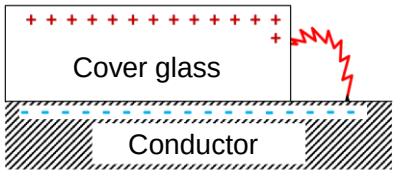
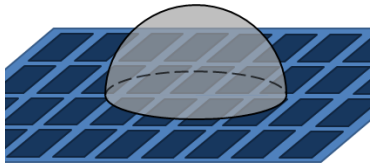
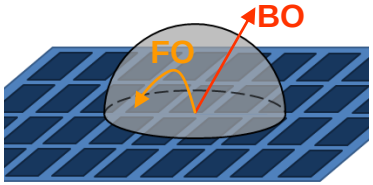
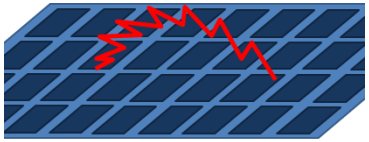
Flash-over propagation model on spacecraft solar panels

Loanne Monnin

Sébastien Hess, Jean-François Roussel, Pierre Sarrailh, Denis Payan

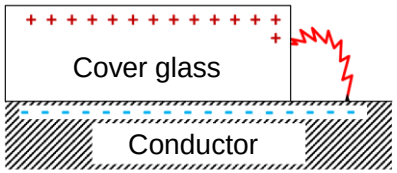
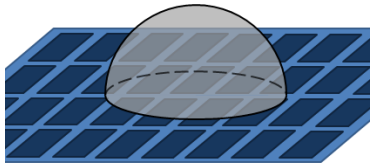
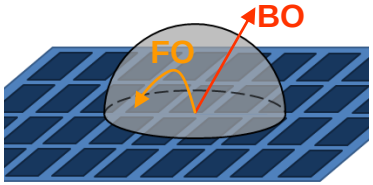
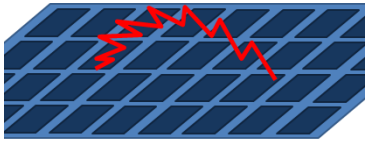
28th SPINE workshop – 8th June 2021

Context

ESD	Plasma bubble	BO & FO	Secondary arc
			
A cathodic spot is created	The plasma bubble expands over the SP	Two currents are carried by the plasma	Cause permanent dammage

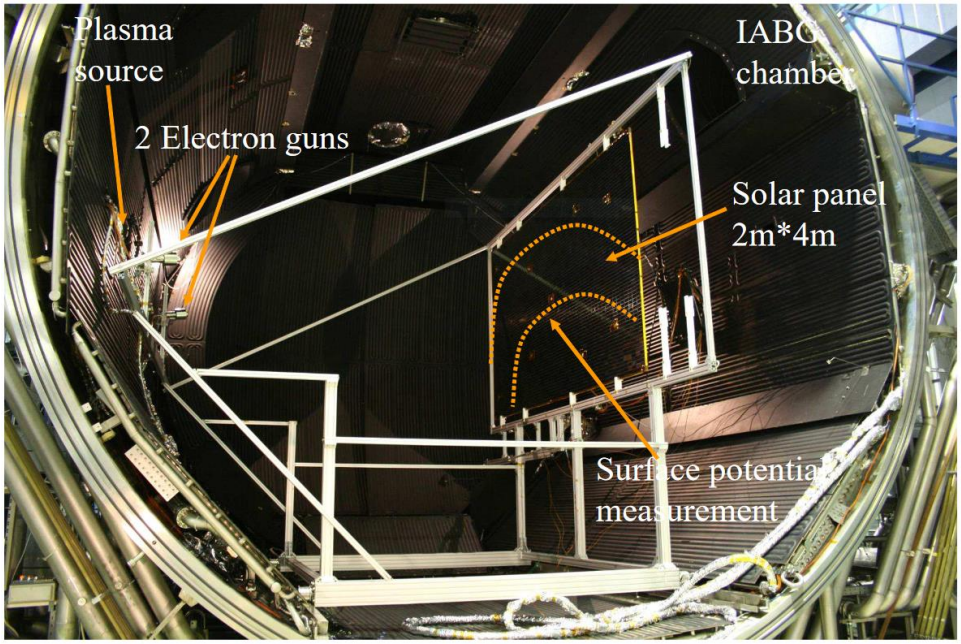
- Because of interactions with space environment Electrostatic Discharges (**ESD**) appear on spacecrafts solar panels (**SP**)
- It leads to a plasma bubble that expands over the SP
- The plasma carries two currents : the blow-off (**BO**) that empty the conductor capacitance and the flash-over (**FO**) that is recollected over the SP
- The plasma bubble is a conductive environment that may lead to secondary arcs

