Alternative polishing technique of Niobium for SRF applications

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OUTLINE

- Motivation for SRF applications (Why polish? Why alternative?)
- Alternative path for SRF cavity fabrication and surface processing
  - Requirements for Niobium
  - Requirements for industrialization
- Metallographic polishing as an alternative technique
  - R&D on the small samples
  - Surface characterization (roughness, EDS, EBSD…) & cryogenic RF test
  - Transfer of recipe to large disks
- Conclusion and perspective

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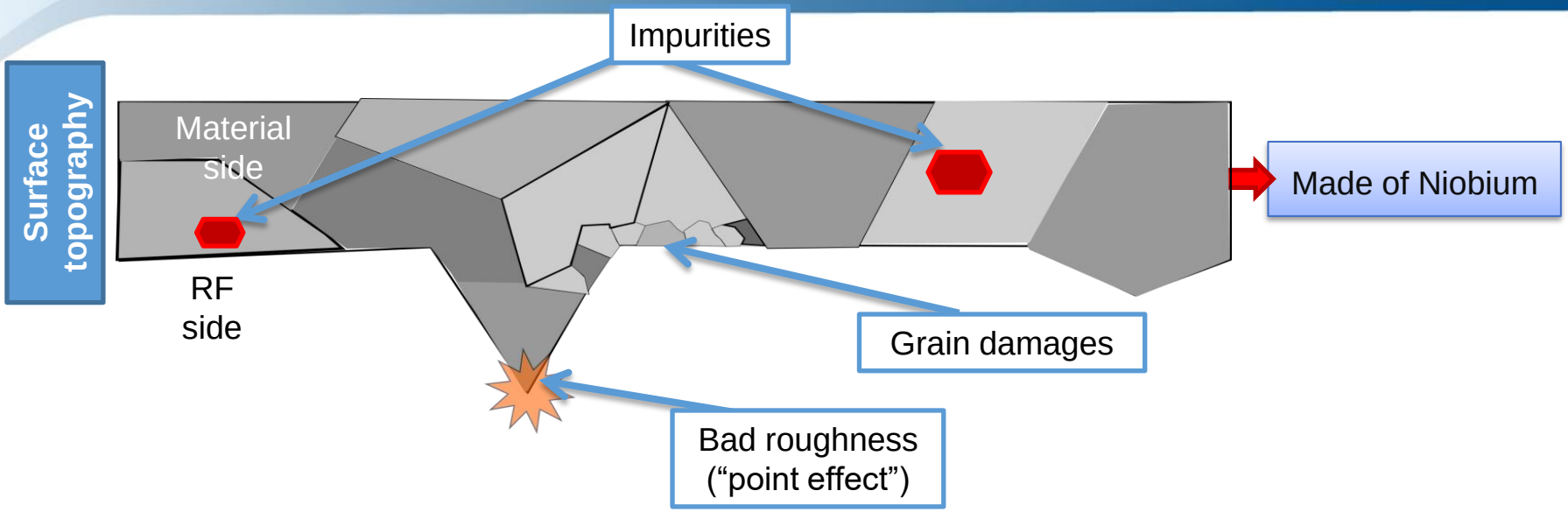
Particle acceleration via SRF. Why polish?



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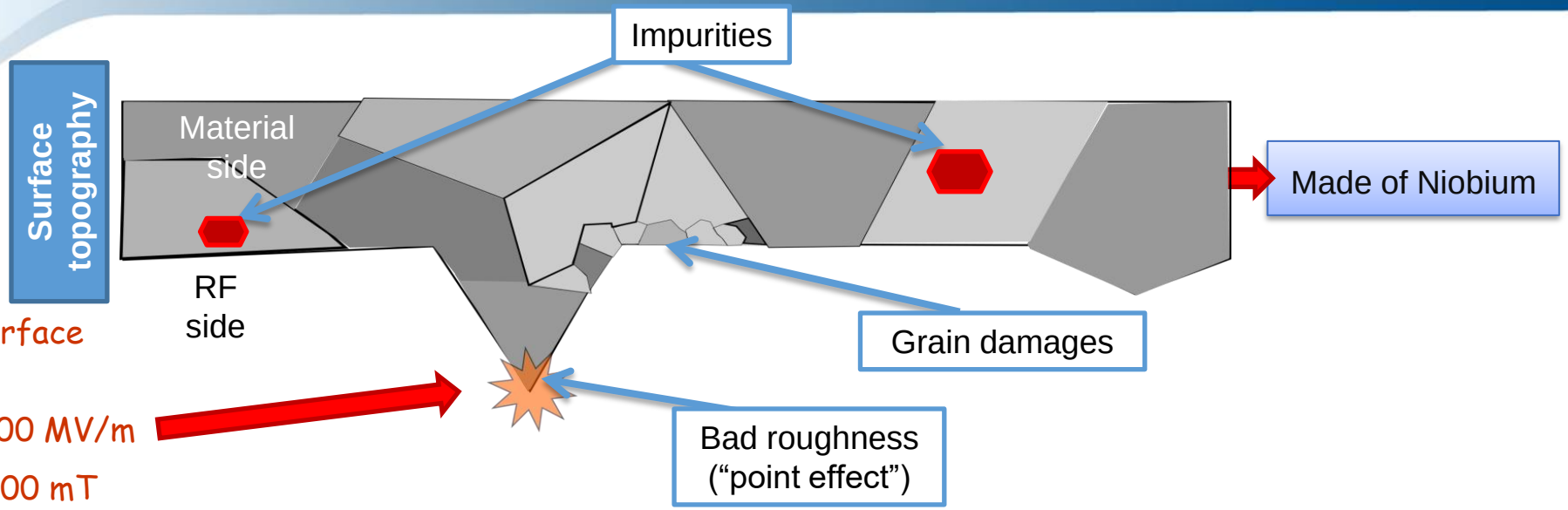

Peak surface fields:

- E_{pk} = 100 MV/m
- B_{pk} = 200 mT

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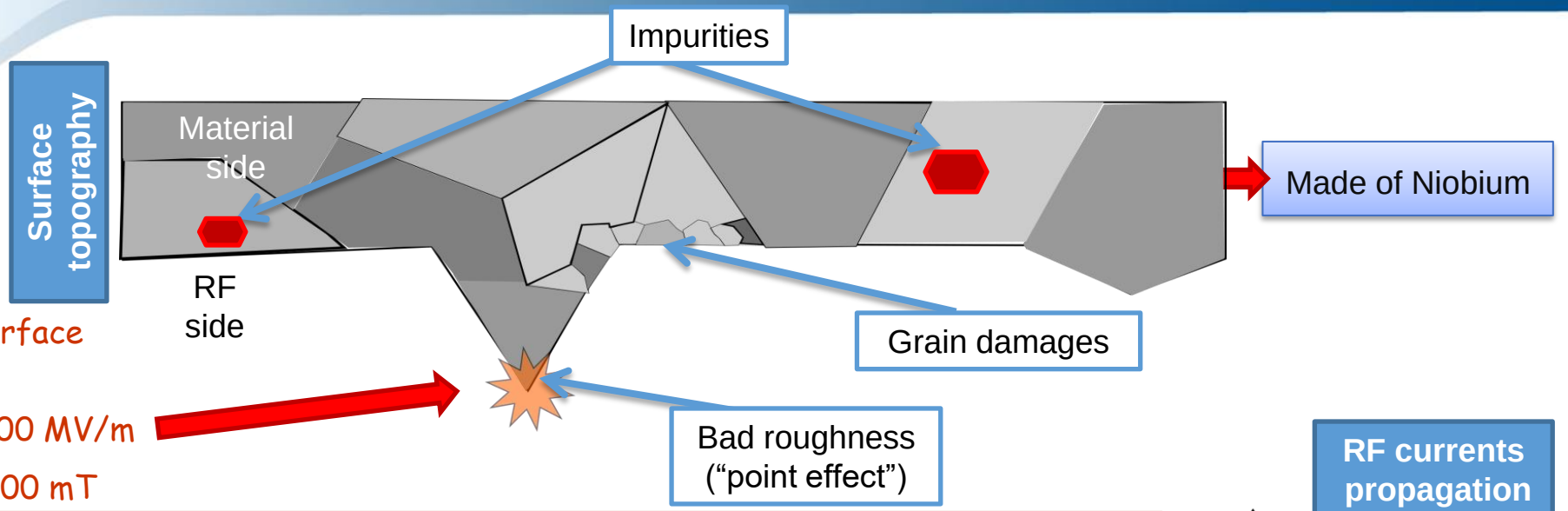
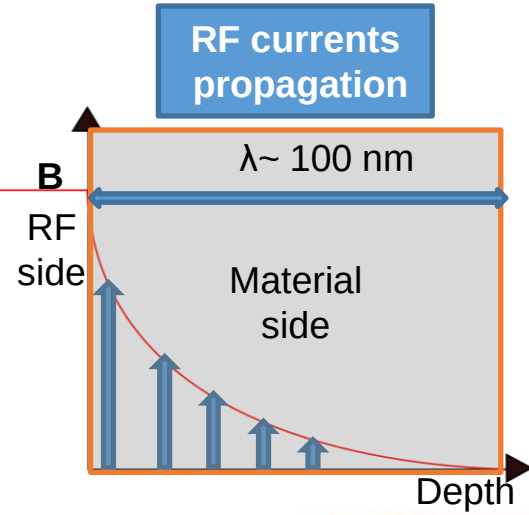


Requirements to the surface:

- Within several London depth (~100 nm) ensure chemical purity and few crystalline damages to avoid reduction of superconducting properties;



