Cu electrodeposition for the manufacturing of seamless SRF cavities

G. Rosaz, on behalf of the working group

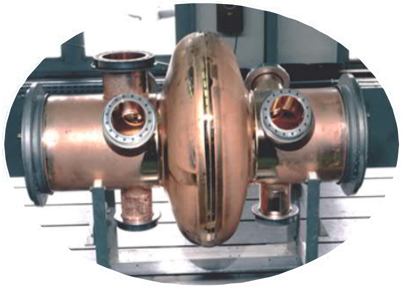
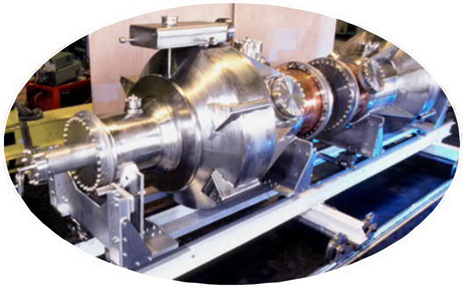
CERN, Esplanade des particules 1, 1211 Geneva 23

OUTLINE

1. Context / problematic
2. Technical proposal
3. Samples characterization
4. Toward a real cavity fabrication
5. Conclusion / perspectives

1. Context / Problematic

1. Nb/Cu Cavities - Background

LEP-2	LHC	SOLEIL	HIE-ISOLDE
			

COST

Manufacturing: Cu OFE (10euros/kg) vs Nb RRR300 (800euros/kg)

Operational: Operation @ 4.2 K / Simpler cryostat (stainless steel vs Titanium)

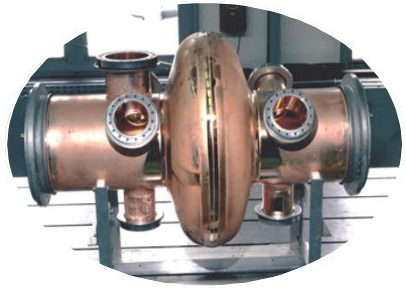
Thermal Stability

Cu substrate ensures SC film stabilization wrt thermo-magnetic breakdown

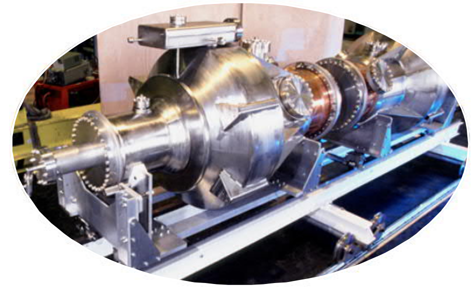
1. Nb/Cu Cavities - Background

LEP-2

LHC



SOLEIL



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What about the performances?

1. Objective

Performances goal

Nb/Cu should compete with bulk Nb cavities

→ High Q

→ High Gradient

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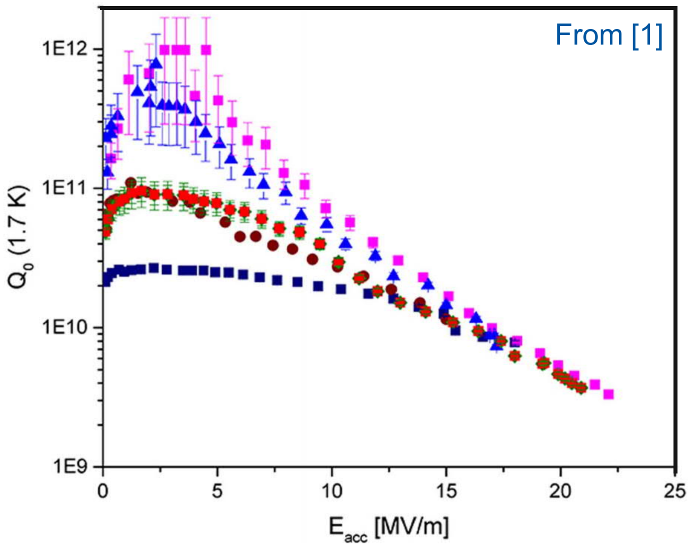
90's achievements



High Q are reachable
→ Surface state is the key!!!
→ Electro-polishing at that time

[1] Benvenuti et al, Study of the residual surface resistance of niobium films at 1.5 GHz, Physica C: Superconductivity, 351 (2001), 421-428

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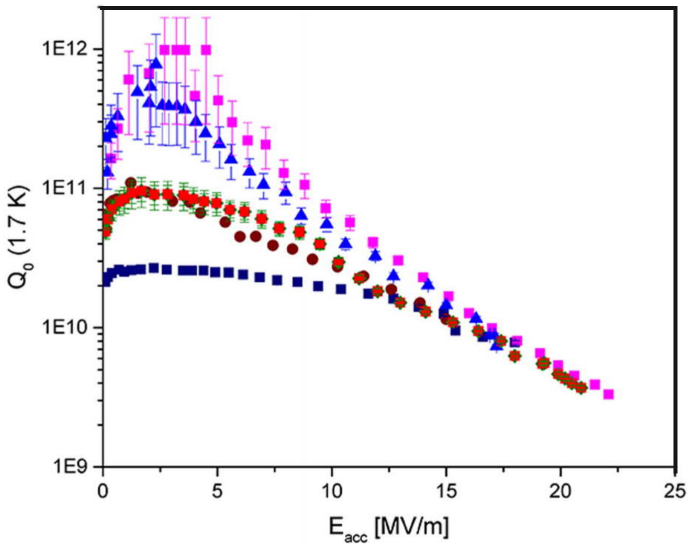

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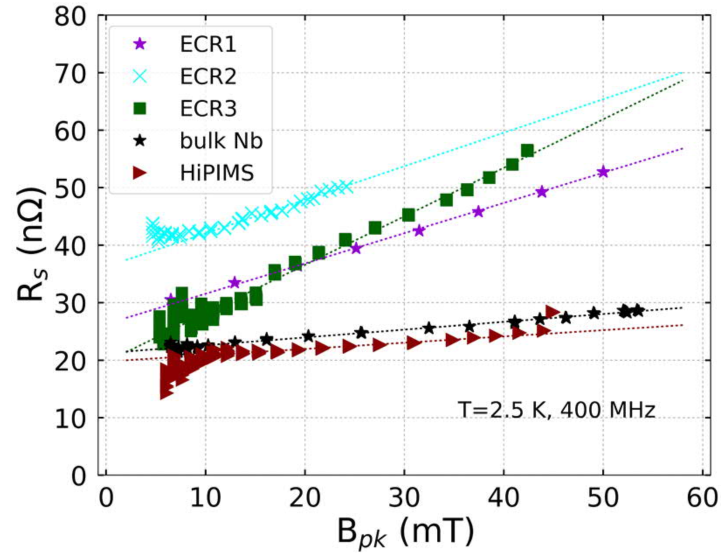

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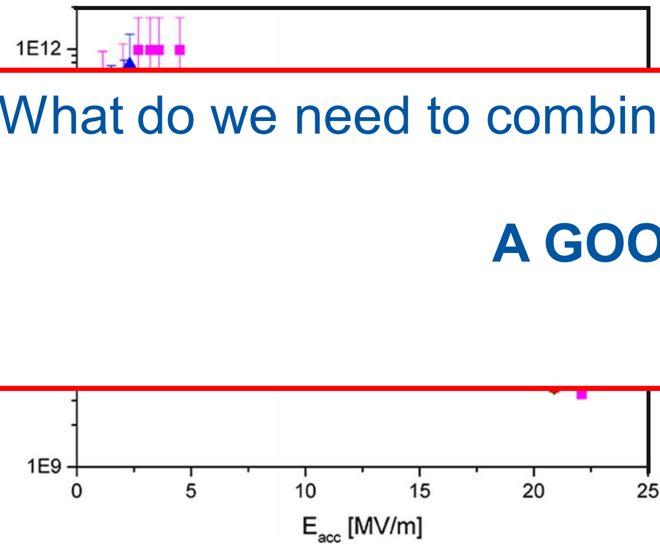

