Electrodeposition of copper applied to the manufacture of seamless SRF cavities

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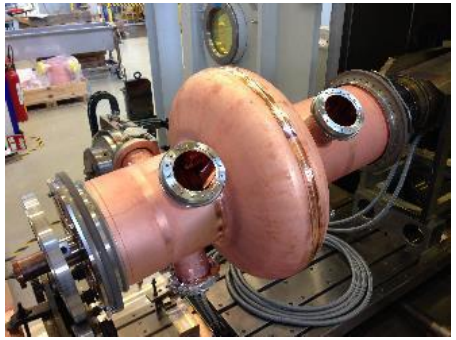
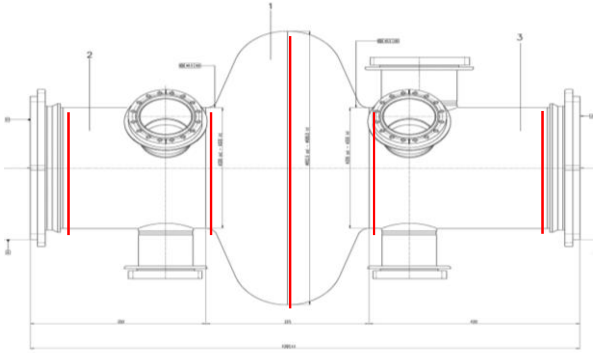
Outline

1. Current production process/problematic
2. Technical proposal
3. Samples characterization
4. Dislocation density by EBSD
5. Towards first 1.3 GHz cavity
6. Optimization of the process

Production of copper SRF substrates

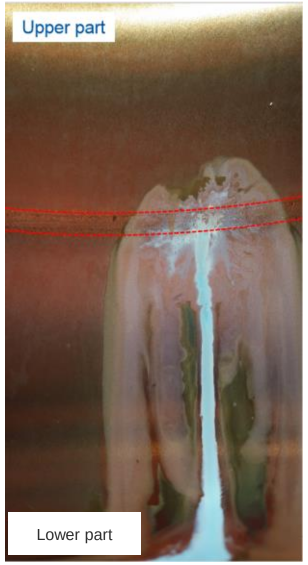
STANDARD METHOD - Half cell spinning and welding

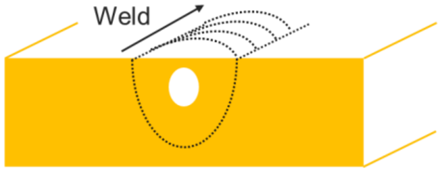
Half cell spinning

Welding

Possible defects





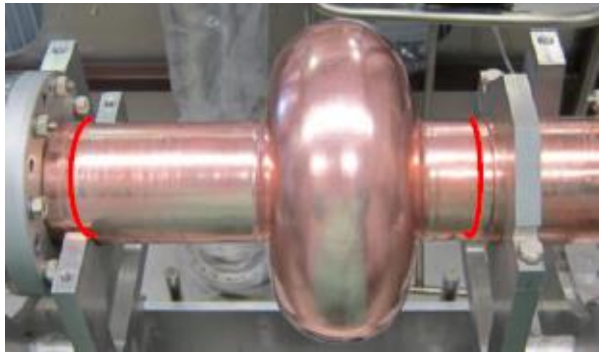
Weld porosities

- Presence of porosities along the junction caused by the welding process
- Copper sheets can contain defects

Production of copper SRF substrates

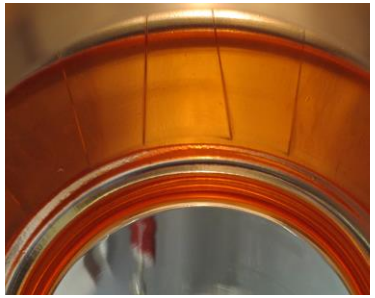
SEAMLESS METHOD - Cell spinning around mandrel

Cell spinning

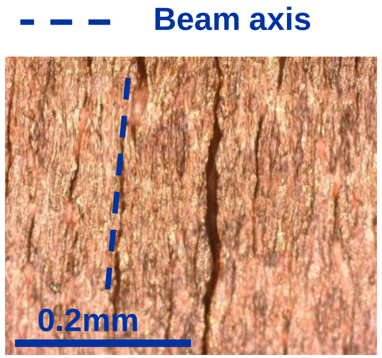


Cut-offs welding

Additional possible defects



Mandrel footprint

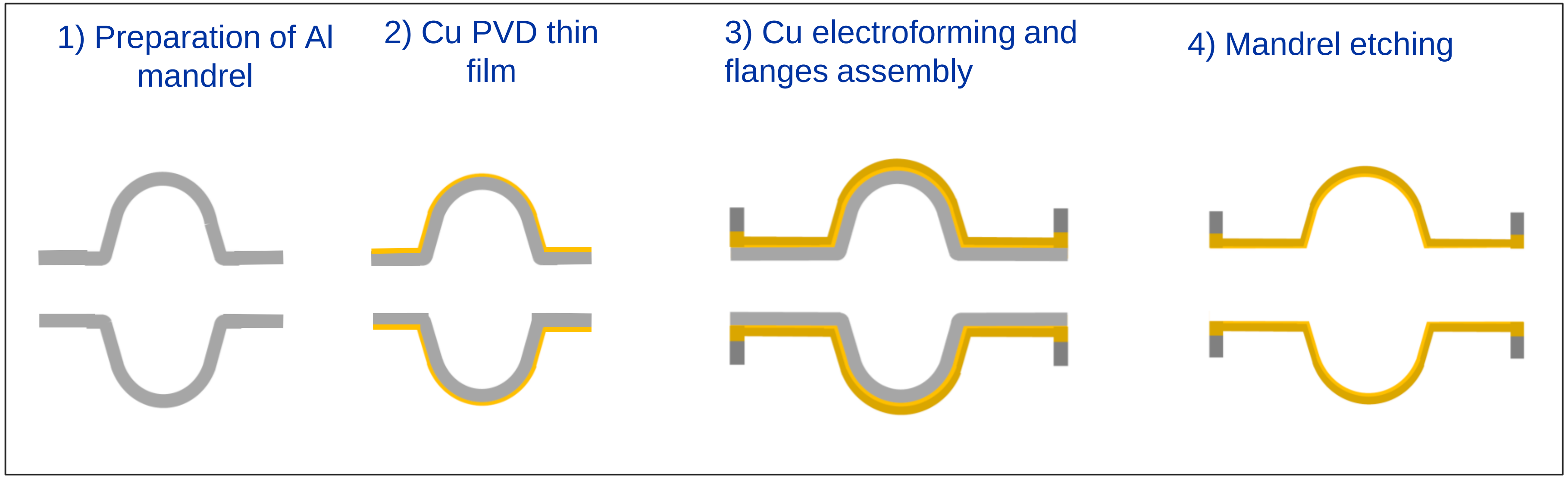


Cu cracking

- Mandrel footprint can appear on the copper surface
- Large deformation introduced in the process can lead to high cracking

Cu electroforming - approach

The cavity is produced by copper electroforming around a sacrificial aluminium mandrel which is pre-coated with a copper thin film.



- Seamless cavities (**No EB welding**)
- Stainless steel flanges assembled during electroforming

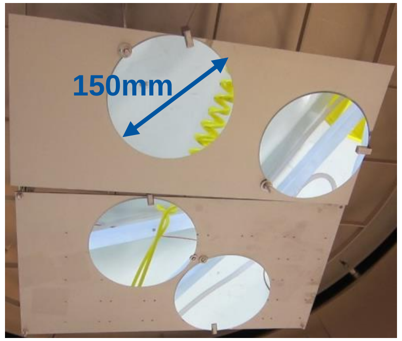
Challenges

- Robust and leak-tight seamless cavity
- Smooth inner surface state
- High copper purity and conductivity

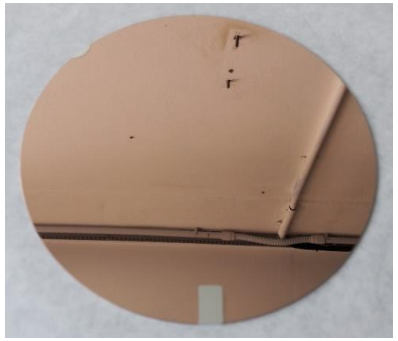
Cu electroforming - approach

- Study the properties of electroformed copper in flat samples

AW-6082



Flat Al disks



Cu sputtering

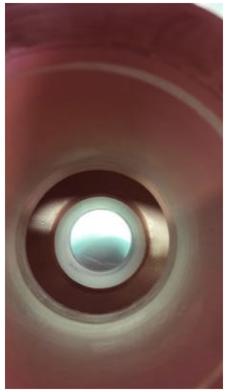
DC plating

Pulsed plating (PP)