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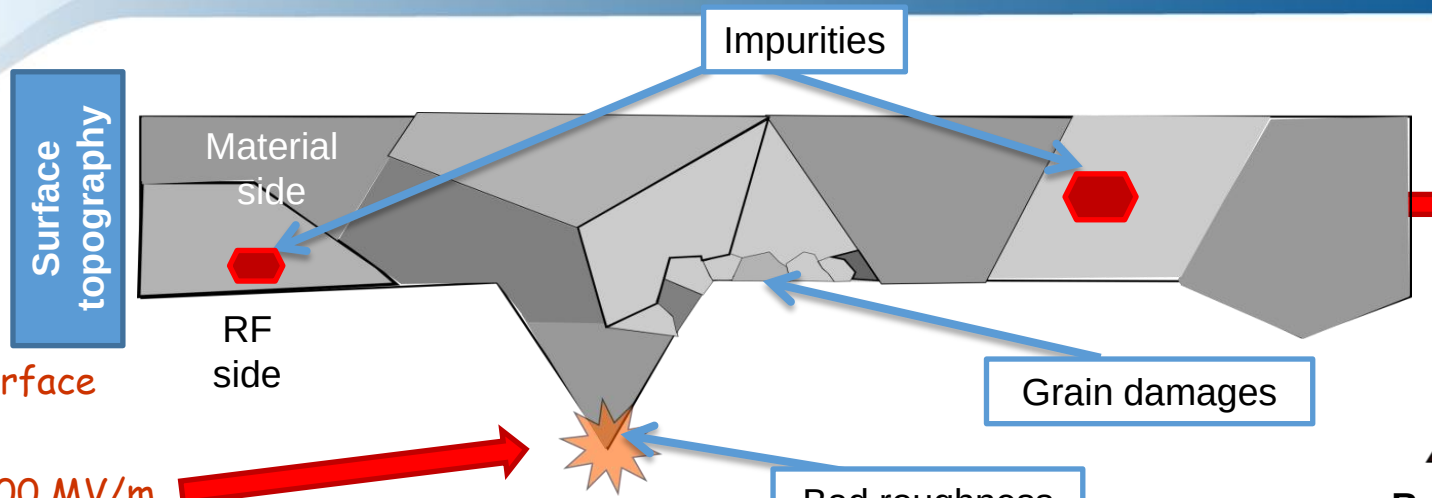

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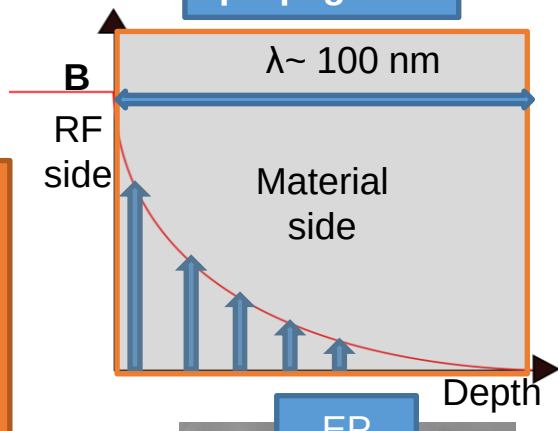
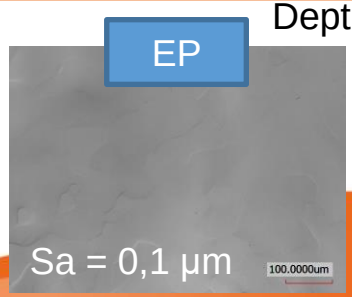
RF currents propagation

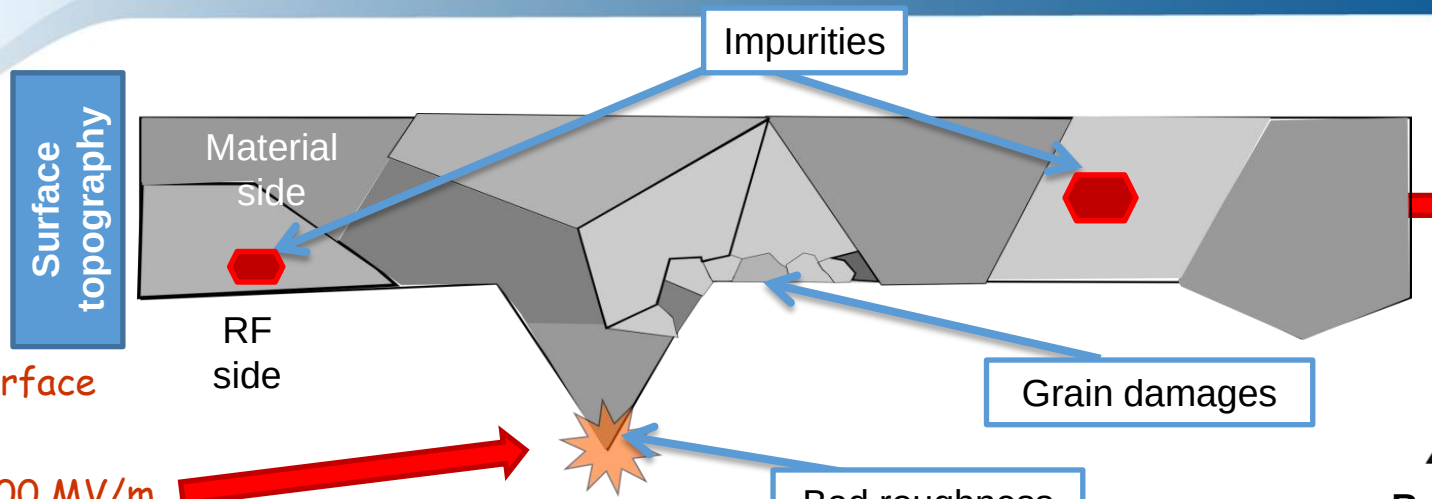


Requirements to the surface:

- Within several London depth (~100 nm) ensure chemical purity and few crystalline damages to avoid reduction of superconducting properties;
- Ensure roughness at least as good as with EP (Sa ≤ 0.1 μm);



Particle acceleration via SRF. Why polish?



Peak surface fields:

- E_{pk} = 100 MV/m
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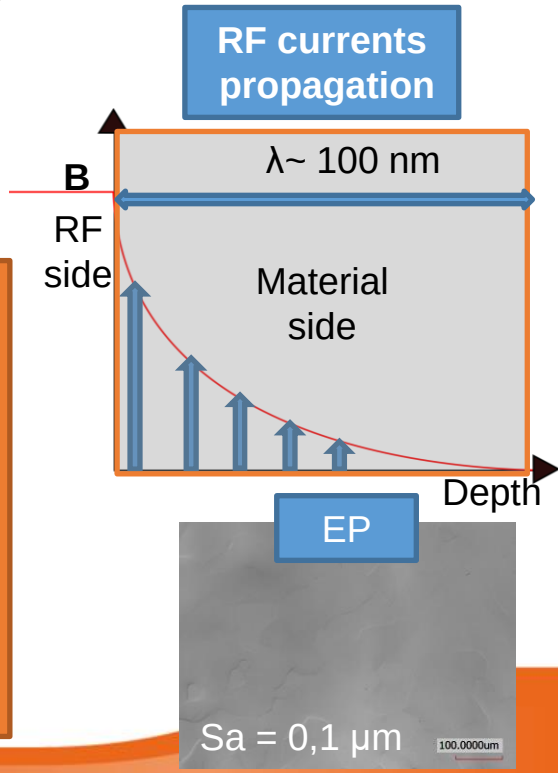
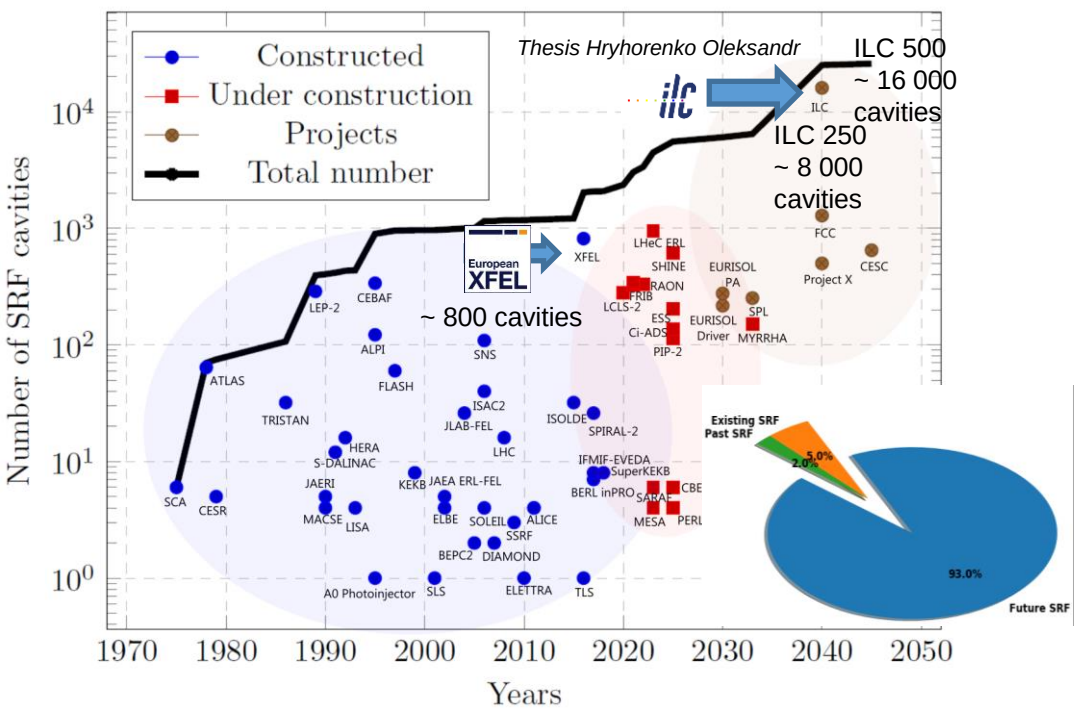


Requirements to the surface:

- Within several London depth (~100 nm) ensure chemical purity and few crystalline damages to avoid reduction of superconducting properties;
- Ensure roughness at least as good as with EP (Sa ≤ 0.1 μm);
- Ensure and maintain high thermal conductivity of bulk Nb (for high gradient operation)

Why alternative polishing?

- Possible reduction of the cost of cavity surface processing (replace bulk EP and BCP).



