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# EVOLUTION OF M-TYPE CATHODE EMISSION DURING LONG-TERM LIFE-TESTS

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# Experimental data

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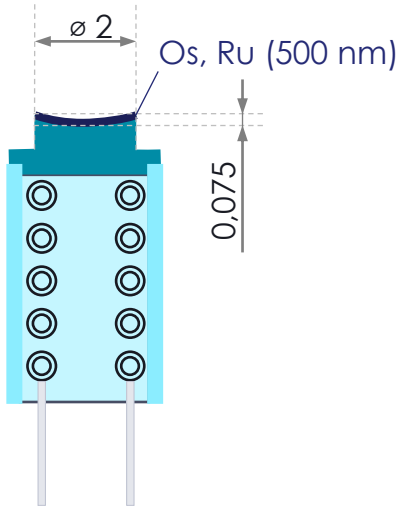
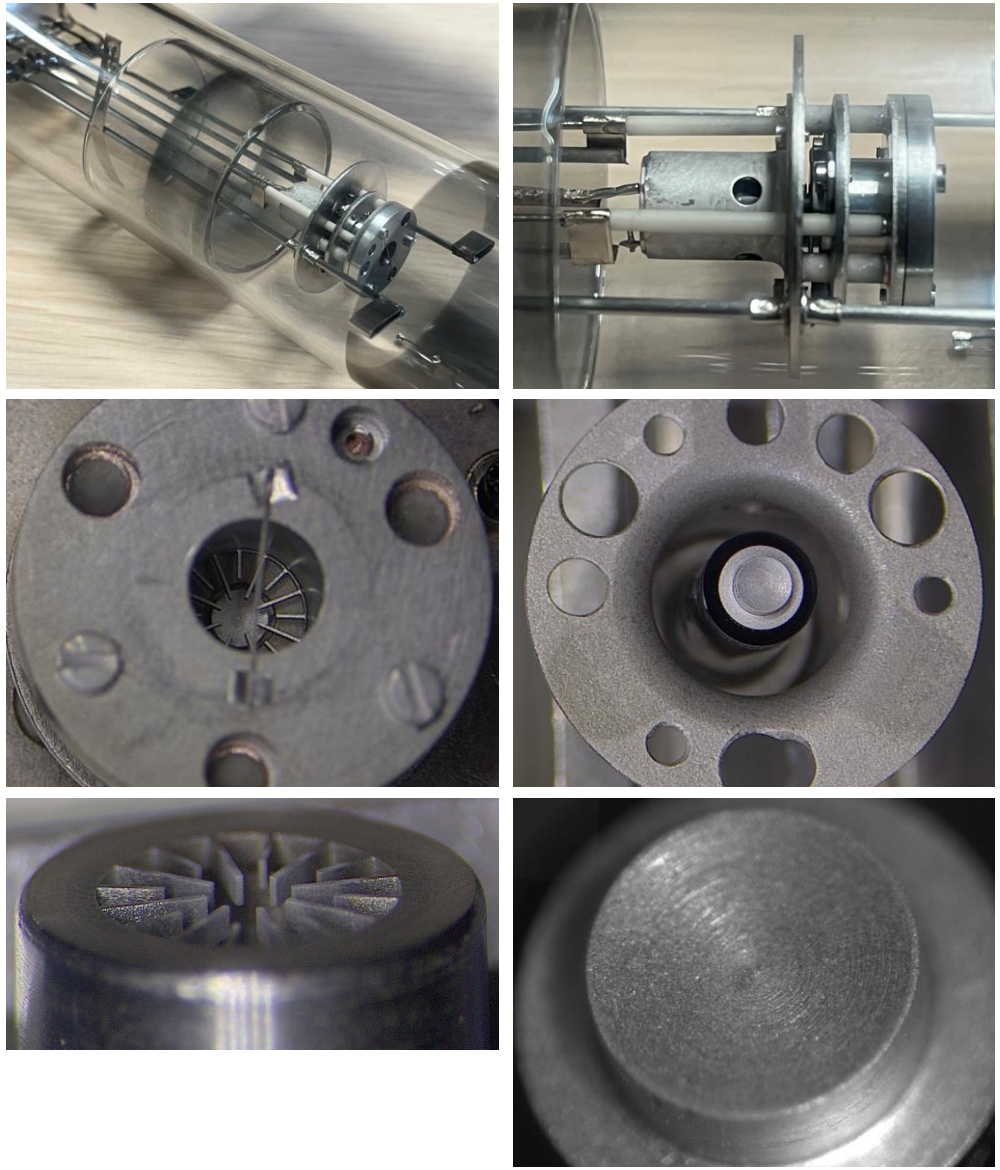
# Description

## > Cathode from Semicon

- Produced in 1984
- Diameter = 2 mm
- Central concavity = 0,075 mm
- Impregnated with 4.1.1 material
- Coated with an Os / Ru layer (500 nm)
- → M-Type



M-Type



## > Experimental setup

- Cathodes mounted in diode setup: cathode + anode
- Finger shaped anode
- Cathode – anode distance = 360 µm
- Stored in glass bulbs and pumped to ~ $10^{-8}$ mbar (initial)

# Experimental Protocol

## > Initial conditions: started in 1984

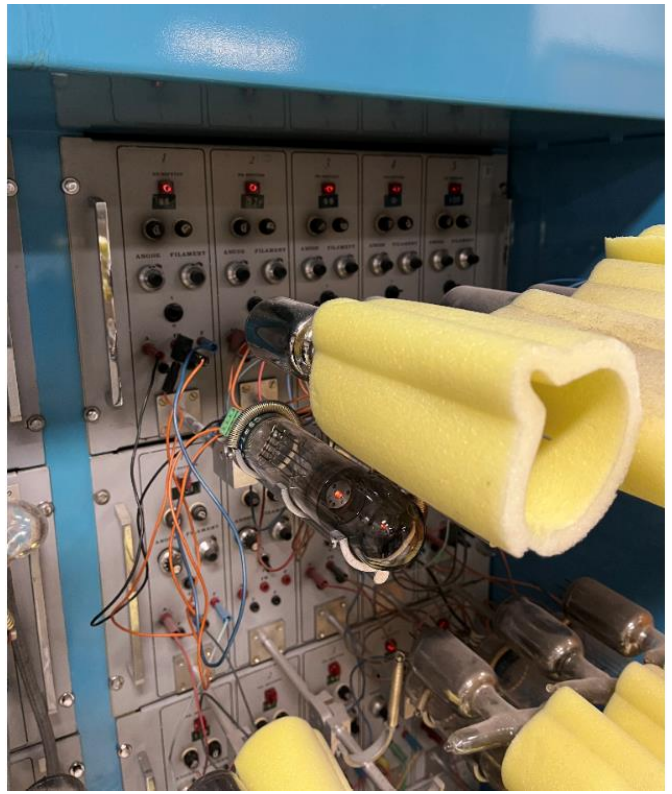
- 13 cathodes divided in 4 groups: 4 temperatures
- Filament current set to match the desired temperature
- Anode voltage set to have a current density of 1,5 A/cm²

## > Measurement protocol since 1984

- Periodically: saturation current density measurement -- J0
- Remark: some cathodes were broken, some were stopped
- Some measurements stopped in 2021 after 37 years of experiments

