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Optimisation of copper electroforming for manufacturing superconducting radiofrequency cavity substrates

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Introduction

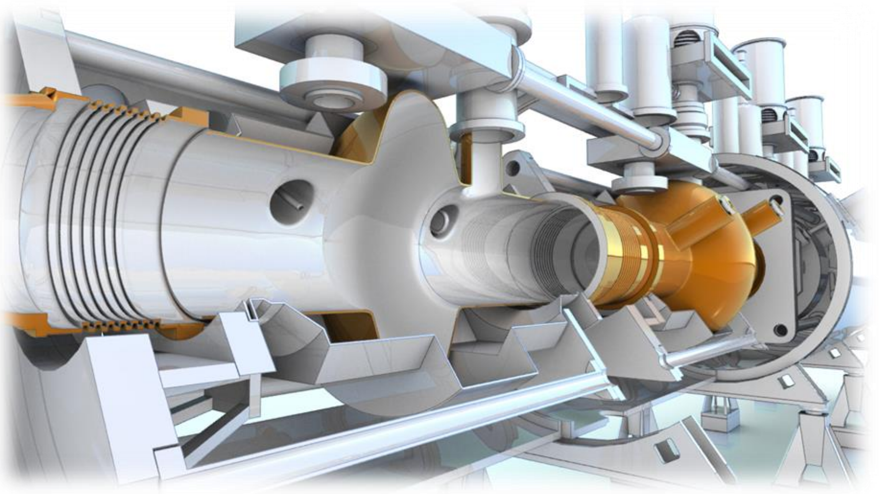
Future Circular Collider (FCC) study

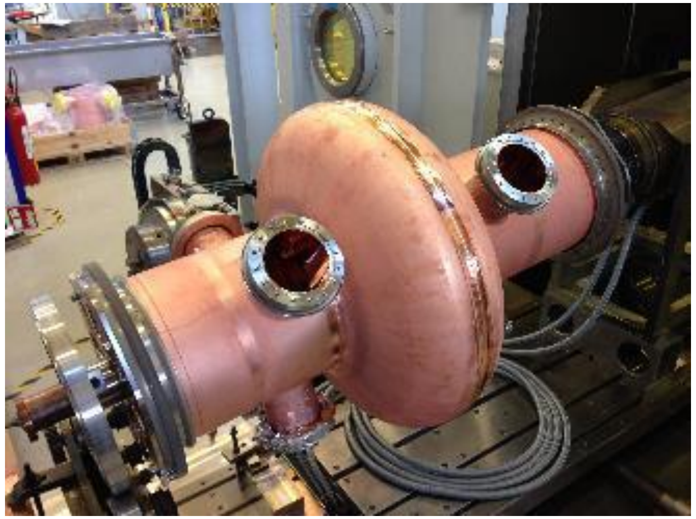
- Develops designs for the next generation particle collider after LHC.

- SRF cavities will be produced by applying niobium superconducting thin films onto copper substrate cavities.

Copper elliptical cavities

- Copper substrates are traditionally produced by mechanical forming and welding several subcomponents.

