"Surface roughness and correlated field emission investigations of electropolished Nb samples"

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- Motivation
- Measurement technique and main parameters
- Actual results
- Conclusion

Motivation

- EFE from particulate contaminations or surface irregularities ⟶ one of the main field limitations of the high gradient SC Nb required for XFEL and ILC [1]
- Surface irregularities might cause high-field Q-drop and quenches [2]
- Number density and size of particulates on metal surfaces can be much reduced by HPR [3], DIC [4] and clean room assembly, but influence of surface defects of the actually EP and EB-welded Nb on EFE has been less studied yet

1-st step Systematic measurements of the surface roughness of Nb samples by means of optical profilometry and AFM is finished:

Samples:
- ⇨ Samples cut out of real nine-cell Nb cavity
- ⇨ Typically prepared flat Nb samples

Aims:
- ⇨ Average surface roughness
- ⇨ Geometry of defects
- ⇨ Electrical field enhancement factor of defects

2-nd step Systematic investigations by means of FESM (after HPR) to be done

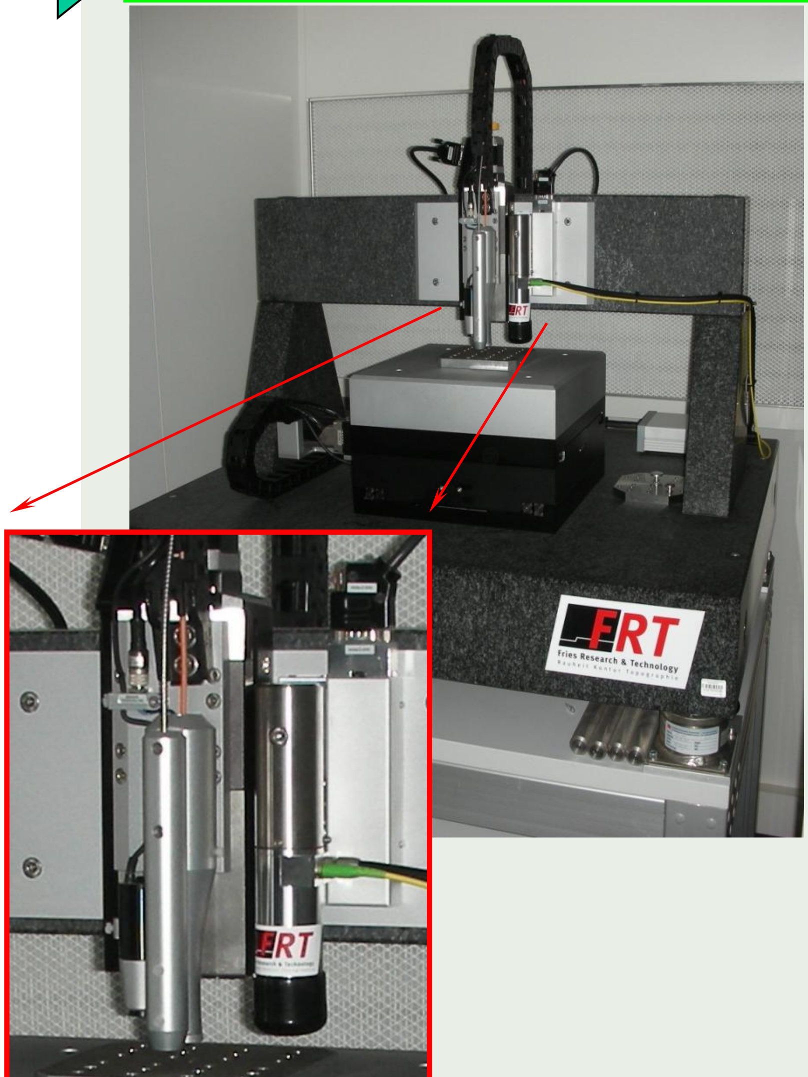
3-d step Correlation study between FE and surface defects to be done

[1] A. Dangwal et al., Phys. Rev. ST Accel. Beams 12, 023501 (2009). [2] J.Knobloch et al., Proc. 9th Workshop on SRF (1999), p.77.
[3] P. Kneisel et al., Proc. 7th Workshop on SRF (1995),p.311. [4] A. Dangwal et al., J. Appl. Phys. 102, 044903 (2007).