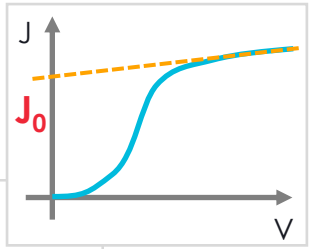
## > Objectives

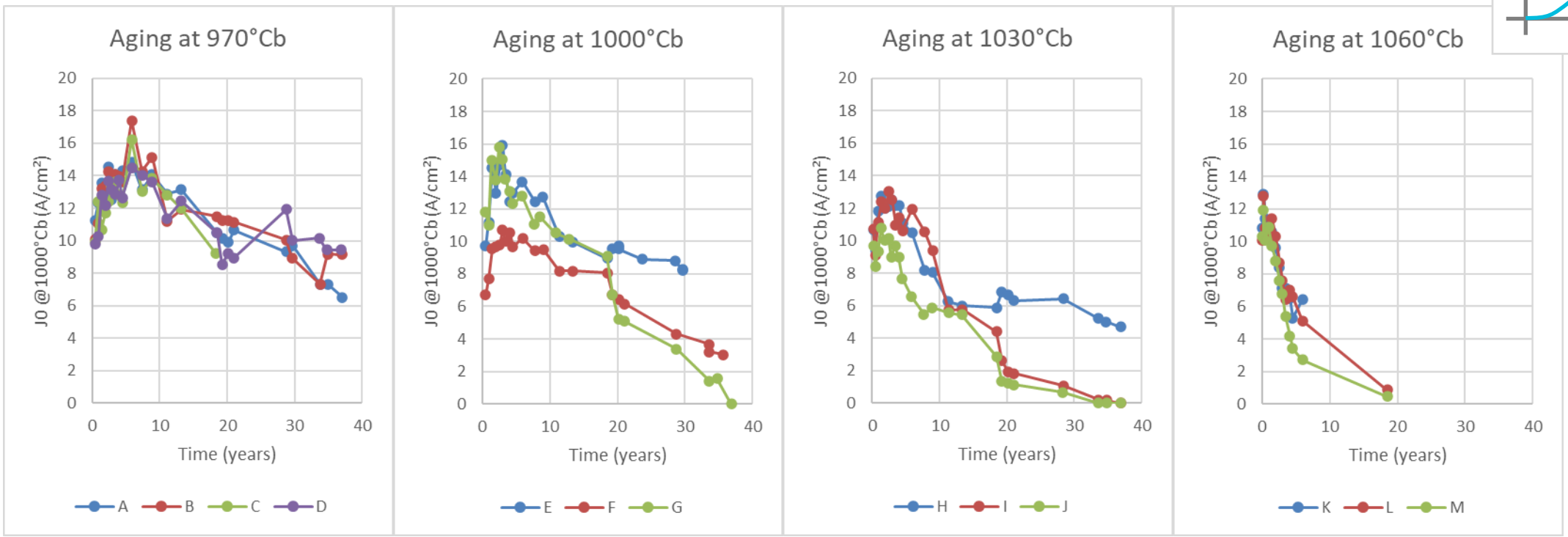
- Monitor the evolution of the cathode performances over time
  - Comparison with our mathematical model
- Observe the end of cathode life
  - Cathode autopsy



| Temp. (°Cb) | Cathodes |
|---|---|
| 970 | A, B, C, D |
| 1000 | E, F, G |
| 1030 | H, I, J |
| 1060 | K, L, M |

# Emission results

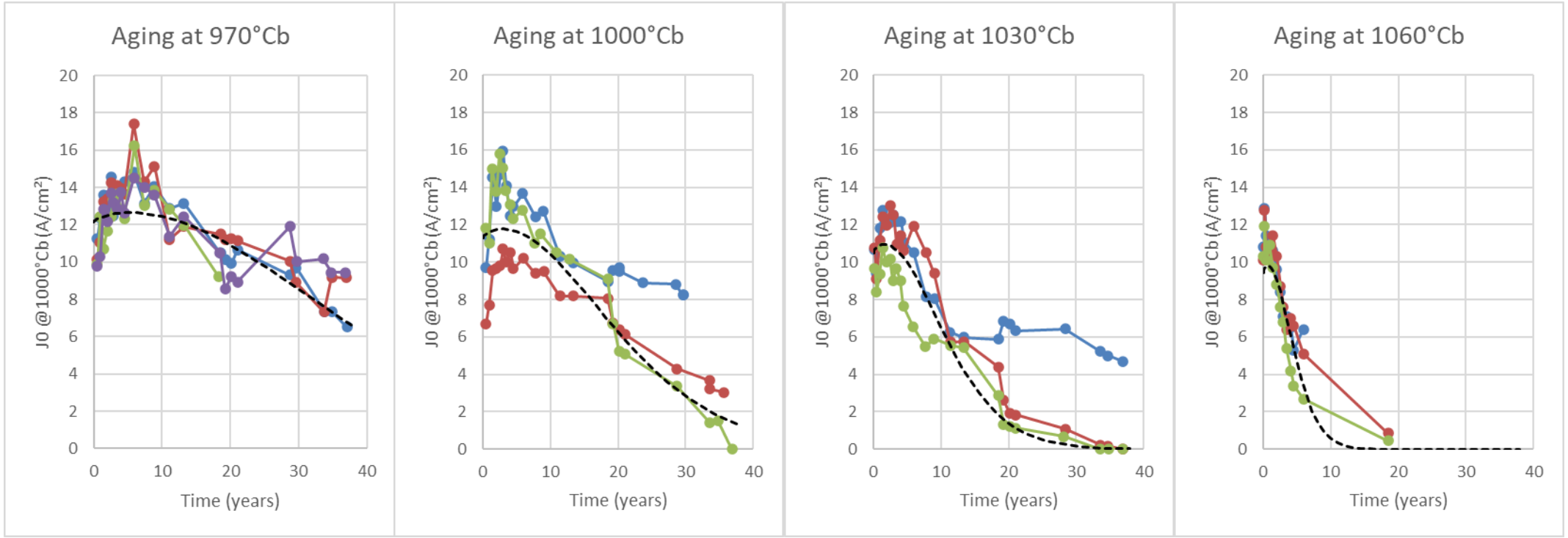



## > Saturation current density measured at 1000°Cb (≠ ageing temperature) for 37 years

- The higher the temperature, the faster the saturation current decreases
- Important for our space products: Aging at 1000°Cb, lifetime > 20 years.
- Long-term experimental datasets are now available to confirm the calibration of our mathematical models

# Emission results vs Model




------- Model – J.M Roquais *et al,* 'Life prediction model of dispenser cathodes ', IVESC 2019

- Model based on the ***prediction of barium depletion*** and on the ***evaluation of the work function*** of the surface
- *Very good agreement between prediction and experimental data*

## Confidence in our product lifetime predictions

# Post emission analysis of the cathodes

## > After 37 years of operation

- Cathodes running at 970°Cb are still emitting: $J_0 > 6$ A/cm²
- Cathode at higher temperatures are at the end of their life: $J_0 < 2$ A/cm²
- Decision to autopsy the dead ones and to sacrifice some others.

## > What kind of analysis?

- Emitting surface analysis
  - Surface morphology and topography: Optical microscopy + SEM
  - Surface composition analysis:
    - Auger Electron Spectroscopy (AES)
    - Energy-Dispersive X-ray Spectroscopy (EDS)
- Bulk analysis: cleavage of the pellet
  - Mapping of the species inside the cathode

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# Cathodes Analysis

## Emitting surfaces

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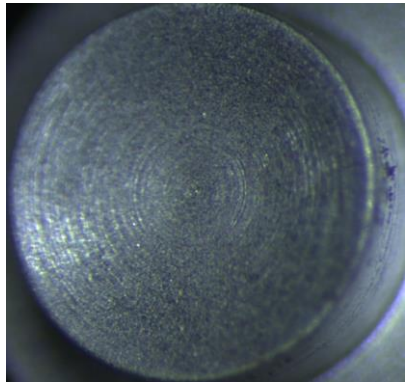
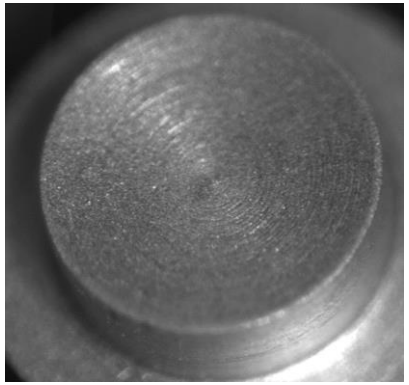
# Emitting surface analysis: Morphology and topography