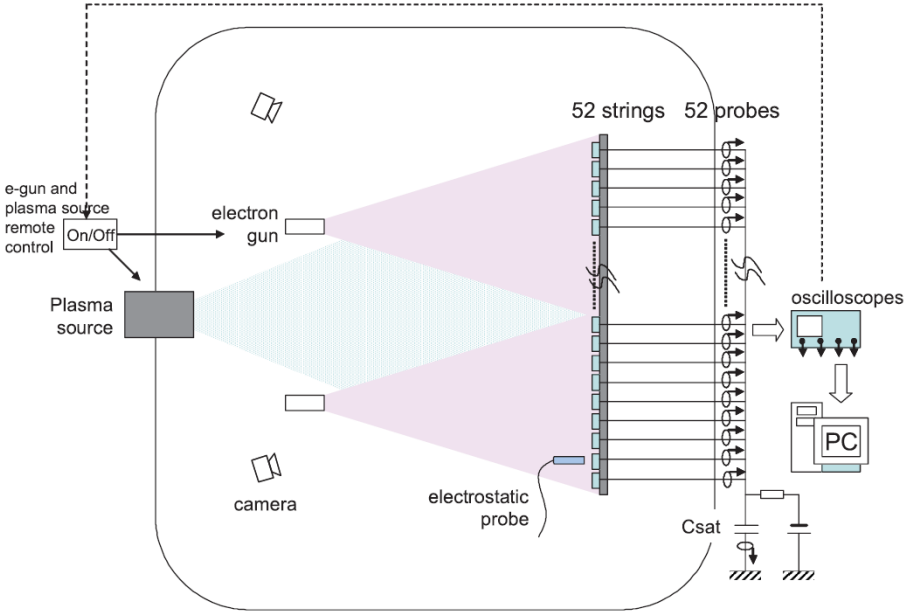
Context

ESD	Plasma bubble	BO & FO	Secondary arc
			
A cathodic spot is created	The plasma bubble expands over the SP	Two currents are carried by the plasma	Cause permanent dammage

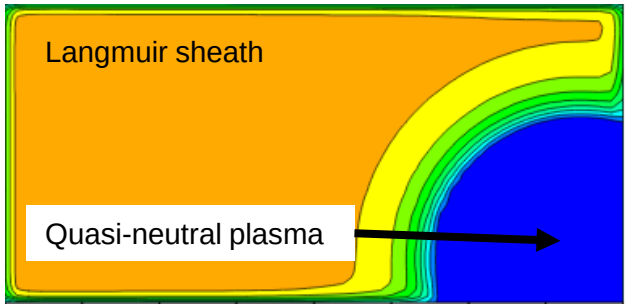
Our objective is to study the evolution of the FO over the SP from the plasma creation at the cathode spot to the extinction