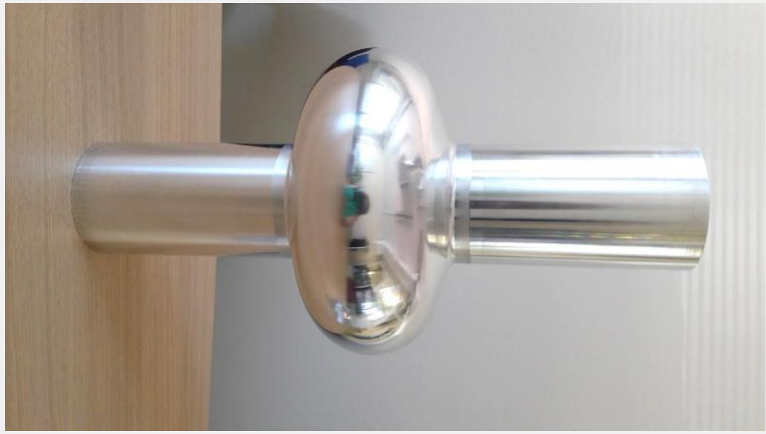


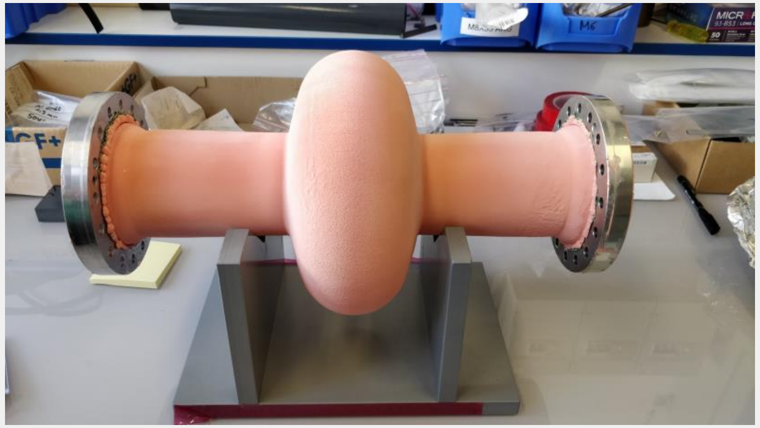


Introduction

- The presence of the weld groove in the most critical place of the cavity for RF performance (equator) has been problematic.
    - A seamless process, which guarantees a high quality Cu substrate and very smooth surface finishing, is pursued.

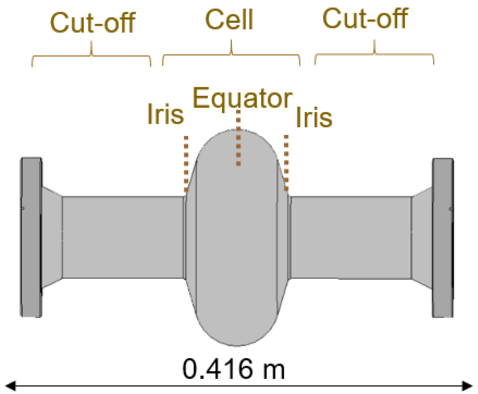
- In the present innovative approach, seamless cavities are produced by **copper electroforming** on a sacrificial aluminium mandrel which has the internal shape of the cavity.





Motivation

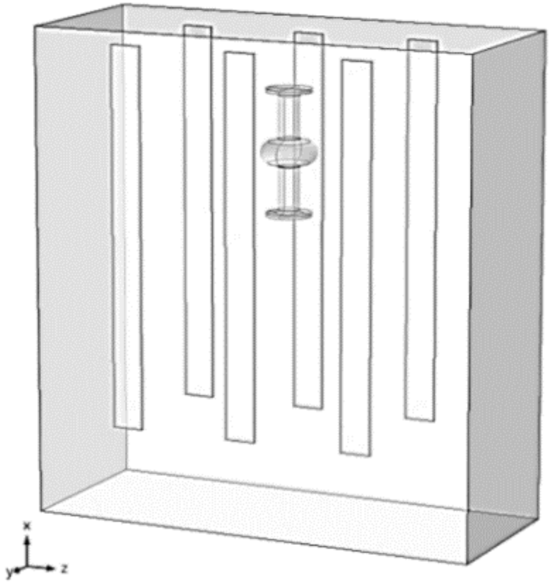
- The bottleneck of the process is the heterogeneous distribution of the plated copper layer along the cavity and the resulting thinner section at the cavity iris.



COMSOL® simulations are performed to optimise the copper thickness uniformity along the cavity.

Secondary Current Distribution (SCD) physics module.

- Voltage
- Local current density
- Deposited thickness



Computational methods

The electron transfer reactions that take place are:

Anode: $Cu \rightarrow Cu^{2+} + 2e^-$
Cathode: $Cu^{2+} + 2e^- \rightarrow Cu$

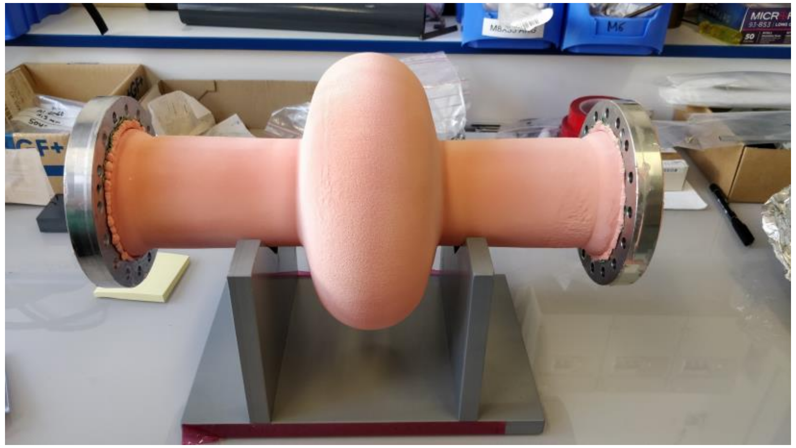
Local current density and the local potential derivative are described by the Ohm's law.