970°Cb

A

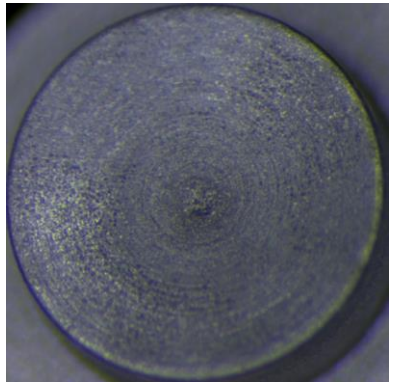


B



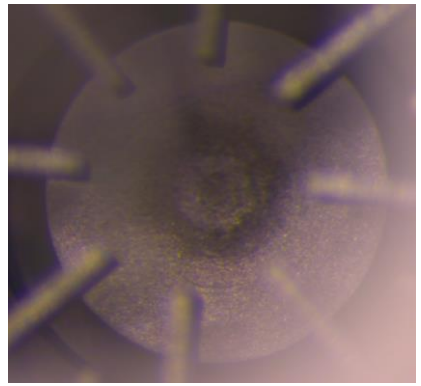
1000°Cb

F

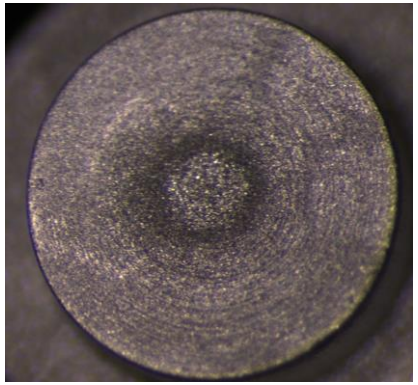


1030°Cb

I



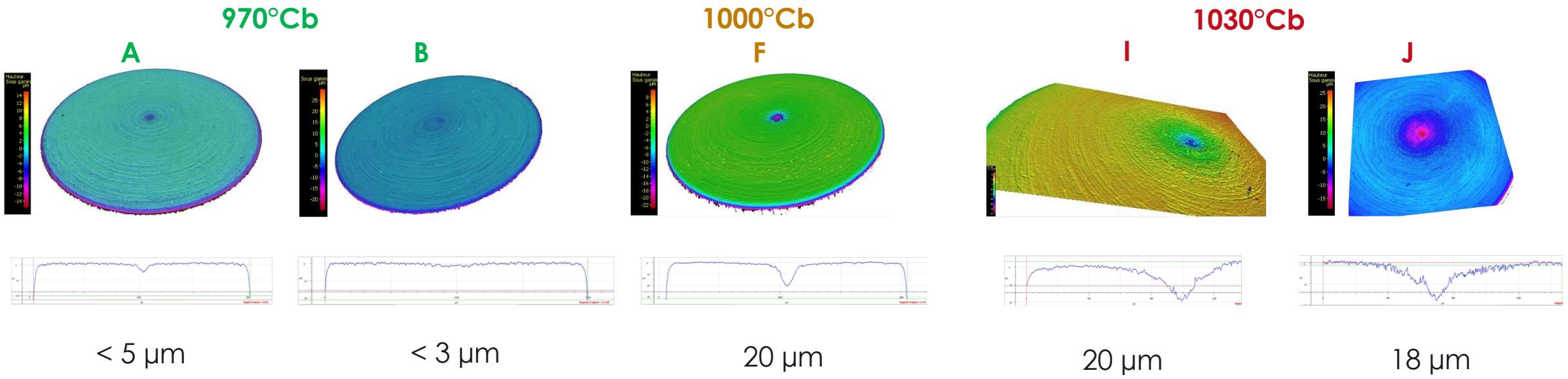
J



## > Visual inspection

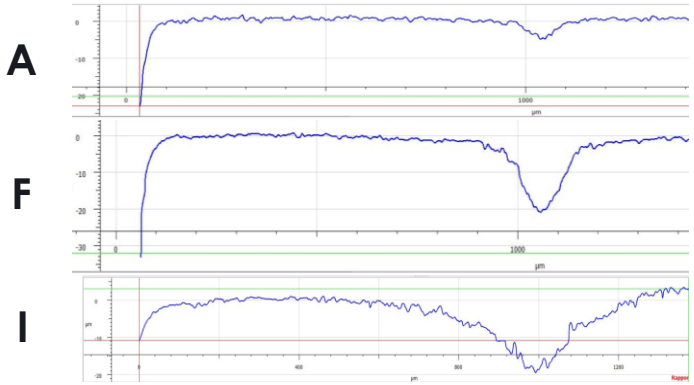
- A dark ring appears at the center of the cathode as the running temperature increases…

# Emitting surface analysis: Morphology and topography




## > Optical surface profilometry

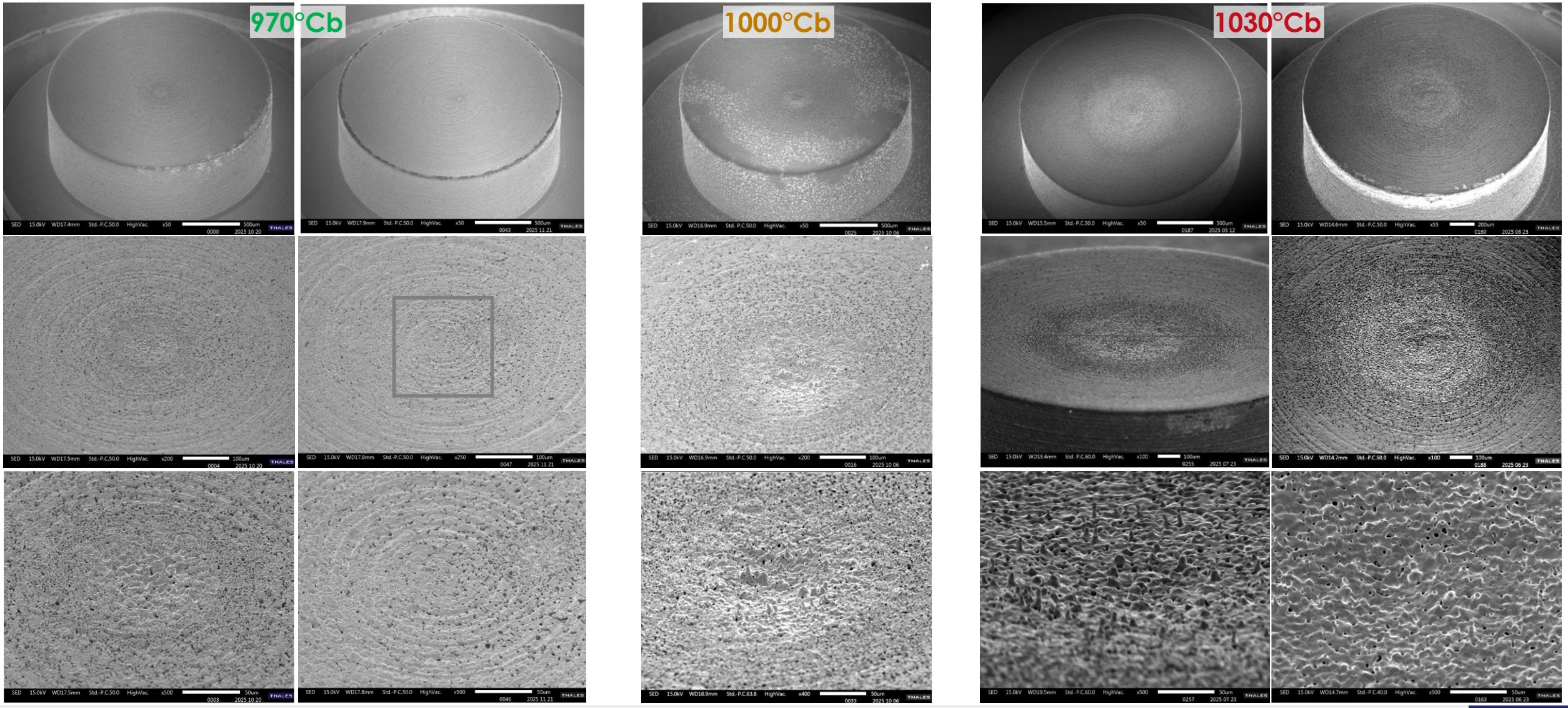
- No ring profile
- Hole at the center
  - Deeper for temperature above 970°Cb
  - Larger and more ‘noisy’ at 1030°Cb