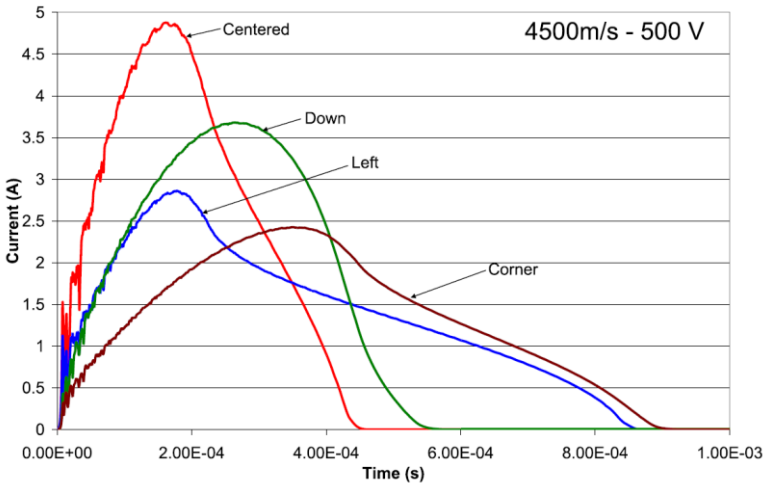
Presentation of EMAGS3 campaign : experimental setup





Presentation of EMAGS3 campaign : numerical model

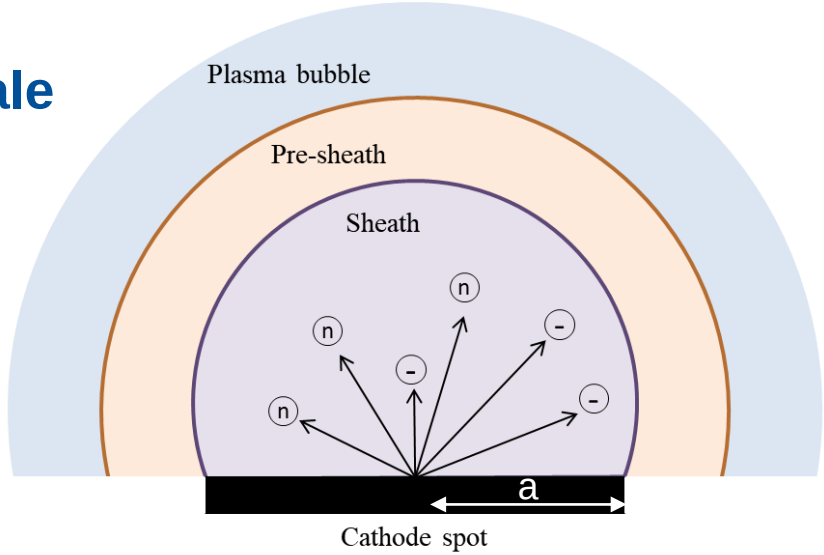




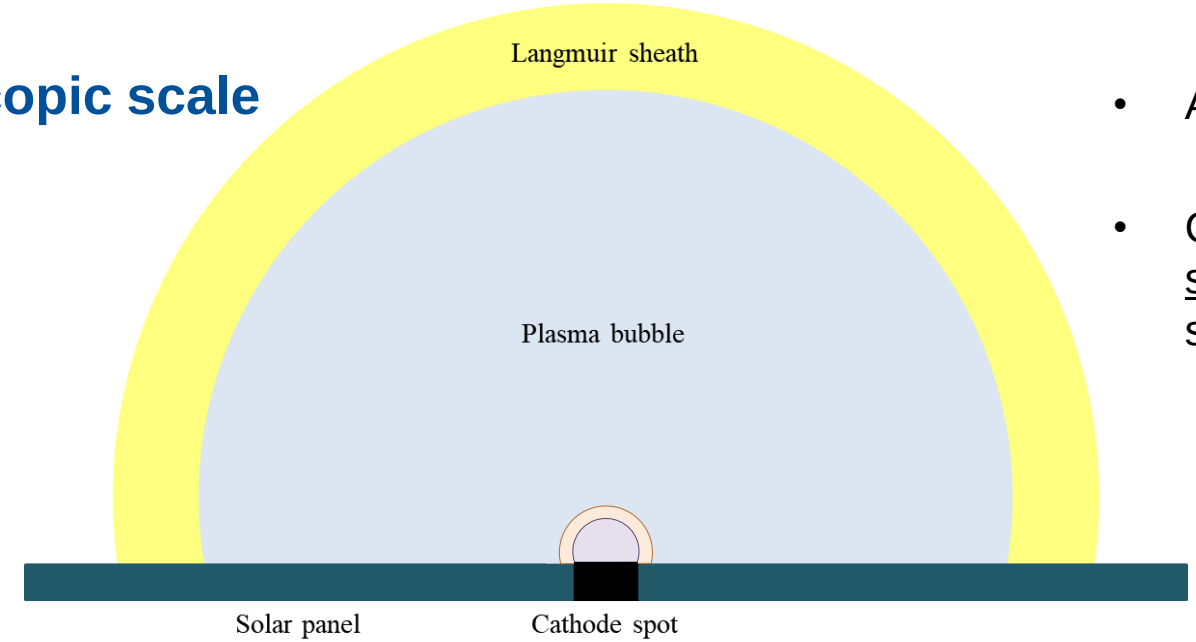
- Expansion = Bohm velocity
- Many parameters manually imposed
- No information about the FO end