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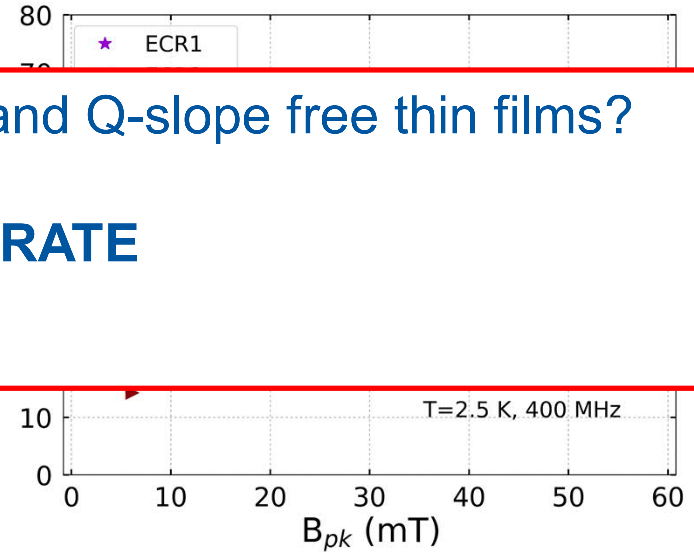

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What do we need to combine High Q and Q-slope free thin films?

A GOOD SUBSTRATE

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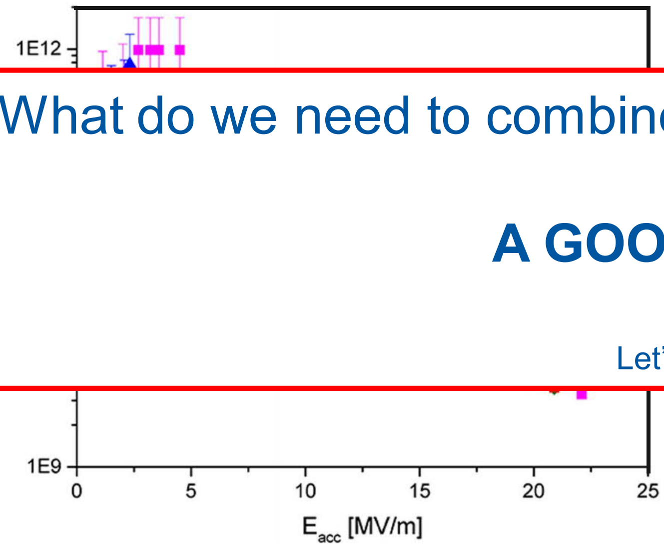

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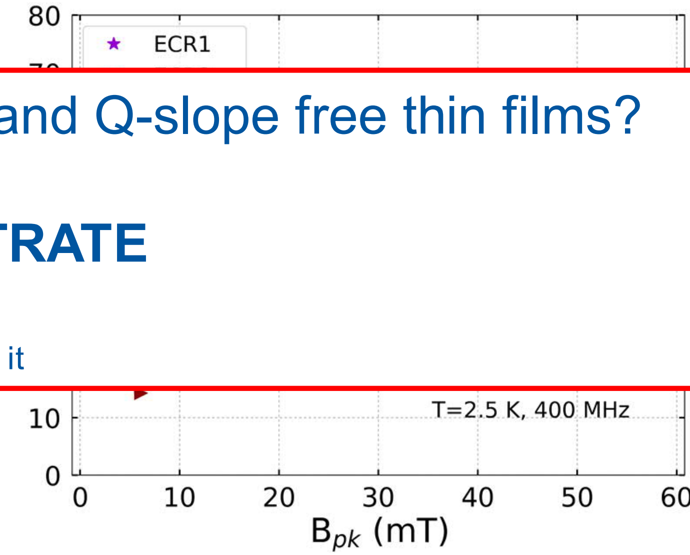

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Let's have a look at it

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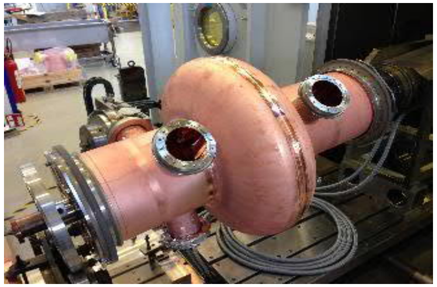
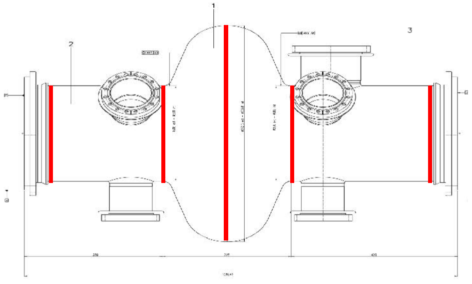
1. Nb/Cu Cavities - Forming

Standard Route

½ cell spinning



Welding



12 welds

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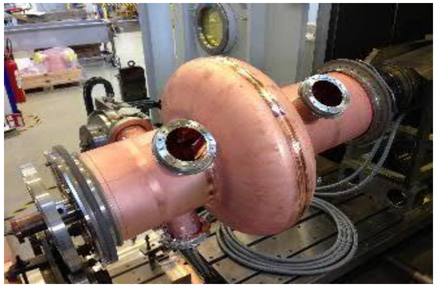

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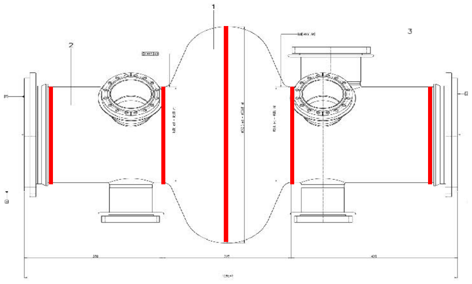
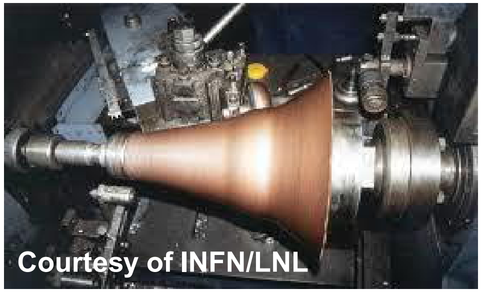
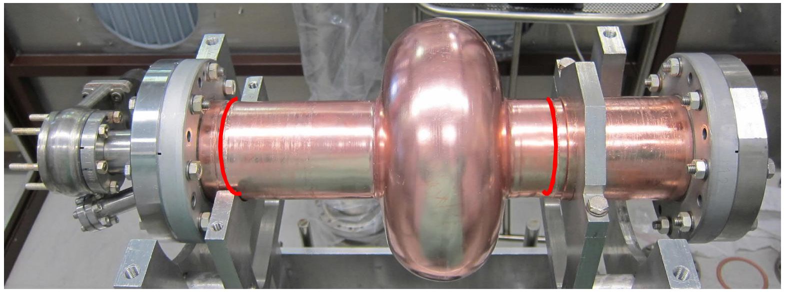


12 welds

Seamless Route

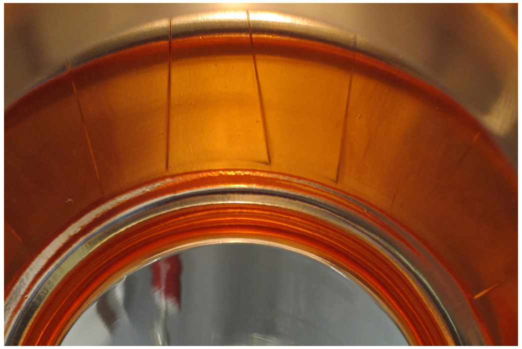


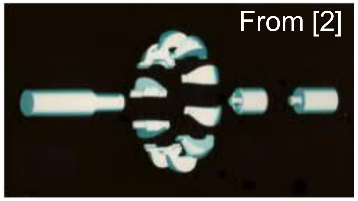
cell spinning



Cut-offs welding

Nb/Cu Cavities - Defects





Mandrel footprint

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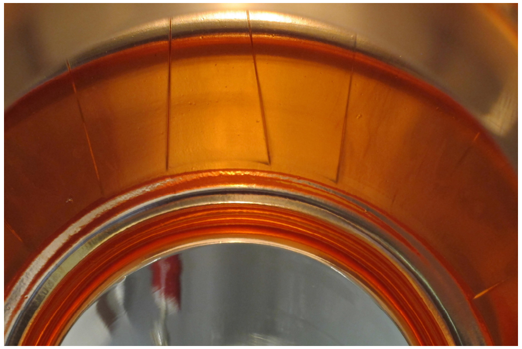