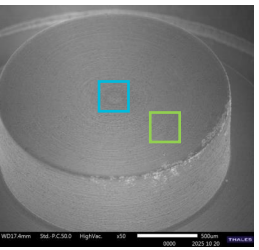



26/08/2026 - Thales / Template: 87211168-COM-GRP-EN-007

# Emitting surface analysis: Morphology and topography



# Surface composition analysis: EDS



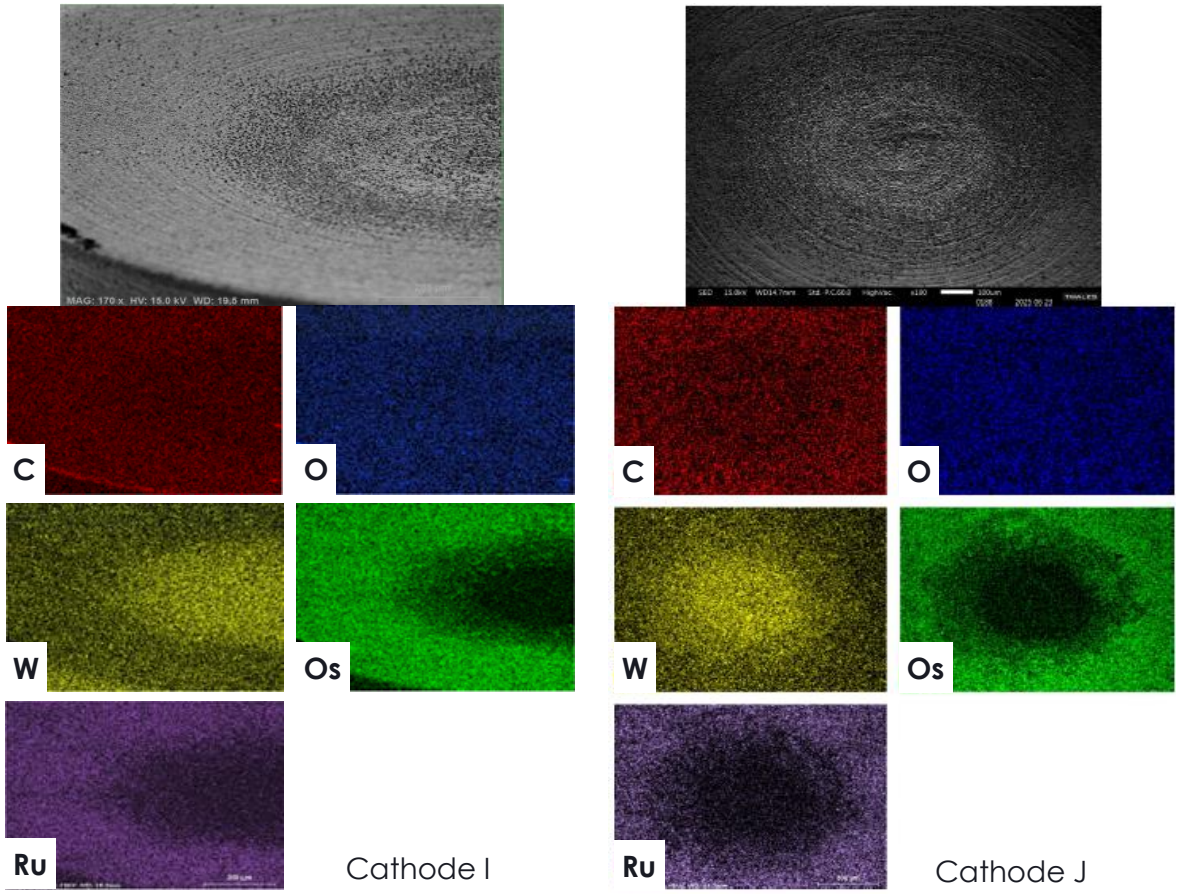




## > EDS analysis (depth ~ 1–2 µm)

- Same observations for each temperature
- At the center: only W
- Around the center: W, Os, Ru

1030°Cb

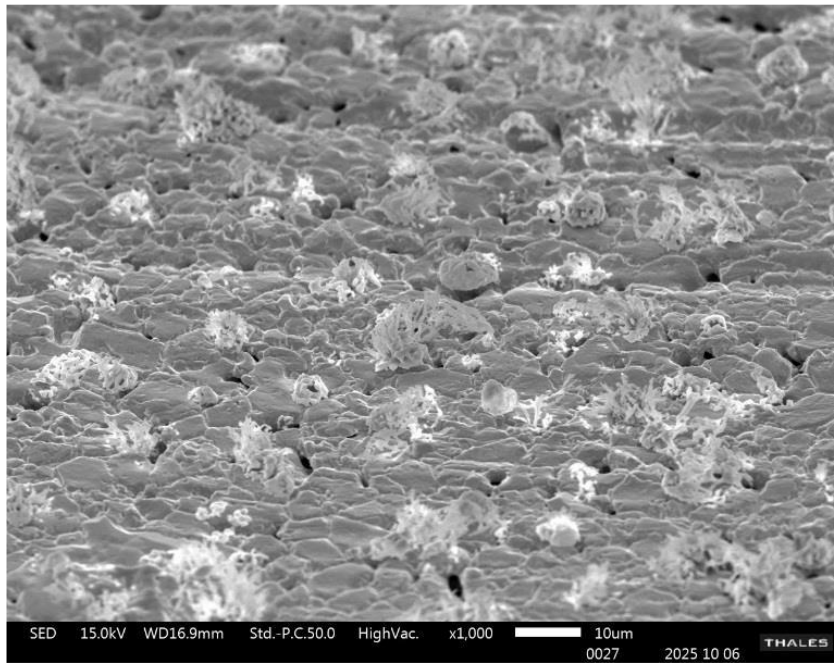


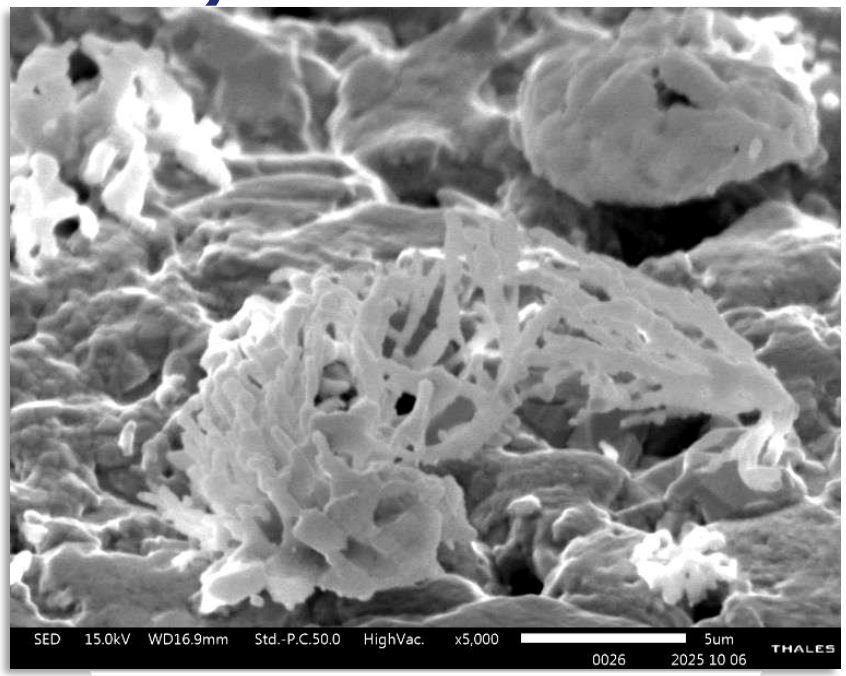

# Surface composition analysis: EDS mapping

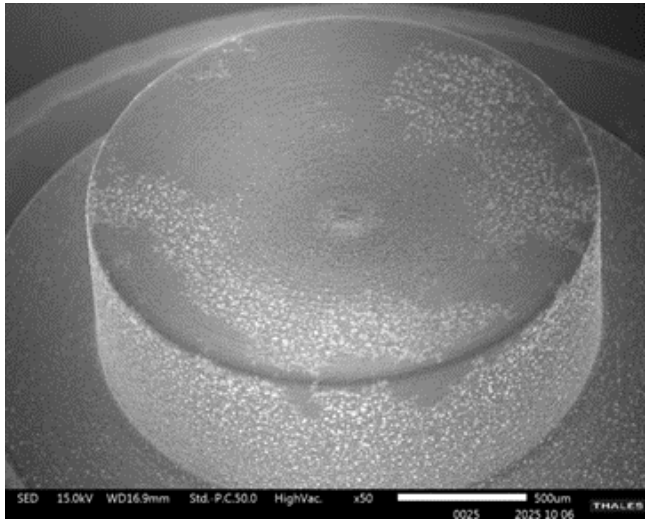
## > Same observations

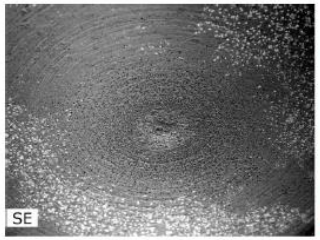
- Around the center, Os/Ru layer on tungsten
- At the center: Os/Ru has disappeared