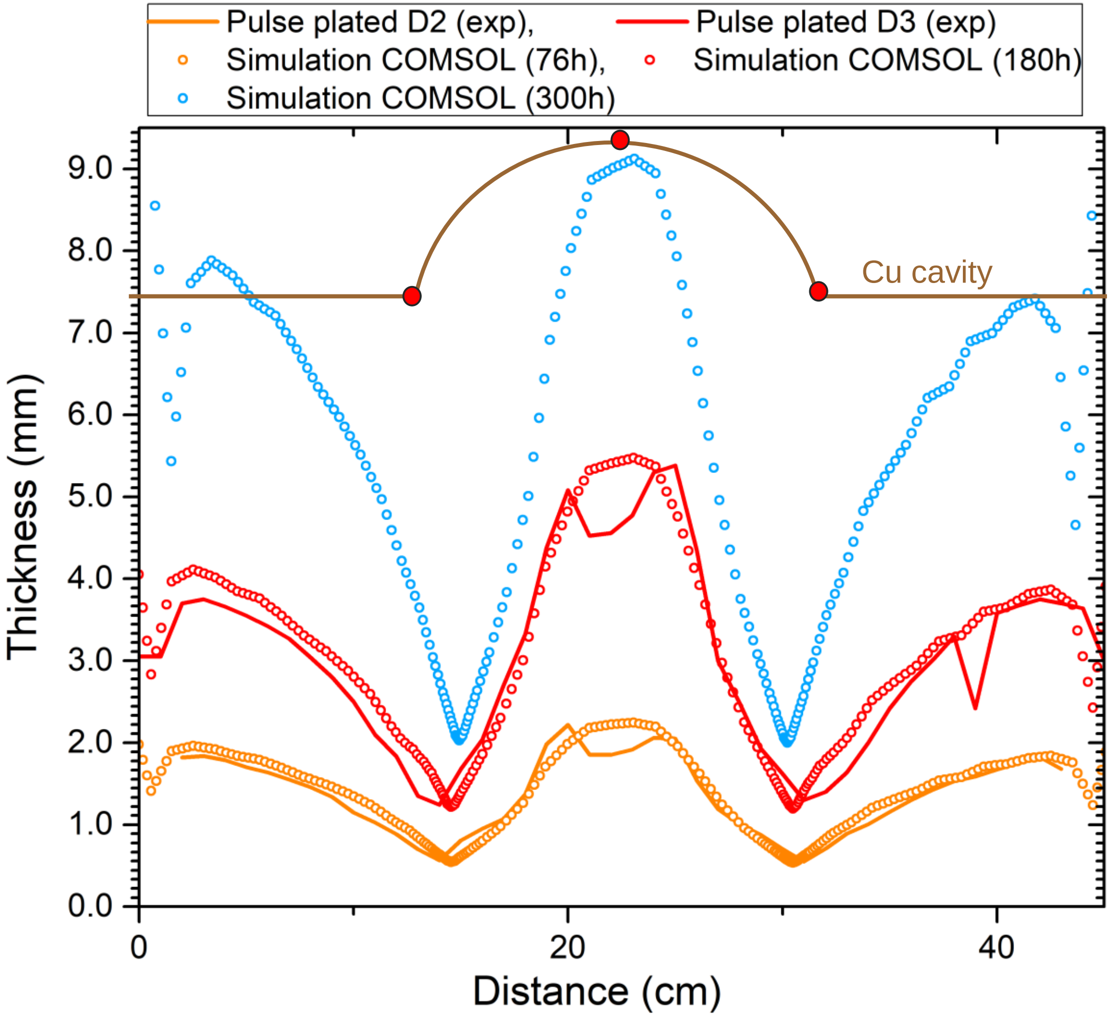
The local current at the electrode surface follows the Butler-Volmer equation:

$$i_{loc,Cu} = i_{0,Cu}\left(exp\left(\frac{\alpha_a \cdot F \cdot \eta_{Cu}}{R \cdot T}\right) - exp\left(\frac{-\alpha_c \cdot F \cdot \eta_{Cu}}{R \cdot T}\right)\right)$$

The simulations were run with a moving mesh in order to simulate the boundary displacement resulting from the plating on the cathode and the consumption of the secondary anodes.

