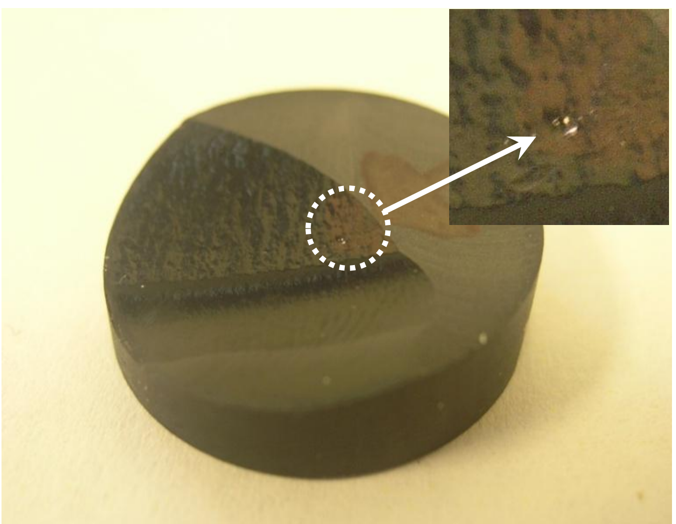
Surface replica – extraction and surface scan



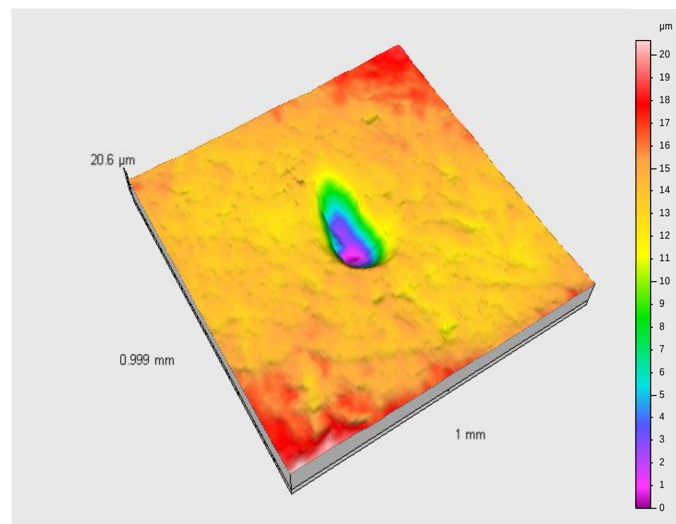
Silicone pouring into an open half cell with a string embedded



Visually indentify the features

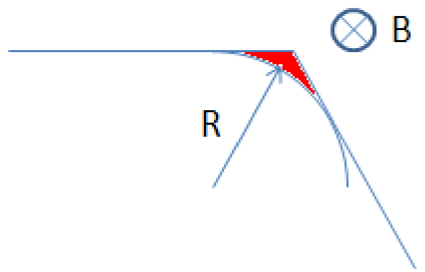


Epoxy casting on silicone



Feature's 3D shape by profilometer scanning

A discussion about surface detail



As magnetic field at the edge of the defect approaches the thermal critical magnetic field, the magnetic flux then enters the corner area deeper, depending on the field enhancement factor.

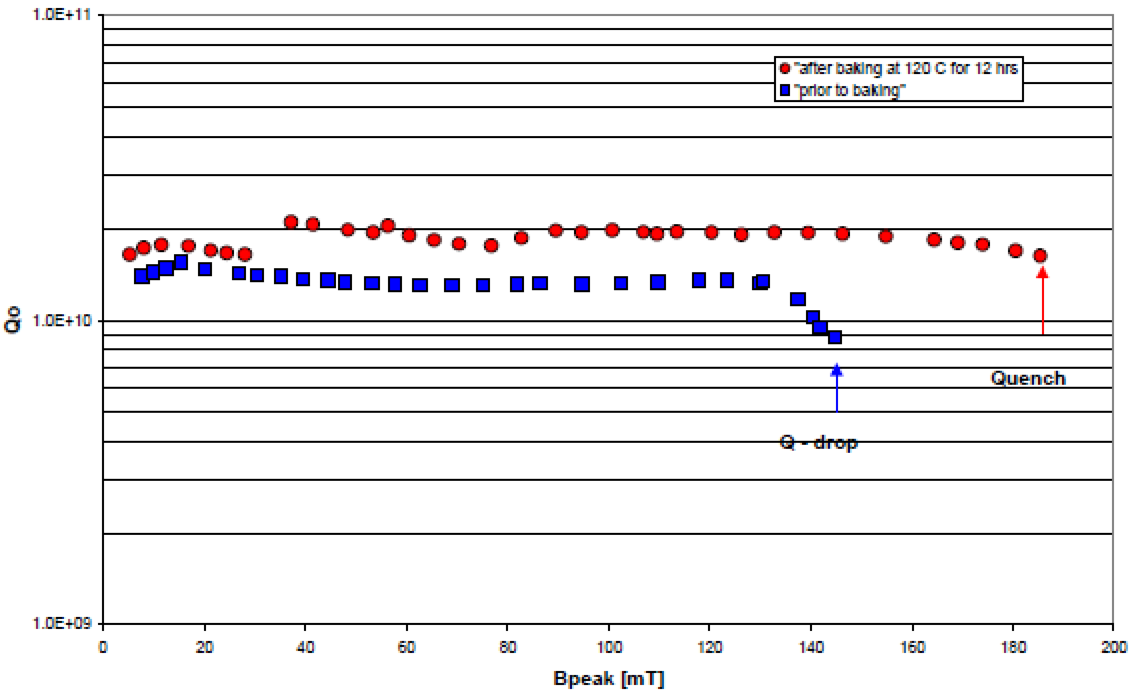
At this time, the defect can be divided into one lossy corner and a remaining flux-free body.