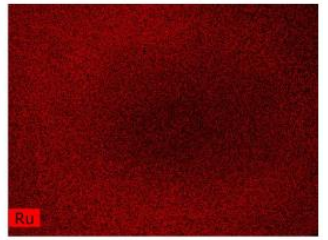
# Particularity of cathode F (1000°Cb)

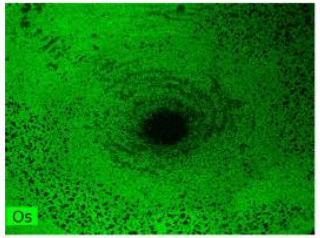


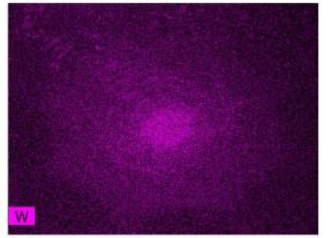



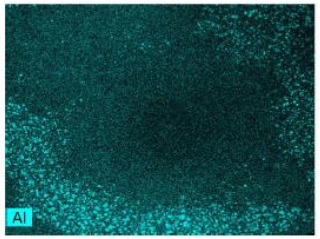



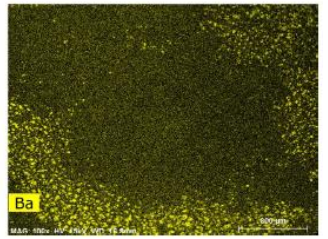



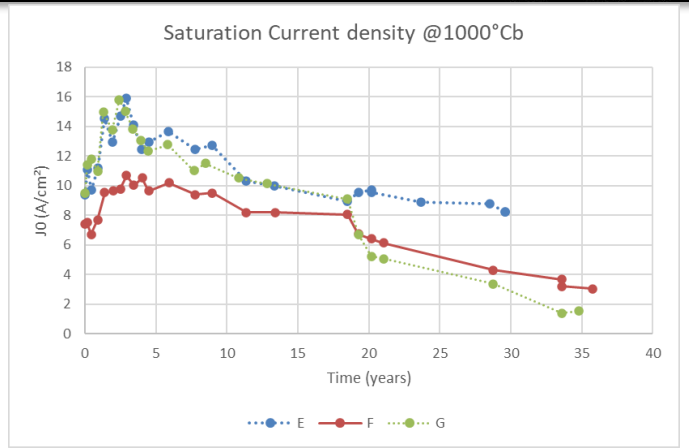



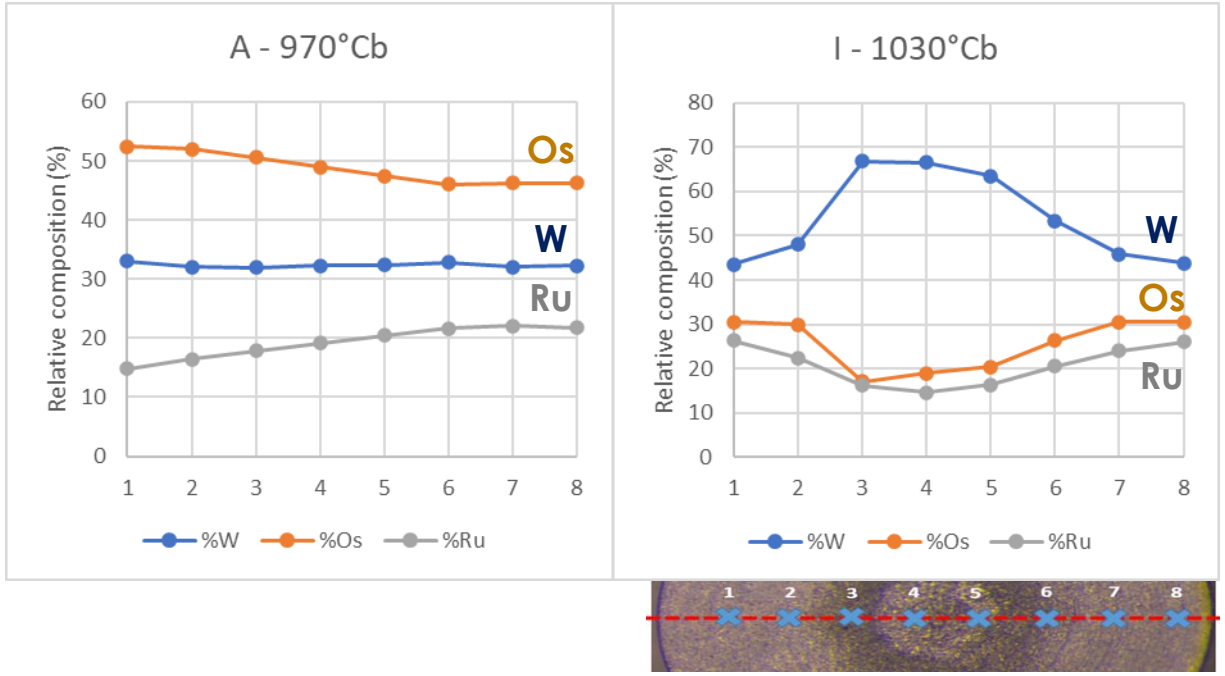

## > For one cathode

- Apparition of barium aluminates
- Generally linked to oxygen exposure
- Saturation current density initially lower than other cathodes from the 1000°Cb aging group (red curve)



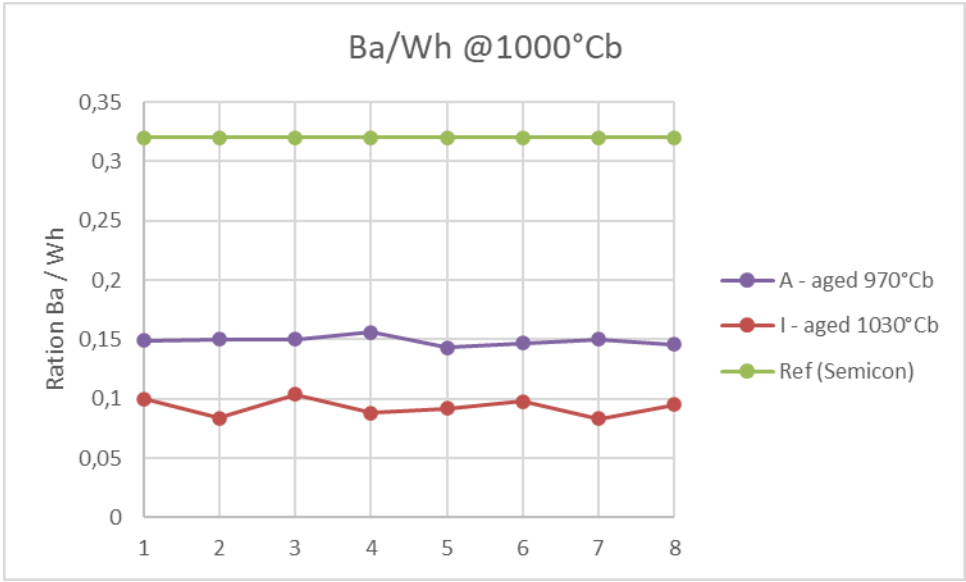
# Surface composition analysis: Auger Electron Spectroscopy

## > Os / Ru layer




- 970°Cb: no variation over the surface
- 1000°Cb: Os/Ru depletion at the center
- Remark: AES analysis depth ~ few nm

## > Barium coverage (@1000°Cb)




*In Thales AES, cathodes are heated during the analysis*

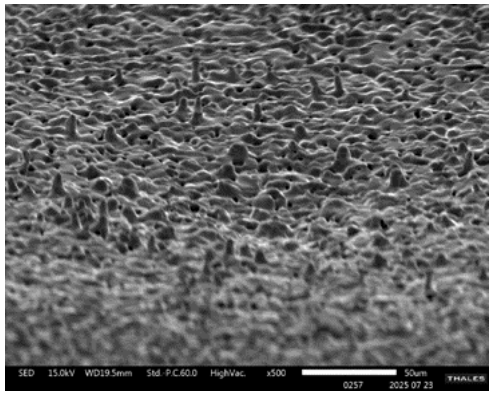
- Compared to a cathode at the beginning of its life: Ba/Wh ratio decreases with the aging temperature
- At high temperature, there is less barium at the surface