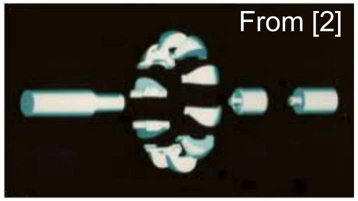

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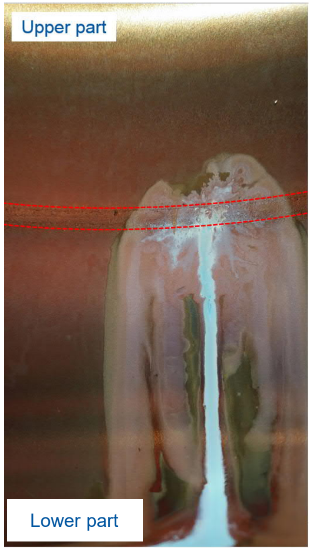
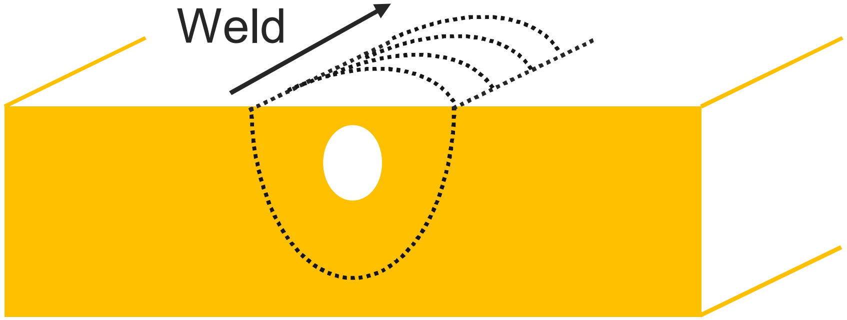


Weld porosities



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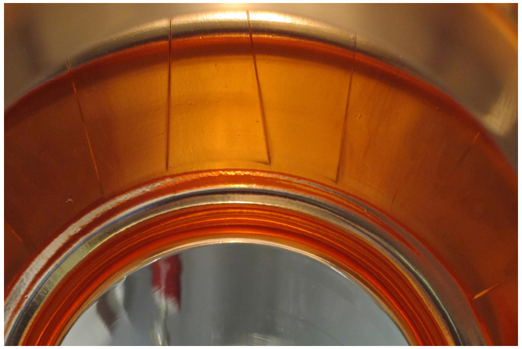

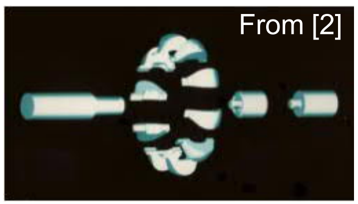

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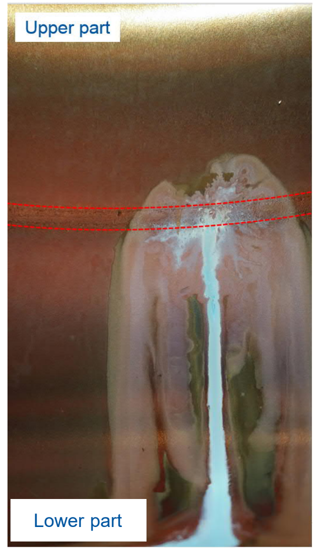

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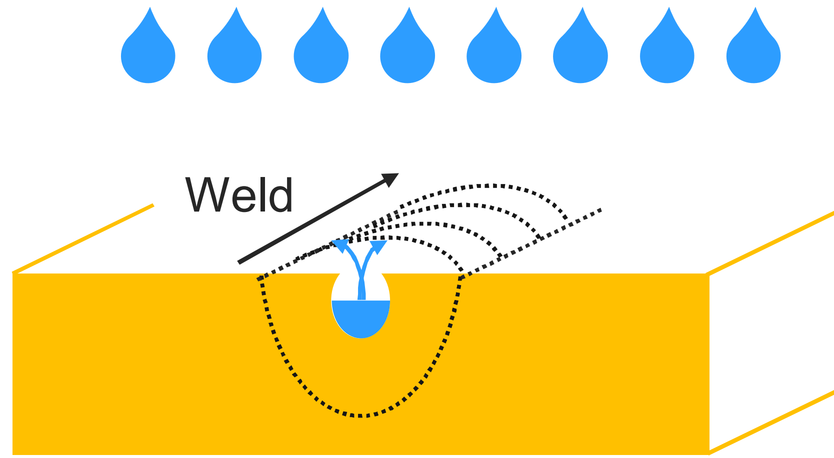

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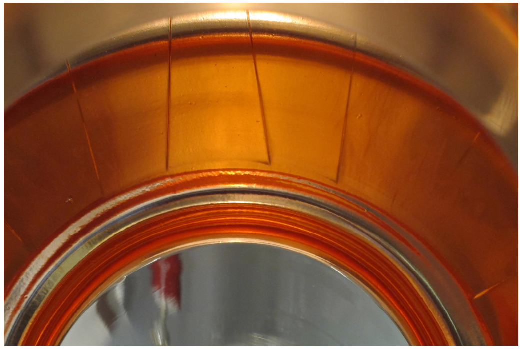

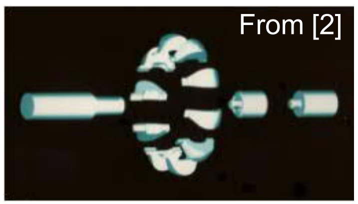

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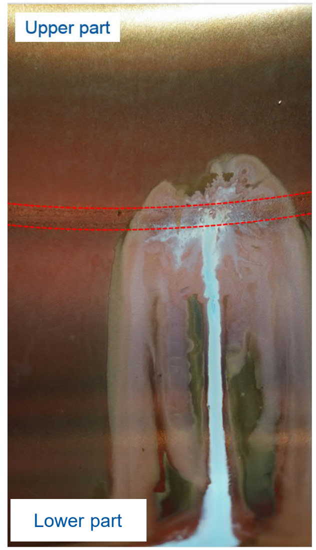

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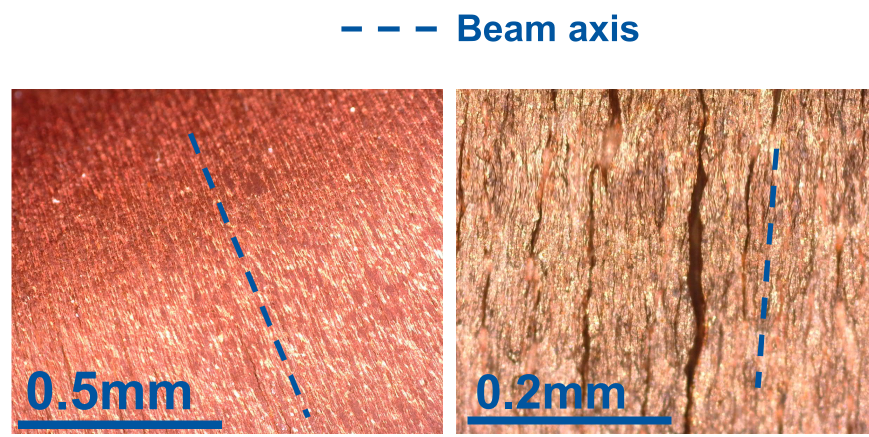