The corner is in micron scale.

Surface replica resolution sufficient to characterize the RF surfaces

J. Knobloc, et al., "High Field Q Slope in Superconducting Cavities Due to Magnetic Field Enhancement at Grain Boundaries," in *Proc. of 9th Workshop on RF Superconductivity*, Santa Fe, New Mexico,1999, pp. 77-91

1-cell cavity: PKU-LG1



43 MV/m. 185 mT

NingXia large grain RRR niobium

Post purified
BCP only
Low temperature baking

Features found:
- BCP stains
- BCP etching pits
- Weld Pits
- Steep grain boundaries

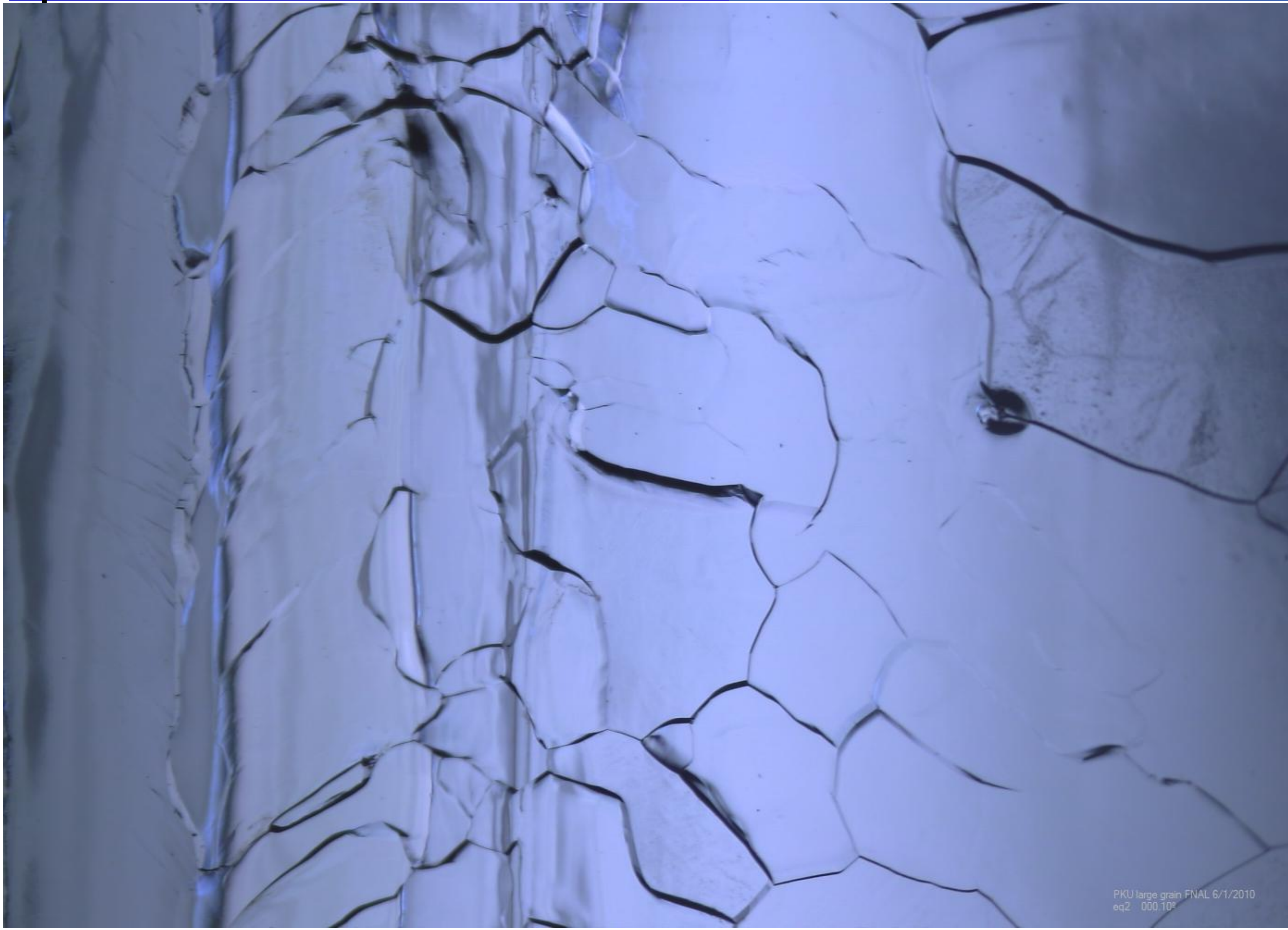
P. Kneisel, "Progress on Large Grain and Single Grain Niobium – Ingots and Sheet and Review of Progress on Large Grain and Single Grain Niobium," in *Proc. of 13th Workshop on RF Superconductivity*, Beijing, China, 2007.