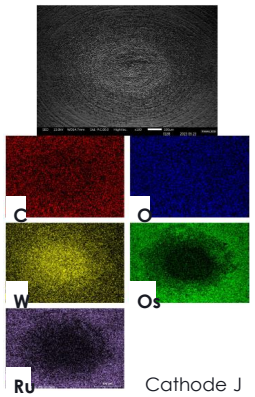
# Conclusions for the surface analysis

## > Cathode M: Os/Ru layer

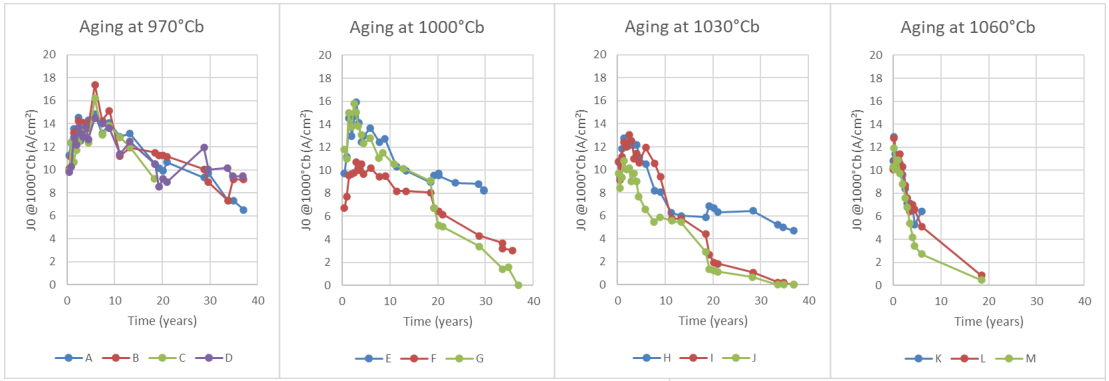
- **Surface topology and composition: Ionic bombardment**
- Central ion bombardment resulting in surface erosion
  max depth ~ 20 µm
- Os/Ru still present but thin at the center (not seen by EDS)
- Effect more pronounced for cathodes aged at higher temperatures
  - The higher the temperature, the higher the Ba evaporation rate
  - More species between cathode and anode ➔ more ions

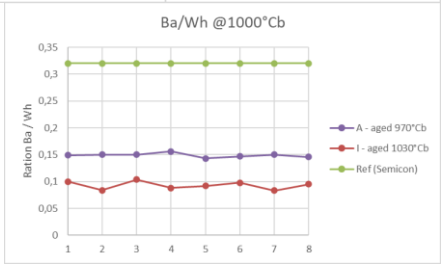
  = More bombardment at higher temperatures






Cathode J




## > Barium coverage

- Barium coverage decreases with the aging temperature
- Consistent with saturation current density measured

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# Cathodes Analysis

## Bulk analysis: cleavage of the pellet

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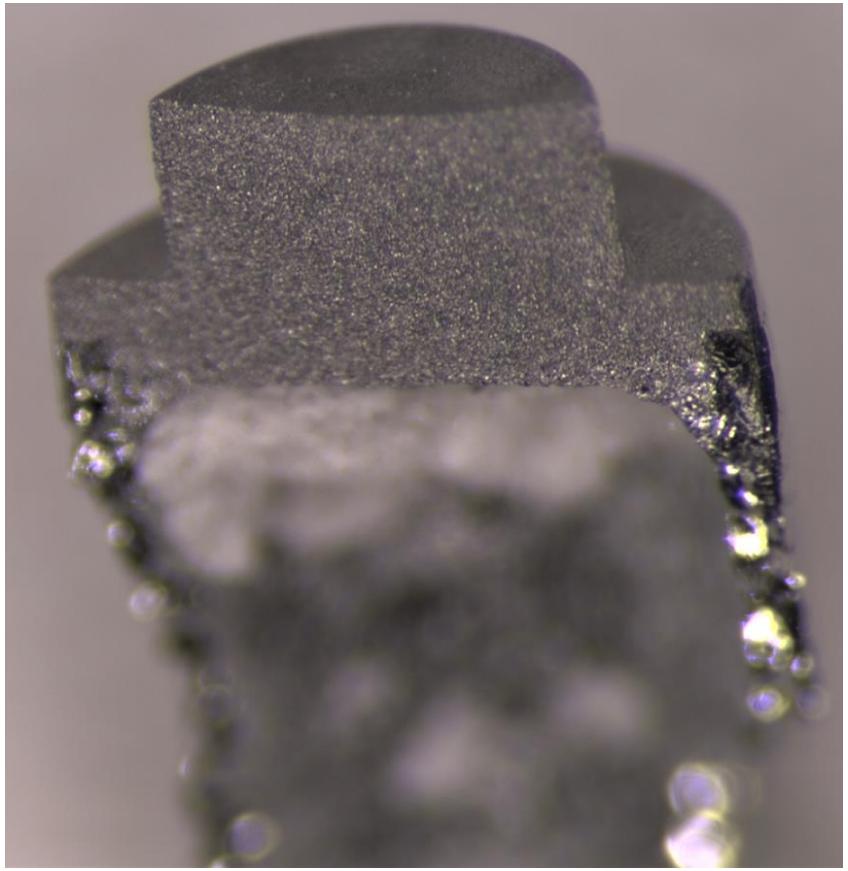
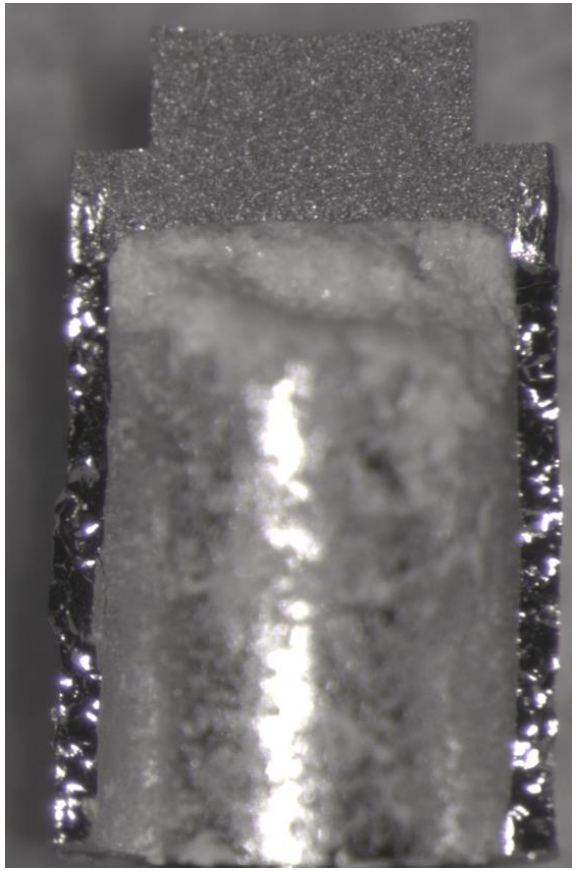
# Bulk analysis: cleavage of the pellet

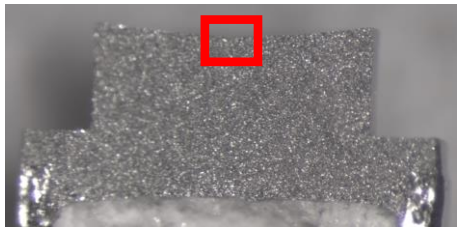
## > Cleavage of the cathodes + EDS mapping