Cathode spot stability

Microscopic scale

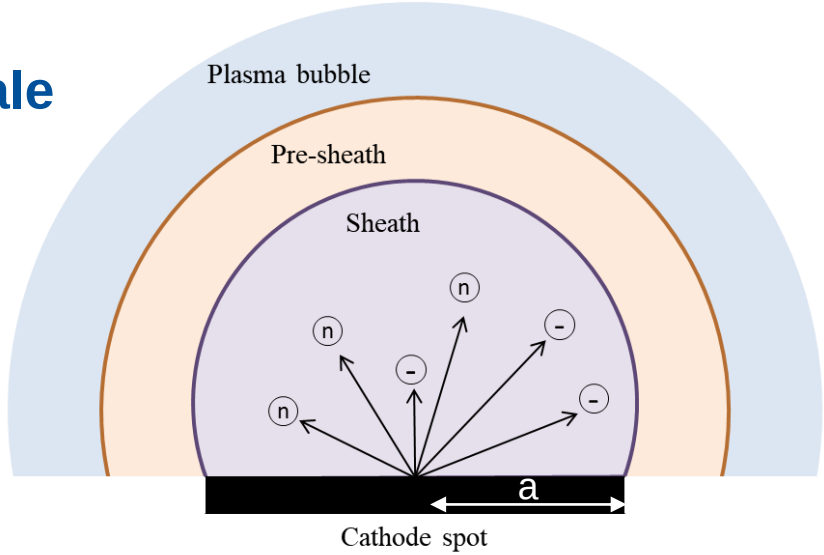


Macroscopic scale

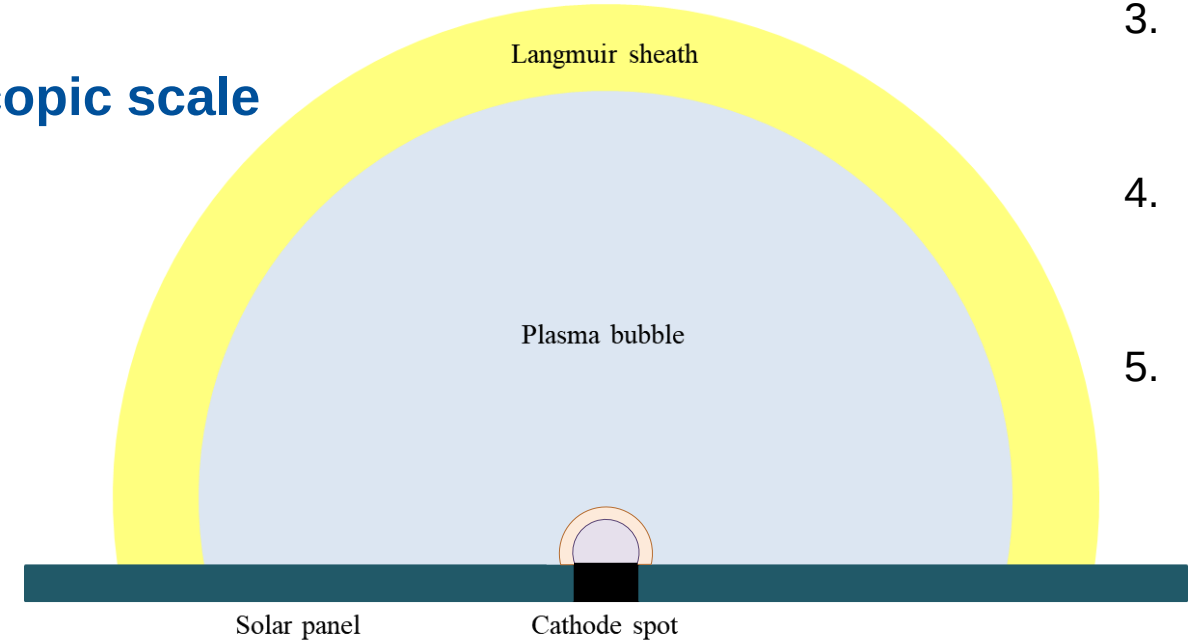


- Ultra-high vacuum (mass and charge conservation)
- Diffuse anode
- Axial geometry
- Cathode material : <u>silver</u>, aluminium or silicon (+ <u>copper</u>)

Microscopic scale



Macroscopic scale



1. Current conservation between the spot and the plasma
2. Energetic balance at the surface
3. Energetic balance in the pre-sheath
4. Poisson's law in the sheath
5. Current conservation between the plasma and the panel

Current conservation by the cathode

Secondary electrons

Incoming ions

Emitted electrons

Electrons coming back from the plasma

$$J = J_{cat} + J_{sec} + J_i - J_{bk} = J_{ep} - J_{ip}$$

Total current density

Current density at the spot surface

Current density in the plasma

$$J_{cat} = (A_T T^2 + A_F E^x) exp\left(-\left(\frac{T^2}{B_T} + \frac{E^2}{B_F}\right)^{-\frac{1}{2}}\right)$$ Murphy & Good thermo-field equation

Energetic balance at the surface