Optical features of PKU-LG1

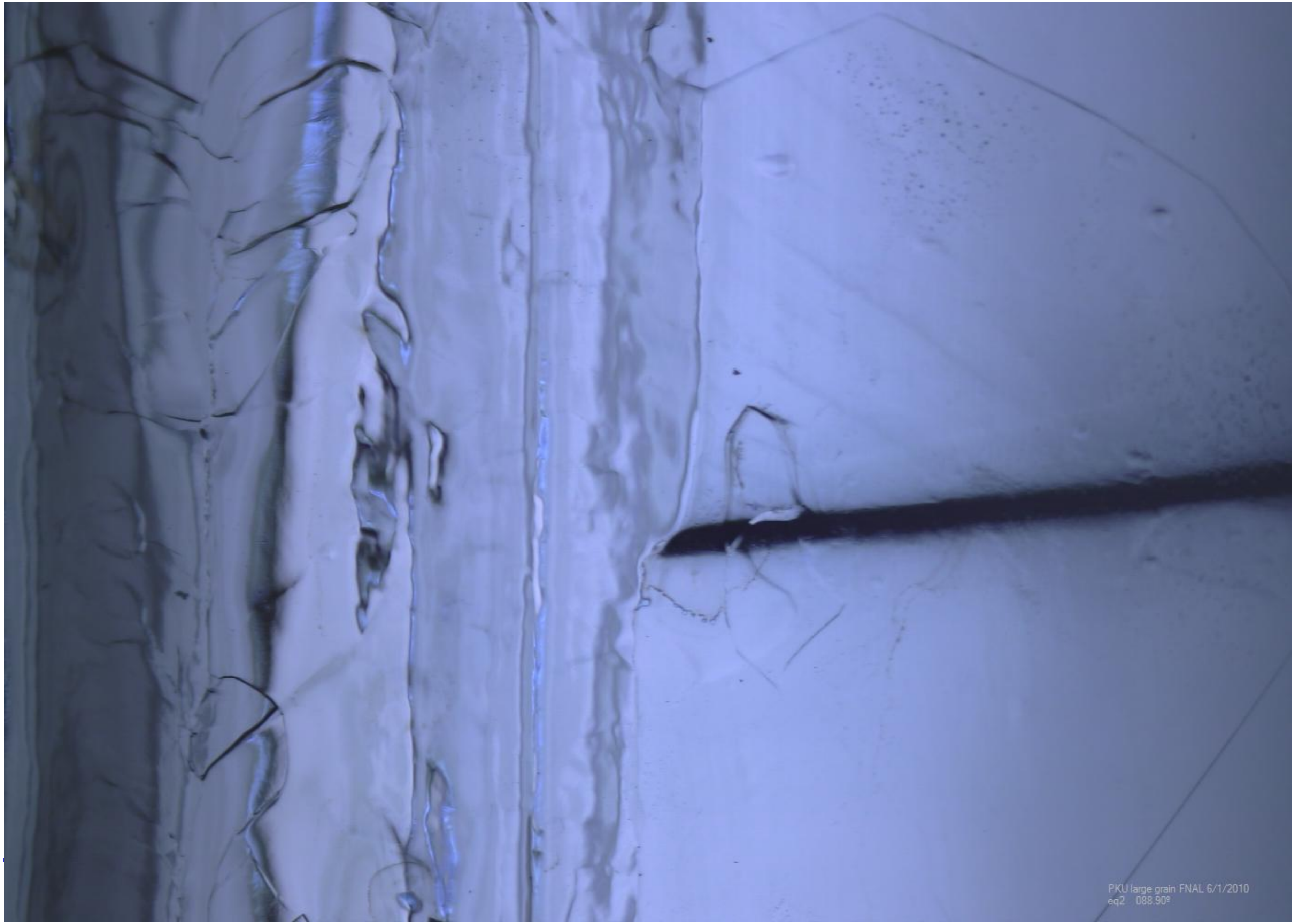
Fermilab

Optical features of PKU-LG1

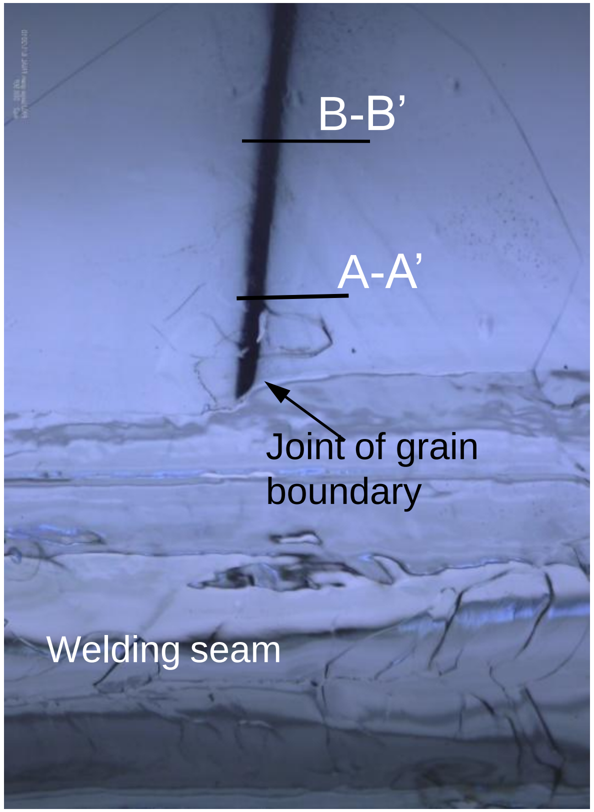
Optical features of PKU-LG1



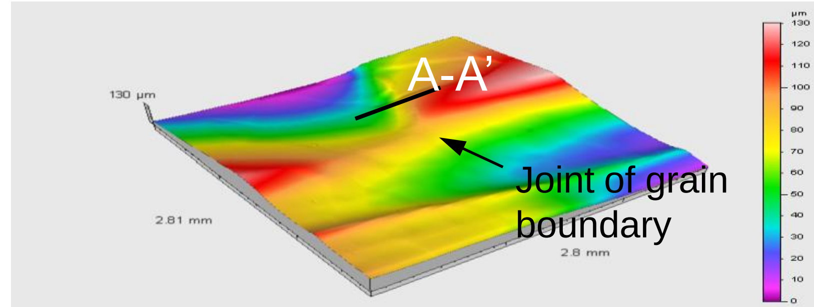