Validation of simulation model

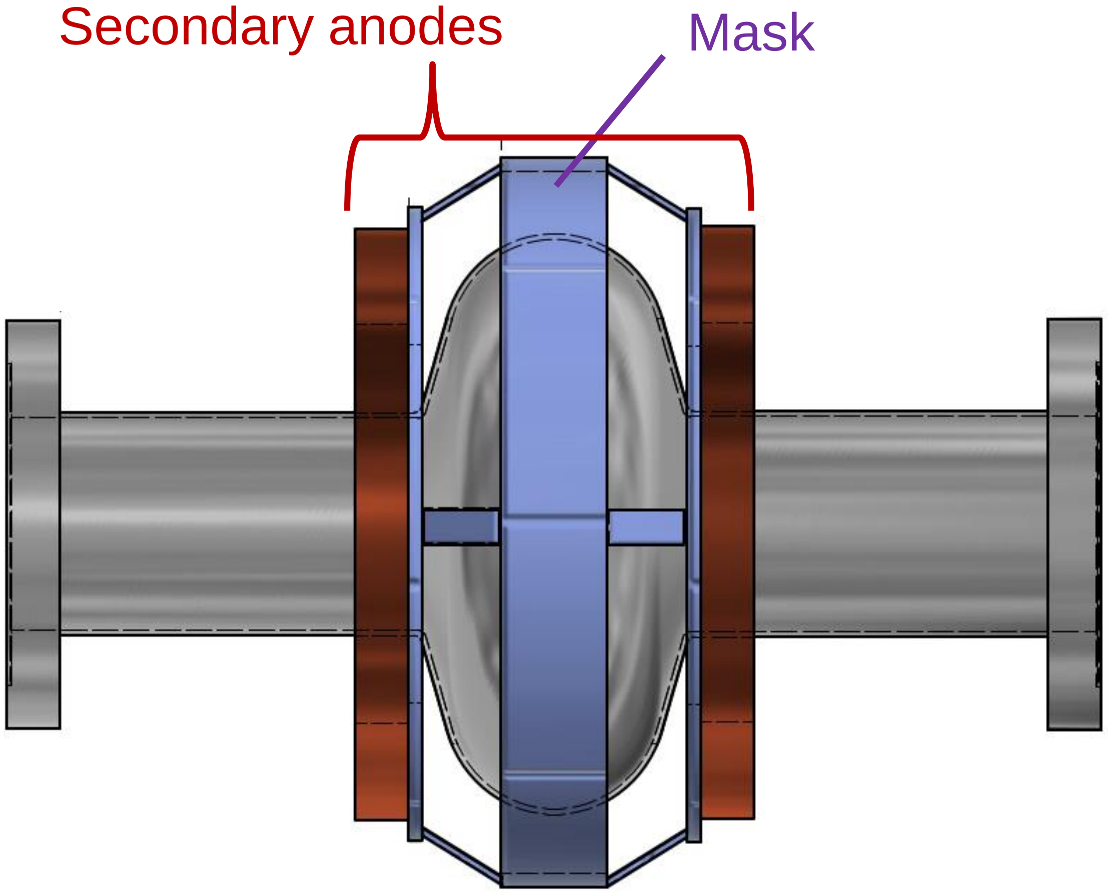




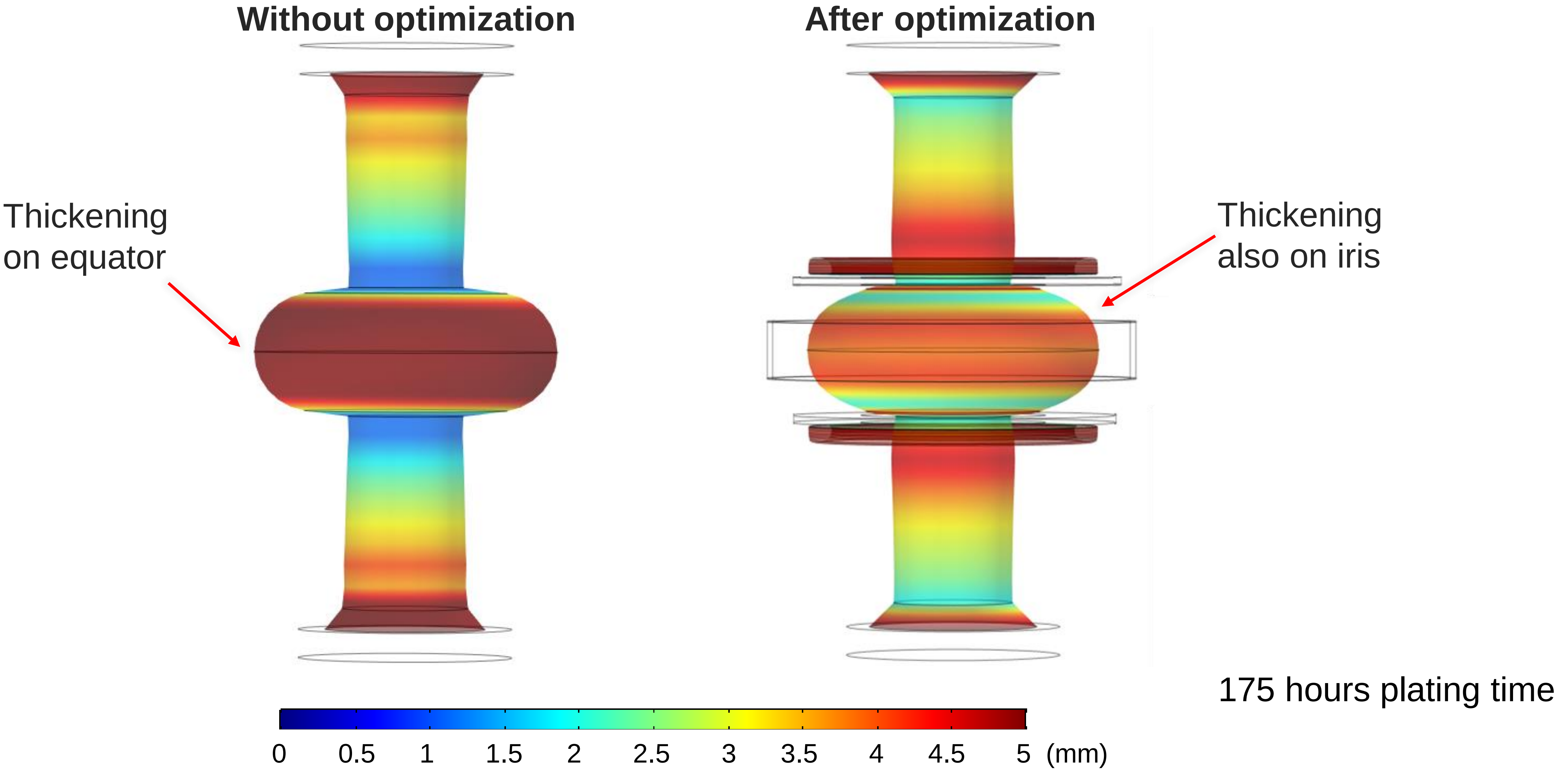
- The simulated thickness agrees with the experimental values.
- The maximum thickness is located at equator, the minimum at the iris.
- 300 hours to achieve a thickness of 2 mm at the iris.

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.