Measurement technique:

1-st step

Optical profilometer with AFM (FRT):

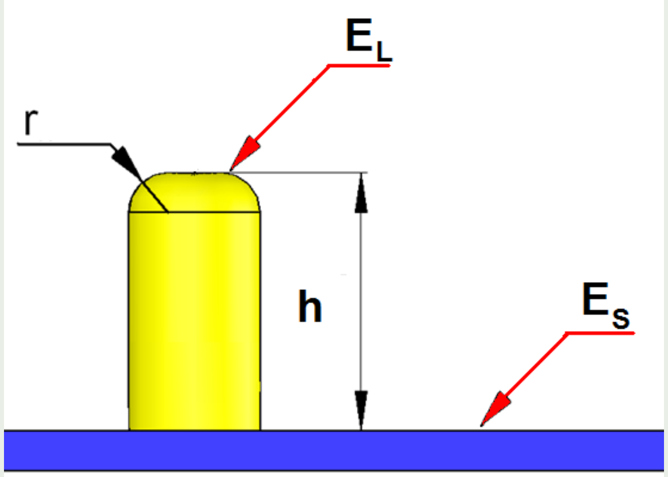


- Optical profilometer:
  - white light irradiation and spectral reflection (chromatic aberration)
  - up to 20×20 cm^2 and 5 cm height difference
  - 2 µm (3nm) lateral (height) resolution
- further zooming by AFM:
  - 2 µm precision of positioning with respect to the optical profilometer
  - 34×34 $µm^2$ scanning range
  - 3 (1) nm lateral (height) resolution
  - contact or non-contact modes
- CCD camera for positioning control
- granite plate with an active damping system for nm measurement
- clean laminar air flow from the back to reduce particulate contamination

Calculation of main parameters:

1-st step

Geometrical enhancement factor of electric field on defects:



$$\beta_E \approx \frac{h}{r} \quad \Rightarrow E_L = \beta_E E_S$$

h = height of defect
r = curvature radius
E_L = local electric field on defect
E_S = electric field on clean surface

and **maxima $\beta_{E,max}$** found

Definitions of surface roughness:

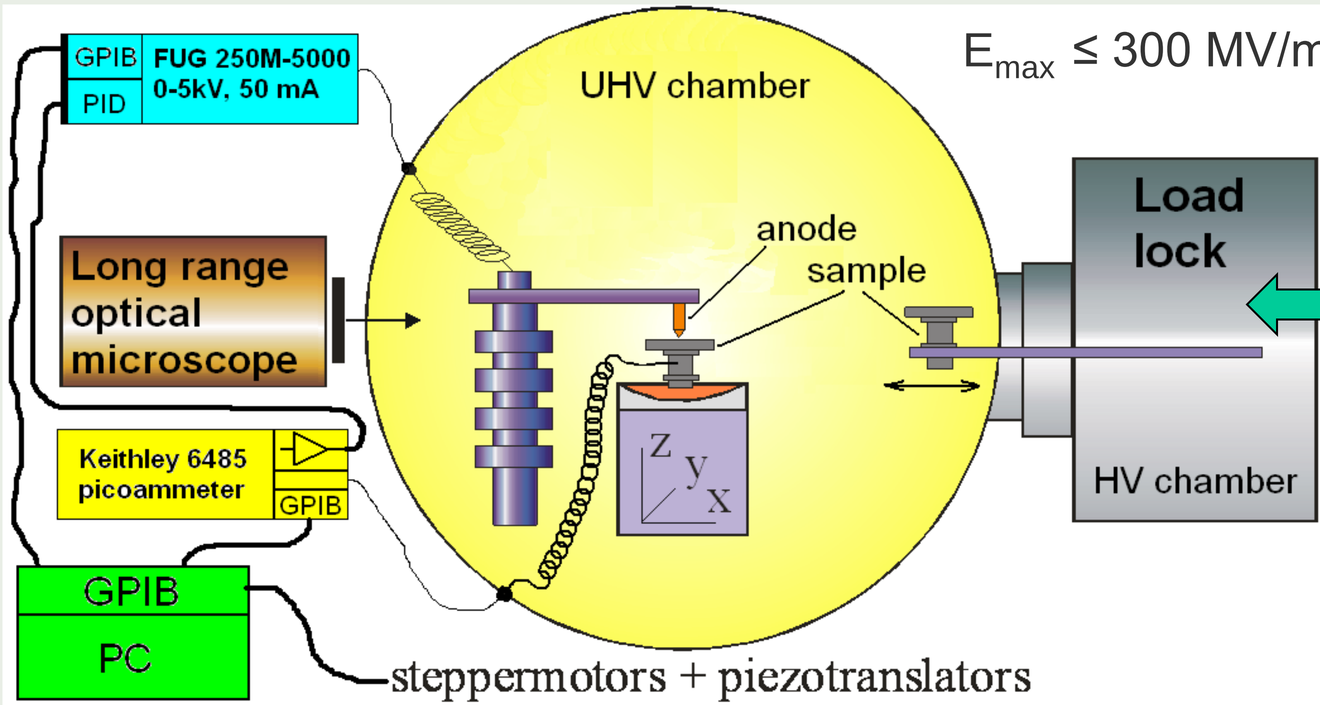
$$R_a = \frac{1}{n \cdot m} \sum_{i=1}^{n} \sum_{j=1}^{m} \left| z(x_i y_j) - \bar{z} \right|$$