Optical features of PKU-LG1

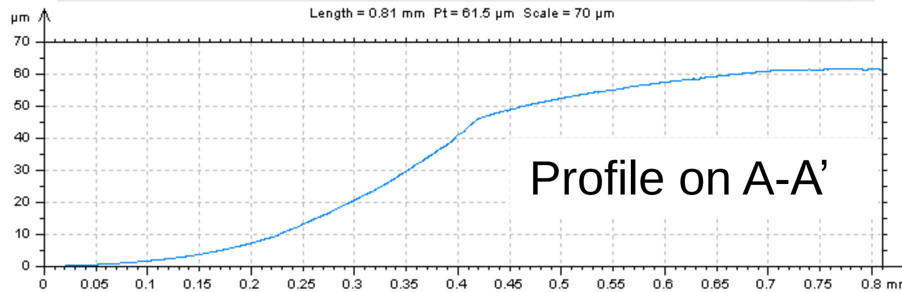


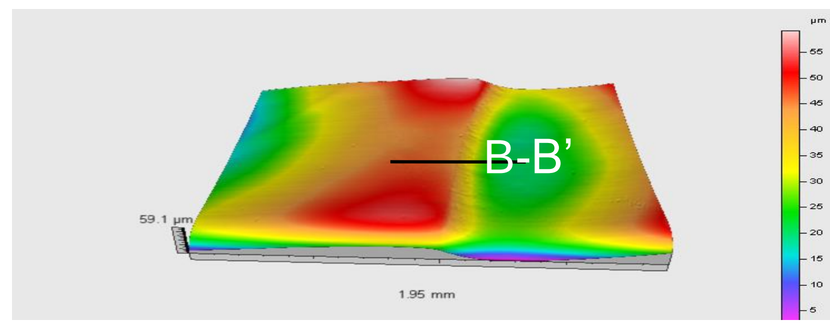
The measurement of grain boundary step

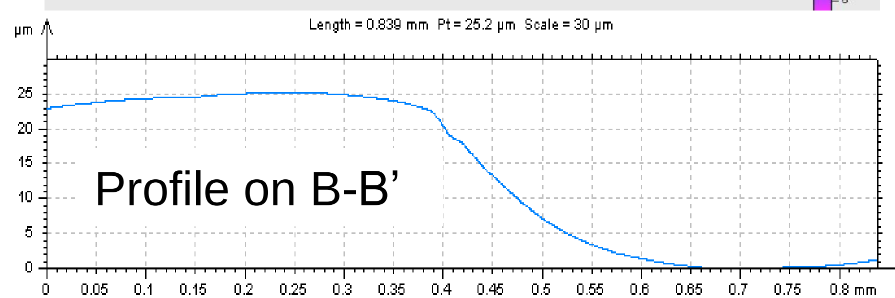