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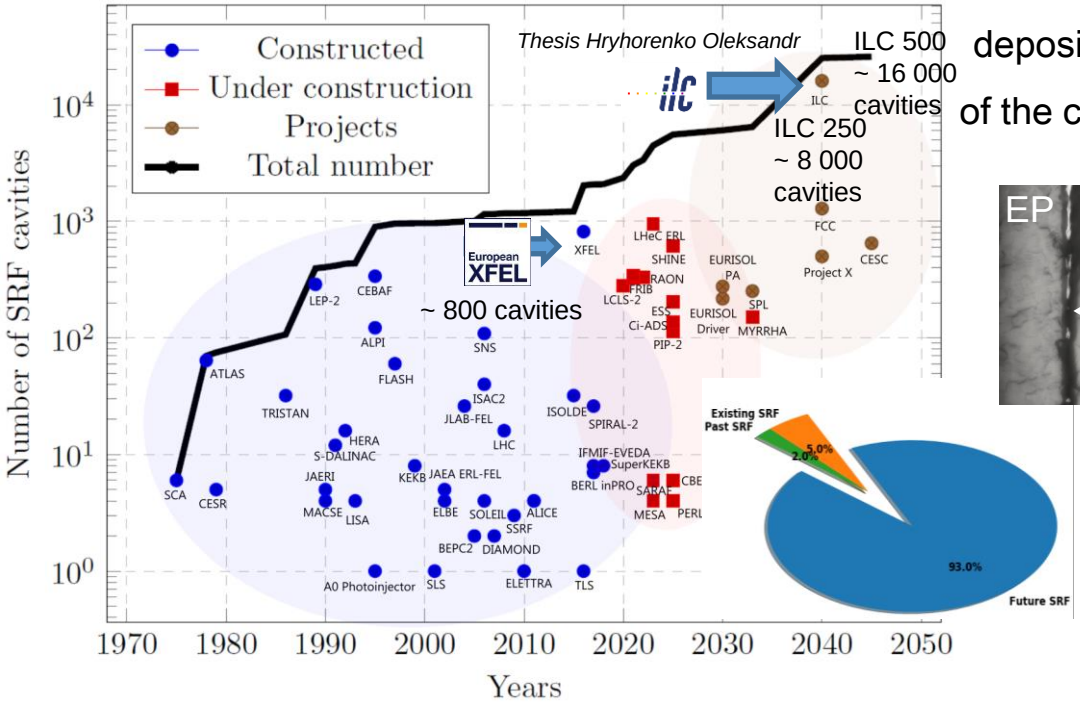
Why alternative polishing?

Possible reduction of the cost of cavity surface processing (replace bulk EP and BCP).

Achieve better surface roughness to improve the performance (removal of all type of defects, substrate preparation for thin film deposition) => possible reduction of the cost of accelerator operation



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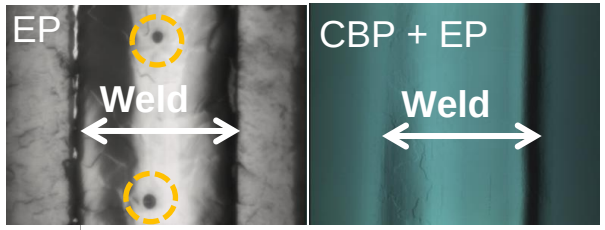
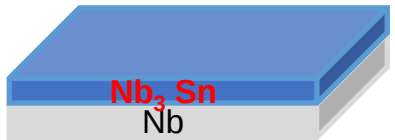


A.D. Palczewski et al. "R&D Progress in SRF Surface Preparation With Centrifugal Barrel Polishing (CBP) for both Nb and Cu", in *Proc. 16th Int. Conf. RF Superconductivity (SRF'13)*, Paris, France, Sep. 2013, paper TUIOB01, pp. 398-403.

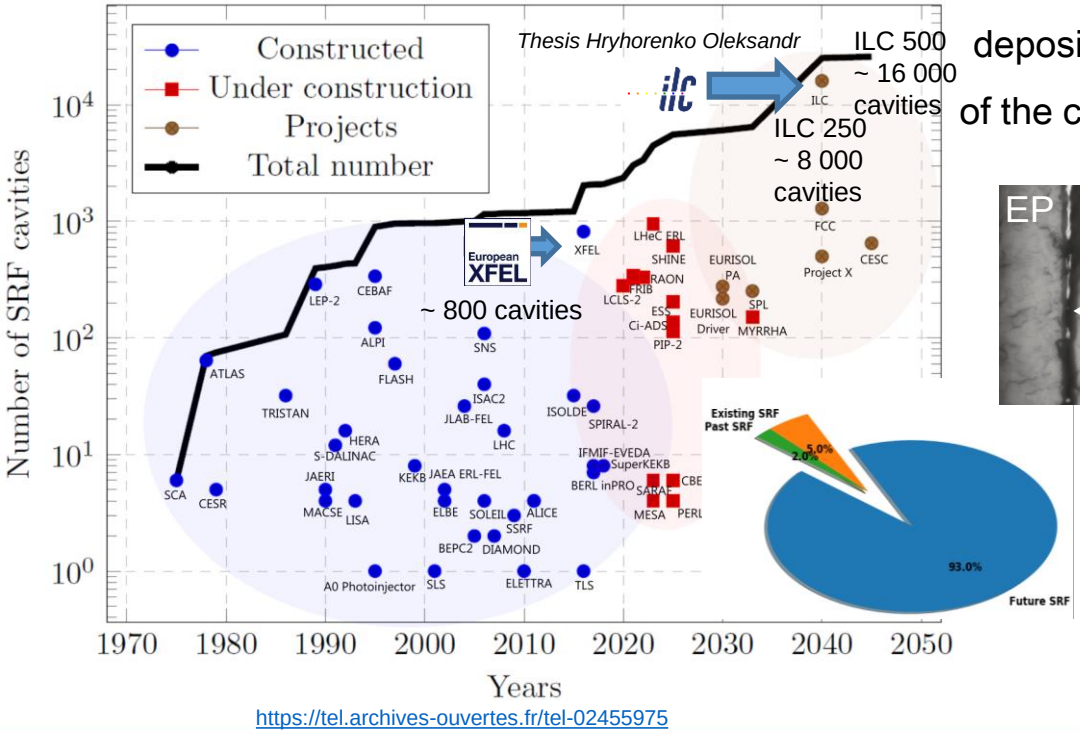


Why alternative polishing?

I Possible reduction of the cost of cavity surface processing (replace bulk EP and BCP).

II Achieve better surface roughness to improve the performance (removal of all type of defects, substrate preparation for thin film deposition) => possible reduction of the cost of accelerator operation

III Improve environmental footprint and worker safety (remove or at least reduce the amount of used acids)



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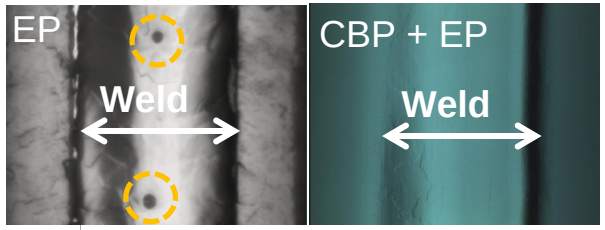

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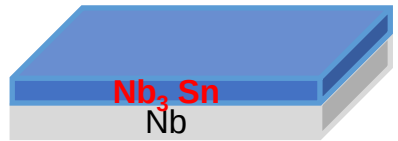

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Alternative path for SRF cavity fabrication.

Standard path :

Niobium sheet

Cavity forming

EP or BCP polishing and cleaning

Final light cleaning

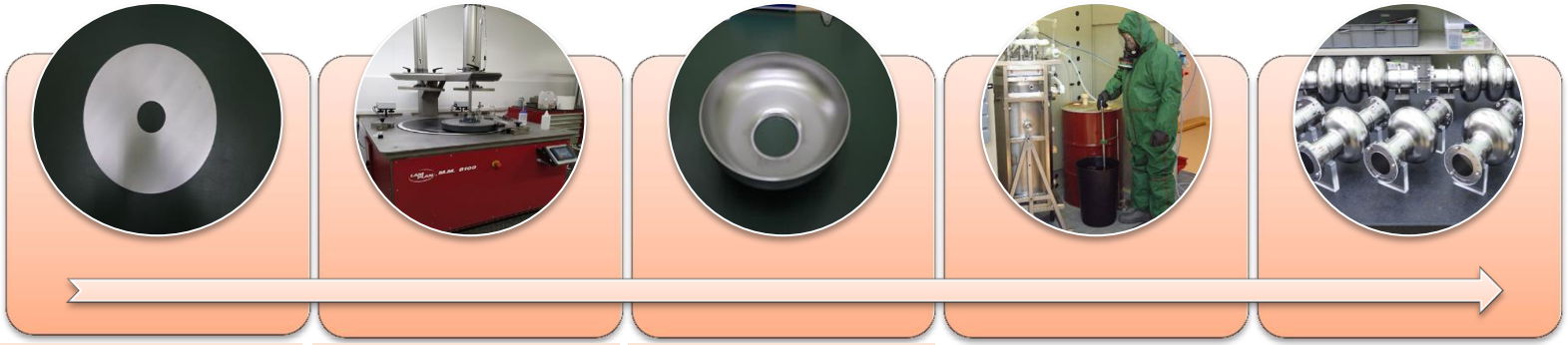
Cavity prepared for RF acceleration

Alternative path for SRF cavity fabrication.

Standard path :

Niobium sheet | Cavity forming | EP or BCP polishing and cleaning | Final light cleaning | Cavity prepared for RF acceleration

Alternative path :

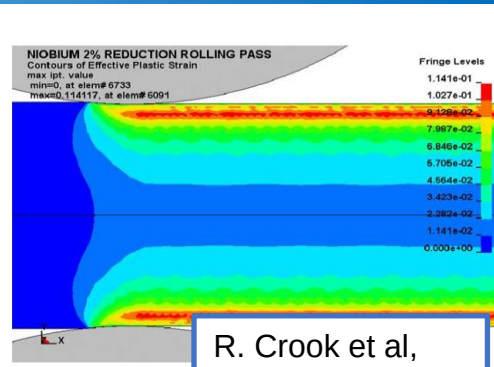


Niobium sheet | Alternative polishing | Cavity forming | Final light cleaning | Cavity prepared for RF acceleration

Requirements for alternative polishing

Requirements for Niobium:

1. Remove the polluted & damaged layer induced by Nb sheet fabrication.
2. Smooth and compataible roughness with EP & BCP (average surface roughness less than 1 μm)
3. Chemically clean (heavy elements < 0.01 wt%:Ta, W, Si, Fe; light elements <0.001 wt%: O, N, H, C)
4. Minor crystallographic damages (stress as low as possible)



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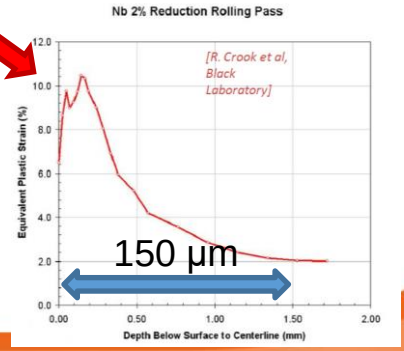
Requirements for industrialization:

1. Time of treatment should be shorter than conventional polishing (~5 hours BCP, ~8 hours EP) => High removal rate ~μm/min.
2. Limit manipulations and process to 2 steps.