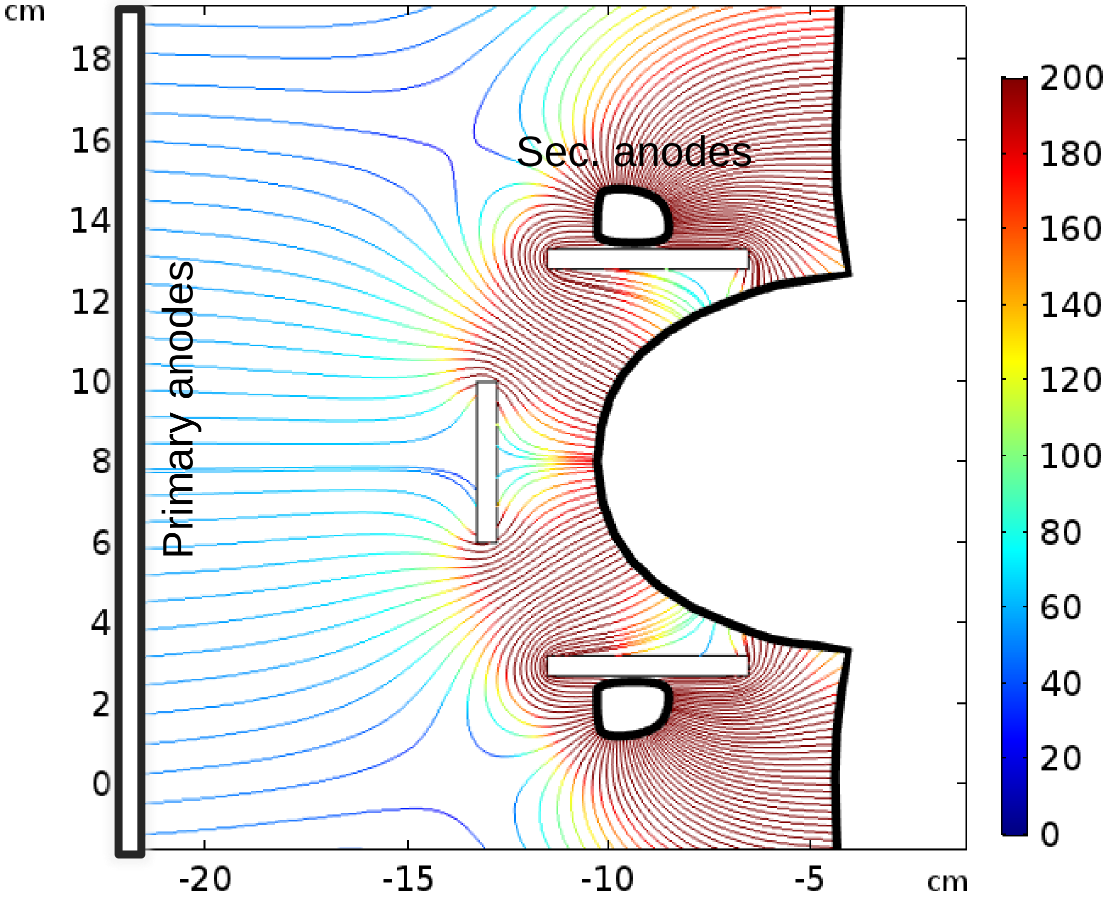
Design of secondary anodes and masking



175 hours plating time

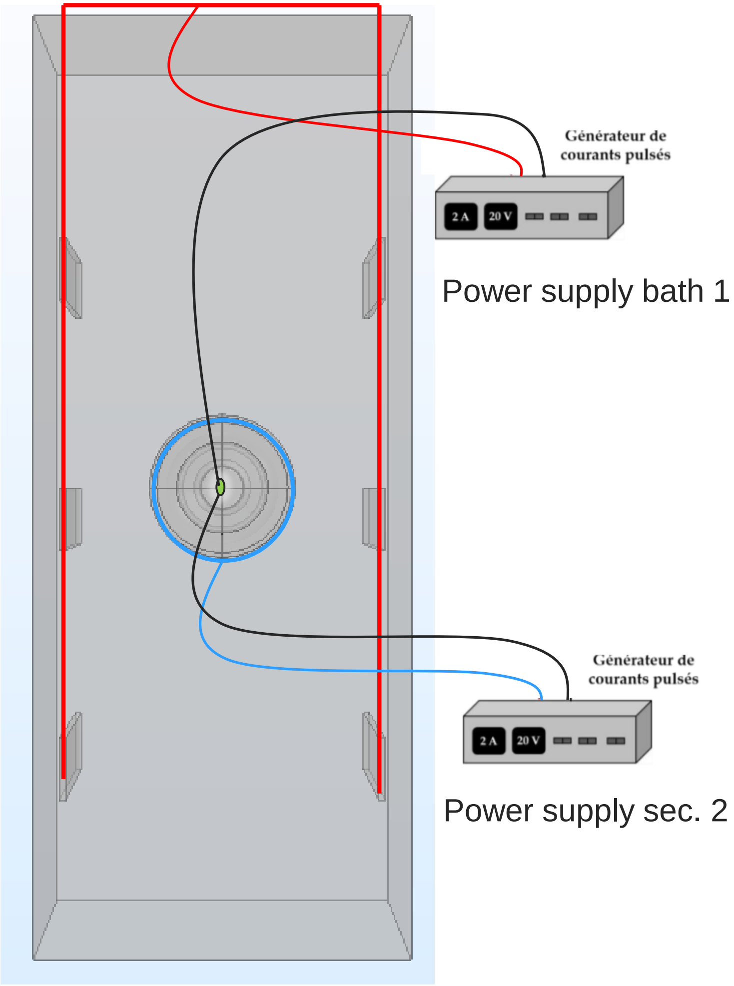
Optimisation of anodic dissolution