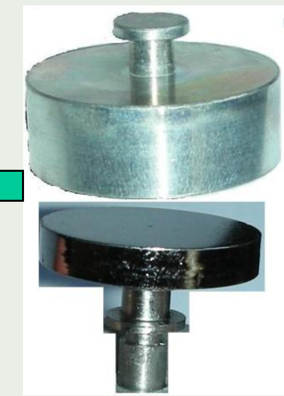
$$R_q = \sqrt{\frac{1}{n \cdot m} \sum_{i=1}^{n} \sum_{j=1}^{m} \left(z(x_i y_j) - \bar{z} \right)^2}$$

$z(x_i, y_j)$ = actual height value of profile
n, m = No. of points in *x* and *y* direction
$\bar{z}$ = average height value

Measurement technique:

2-nd step **Field Emission Scanning Microscope (FESM):**





Dust-free transport
Opening under UHV

⇒ Regulated V(x,y) scans for a fixed FE current and gap ⇒ maps of defects

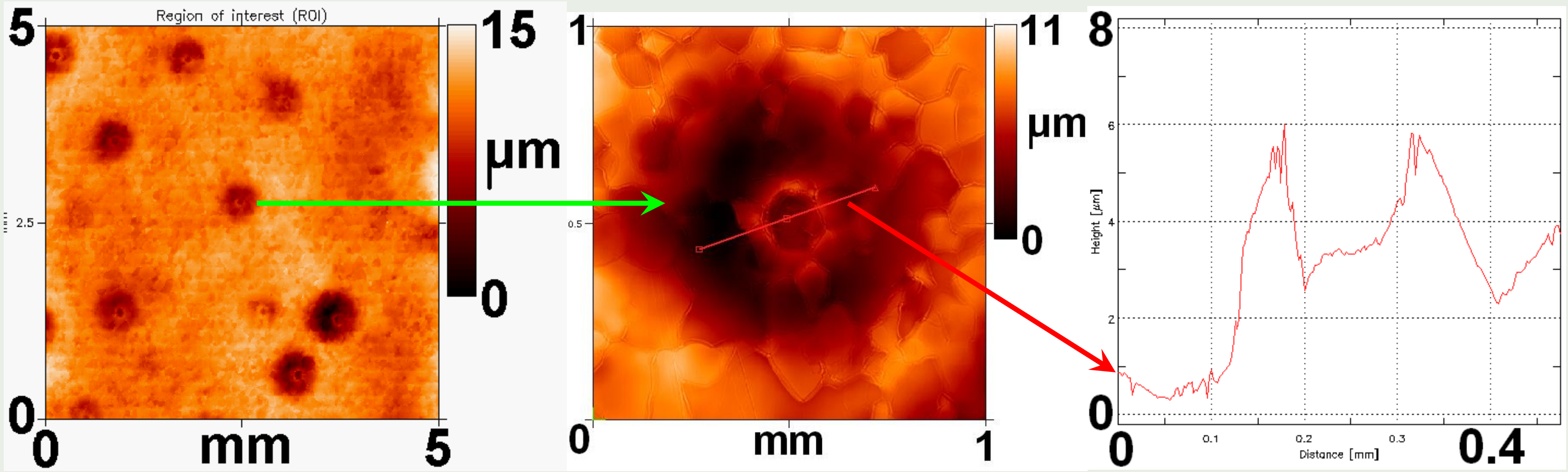
⇒ Spatially resolved I(E) measurements of single defects ⇒ Eon, β'_E