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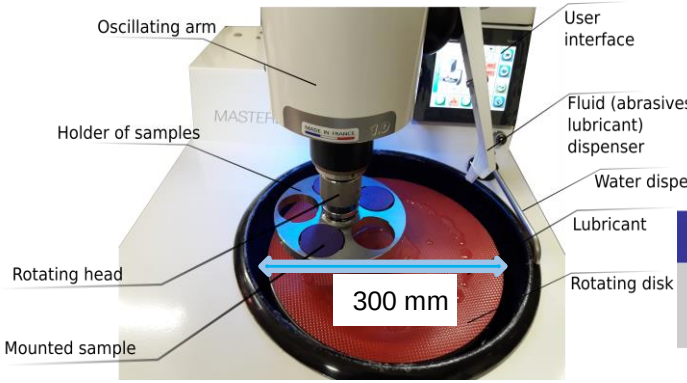
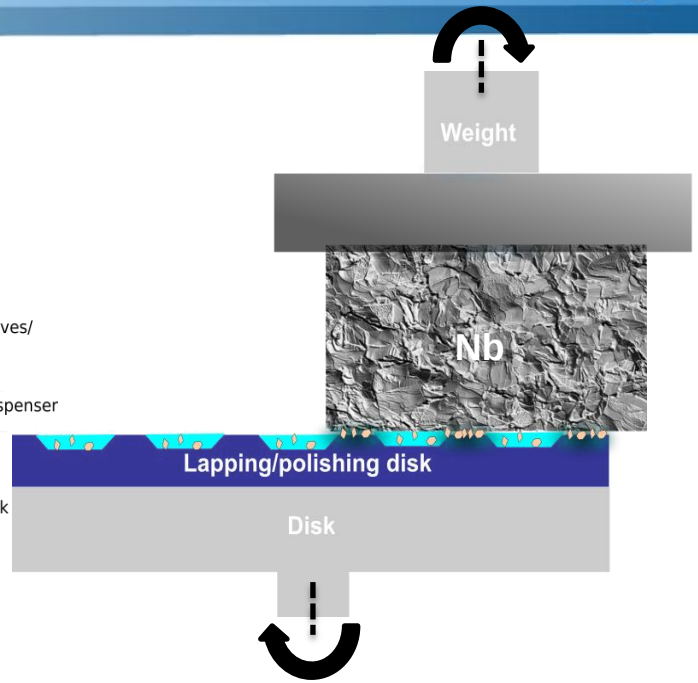
Metallographic polishing as an alternative





Polishing protocol

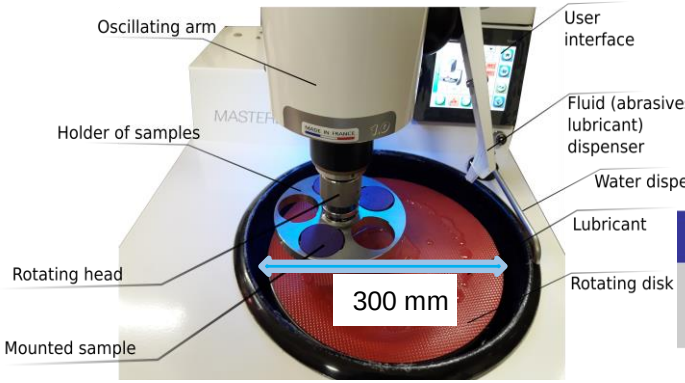
First step:

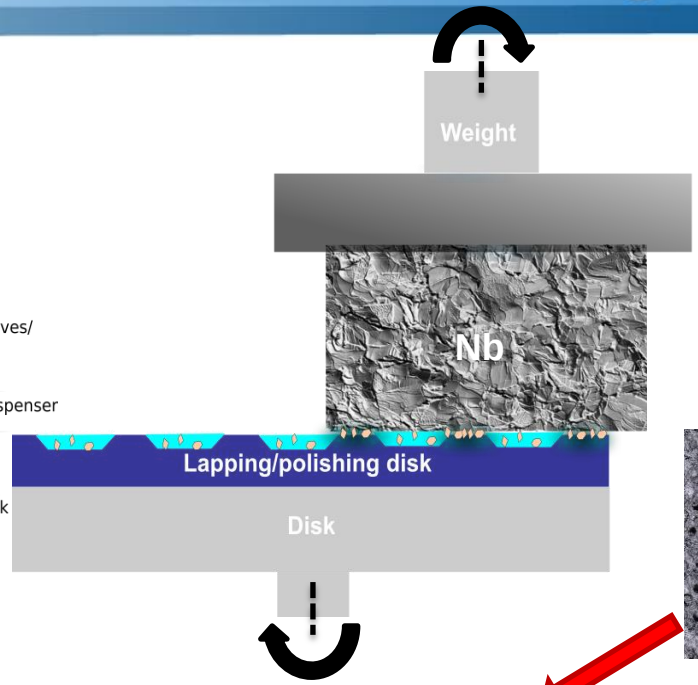
1. Coarse planarization
2. Remove the damaged layer due to the rolling of sheets (150 microns).

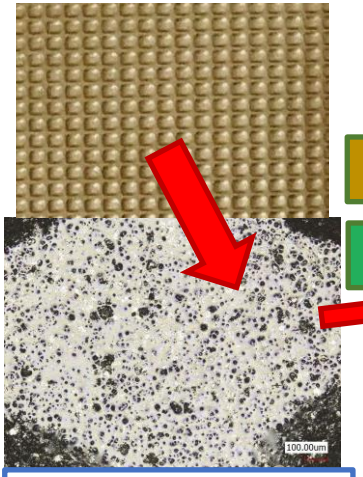
Second step:

1. Remove damages and pollution from previous step
2. Achieve the final surface requirement (Sa≤0.1 um),
3. Limit pollution, minor crystalline damages

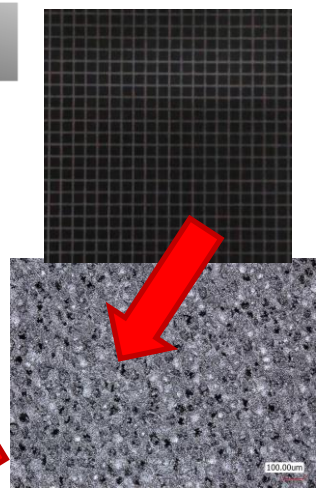
Metallographic polishing as an alternative







Resin and Cu powder



Polishing protocol

First step: RCD + diamonds of 3 µm

1. Coarse planarization
2. Remove the damaged layer due to the rolling of sheets (150 microns).

Second step: polyurethane cloth + SiO_2 (pH=10)

1. Remove damages and pollution from previous step
2. Achieve the final surface requirement (Sa≤0.1 µm),
3. Limit pollution, minor crystalline damages

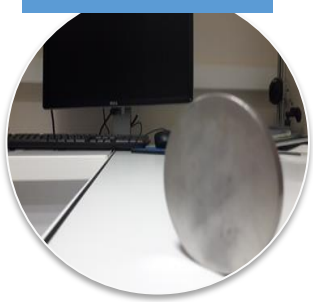
R&D on small samples

Optimization of polishing recipe

RF test at SLAC

Extended to larger area

Before:

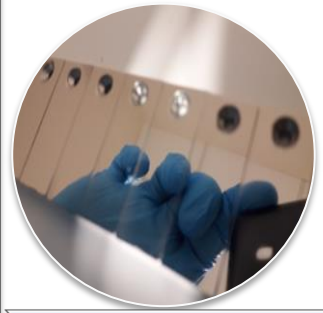


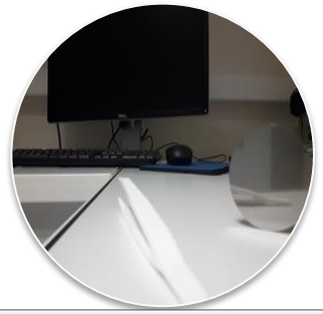
After:

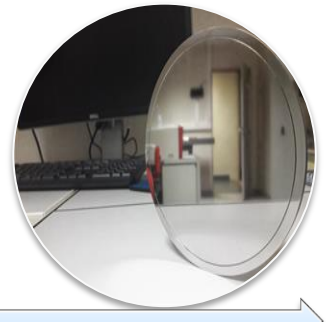
15x40 mm

Ø 50 mm

Ø 126 mm







Roughness

Size, mm

Temperature is fixed below 40 degrees

R&D on small samples

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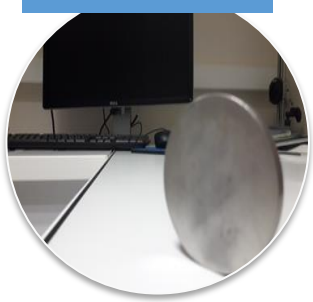
RF test at SLAC

Extended to larger area

Before:

After:

Roughness



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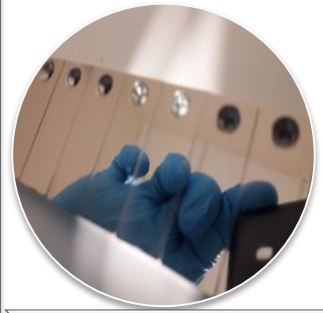
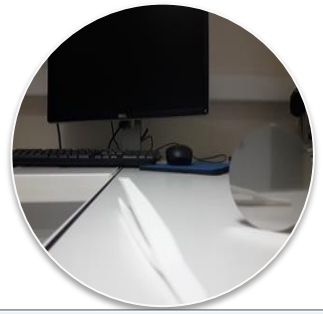




Size, mm

400 300 200 Pressure, g/cm2

3 1,1 0,6 Removal rate, µm/min

Temperature is fixed below 40 degrees

Pressure:
(200 g/cm2<P<400 g/cm2)