Optical image of PKU-LG1





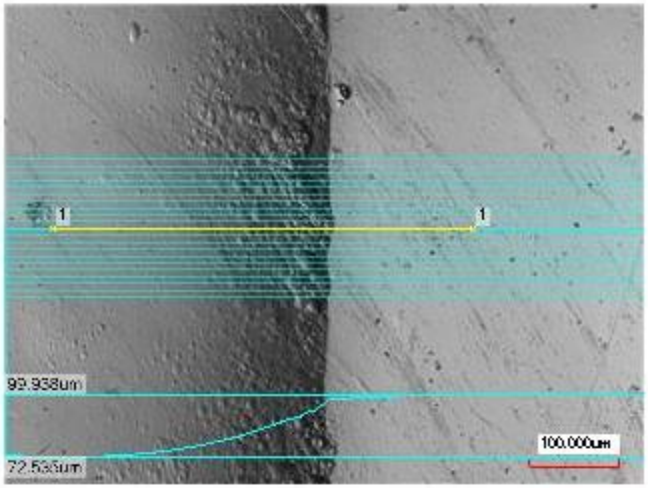


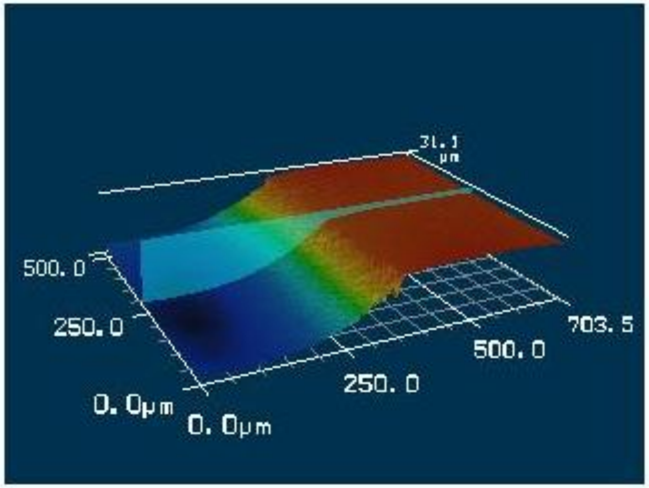


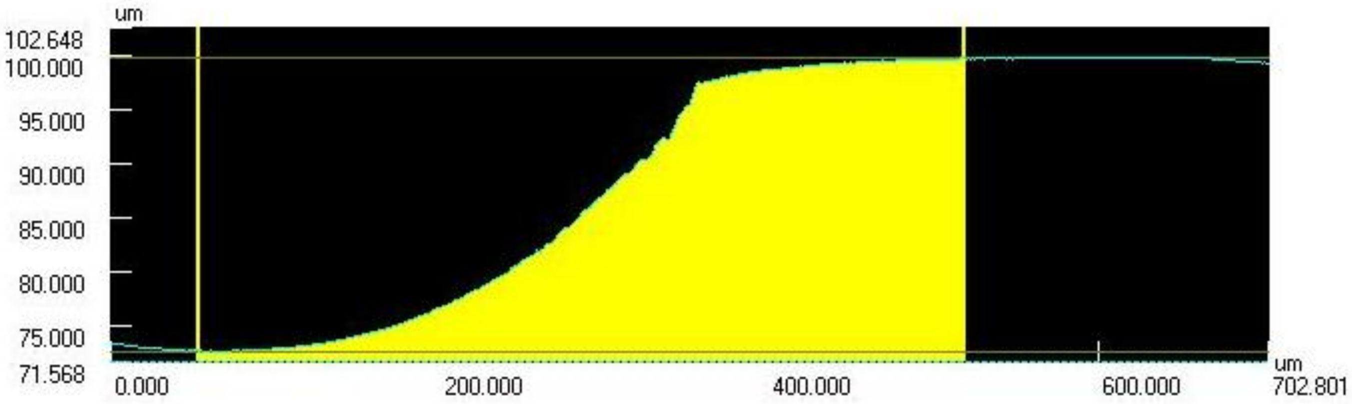
The height of step on A-A': 60µm
The height of step on B-B': 25µm