⇒ Correlation between geometry of defects (+ estimated β_E) and FE properties (measured Eon and β'_E), positioning accuracy ~ 100 µm

Results of 5 curved samples from nine-cell Nb cavities

1-st step

1) Pits on a half-cell surface of tested Nb cavity (E_{acc} < 16 MV/m):



⇒ ≤ Ø 800 µm with crater-like centers (~Ø 100µm) and sharp rims (5-10 µm height)

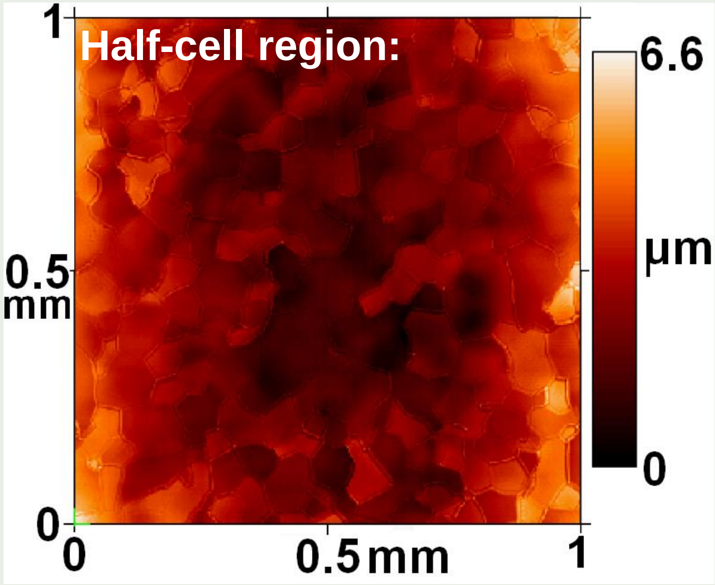
⇒ R_a = 0.418 µm, R_q = 0.557 µm, β_{max} ≈ 9.6

⇒ Hints for problems with washing off the acid solution after electropolishing

Results of 5 curved samples from nine-cell Nb cavities

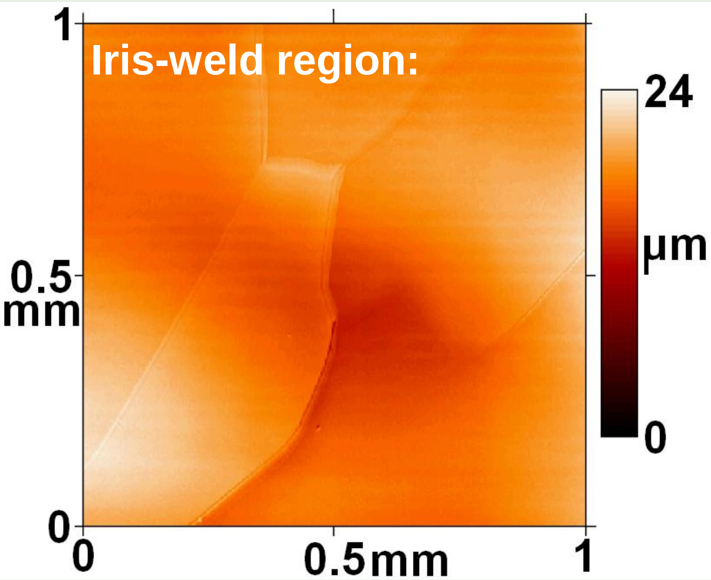
1-st step

2) Comparison of grain boundaries:



average grain size ≈ 152 μm
step height < 1.964 μm
r ≈ 0.45 μm → β_{max} = 4

R_a = 0.180 μm
R_q = 0.250 μm

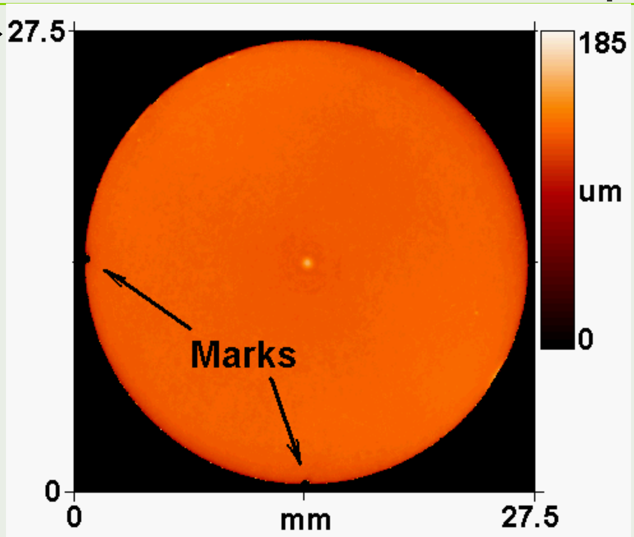


average grain size ≈ 640 μm
step height < 1.917 μm
r ≈ 0.41 μm → β_{max} = 4.67

R_a = 0.115 μm
R_q = 0.159 μm

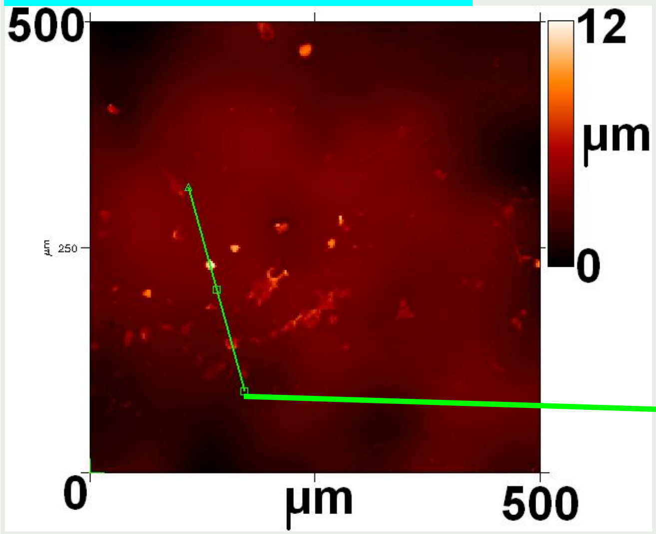
⇨ Welds have factor of ~4 larger grains but similar R_a, R_q and β values

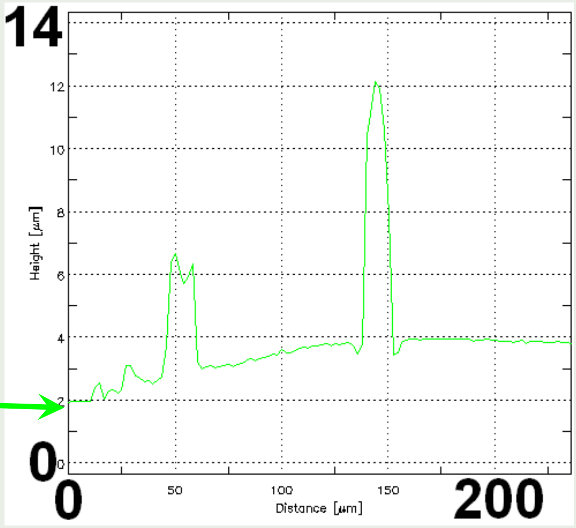
Results of 6 flat Nb samples:



4 types of surface defects:
- particles,
- scratches,
- grain boundaries
- round hills and holes

1) Particles:





< 5 µm	43 %
5 - 15 µm	48.4 %
15 - 25 µm	6.1 %
> 25 µm	2.5 %

R_a = 0.276 µm

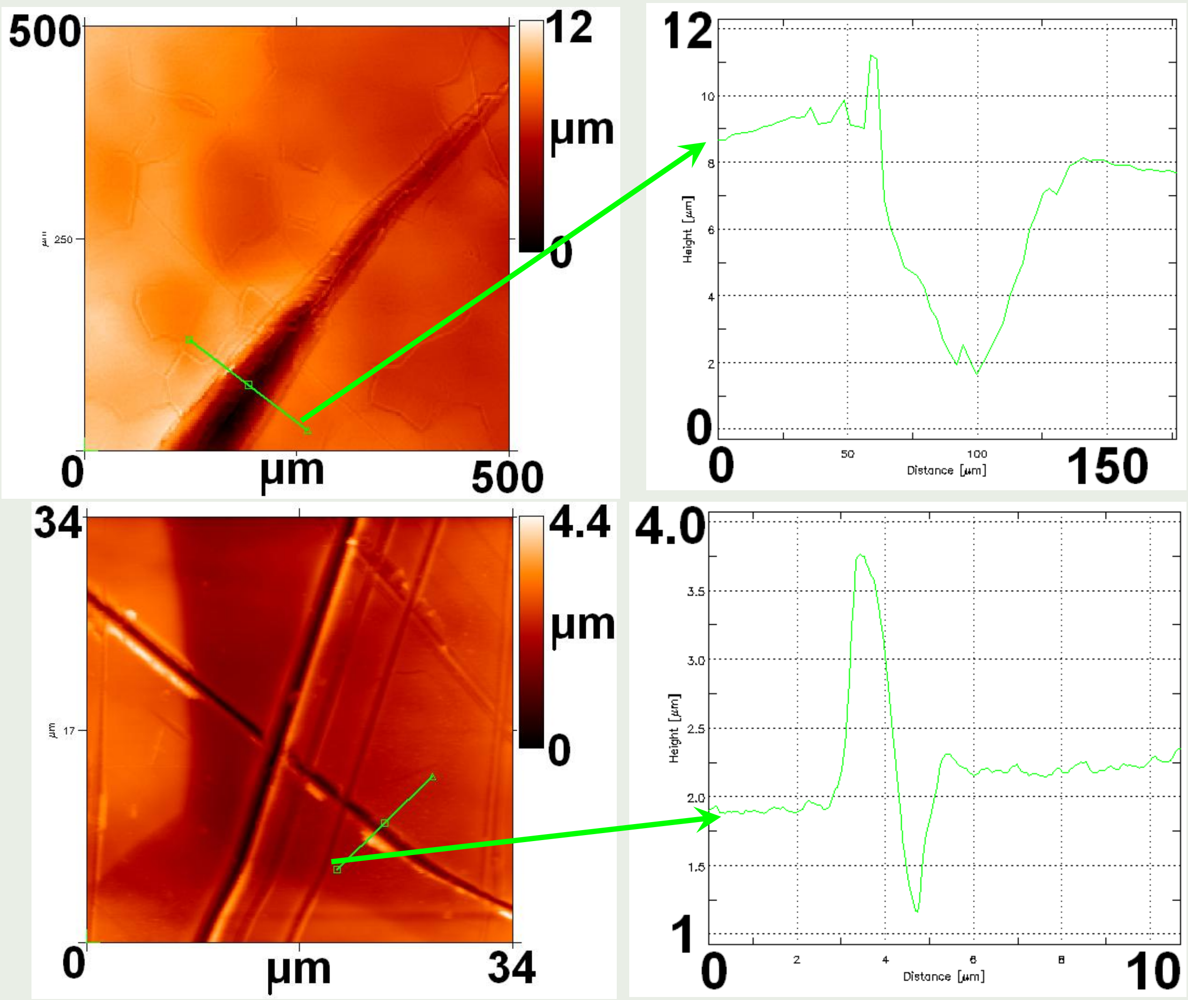
R_q = 0.548 µm

$\beta_{E,max}$ = 15

Results of 6 flat Nb samples:

1-st step

2) Scratches:



4 - 100 µm width

11 µm - 2.7 mm length (on average 326 µm)