Lost by the secondary electrons emission

Lost by the electrons emission

Lost by the neutrals emission

Lost by conduction

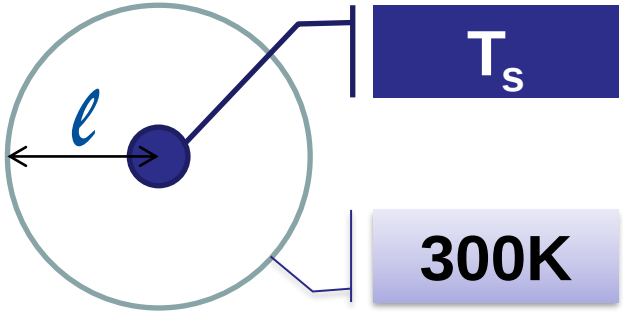
$$S_i + S_{bk} + S_{jle} = S_n + S_{cat} + S_{sec} + S_{cd}$$

Given by ions

Given by Joule effect

Given by electrons from plasma

Conduction distance computed with Fourier law around the spot



Energetic balance in the pre-sheath

Neutral emission flux	Mass conservation
• Surface near cathodic spot also emit neutrals over a distance l • We integrate the distribution function over a disk of radius l considering a view angle $$\Phi'_n = \Phi_n \left(1 + \frac{1}{2\pi} \ln\left(\frac{l^2 + a^2}{2a^2}\right)\right)$$	• All neutrals are ionized • Mass must be conserved $$\Phi_i = \Phi'_n$$

Energetic balance in the pre-sheath

Given by ionizing electrons

Given by Joule effect

Given by incoming neutrals

$$S_{joule} + S_{e,in} + S_{n,in} = S_{i,out} + S_{e,out}$$

Lost with ions

Lost with electrons

Z is calculated with the Saha equation (2-3 for silver)