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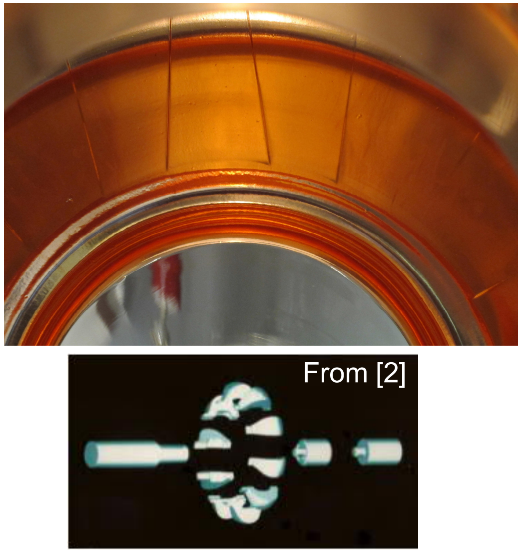

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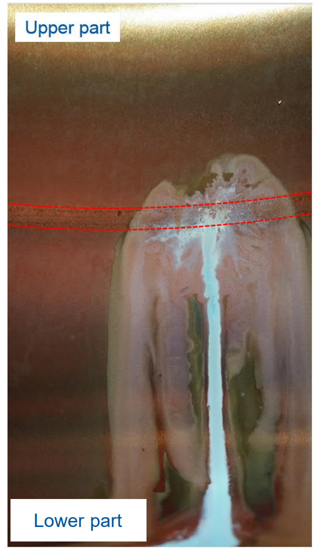

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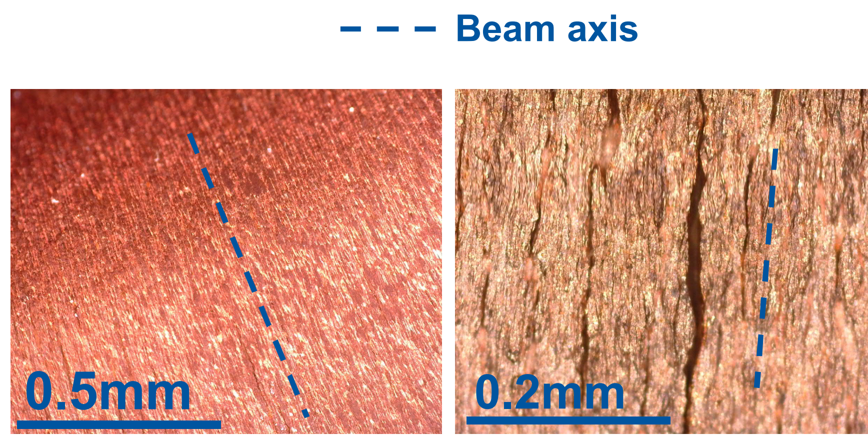

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Shape tolerance requirement in seamless process by spinning need strong R&D effort. On-going in INFN-LNL.

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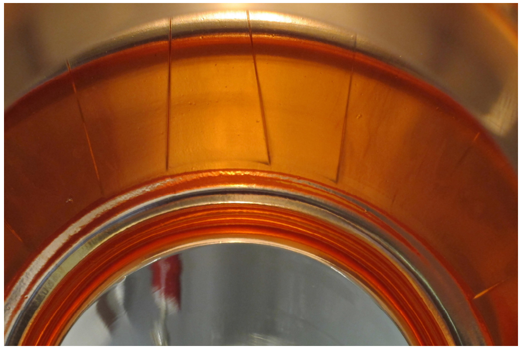
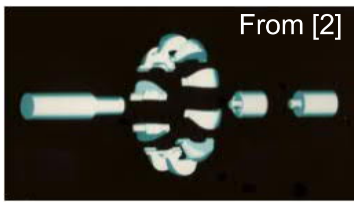

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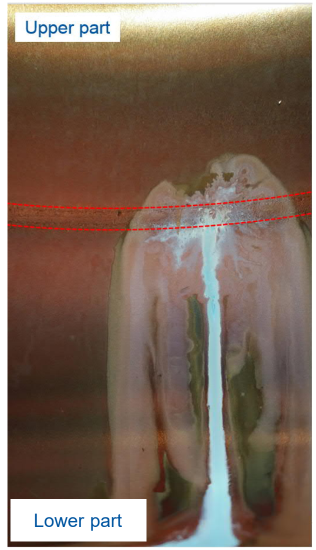
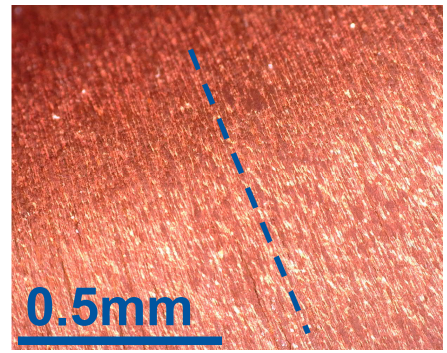
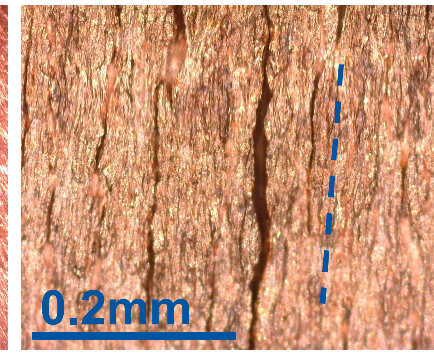


Weld porosities

- - - Beam axis





Cu cracking in seamless process

Shape tolerance requirement in seamless process by spinning need strong R&D effort. On-going in INFN-LNL (see Cristian Pira's talk).

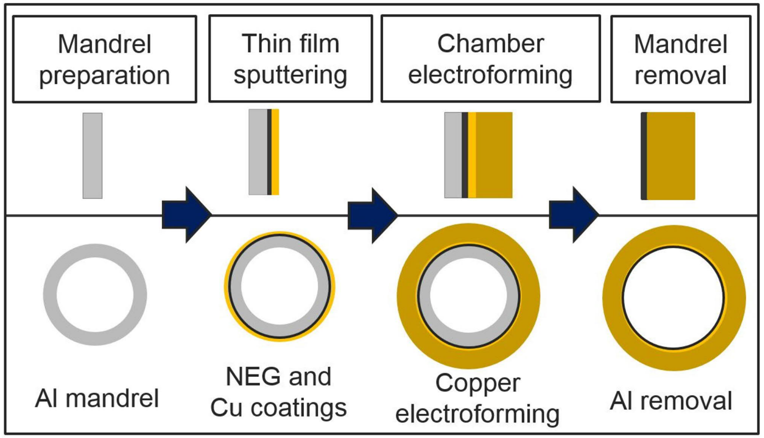
Could we manufacture a seamless cavity with a controlled surface state and "machine grade" tolerances ?

[2] V. Palmieri, Seamless cavities: the most creative topic in RF superconductivity, 1997, workshop on RF superconductivity, SRF97C18

2. Technical Proposal

2. Cu electroforming - proposal

Small diameter UHV chambers



Successfully developed at CERN [3] for CLIC and new generation light sources.