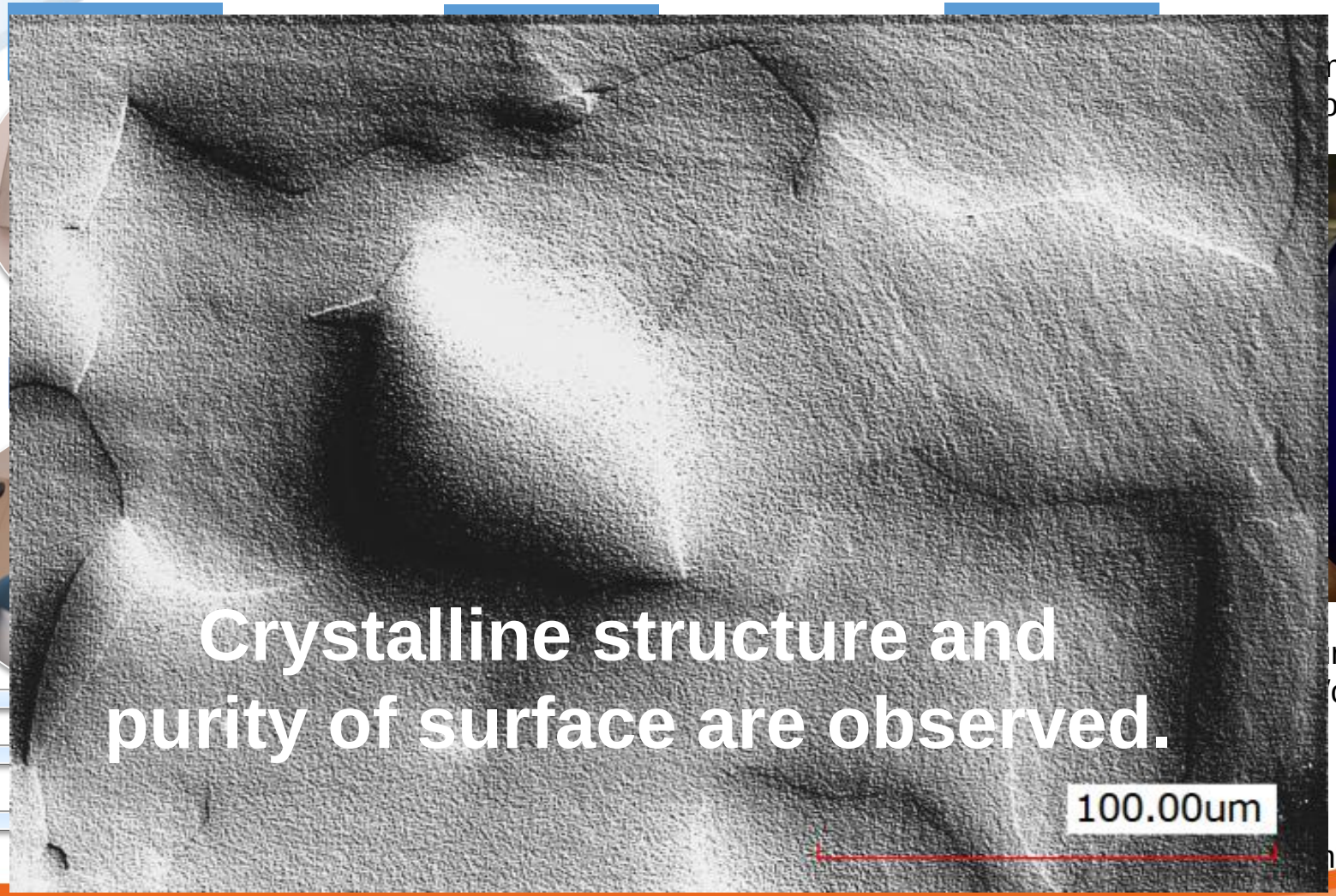
Removal rate:
EP – 0.3 µm/min
BCP – 0.5 µm/min

R&D on small samples

Before:

After:

Roughness



mperature is fixed
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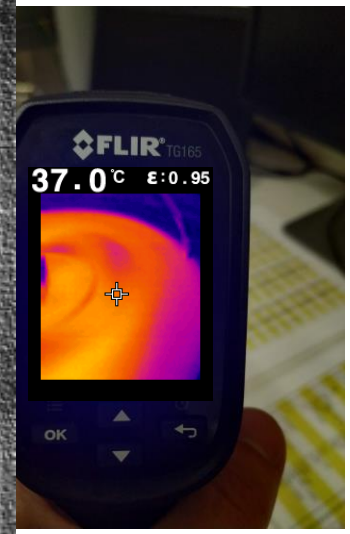
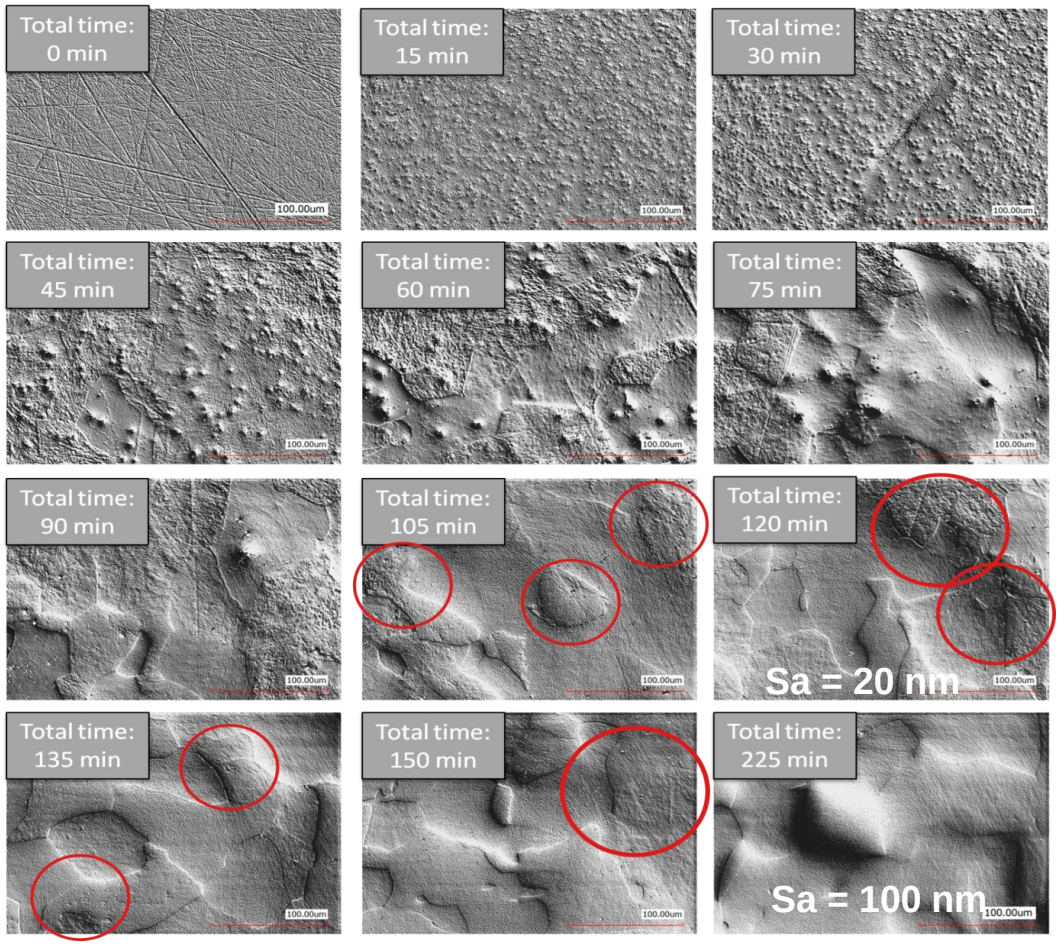


re:
/cm2<P<400 g/cm2)

Removal rate:
EP – 0.3 μm/min
BCP – 0.5 μm/min

Surface depollution with SiO_2

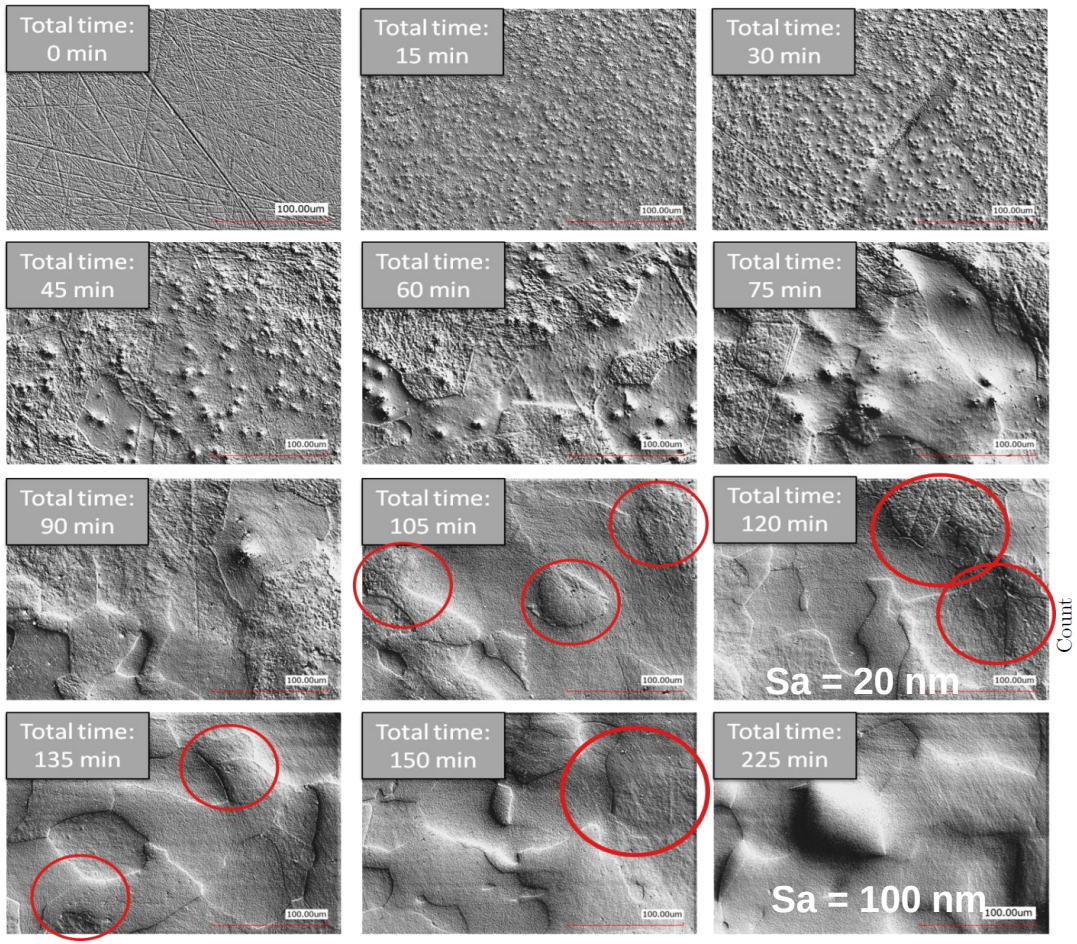
Final polishing step



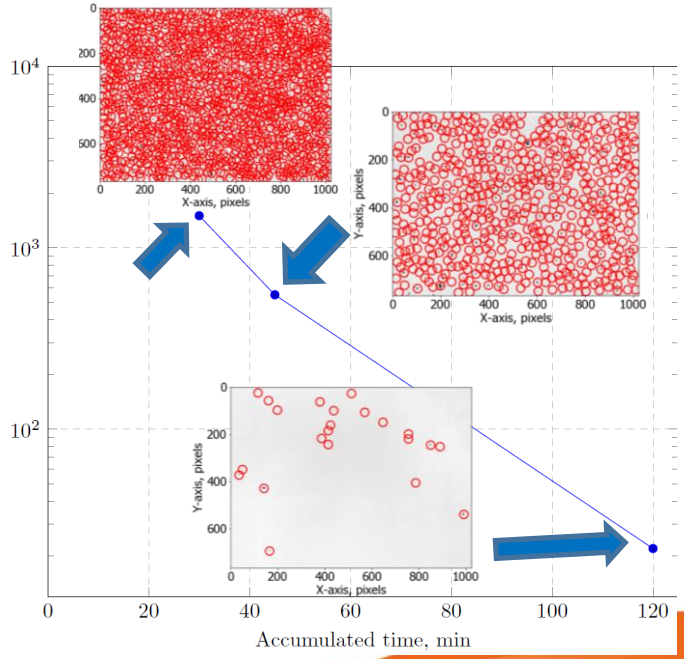
➢Contamination is observed after lapping (diamond particles)