A result from surface scanning profilometer

The measurement of grain boundary step







A result from confocal laser scanning microscope

Field enhancement factor with step model

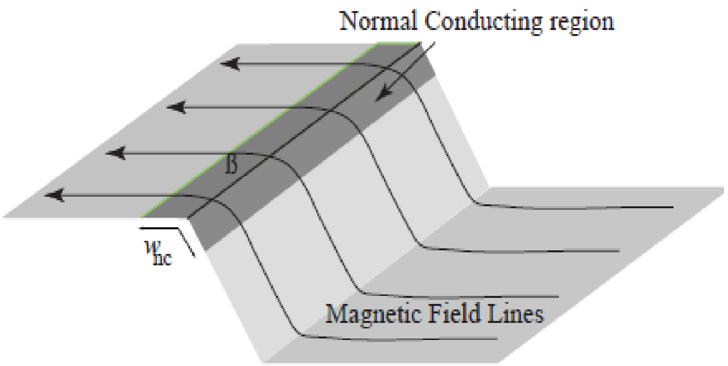


TABLE 1: Field enhancement factor of cavity defects

Cavity	Field enhancement factor	Maximum H field [mT]
TB9ACC017	2.2	54.1
AES001	1.5	96.8
TE1AES004	1.2	168.0
PKU-LG1	1.6	185

Magnetic field enhancement model suggested the features in this cavity cannot fully explain the cavity performance limitations.

Geometric topology serves only a secondary role in limiting cavity performances.

- Cavities have apparent geometric defects
  - Bumps
  - Pits
  - Scratches
  - Grain boundaries (Large grain)
- Cavities have no visible defects

  <u>Surface roughness in</u>
  - Weld seam
  - Heat Affected Zone (HAZ)
  - Normal area.

  <u>Cavities represent six categories</u>
  - Fine grain BCP
  - Large grain BCP
  - Single crystal BCP
  - Fine grain light EP
  - Fine grain heavy EP
  - Fine grain Tumble polishing plus light EP

Cavity surface roughness

Fermilab

Welding seam | HAZ | Normal area

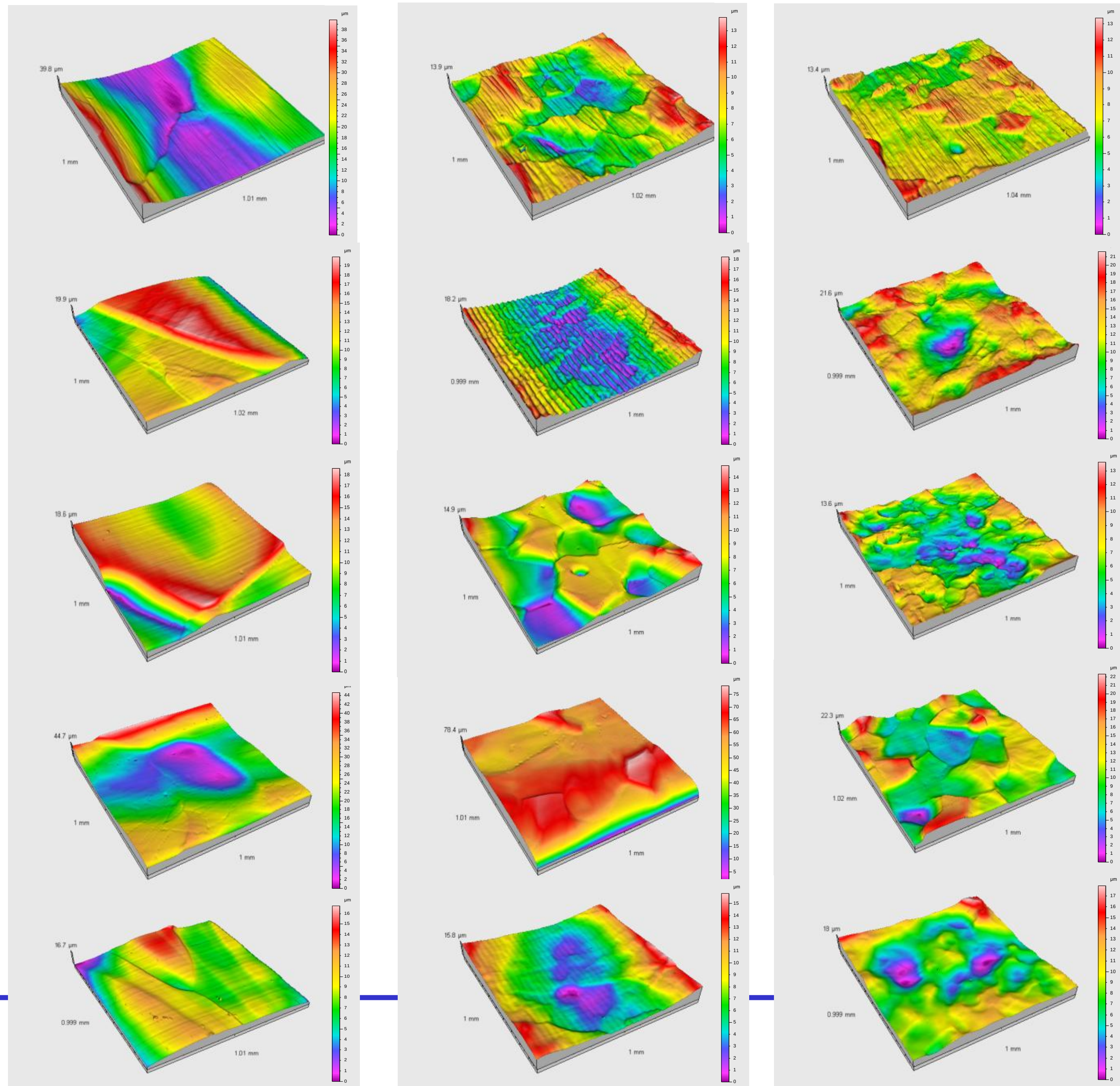
Brand new
TE1PAV001
(3 similar cavities)