[3]: Journal of Vacuum Science & Technology A 36, 021601 (2018); doi: 10.1116/1.4999539

2. Cu electroforming - proposal

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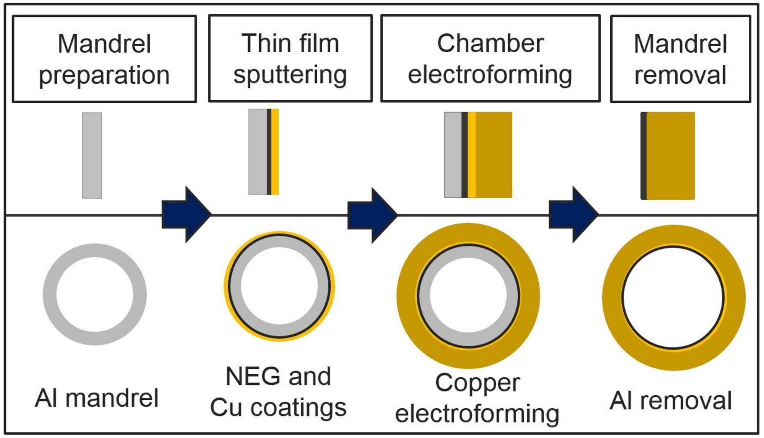

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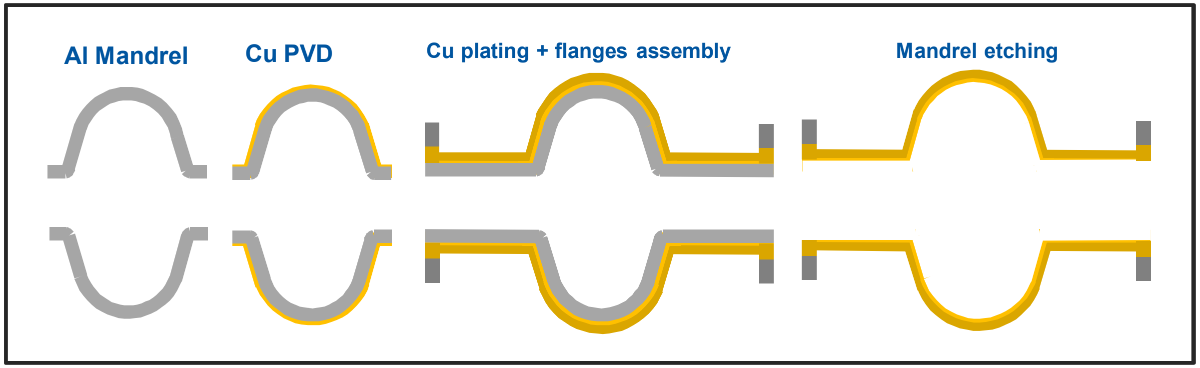
Toward SRF cavities substrates ?



Is the plated copper compatible with such an application?

Is the shape problematic?

Is this technique scalable?

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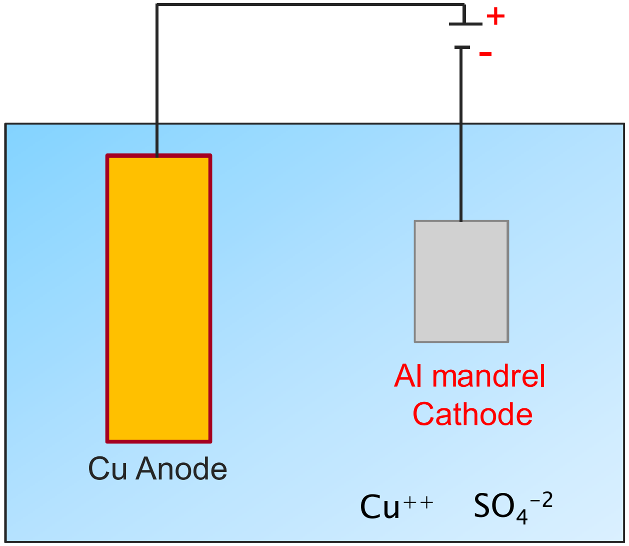
2. Cu electroforming - Principle

Setup Schematic



Chemistry

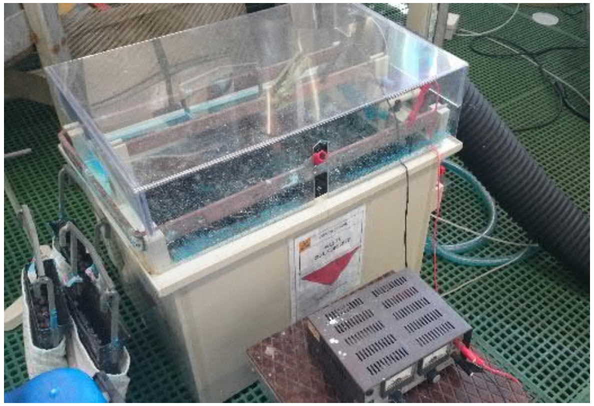
Cathode (reduction):

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

Anode (oxidation):

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

Bench



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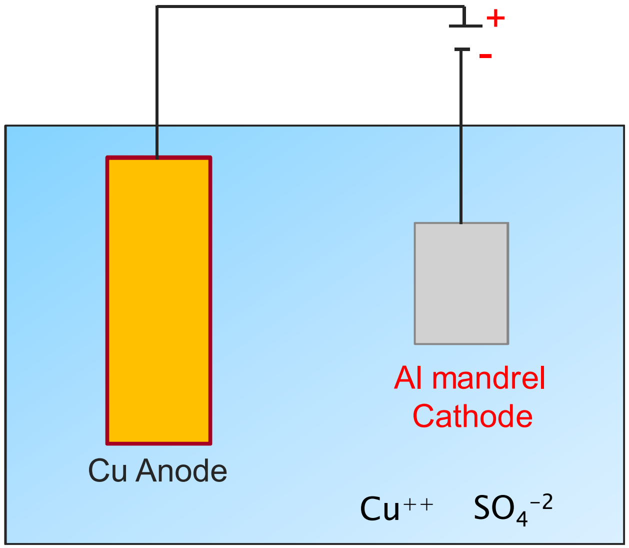

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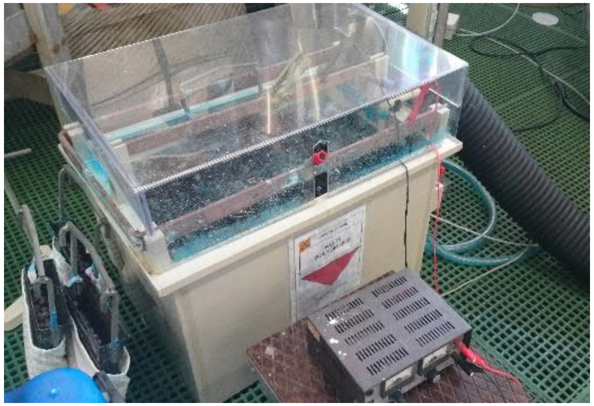
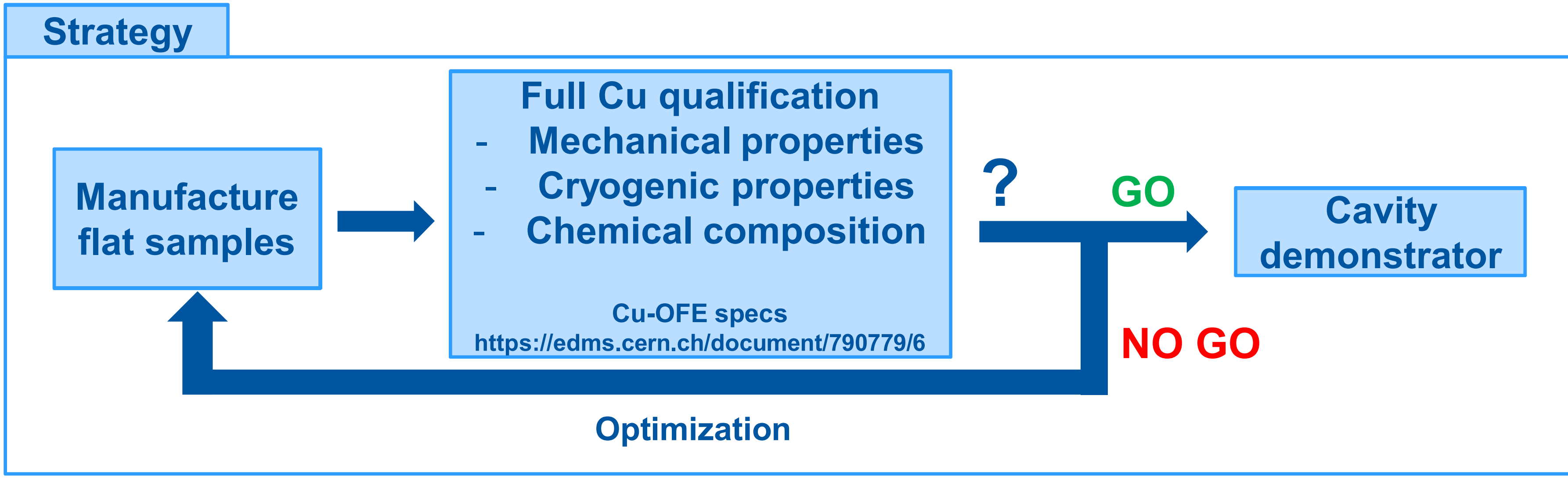