- Study the robustness of the assembly in prepared cavity test dummies


Dummy1

DC plating

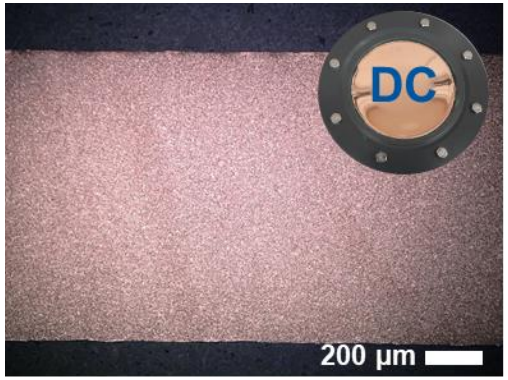
Dummy2

Pulsed plating (PP)

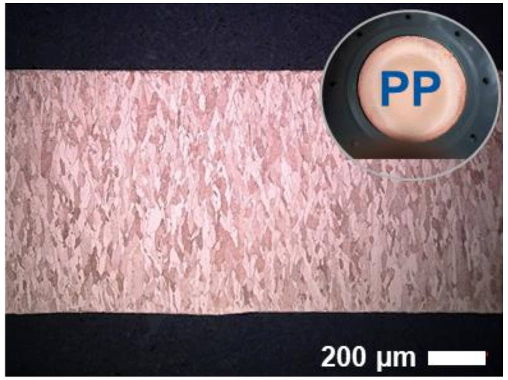
Electroformed copper properties

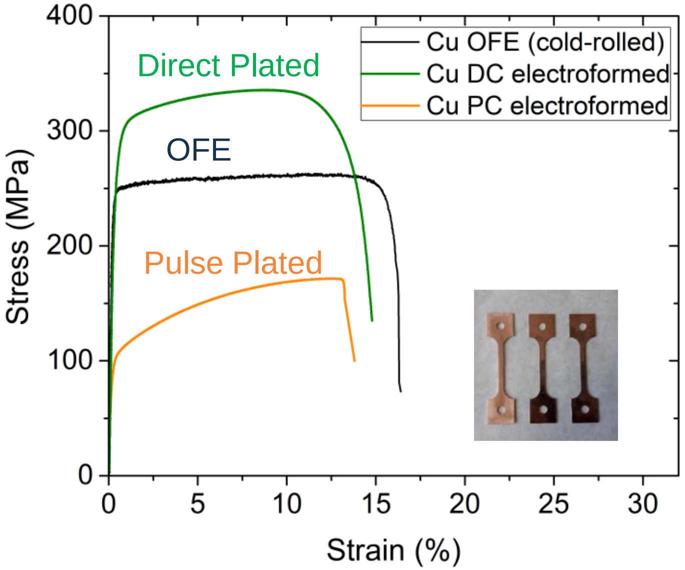
- **UTS/ Young modulus**

Direct Plated



Pulse Plated





Tensile strength:

DC>PP : grains morphology

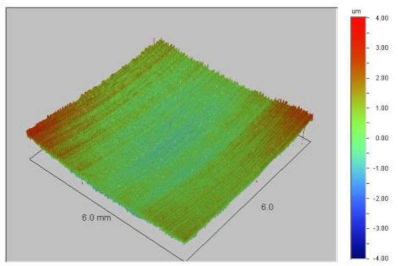
E modulus – impact excitation

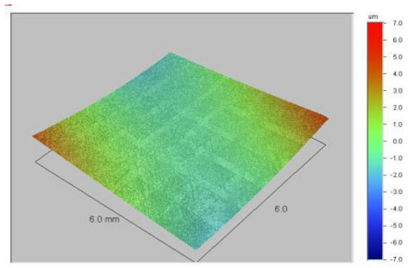
DC	PP
124 ± 15 GPa	131± 15 GPa

- **Roughness**

Standard mandrel machining (Ra 0.49 µm) | **Diamond** mandrel machining (Ra 0.002 µm)

Ra (µm)	DC plated	Pulse Plated	DC plated	Pulse Plated
Cu	0.39	0.65	0.023	0.028

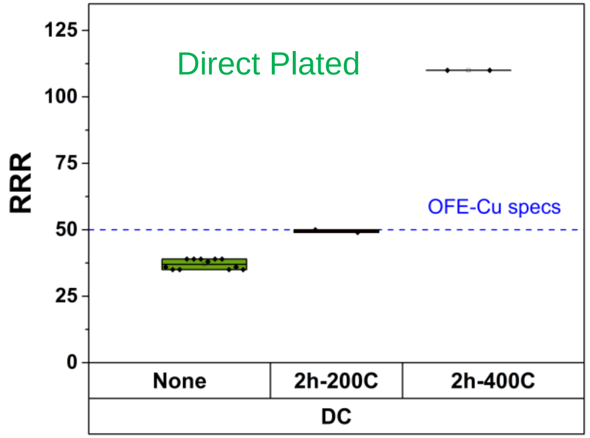


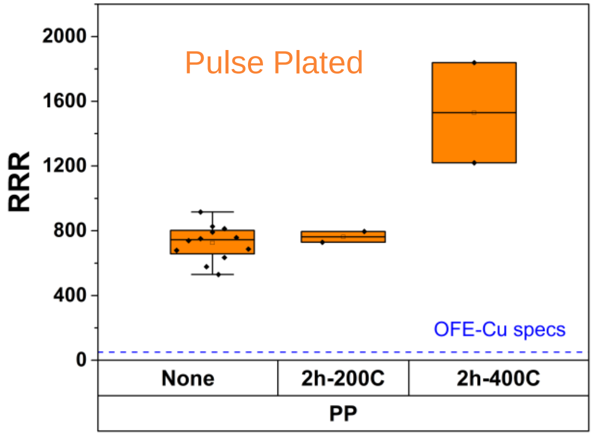


Cu layer reproduces mandrel topography

Electroformed copper properties

- **Residual Resistivity Ratio**

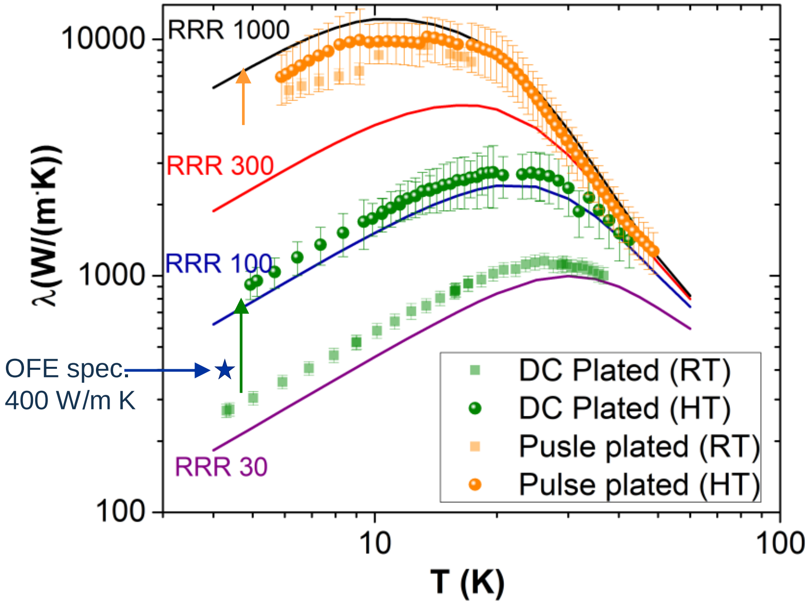




- DC matches Cu OFE specs after thermal treatment
- PP can lead to very high RRR without thermal treatment

- **Thermal conductivity**

- Samples measured after deposition
- Pulse plated sample conductivity 5 times larger than OFE spec.