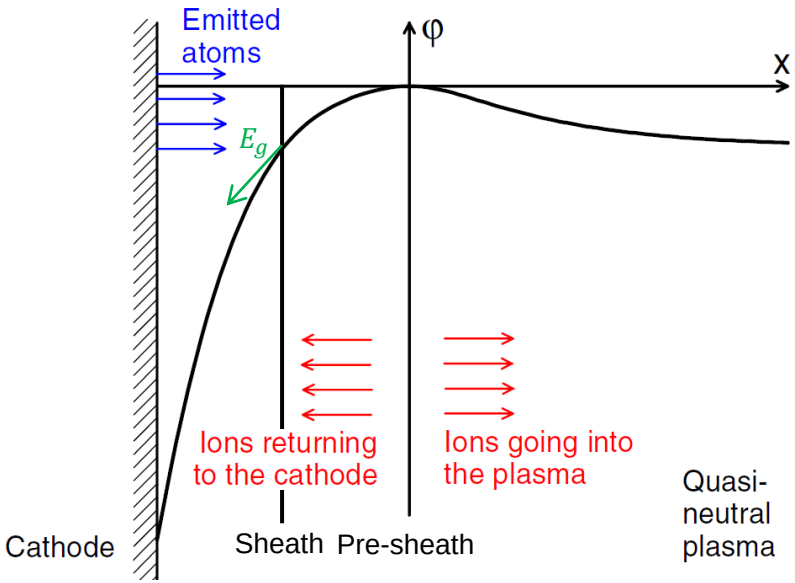
Poisson's law in the sheath

$$\boldsymbol{\nabla\varphi = -\frac{dE}{dx} = -\frac{e}{\varepsilon_0}(Zn_i - n_e)}$$

$$eZn_i(x) = \frac{J_i}{v_i(x)}$$

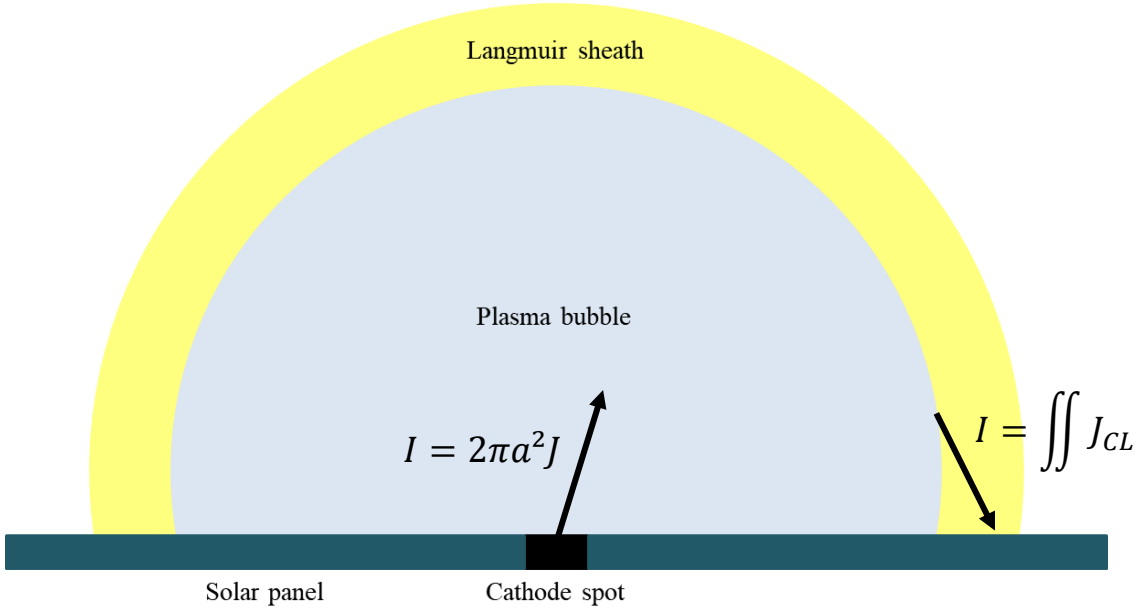
$$en_e(x) = e\left(n_{cat}(x) + n_{sec}(x) + n_{ep}(x)\right)$$
$$= \frac{(J_{cat}+J_{sec})}{v_e(x)} + en_{ep}(x)$$

$$\varphi(0) = 0 \qquad E(0) = E_s$$
$$\varphi(x_g) = \varphi_g \qquad E(x_g) = E_g$$



M S Benilov. Space-charge sheath with ions accelerated into the plasma. Journal of Physics D: Applied Physics, IOP Publishing, 2010, 43 (17), pp.175203.