Electrodeposition of Cu, 2 A/dm^2 , 96 hours, copper sulphate-sulphuric acid bath

- 2-3 mm of Cu deposited (desired chamber wall thickness)
- Two plating procedures: DC plating with brightener and pulse plating without additives

2. Cu electroforming - approach



2. Cu electroforming - approach

Strategy

Manufacture flat samples

Full Cu qualification
- Mechanical properties
- Cryogenic properties
- Chemical composition

Cu-OFE specs
https://edms.cern.ch/document/790779/6

?

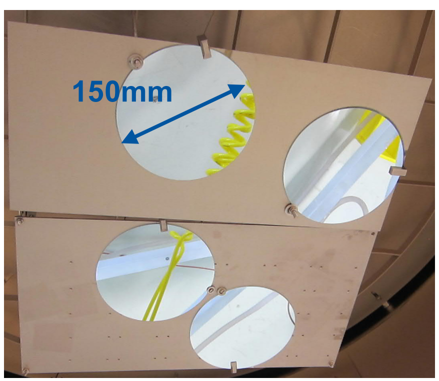
GO

Cavity demonstrator

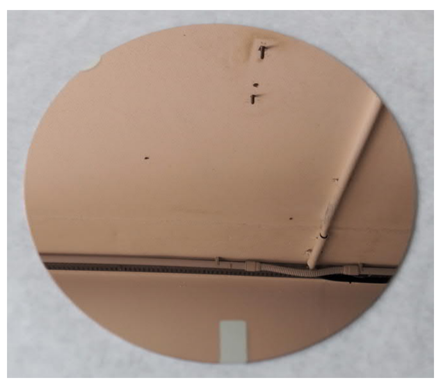
NO GO

Optimization

Samples



Flat Al disks



Cu sputtering

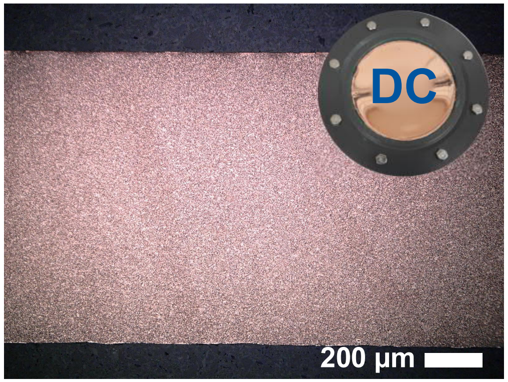
DC plating

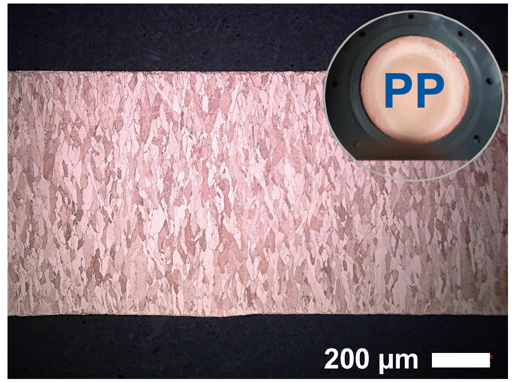
Pulsed plating (PP)

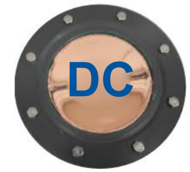
3. Samples characterization

3. Mechanical Properties

Microstructure





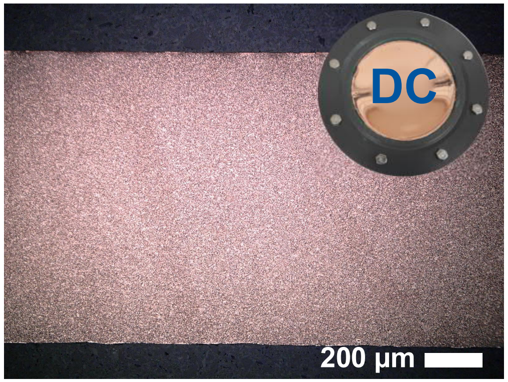


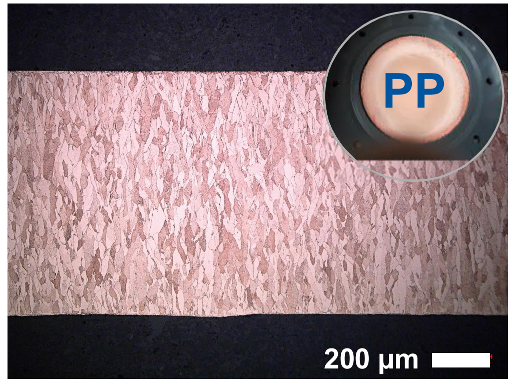
- Equiaxial small grains
- Brightener prevents grain growth

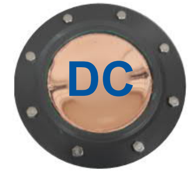
- Elongated grains
- Growth normal to the substrate

3. Mechanical Properties

Microstructure







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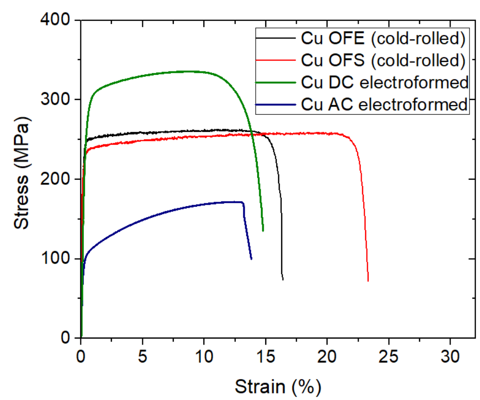
Hardness/Young modulus / UTS