- After 2h at 400°C
- Triplicated conductivity for DC plated after thermal treatment

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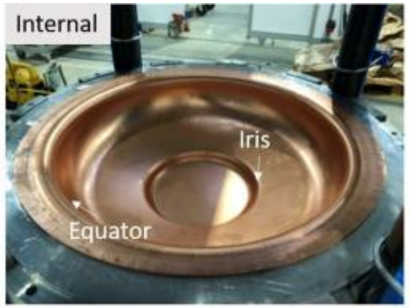
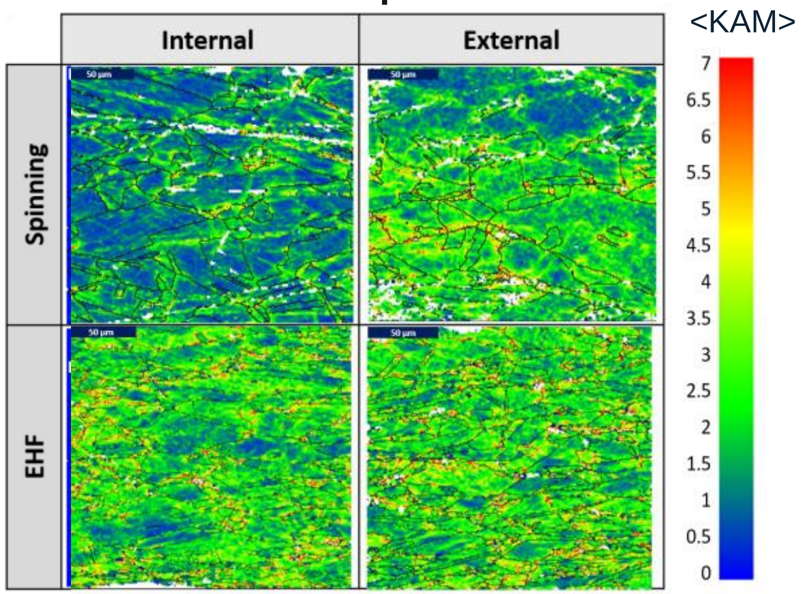
Electron back scatter diffraction (EBSD)

Cu OFE by Spinning and Electro-Hydraulic Forming (EHF)



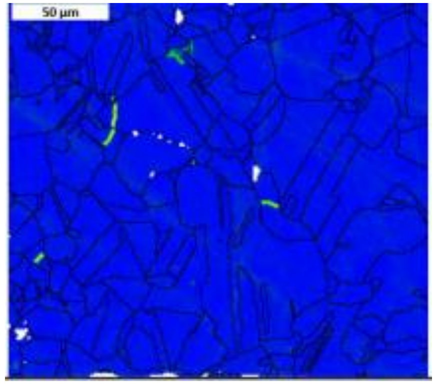
Iris samples

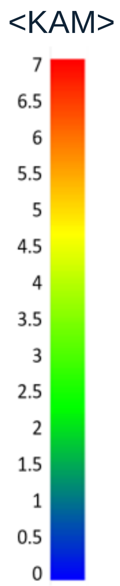


E. García-Tabarés et al, Electron Backscatter Diffraction meeting. Plymouth, April 2018.

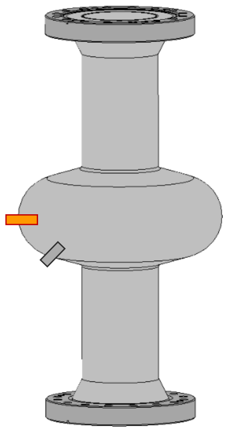
- To accommodate plastic deformation, the material generates dislocations, which disturb the structure of the lattice and lead to local misorientations.
- Study local misorentation by measuring the kernel average misorientation (KAM).
- This criteria displays small orientation gradients, highlighting areas of high Geometrically Necessary Dislocations (GND) density.