Surface depollution with SiO_2

Final polishing step



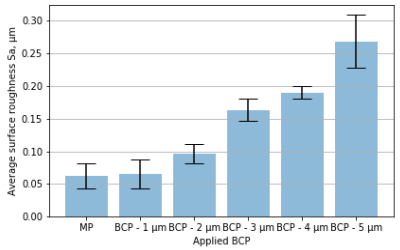
- Contamination is observed after lapping (diamond particles)
- Chemical-mechanical polishing is required (colloidal silica)
- Reappearence of surface crystalline structure

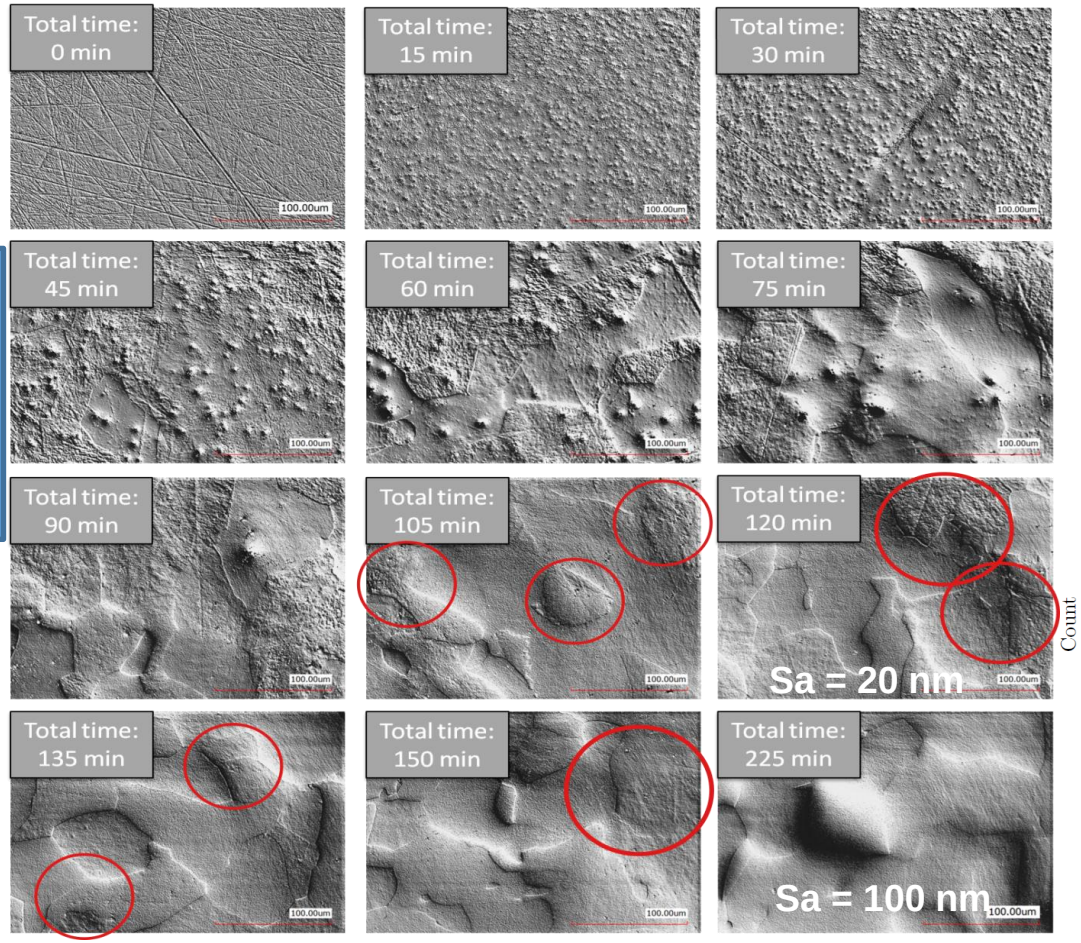


Surface depollution with SiO_2

Final polishing step

5 µm of BCP also efficient to remove the pollution, but not enough to remove the damages, also increases roughness by a factor of 5.





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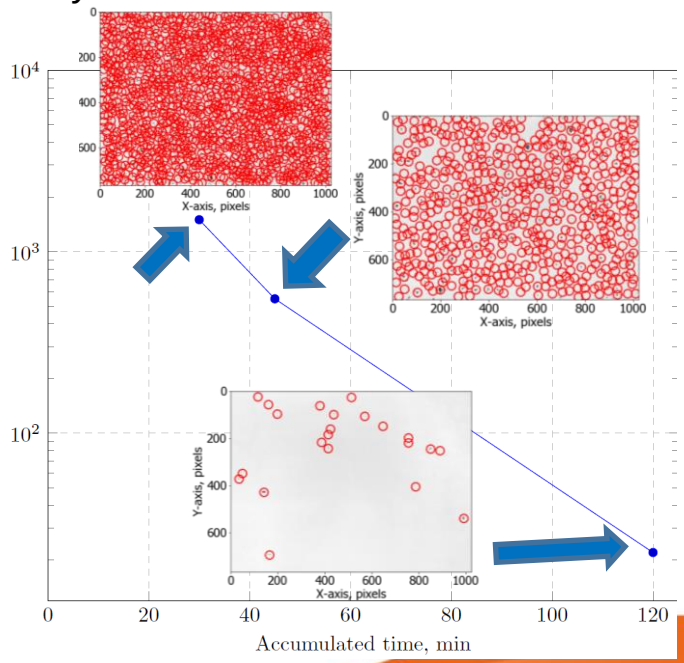
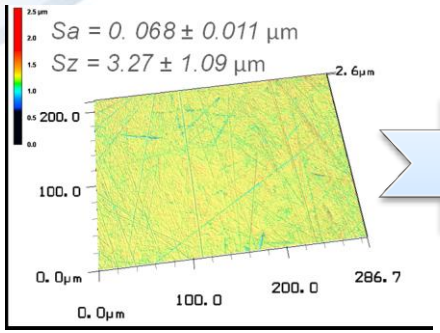


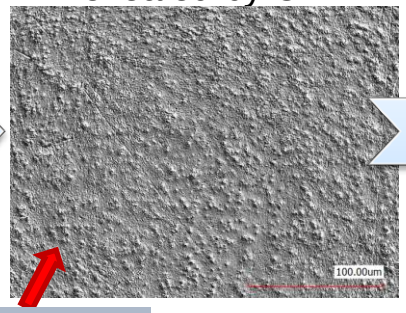
Surface characterization & cryogenic RF test

After first step:

Roughness

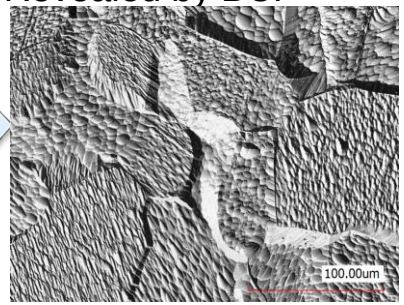


Pollution:
Revealed by CMP



Diamonds

Damages:
Revealed by BCP



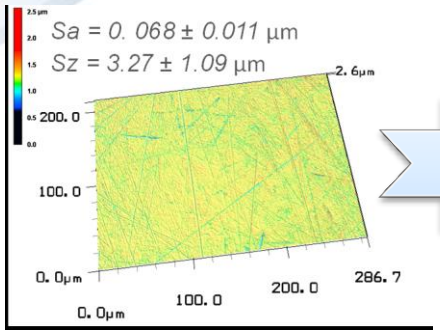
Final results:

- Roughness
- Pollution
- Damages

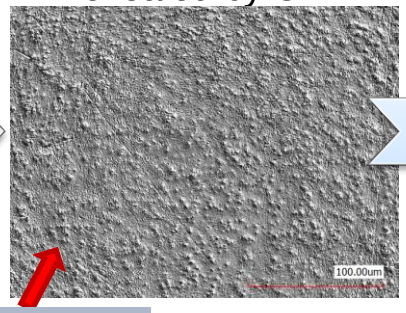
Surface characterization & cryogenic RF test

After first step:

Roughness

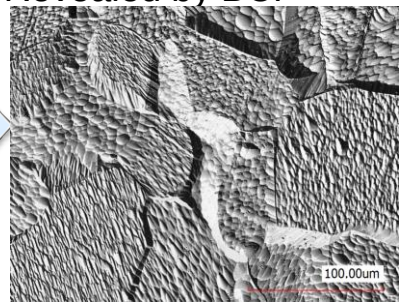


Pollution:
Revealed by CMP



Diamonds

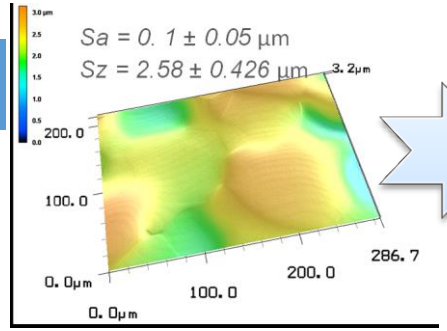
Damages:
Revealed by BCP



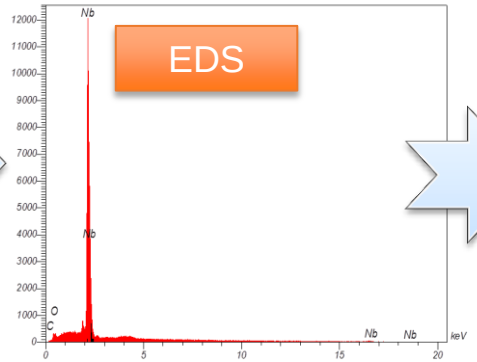
Final results:

- Roughness
- Pollution
- Damages

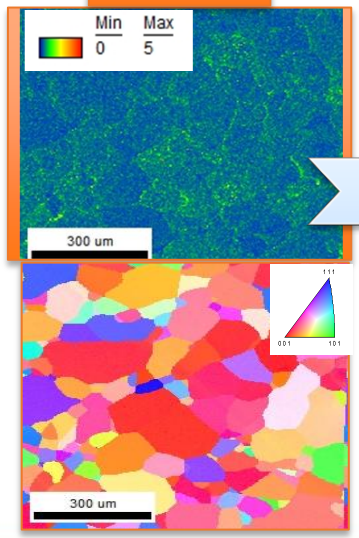
After second step:



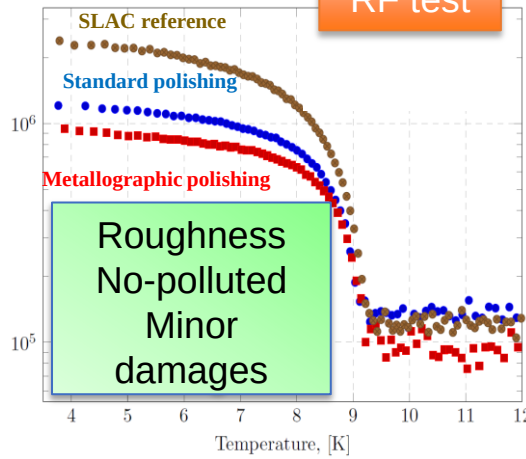
EDS



EBSD



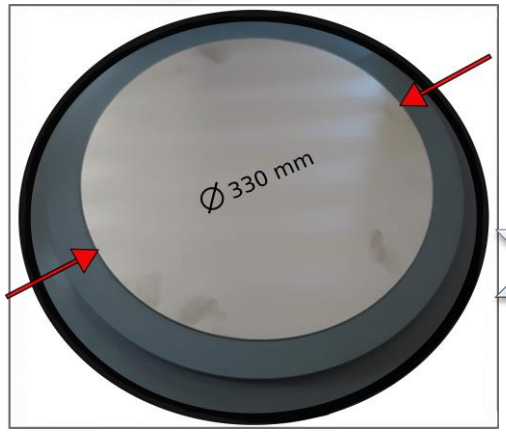
RF test



- Roughness
- No-polluted
- Minor damages

Thesis Hryhorenko Oleksandr: ‘‘Development & Optimization of Mechanical polishing for Superconducting Accelerating Cavities’’
https://tel.archives-ouvertes.fr/tel-02455975

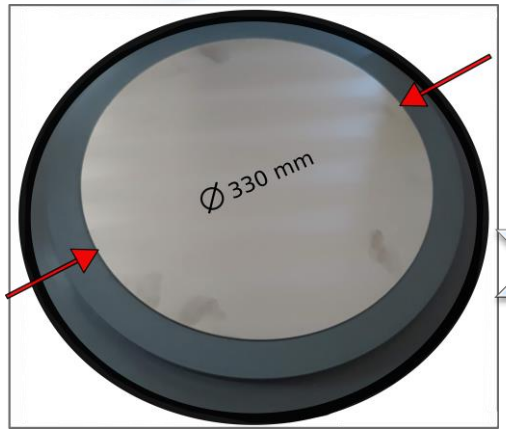
Transfer of recipe to large disks



Polishing on a lapping machine
at LAM PLAN company

https://www.lamplan.com/fr/

Transfer of recipe to large disks



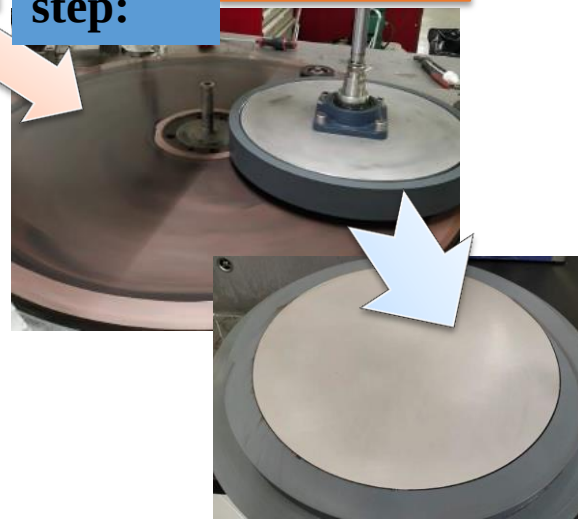
Polishing on a lapping machine
at LAM PLAN company

https://www.lamplan.com/fr/

-Diamonds of 3 µm replaced by 9 µm

First step:

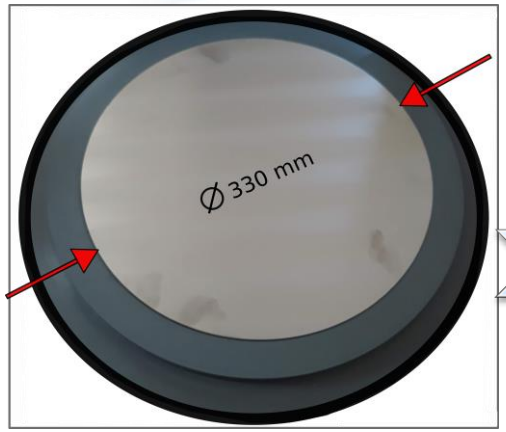
Pressure:
150 g/cm2



Pressure: 150 g/cm2

Removal rate: 0.5 µm/min
EP – 0.3 µm/min
BCP – 0.5 µm/min

Transfer of recipe to large disks



Polishing on a lapping machine
at LAM PLAN company

https://www.lamplan.com/fr/

-Diamonds of 3 µm replaced by 9 µm

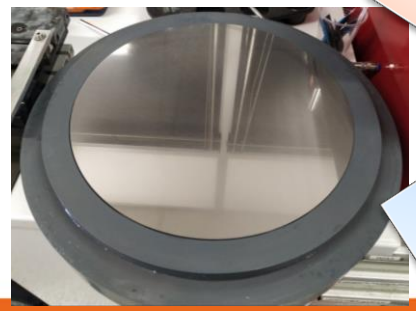
First step:

Pressure:
150 g/cm2

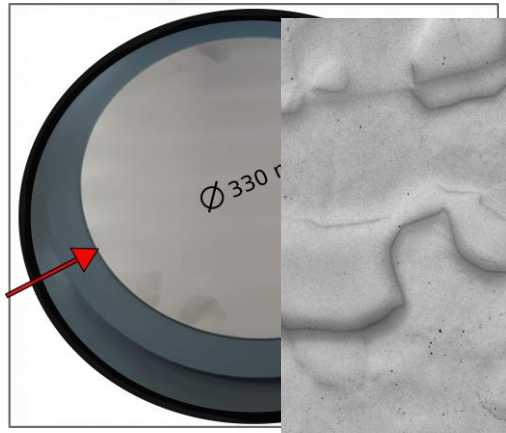
- SiO2 (pH=10)

Second step:

Pressure:
150 g/cm2

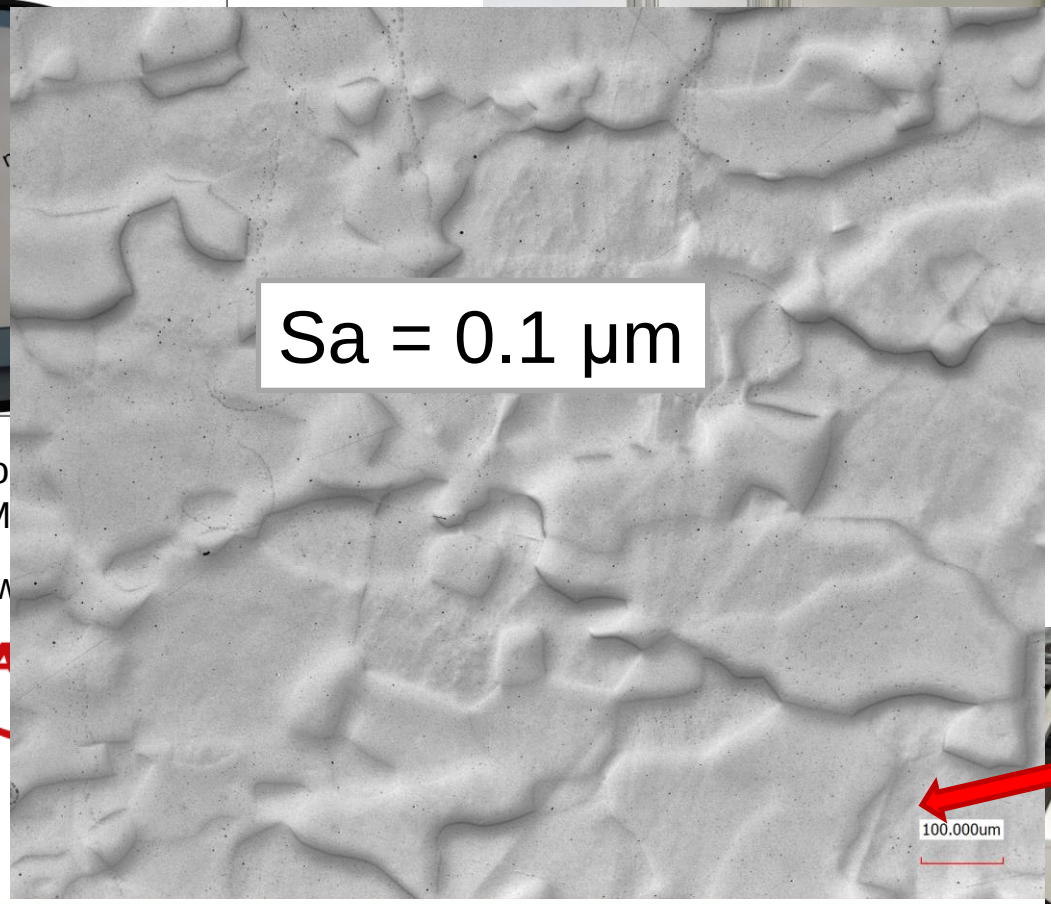


Transfer of recipe to large disks



Polishing o
at LAM

https://www



-Diamonds of 3 µm replaced by 9 µm

First step:

Pressure: 150 g/cm2

- SiO2 (pH=10)

Second step:

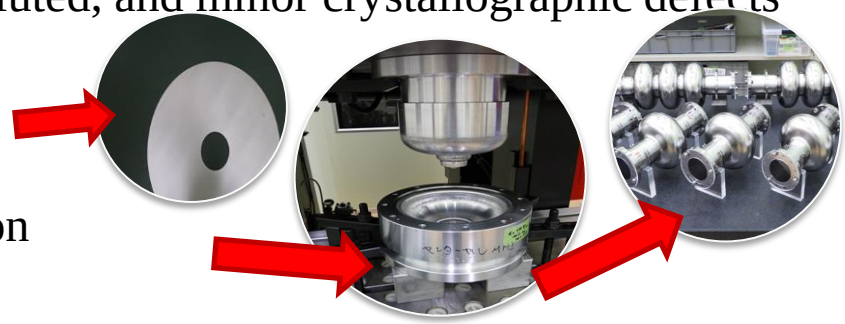
Pressure: 150 g/cm2

OUTLINE

- Motivation for SRF applications (Why polish? Why alternative?)
- Alternative path for SRF cavity fabrication and surface processing
  - Requirements for Niobium
  - Requirements for industrialization
- Metallographic polishing as an alternative technique
  - R&D on the small samples
  - Surface characterization (roughness, EDS, EBSD…) & cryogenic RF test
  - Transfer of recipe to large disks
- Conclusion and perspective

Conclusion & Perspectives

- 2 steps metallographic polishing recipe has been developed compatible with SRF applications (at IJCLab)
- Surface characterizations show smooth (20<Sa<100 nm), non-polluted, and minor crystallographic defects
- Polishing procedure extented to the large sheets (at LAM PLAN)
- Forming of 1.3 GHz half-cells with the following cavity fabrication using the polished disks (KEK – FJPPL program)



- Characterization of surface pollution and crystalline damages after half cell forming (analysis of half cell cut-outs)
- Fabrication of a full single cell (KEK – FJPPL program)
- RF test measurements are mandatory to evaluate the effect of polishing treatment on Nb for SRF applications (at IJCLab & KEK).

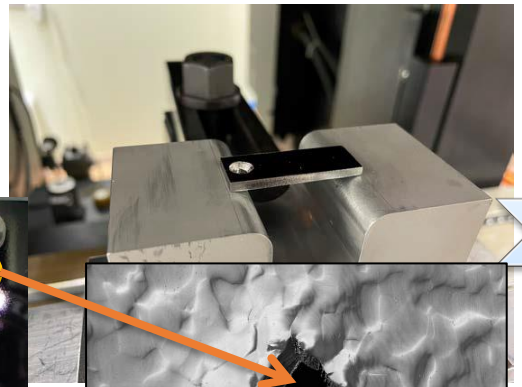
THANK YOU FOR YOUR ATTENTION

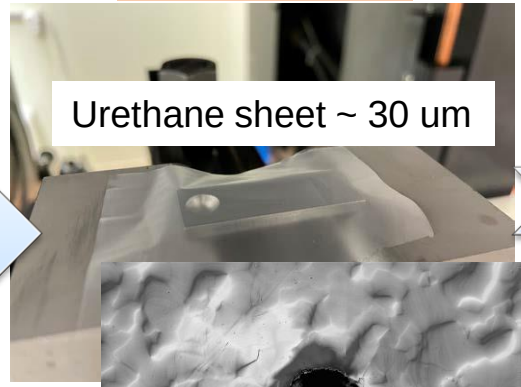
Back-up slides

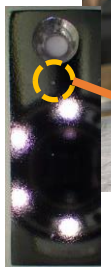
Forming at KEK

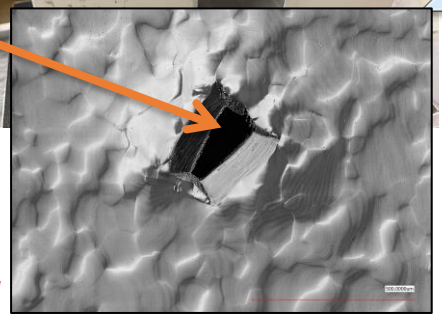
Conventional

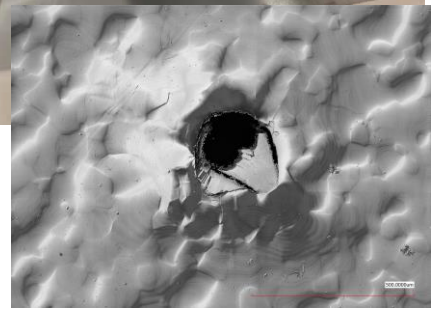
Alternative



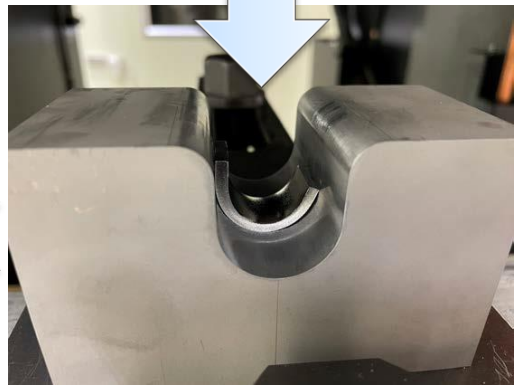


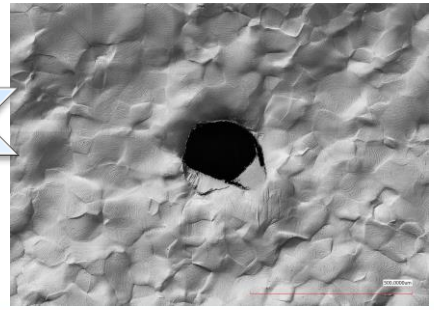


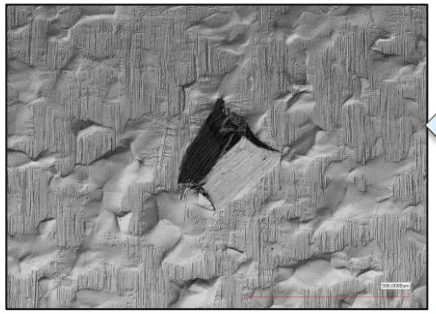




Before forming:



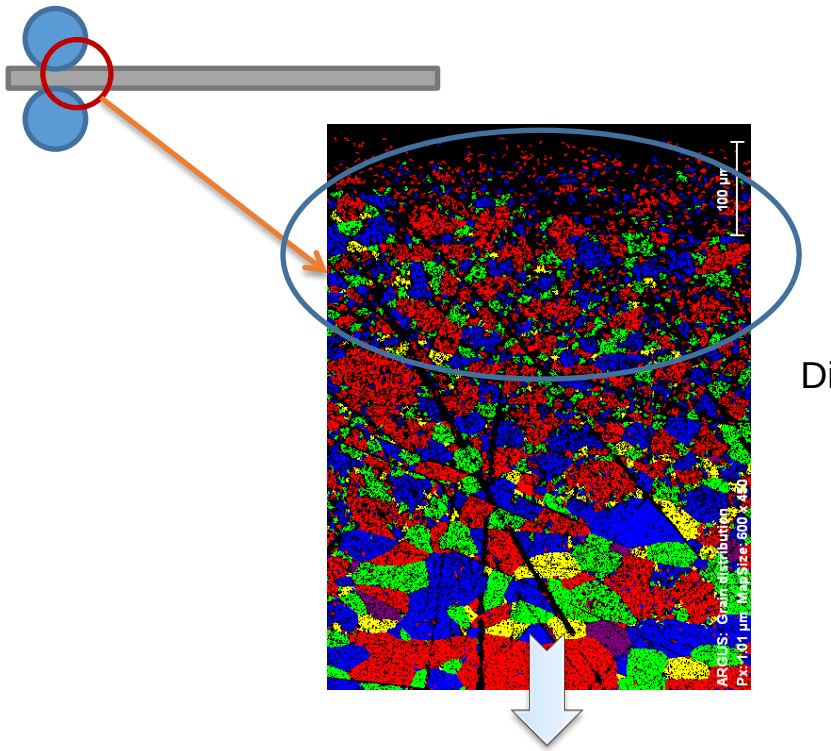




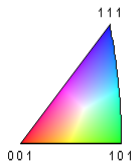
After forming:

Damaged layer versus process

Lamination

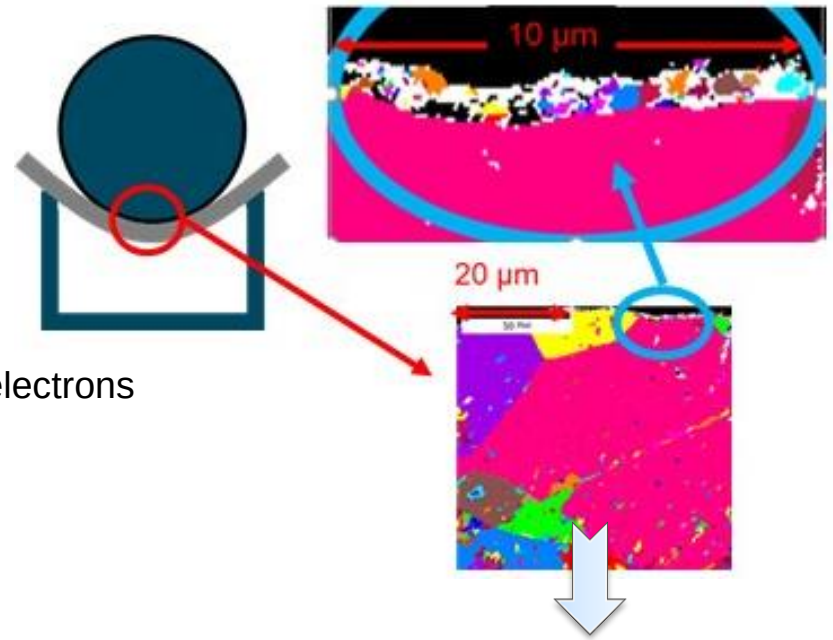


Damaged layer ~ 150 µm



Diffraction planes of electrons

Forming



Damaged layer ~ 1 µm