Hardness – Nano-indentation

DC	PP
1488.4 ± 47.3 MPa	831.4 ± 52 MPa

Young modulus – impact excitation

DC	PP
124 ± 15 GPa	131± 15 GPa



DC - Rm	PP - Rm
352 ± 41 MPa	174 ± 6 MPa

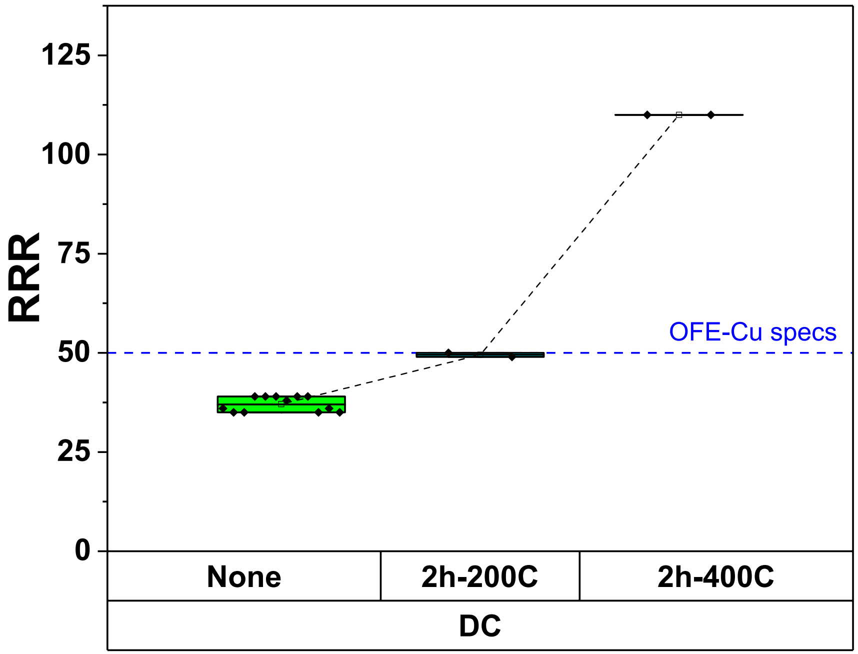
Hardness:
DC>PP : grains morphology

Young modulus
Similar to OFE Cu grade

Tensile strength
DC>PP : grains morphology
DC = bulk OFE Cu
PP = annealed OFE Cu

3. Cryogenic Properties

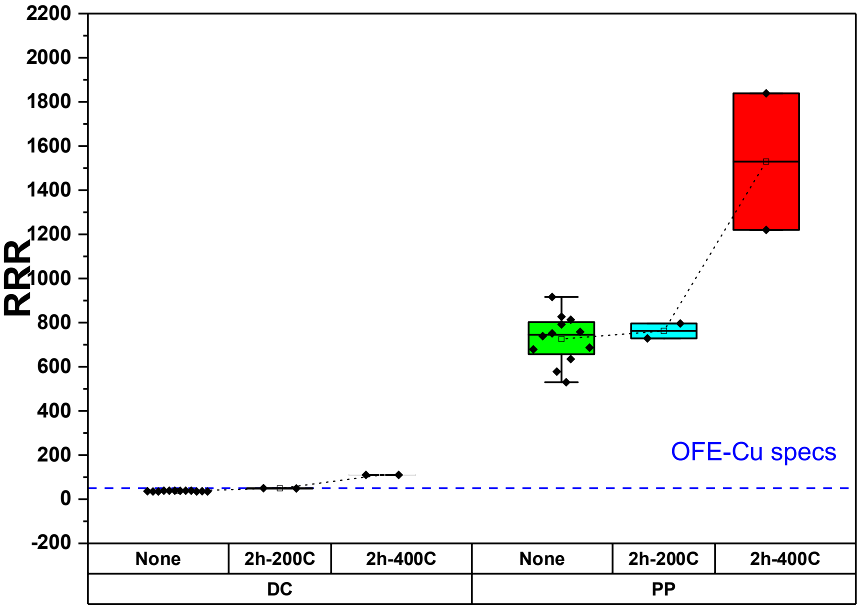
Residual Resistivity Ratio - electrical



- RRR easily matches Cu OFE specs after thermal treatment

3. Cryogenic Properties

Residual Resistivity Ratio - electrical



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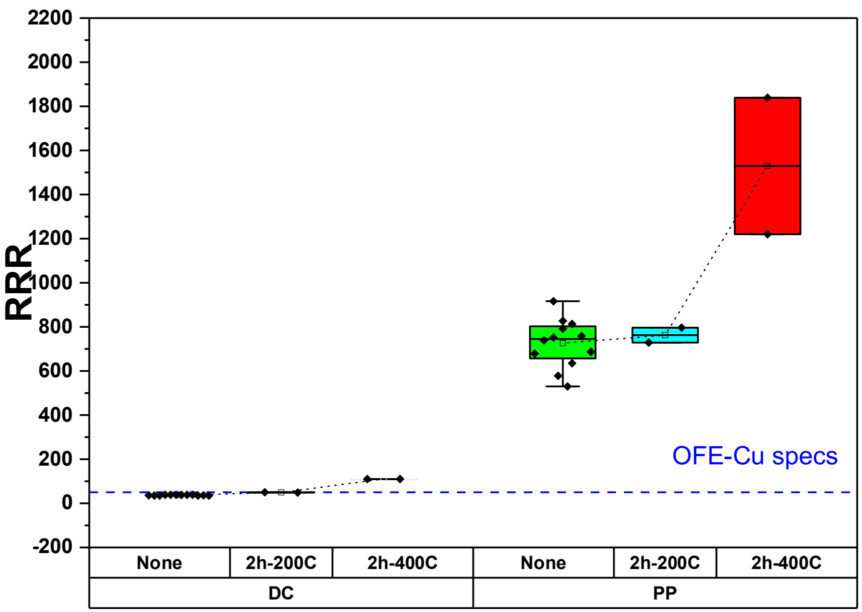
- PP can lead to very high RRR

3. Cryogenic Properties

Residual Resistivity Ratio - electrical



- RRR easily matches Cu OFE specs after thermal treatment
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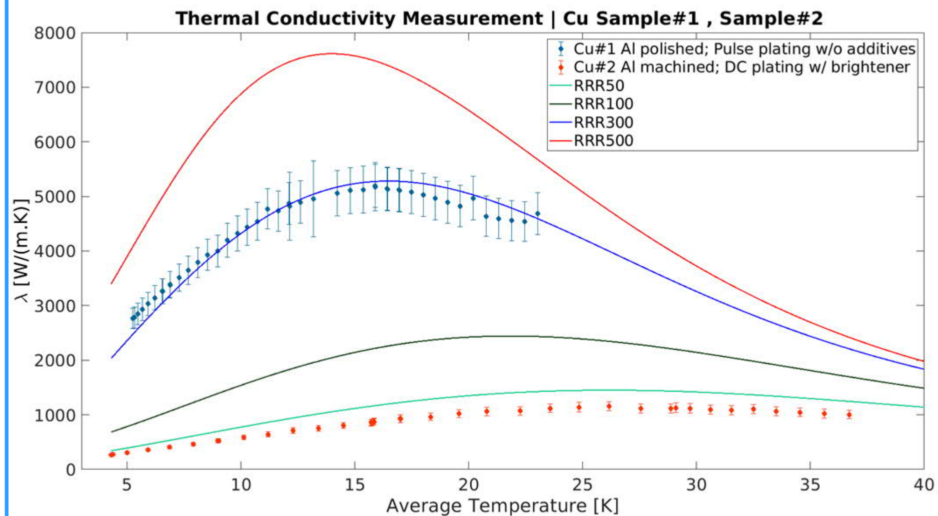
Residual Resistive Ratio - thermal



- Thermal conductivity measurements confirm high RRR for PP
- More to come to study thermal treatment effects

3. Surface quality

Roughness

	Standard mandrel machining		Diamond mandrel machining	
µm	DC plating	Pulse plating	DC plating	Pulse Plating
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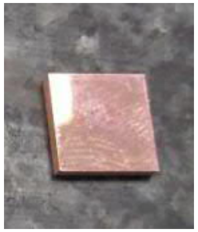

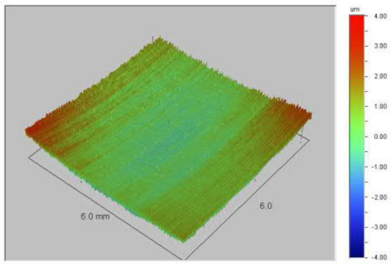

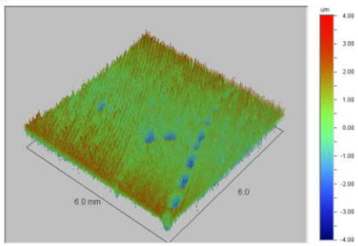

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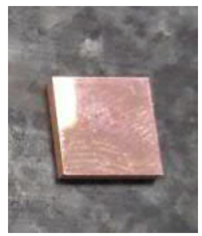