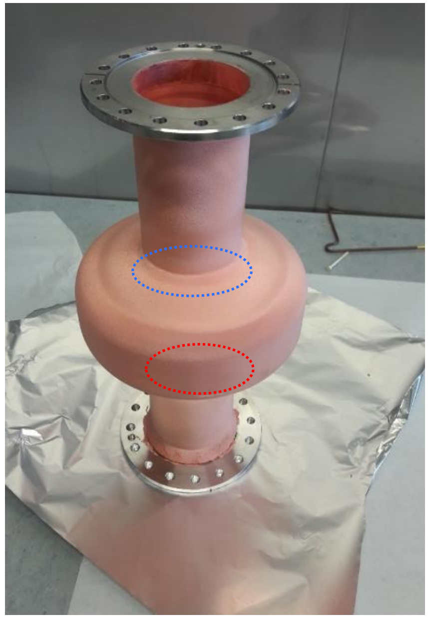
OFE copper Reference





EBSD and dislocation density

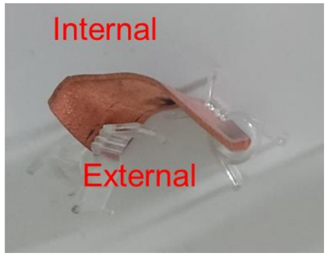




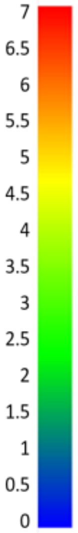
Dummy2

Pulse plated cavity

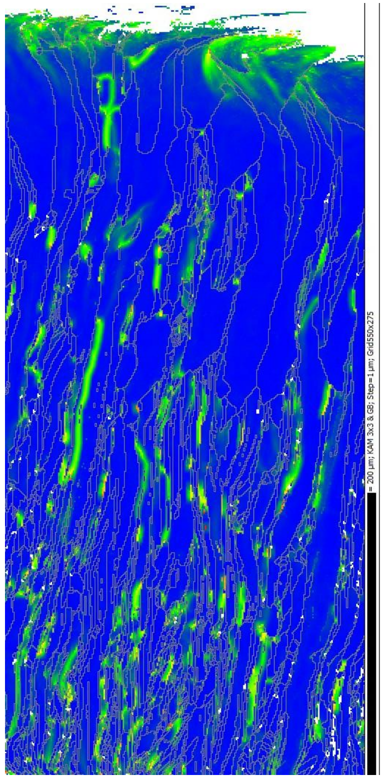
Iris samples



<KAM>

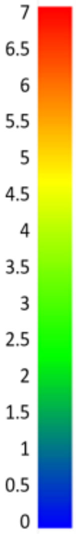


External

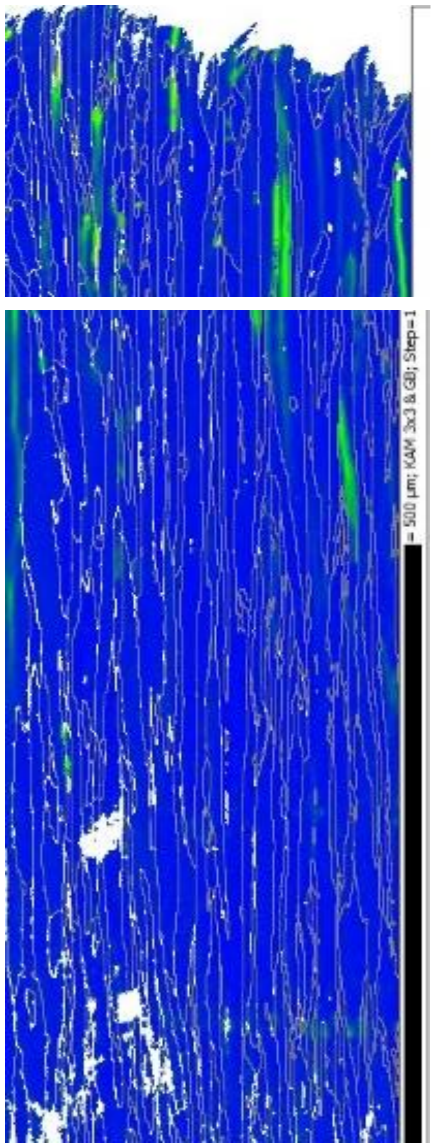


Internal

<KAM>



External

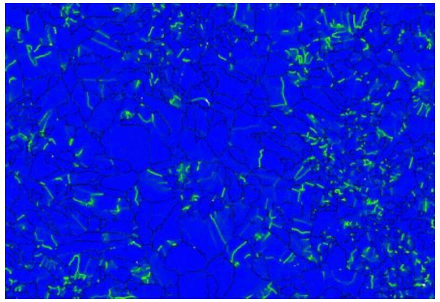


Internal

Equator samples

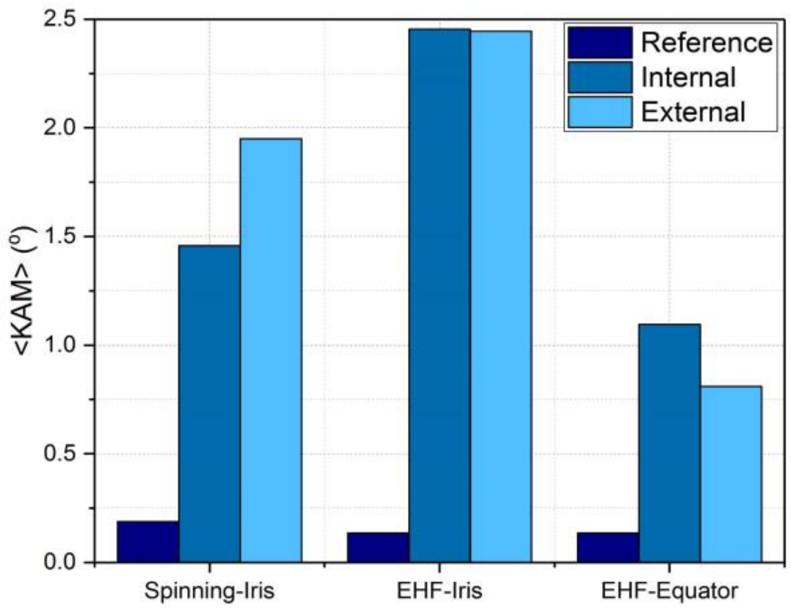
Horizontal plane

200 µm



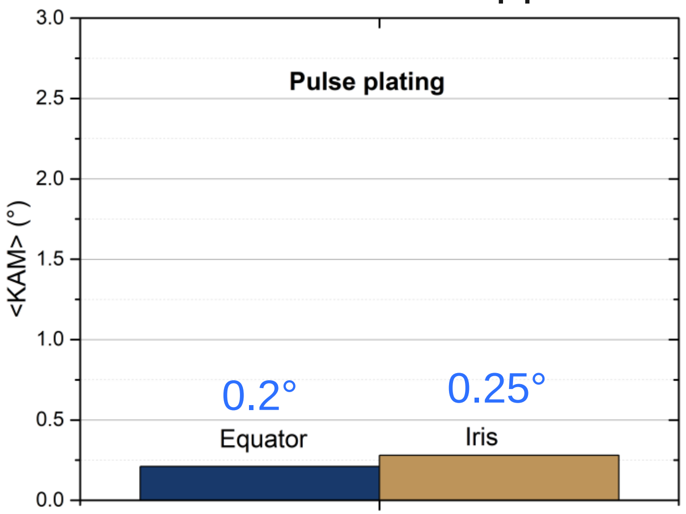
EBSD and dislocation density

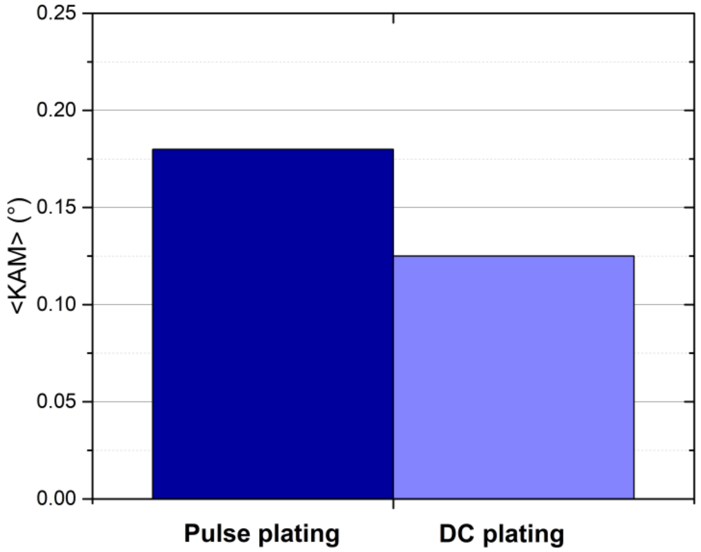
Spinning vs Electro-Hydraulic Forming



Presented by Carolina Abajo Clemente at the FCC Week 2018

Electroformed copper





- Low dislocation density in electroformed copper.
- Similar GND density than reference copper OFE before machining.

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5. **Towards first 1.3 GHz cavity**
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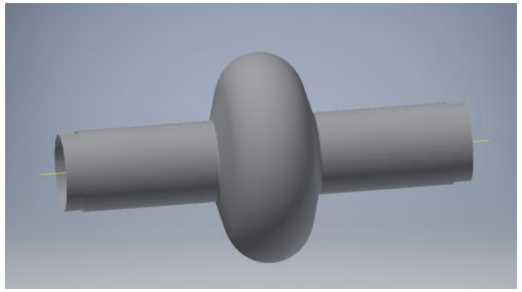
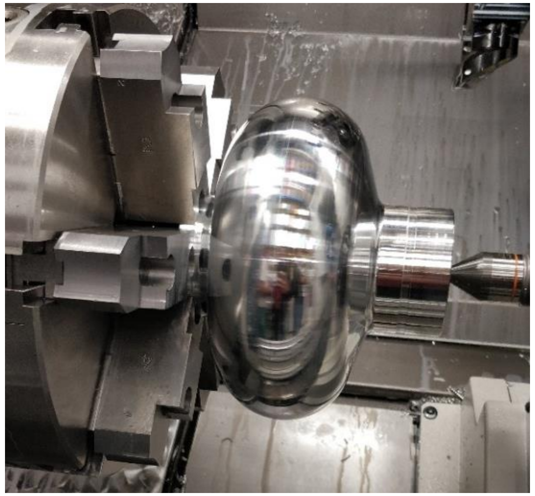
1.3 GHz Mandrel production

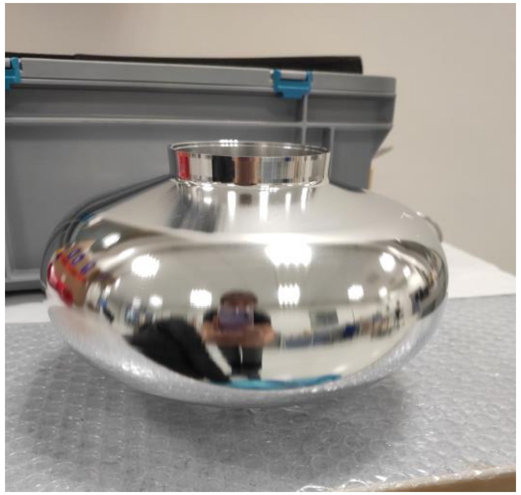


How to produce such an aluminium mandrel?