Electrolyte current density



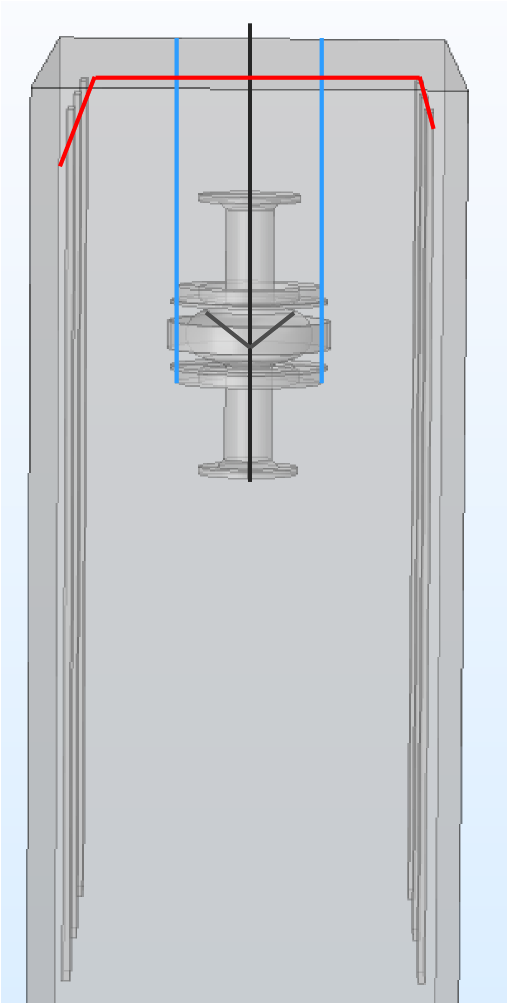
- Current line distribution with both anodes at same voltage (1PS).
- 175 hours plating time