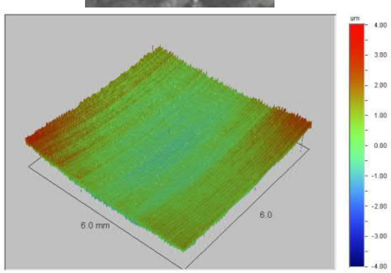
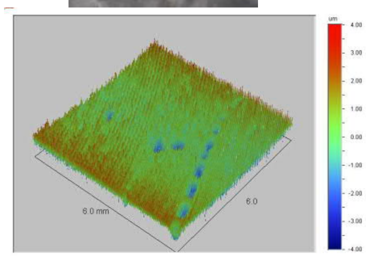
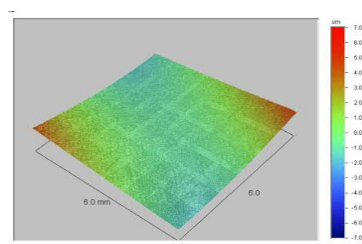
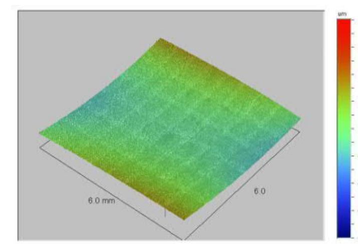

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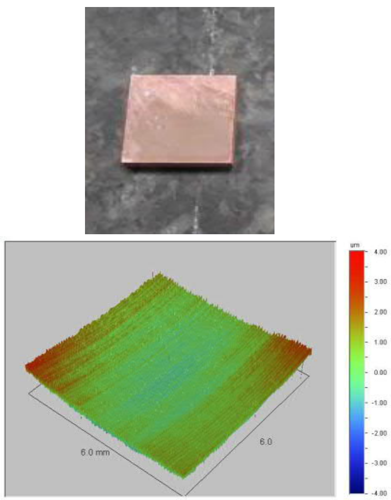

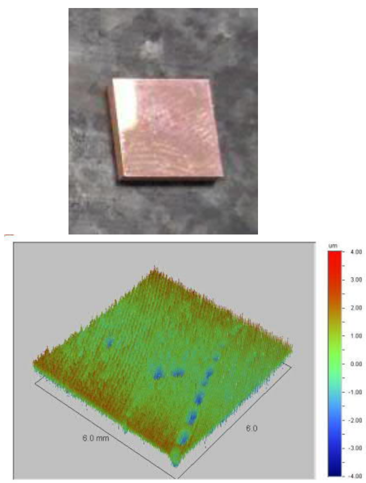

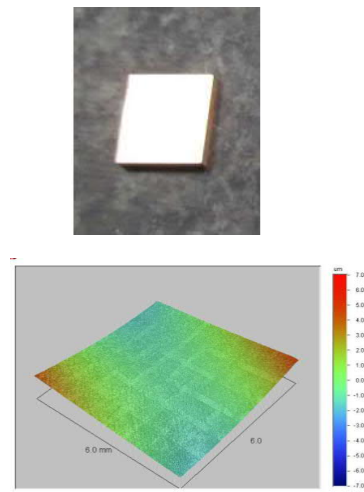

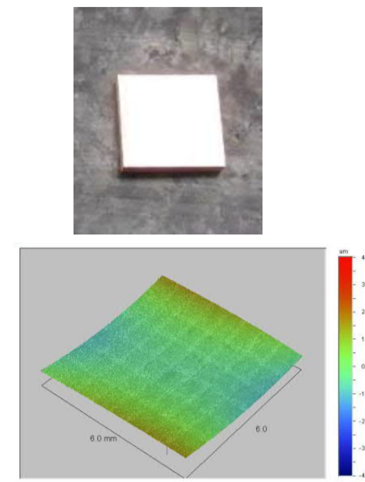

Surface quality can be easily controlled with the mandrel surface finish

3. What can we conclude?

Plated copper as good as OFE grade bulk

Mechanical properties

Cryogenic properties

Surface quality

Let’s try to make a cavity

4. Toward a real cavity

4. First tests on real geometry

Dummy mandrels

For thickness profile evaluation and feasibility test

Old 1.5 GHz Al cavity recycling

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For electroforming optimization on low-cost substrate

Test mandrels (Al tubes welded on convex tanks)

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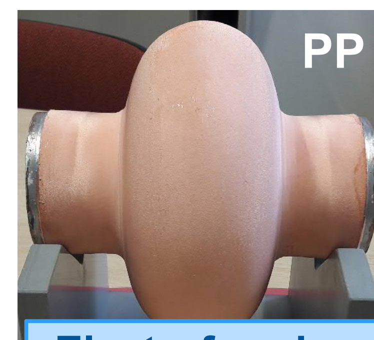
First tests

Mandrel

PVD Cu

EF preparation



Electroforming

4. First tests on real geometry

Dummy mandrels

For thickness profile evaluation and feasibility test

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Test mandrels (Al tubes welded on convex tanks)

First tests

Mandrel

PVD Cu

EF preparation

Electroforming

4. Thickness Profile

Sampling

Cut-out of the cavity

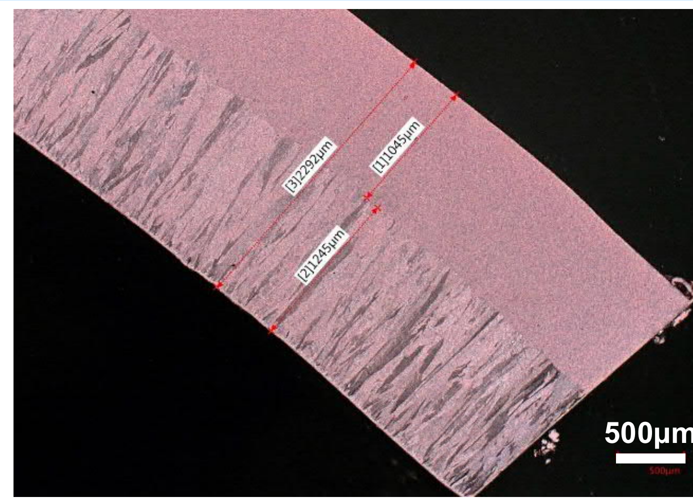
Iris thickness 2 to 3 times smaller than equator
- Anticipated → to be optimized later on

Hardness constant over the profile:

DC: 114 HV0.1

PP: 55 HV0.1

Optical cross section



4. Full scale demonstrator

1st Demonstrator

Dummy cavity in PVD chamber

4. Full scale demonstrator

1st Demonstrator

Dummy cavity in PVD chamber

Flanges assembly

4. Full scale demonstrator

1st Demonstrator

Dummy cavity in PVD chamber

Flanges assembly

After DC plating

4. Full scale demonstrator

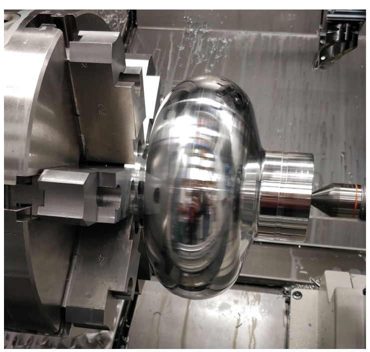
1st Demonstrator

Dummy cavity in PVD chamber

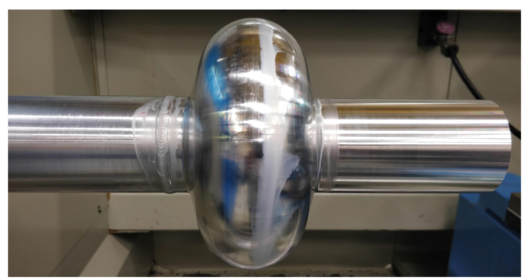
Flanges assembly

After DC plating

1st Prototype



Mandrel cell turning



Tubes welding/machining

Final Mandrel

Ready for plating

5. Conclusion / Perspectives

- Electroformed copper has been extensively characterized
  - RRR up to 2000 upon thermal treatment
  - Roughness controlled by mandrel surface state
  - Mechanical properties comparable to OFE-Cu or annealed OFE-Cu
  - Chemical composition : OFE grade (not shown here)
- Flanges assembly demonstrated

Next steps:

- Real 1.3 GHz cavity to be manufactured – Fully turned mandrel available
- Nb thin film coating using best recipe and RF testing
- Investigate thin film behaviour depending on substrate properties (roughness, purity…)
- Thickness profile optimization
- Cost study

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Full authors list

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