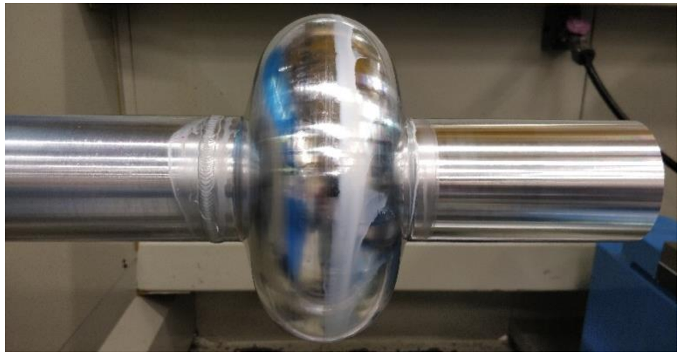
Machined from bulk aluminium



Mandrel cell turning



Mechanical finishing

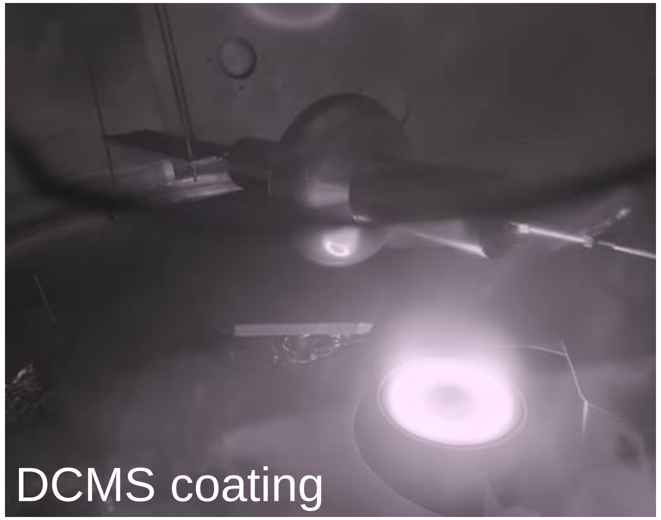


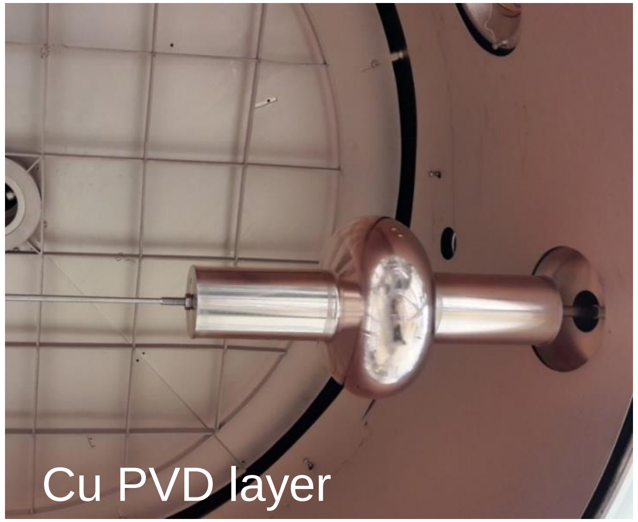
Tubes welding/machining

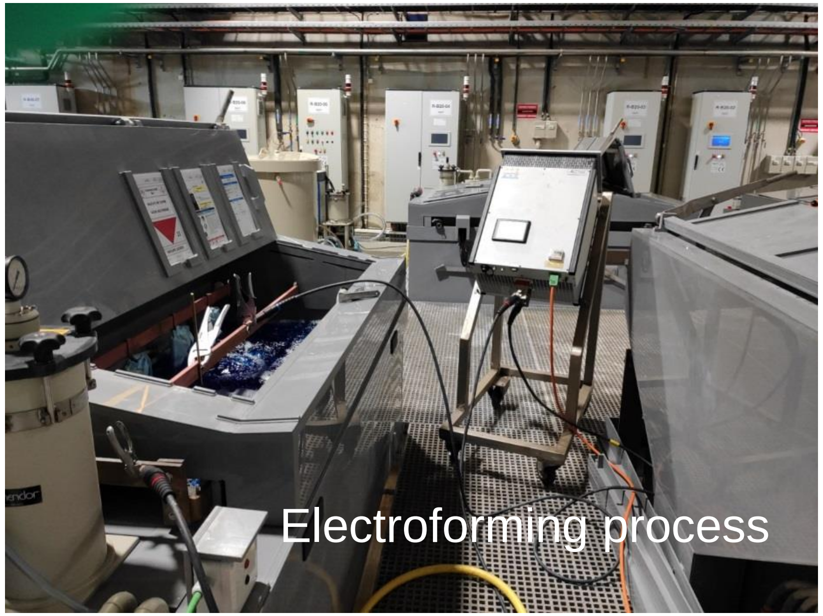
Final Mandrel

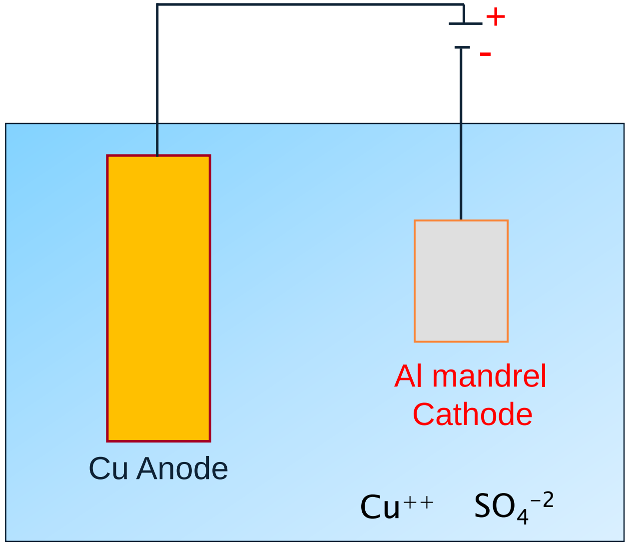
For the moment: Standard machining finishing

First 1.3 GHz cavity









Cathode (reduction):

$Cu^{2+} + 2e^{-} \rightarrow Cu$

Anode (oxidation):