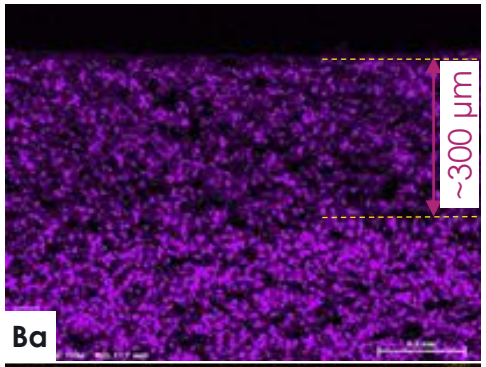


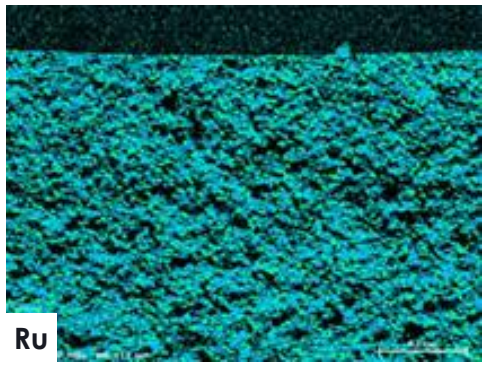


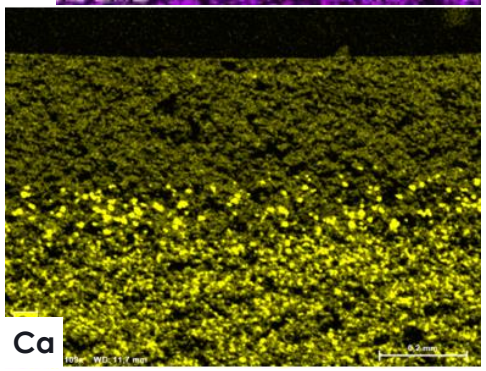
# Bulk analysis: barium depletion

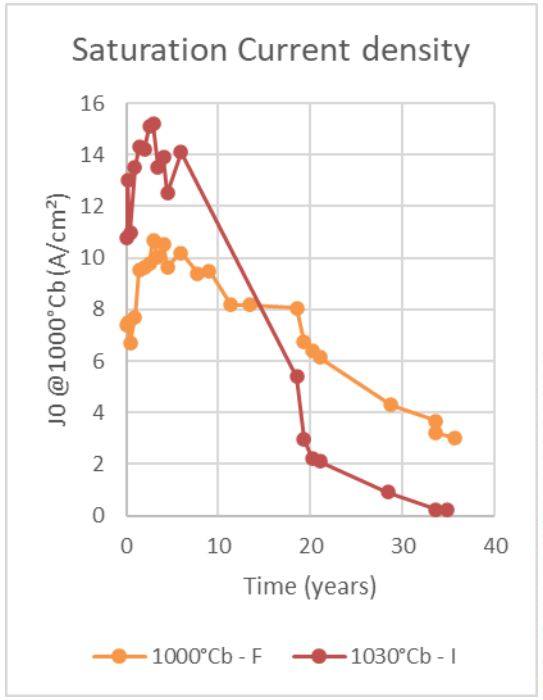
1000°Cb



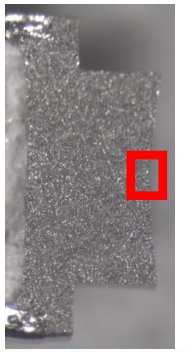


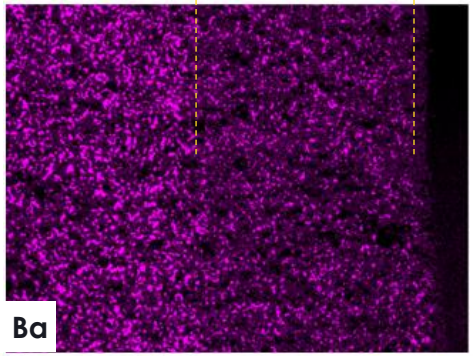



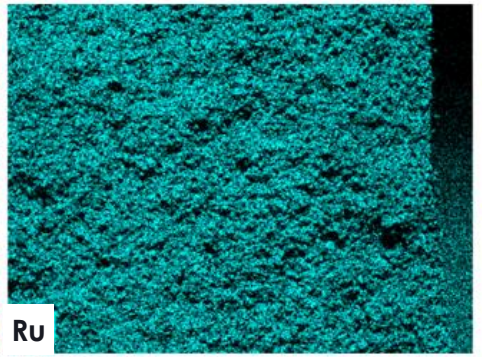



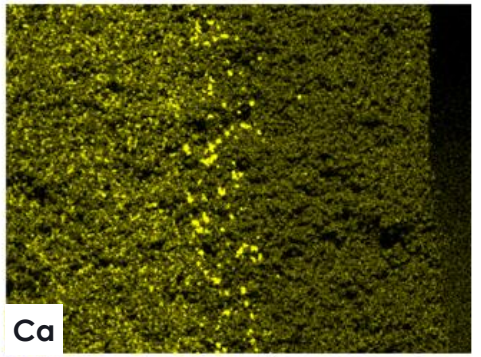




1030°Cb





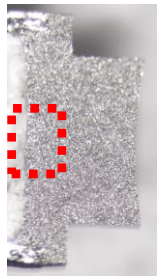



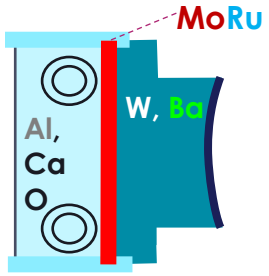

## > EDS mapping: Diffusion of Ba from the core of the pellet to the surface

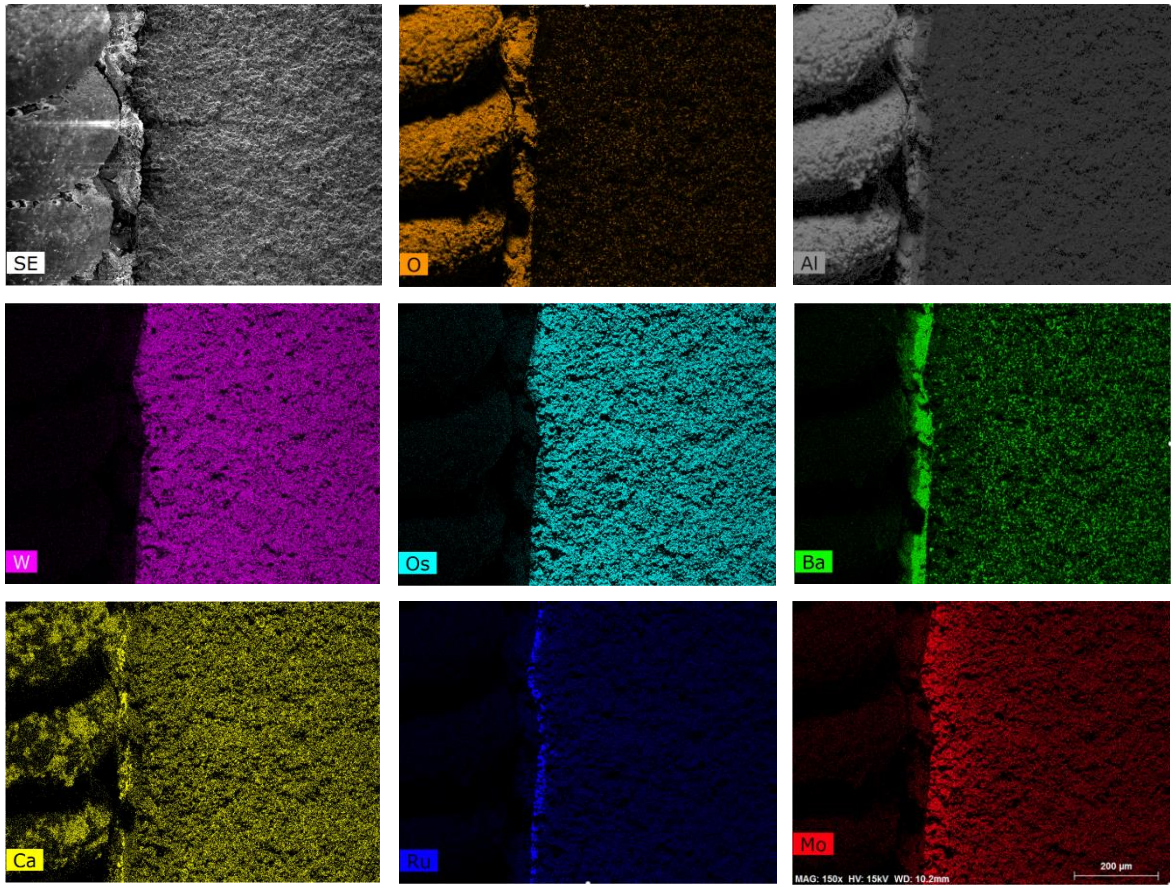
- Ba and Ca depletion from the surface of the cathode: ~300 µm for Ba and Ca
- Depletion more important for high aging temperatures
- Consistent with the lower coverage of barium (AES) and low current density for high aging temperatures