Brand new
TE1ACC006
(2 similar)

PKU single crystal
BCP'd cavity

BCP'd 70µm
NR-6
(3 similar)

EP'd 40µm
TE1ACC005



Cavity surface roughness

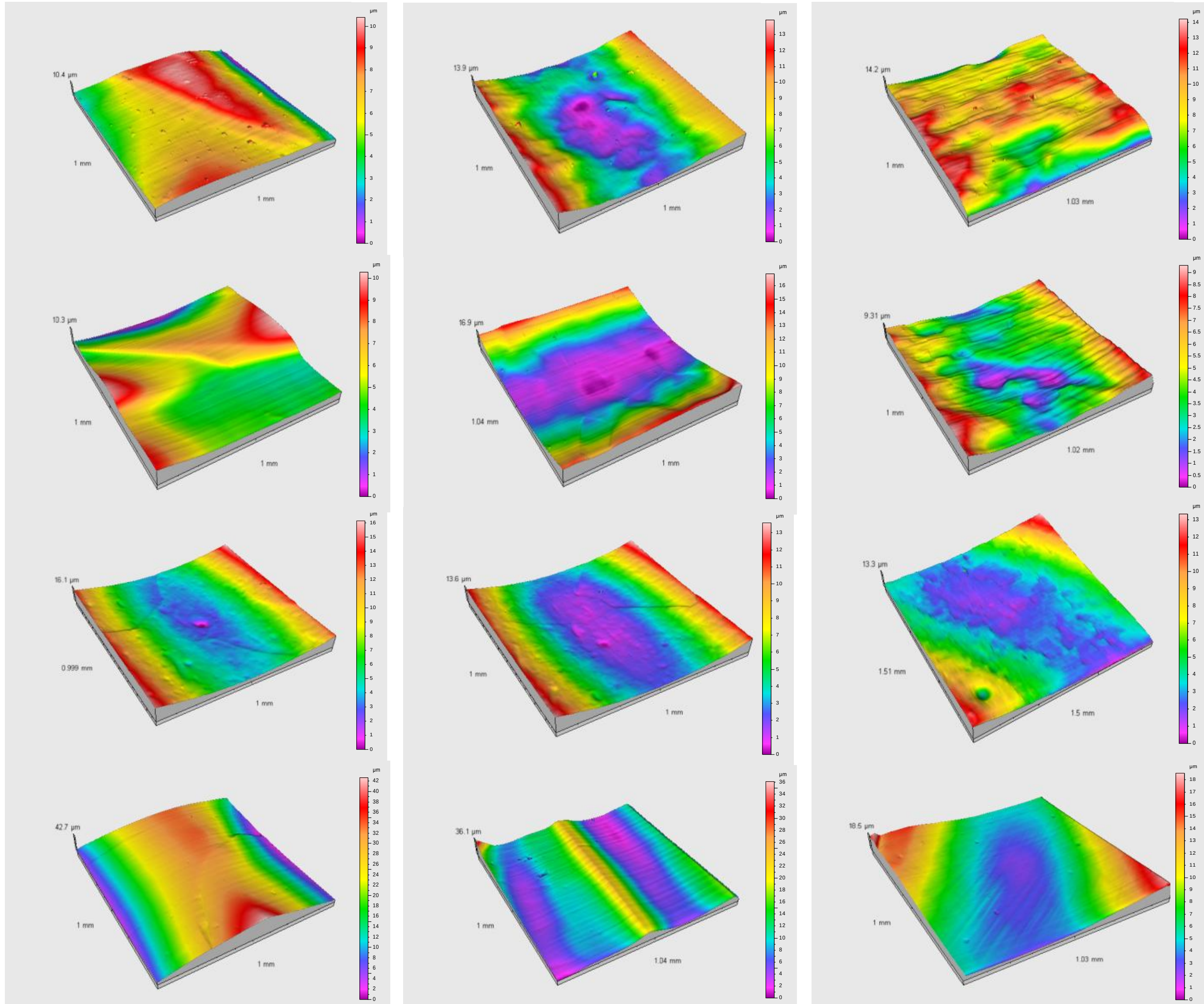
Welding seam | HAZ | Normal area

EP'd 120µm
TE1ACC003
(8 similar)