Optimisation of anodic dissolution

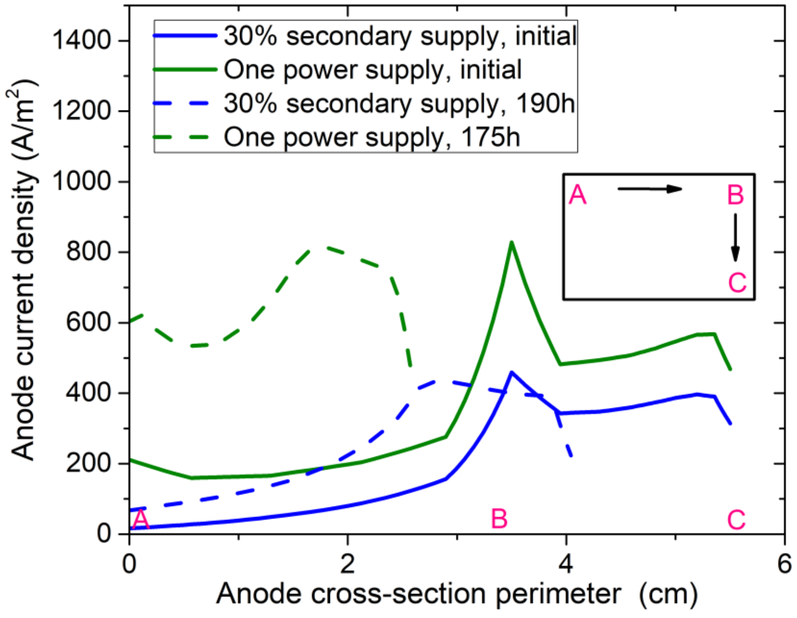


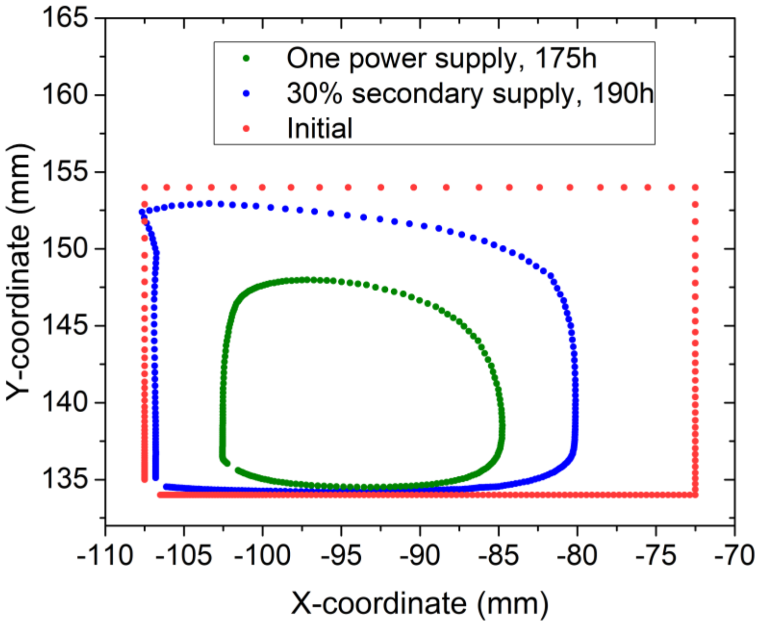
Power supply bath 1

Power supply sec. 2



Optimisation of anodic dissolution

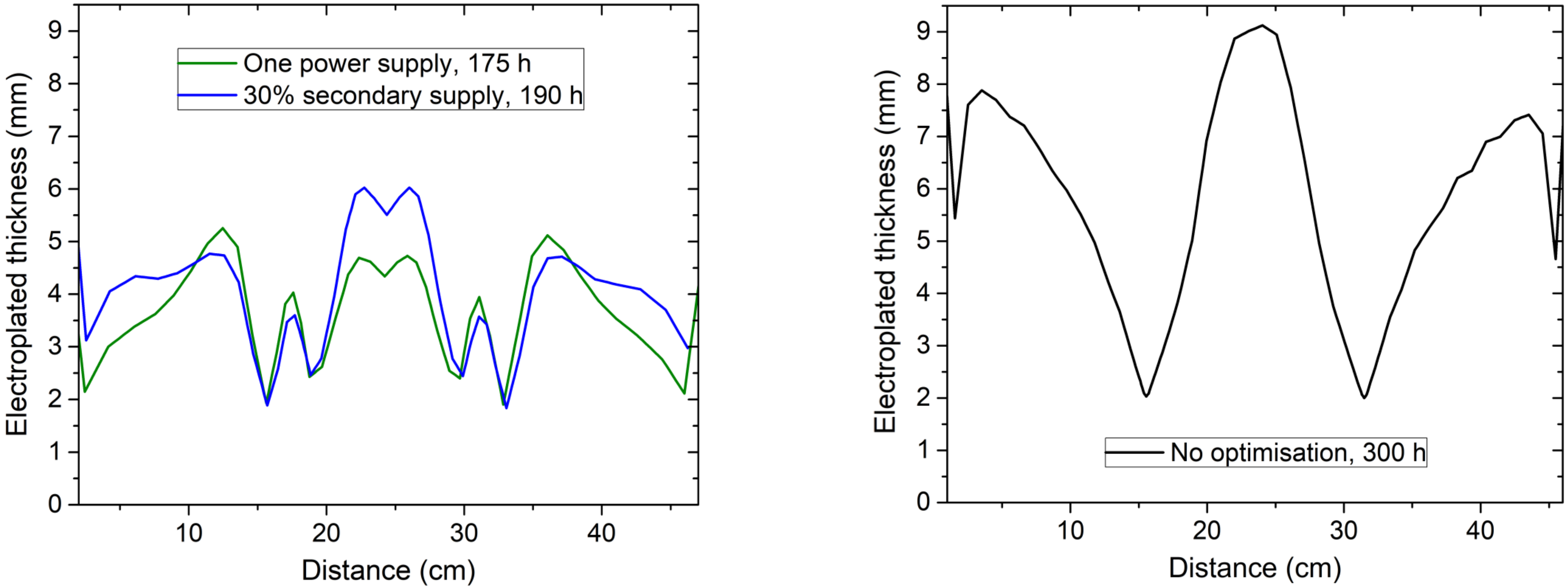




- Severe anodic dissolution and high current density at the sec. anodes with one power supply and both anodes at same voltage.

- Split of 30% of total current on secondary supply on sec. anodes minimize anode consumption and improves control over the process.

Optimisation of anodic dissolution



- To achieve a thickness of 2 mm at the iris, time increased to 190 hours.

Conclusions

- COMSOL modelisation of the electroforming process:
  - Define an optimised geometry of anode and masking that highly improves the copper layer thickness distribution.

- The re-meshing of the anodes:
  - Identify the anode end-life and determine the secondary anode current density.

- Two power supplies were implemented to control independently the primary and secondary anodes.
  - The current density at the sec. anodes was reduced.
    - Minimize anode consumption.
    - Overall control of the process was improved.

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