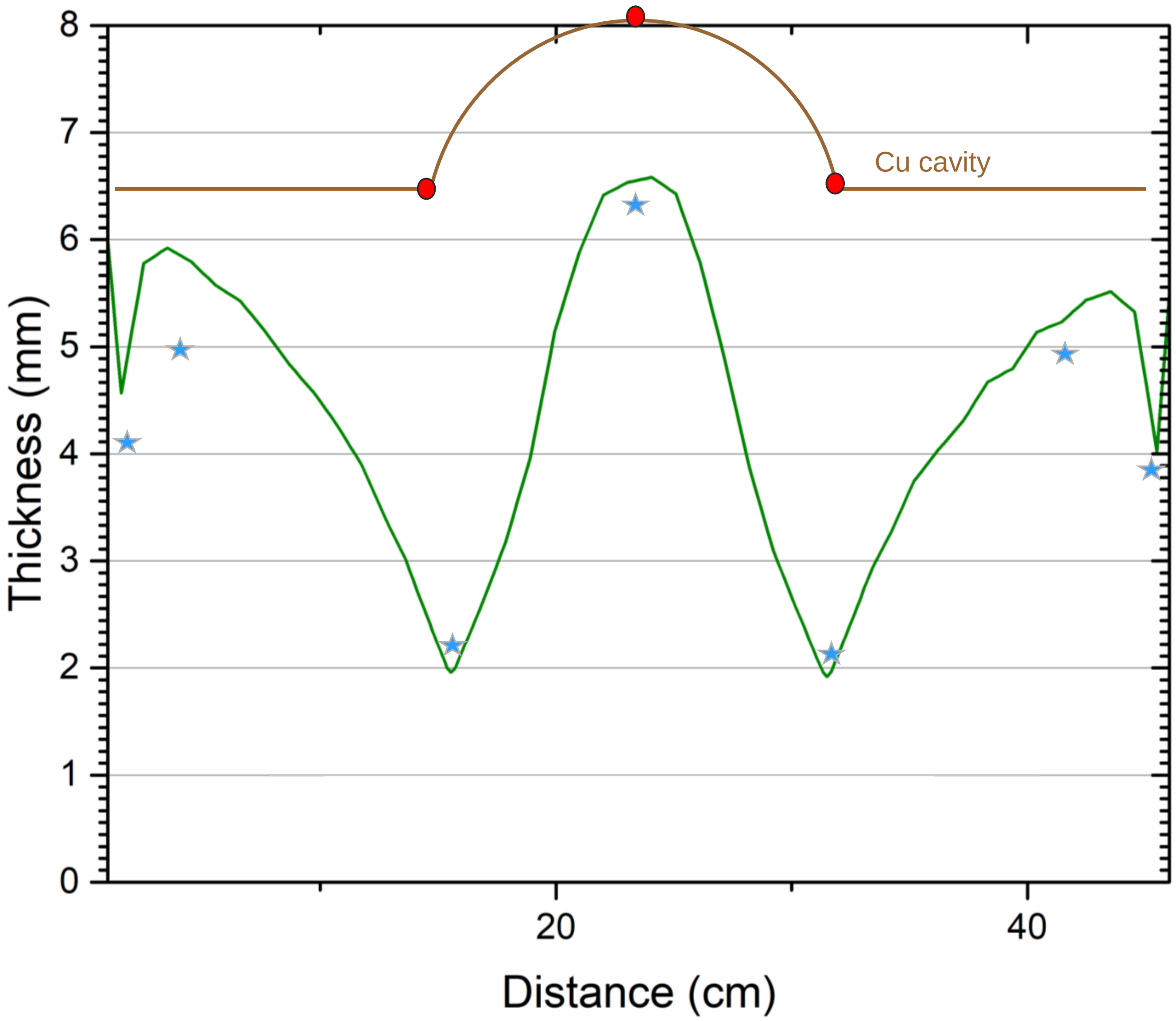
$Cu \rightarrow Cu^{2+} + 2e^{-}$

First 1.3 GHz cavity

1 week 2 week 3-4 week

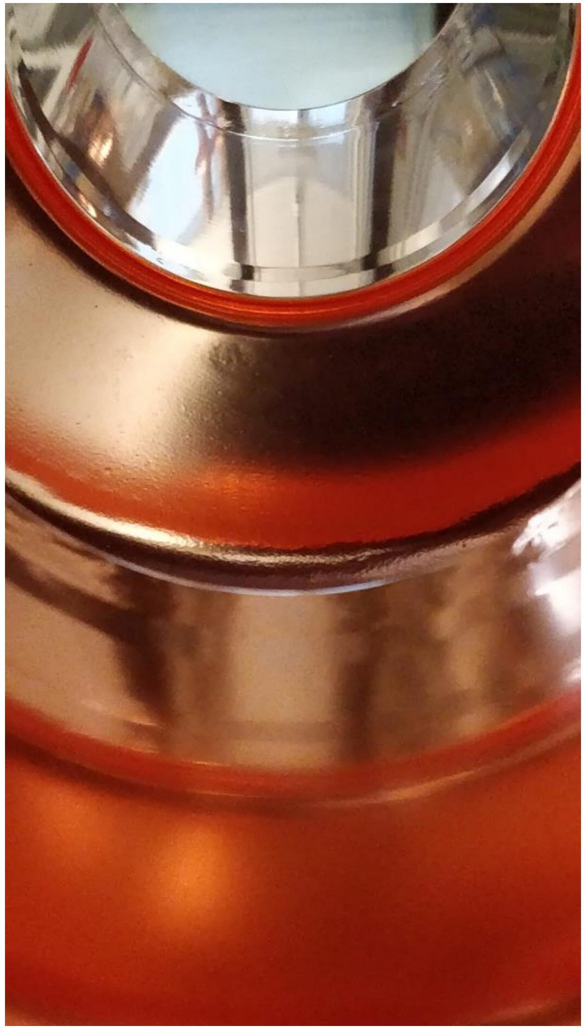
336 hours of plating (Pulse plating + DC plating)

First 1.3 GHz cavity



- 2 mm plating at the iris
- 6.4 mm plating at the equator

First 1.3 GHz cavity



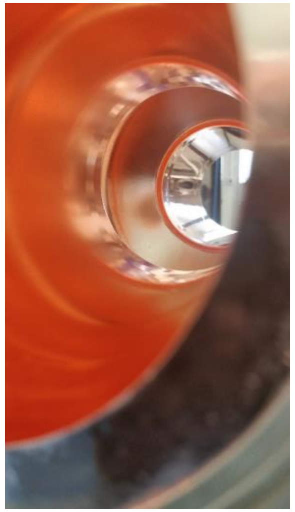
Aluminum dissolution NaOH 5M

Surface preparation: SUBU

First 1.3 GHz cavity

Workflow succesfully evaluated on electroformed cavity

Surface preparation

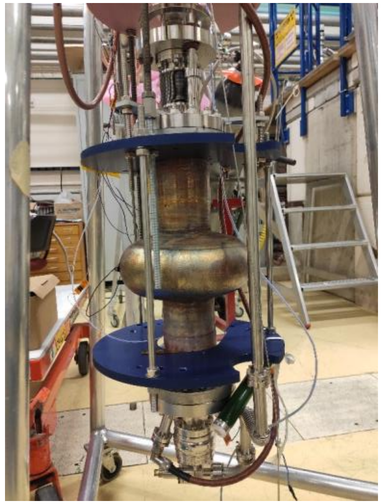


HPR

Nb Coating

HPR

RF testing



Nb stripping

Don’t miss

Dr Lorena Vega Cid
First results of the RF performance of 1.3 GHz Nb coated cavities on high quality copper substrates

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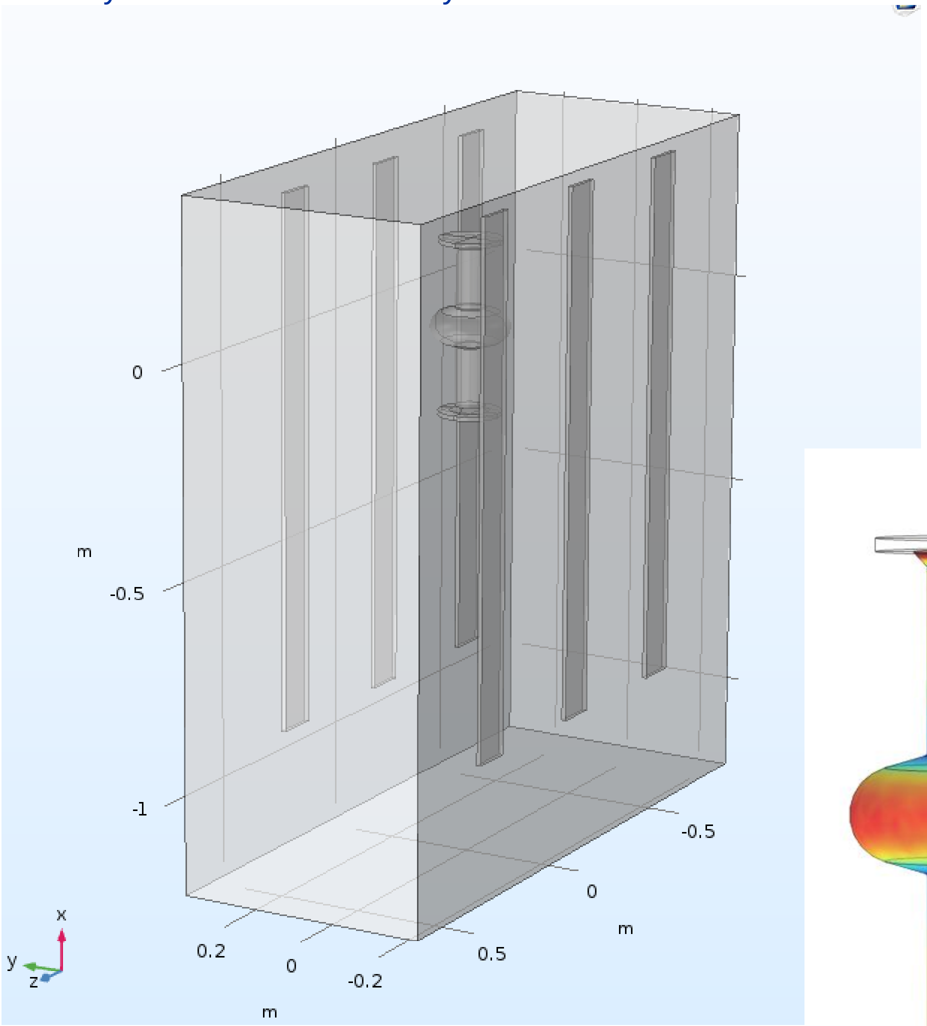
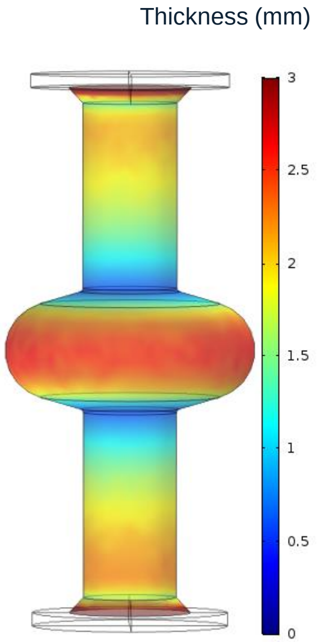
5. Towards first 1.3 GHz cavity
6. **Optimization of the process**
    - Electroforming process