ridge height < 10 µm

R_a = 0.466 µm

R_q = 0.646 µm

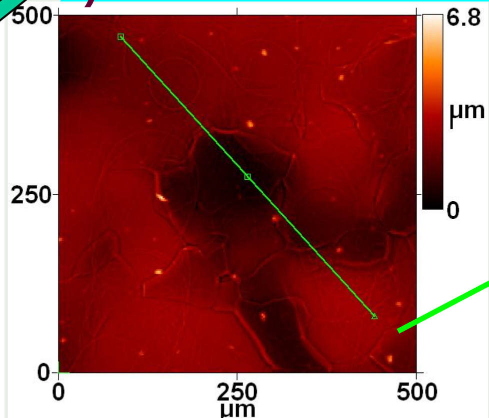
r < 0.77 µm

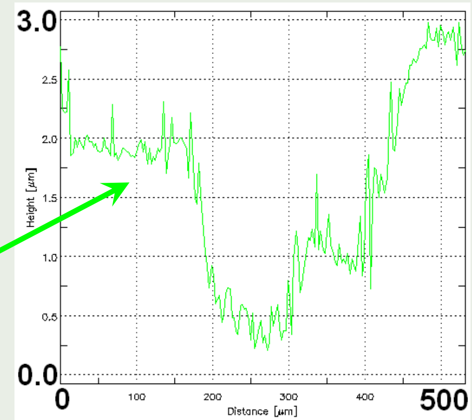
$\beta_{E,max}$ = 13

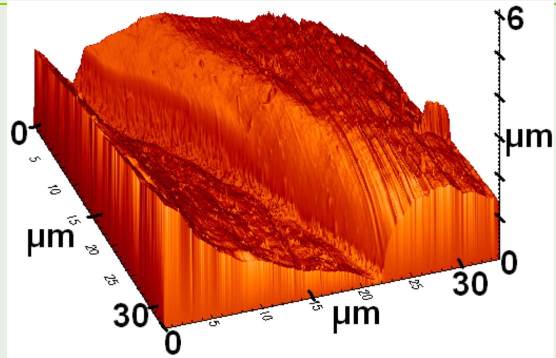
Results of 6 flat Nb samples:

1-st step

3) Grain boundaries:

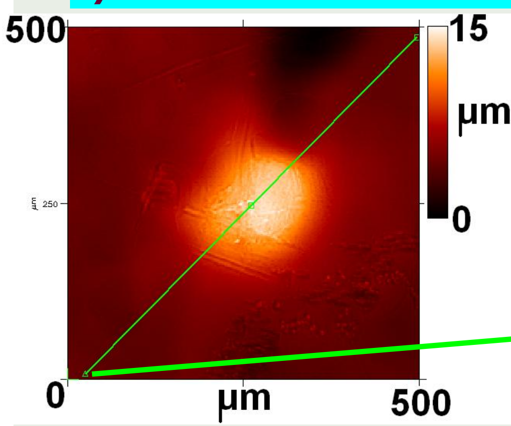


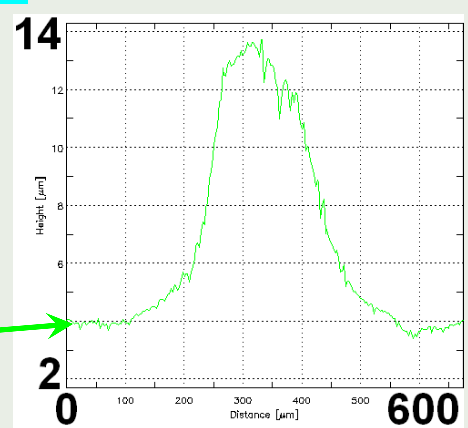




step height < 1.55 µm edge radius < 0.78 µm
$\beta_{E,max} = 4$

4) Round hills and holes:





height < 17 µm size 10 - 440 µm
$R_a = 0.295$ µm $R_q = 0.489$ µm $\beta_{E,max} < 4$

$\Rightarrow$ foreign material inclusions → modified chemical reactions during EP

$\Rightarrow$ small β → only weak EFE expected due to smooth edges

Conclusions and outlook:

1-st step

1. Combination of optical profilometry and AFM is suitable as fast quality control of EP Nb surfaces in terms of roughness and defects.
2. Remaining particles with $\beta_{E,max} < 15$ have to be removed by HPR and DIC.
3. Scratch-like protrusions with $\beta_{E,max} < 13$ must be prevented by a more careful handling.
4. Grain boundaries with step heights < 1.55 µm might reduce the magnetic field limit? $\Rightarrow$ Estimation of magnetic field enhancement β_{magn} follow
5. Round hills and holes with smooth edges cause less EFE but probably quench.
6. Pits with crater-like centers and sharp rims have been found on real cavity surfaces and hint for problems with the speed of acid removal after electropolishing.

2-nd step

3-d step

7. Correlated field emission scanning microscopy will be performed after HPR (and DIC) of these samples especially in the localized surface defect regions.

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Thank you for your attention!