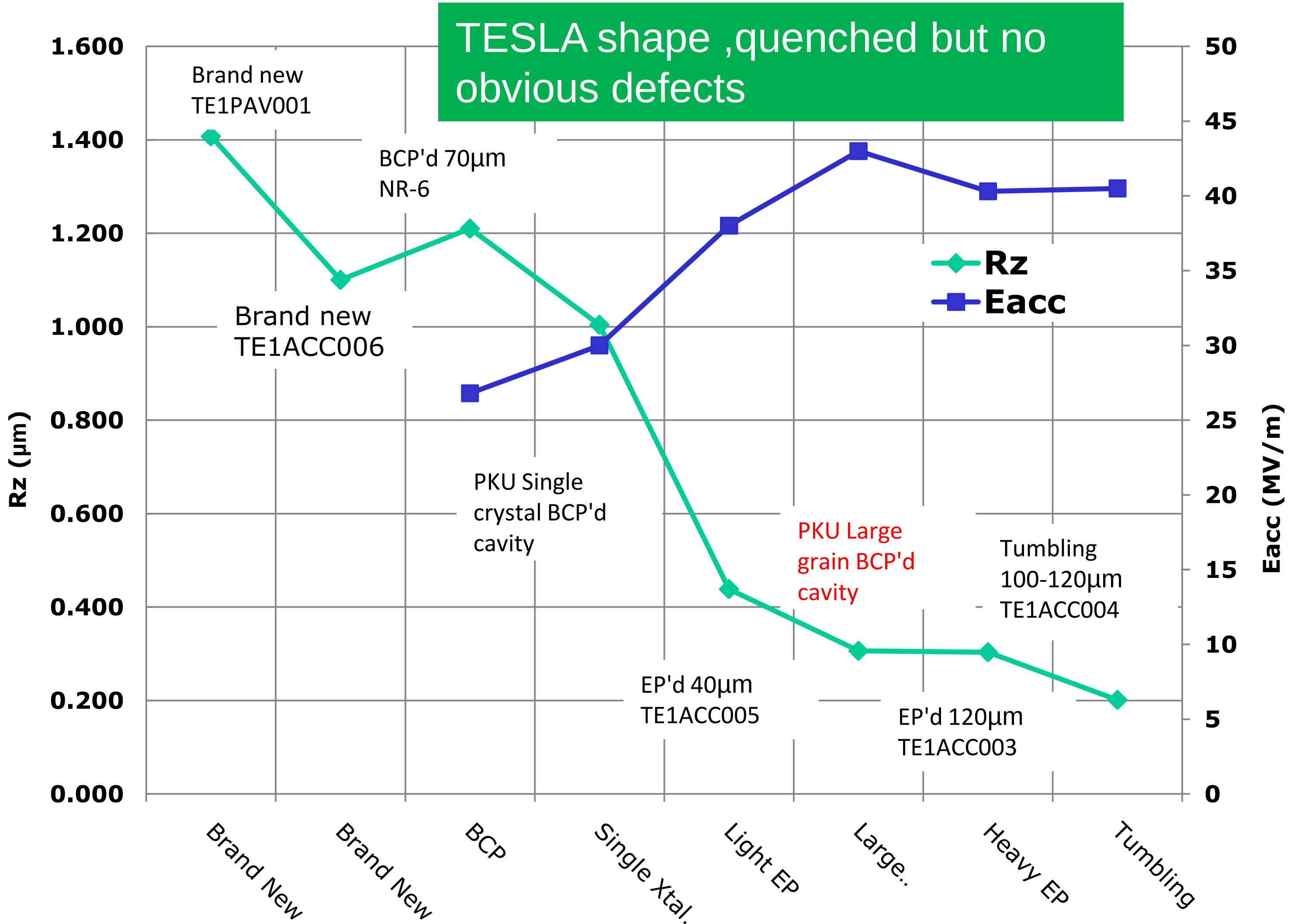
EP'd 150µm
TB9ACC017

Tumbling
100-120µm
TE1ACC004
(4 similar)

PKU Large grain
BCP‘d cavity



Surface roughness vs. Gradient



Cavity performance becomes less dependent on the surface roughness as the maximum magnetic field reached a plateau

What we observed from quench studies

- The defects can be divided as geometric imperfections or intrinsic to the material.
  - Geometric imperfections played a secondary role in limiting cavity performance. The apparent defects are not necessarily harmful other than bearing the risk of trapping acidic water during processing.
  - Standard processing can easily reduce the magnetic field enhancement and push the cavities to a higher gradient
- In cavities that have no apparent material or geometric defects, the surface roughness is sufficiently good for both fine grain cavities with the standard EP process and for large grain cavities using the standard BCP process.

G. Wu, M. Ge, P. Kneisel, K. Zhao, L. Cooley, J. Ozelis, D. Sergatskov and C. Cooper, “Investigations of Surface Quality and SRF Cavity Performance”, manuscript submitted to IEEE transactions on Applied Superconductivity.

Conclusions

- Large steep grain boundaries in large grain cavity are found that performance cannot be explained by magnetic field enhancement.
- Surface roughness inside grains by BCP is comparable to modern electropolished cavities.