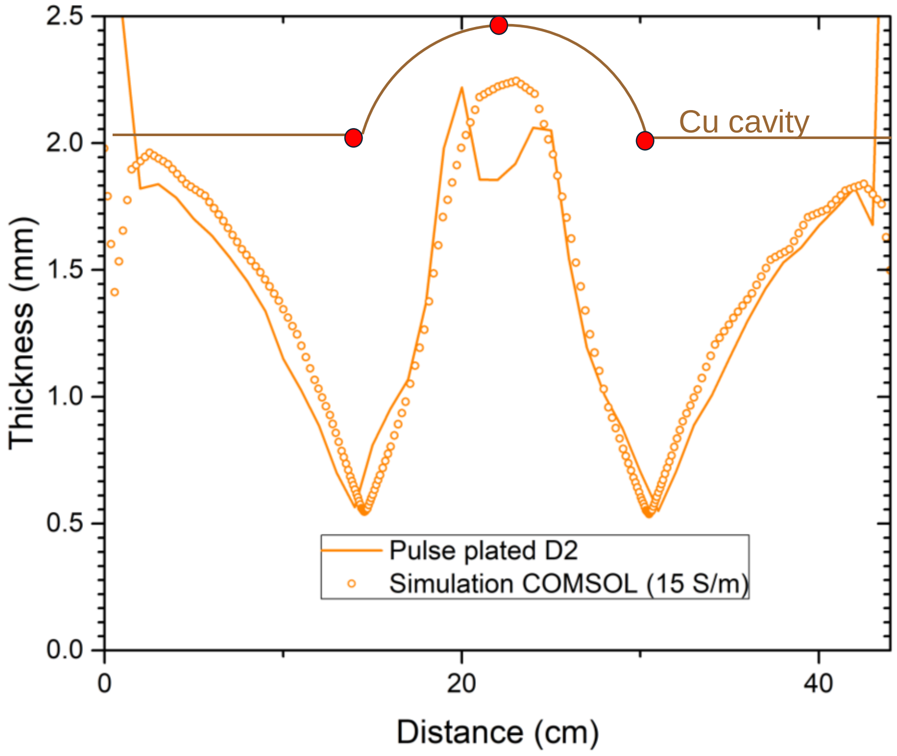
COMSOL simulations for optimization

Thickness profile simulated with COMSOL

Physics module: Secondary current distribution



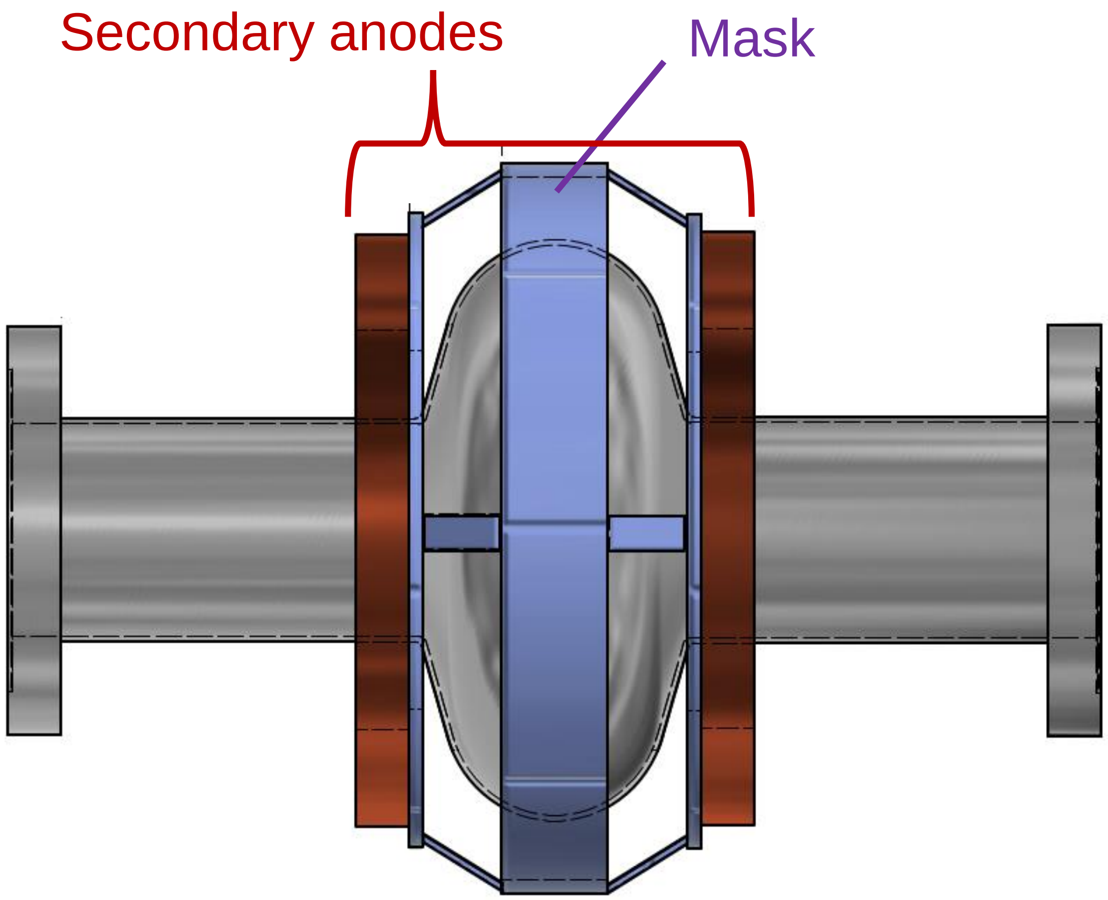




- Good agreement between simulation and experimental.
- Simulation can be used for optimization of anodes and mask.

Design of secondary anodes and masking

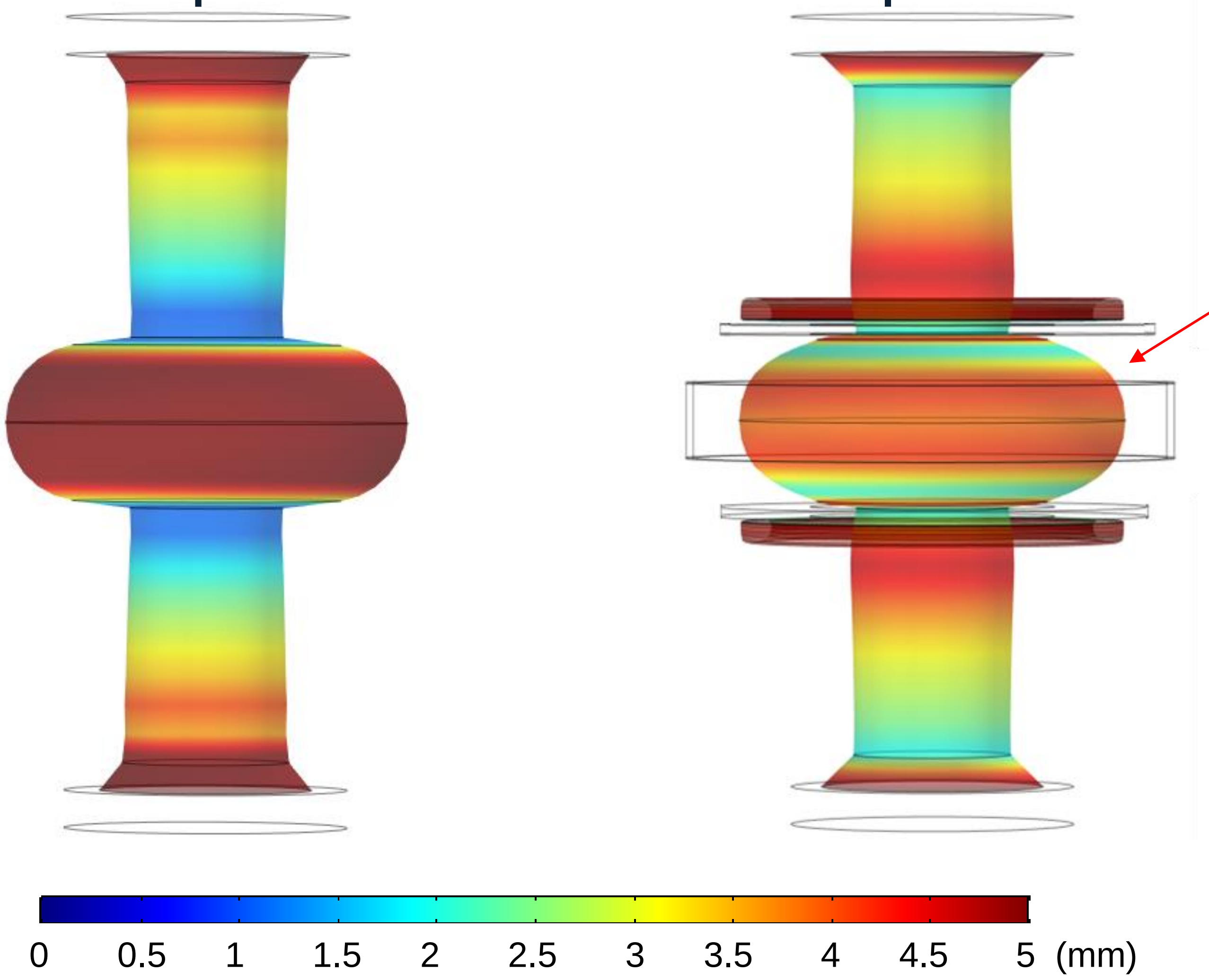
- Solution for uniformity: Secondary anodes positioned at the iris to promote plating, mask at the equator to reduce the deposition.