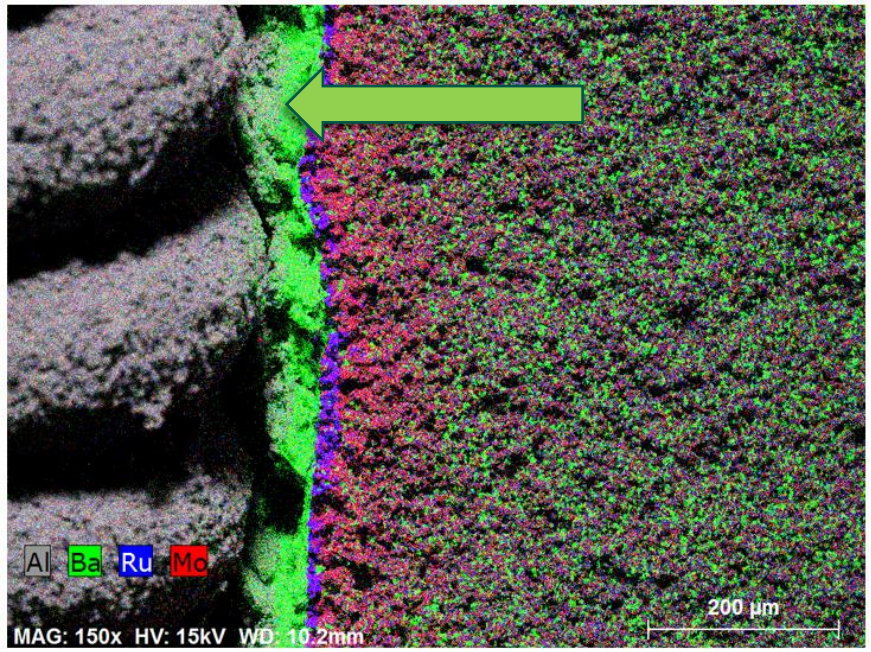
# Migration of Ba at the bottom of the cathode

**Cathode I**
**1030°Cb**





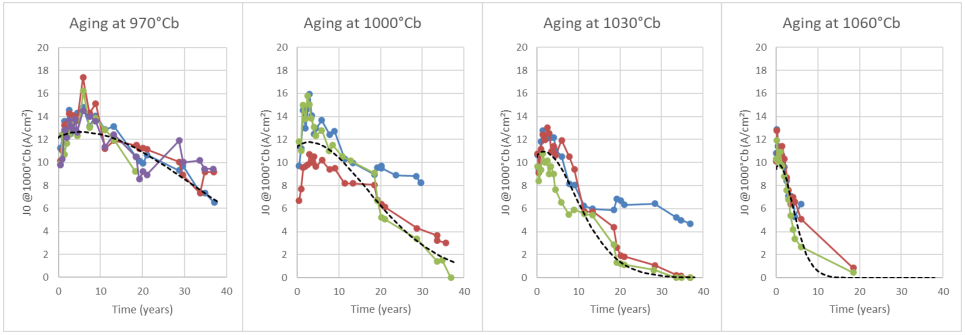

$Al_2O_3$ Ba MoRu W, Ba

- Ba migration toward filament
- Blocked at the interface
- No electrical leakage

# Conclusions

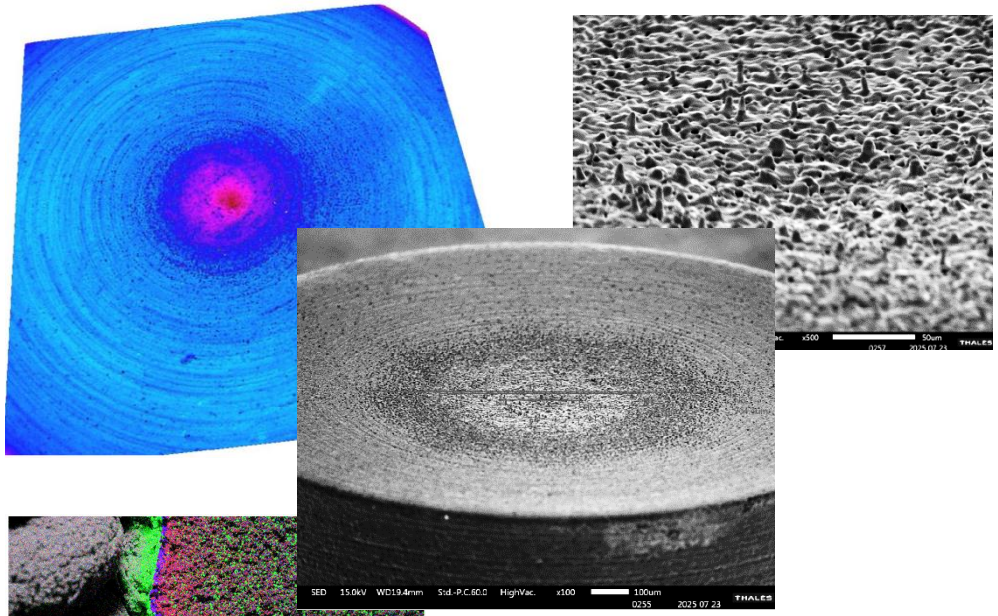
## > Saturation current density

- Good agreement between current measurement and lifetime model
- Confidence in our product lifetime predictions
  - At 970°C cathode is still emitting after 37 years !
  - At 1000°Cb cathodes can operate more than 20 years !



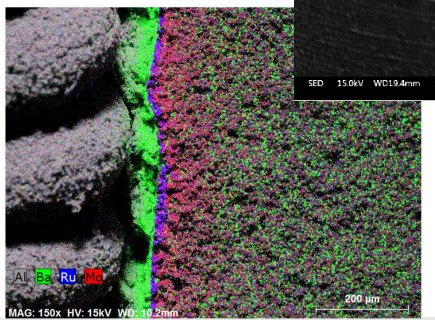

## > Surface analysis

- Clear presence of ionic bombardment at the center of the cathode
- No Os/Ru layer at the center
- No central emission → formation of an annular beam



## > Bulk analysis

- Ca and Ba depletion: around 300 µm after 37 years
- Depletion from the bottom of the pellet "through" the MoRu barrier



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# Thank you

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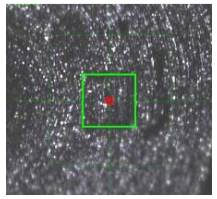
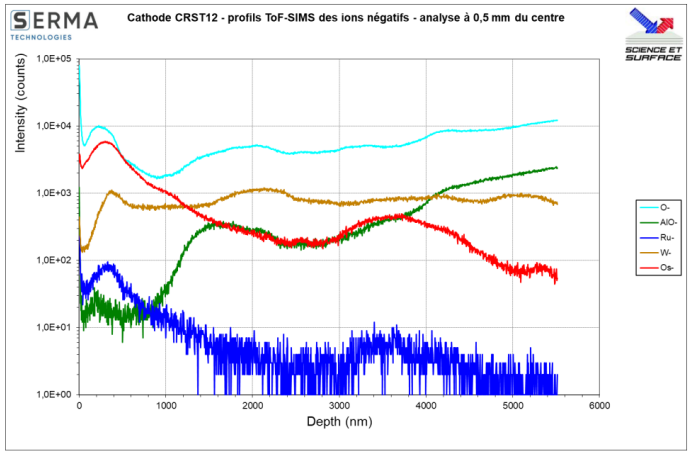
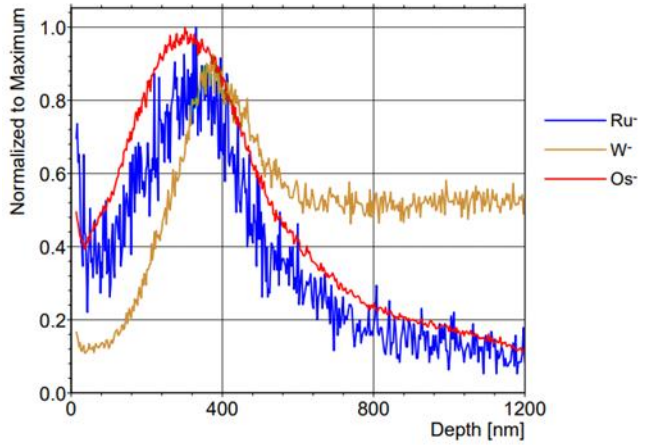
# Surface composition analysis: ToF SIMS

Around the center






Center