Design of secondary anodes and masking

Without optimization **After optimization**

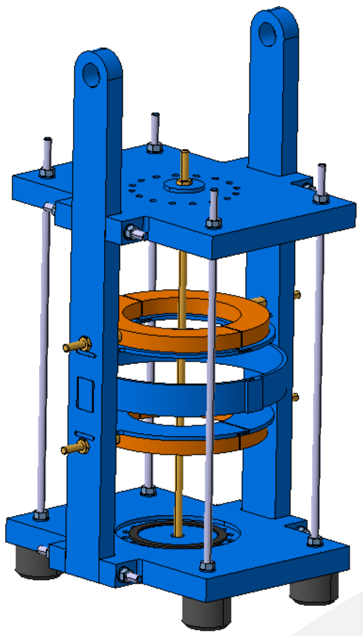
Thickening
on equator

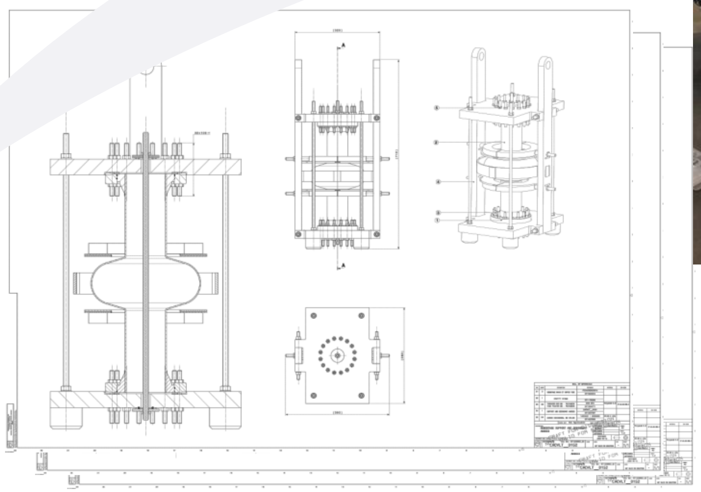


Thickening
also on iris

- 175 hours plating time for 2 mm at the iris
- Decrease plating time in half

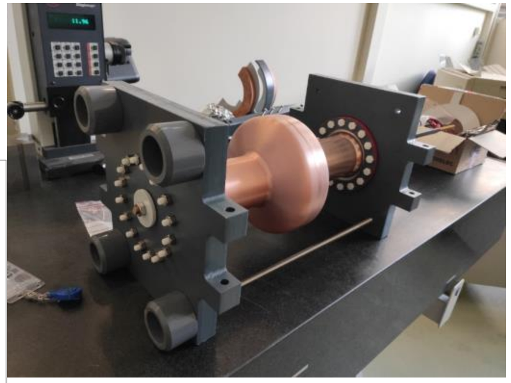
Implementation of support

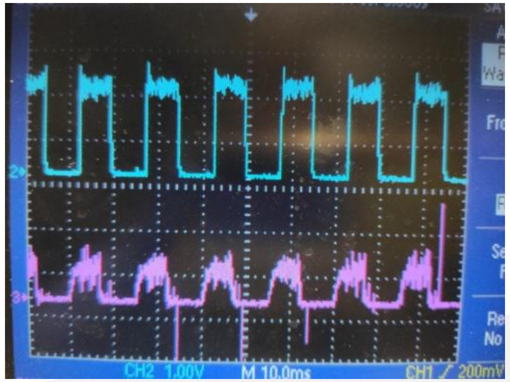




● Design

● Fabrication





● Commissioning

Outline

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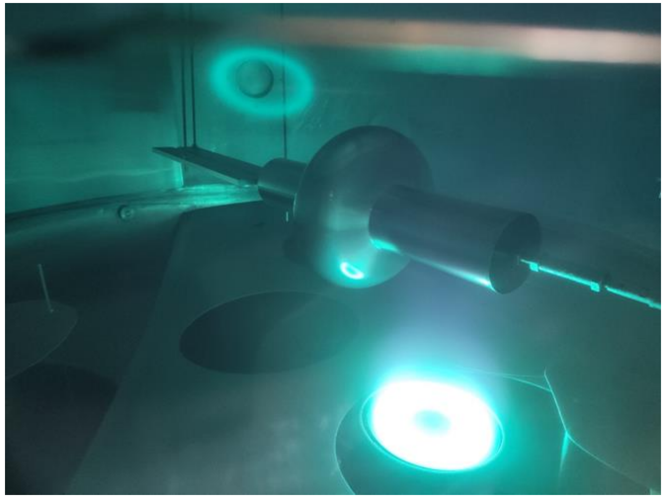
6. **Optimization of the process**

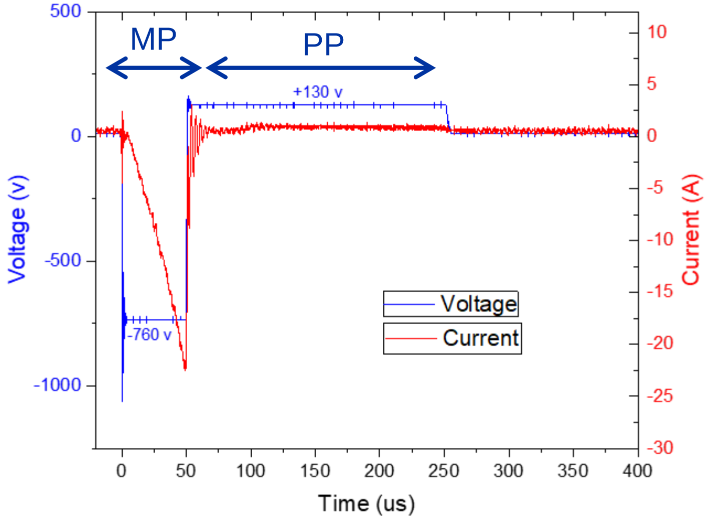
    - Copper PVD process

Optimization of Cu coating process

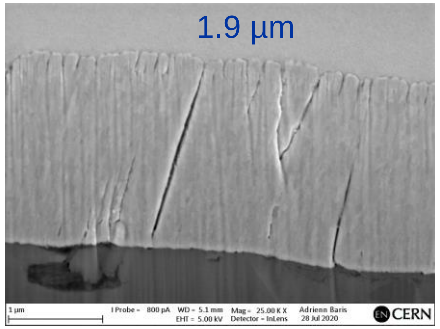
- **HiPIMS sputtering:** high peak power densities in short pulses.
- The sputtered material is highly ionized and is accelerated towards substrate thanks to the positive pulse.
- **High-quality dense homogeneous films**



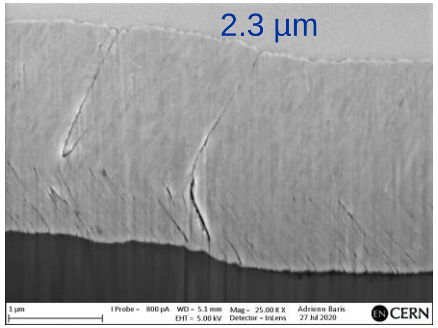
High **P**ower **I**mpulse **M**agnetron **S**puttering



DCMS

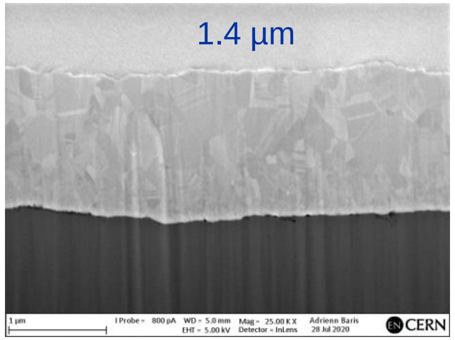


Iris

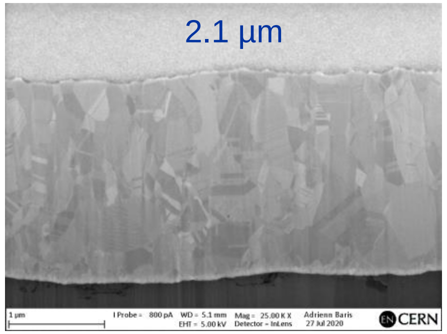


Equator

HiPIMS + PP



Iris



Equator

- Very compact coatings.
- No porosities.

Conclusions

- Cavity lifecycle (production-coating-rinsing-testing-stripping) feasibility has been demonstrated with the electroformed 1.3 GHz cavity.

- The main drawback of the electroforming approach is the non-uniform thickness distribution along the cavity.

  Solution: secondary anodes and masking to the cavity. The plating time will be reduced by half.

- The Cu PVD layer was optimized by applying HiPIMS.

- Very low dislocation density on the iris and equator of electroformed cavity.

Perspectives

- 1.3 GHz cavity production and validation of the secondary anodes support.
- Optimal surface preparation technique before coating.
- Nb thin film coating using best recipe and RF testing.

- Different mandrels surface state: electroforming on polished mandrels.
    - Diamond turning finishing
    - Electro-polishing of the aluminium mandrels

Thank you for your attention!