Current conservation in the plasma bubble

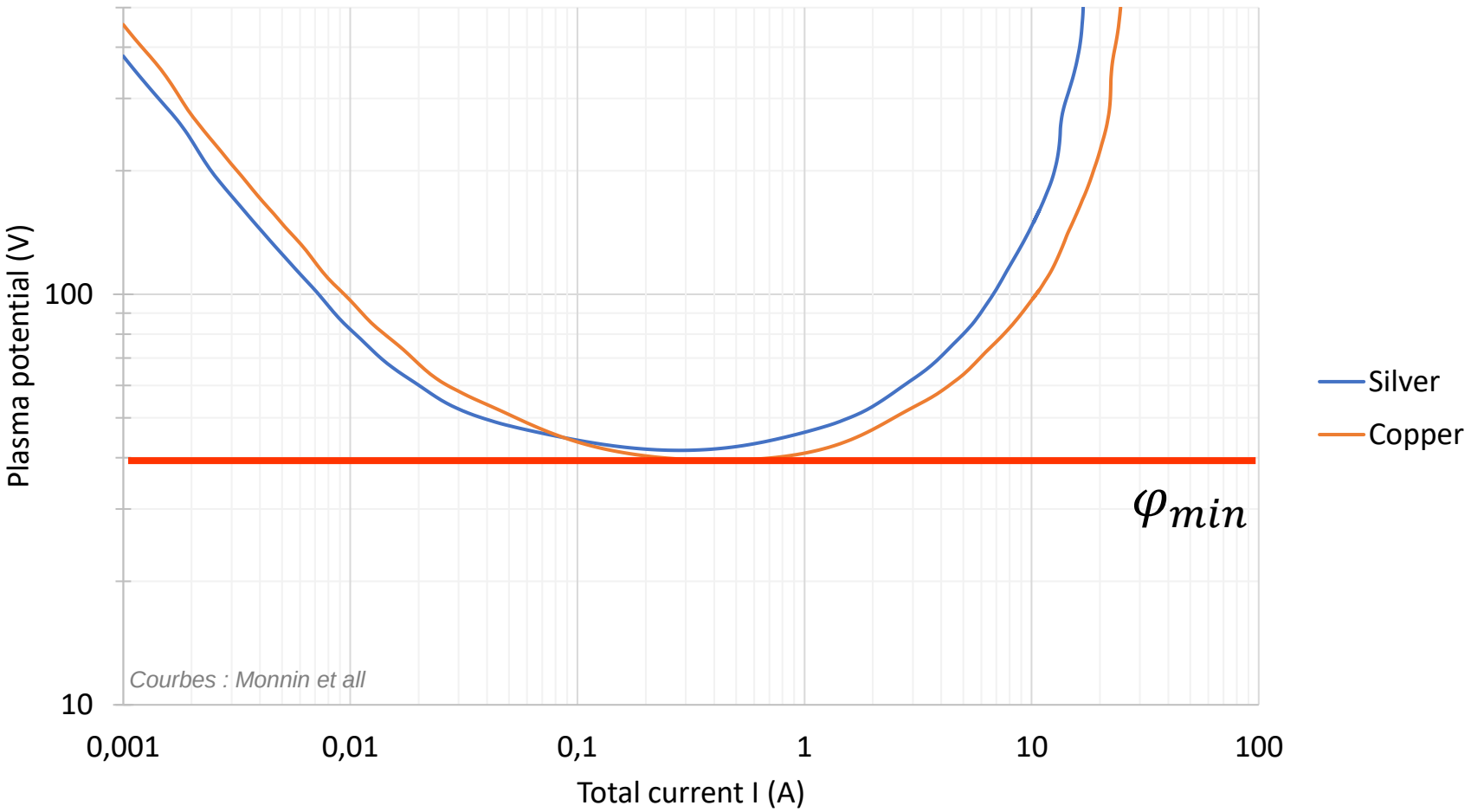


Current emitted by the spot = current collected by the SP

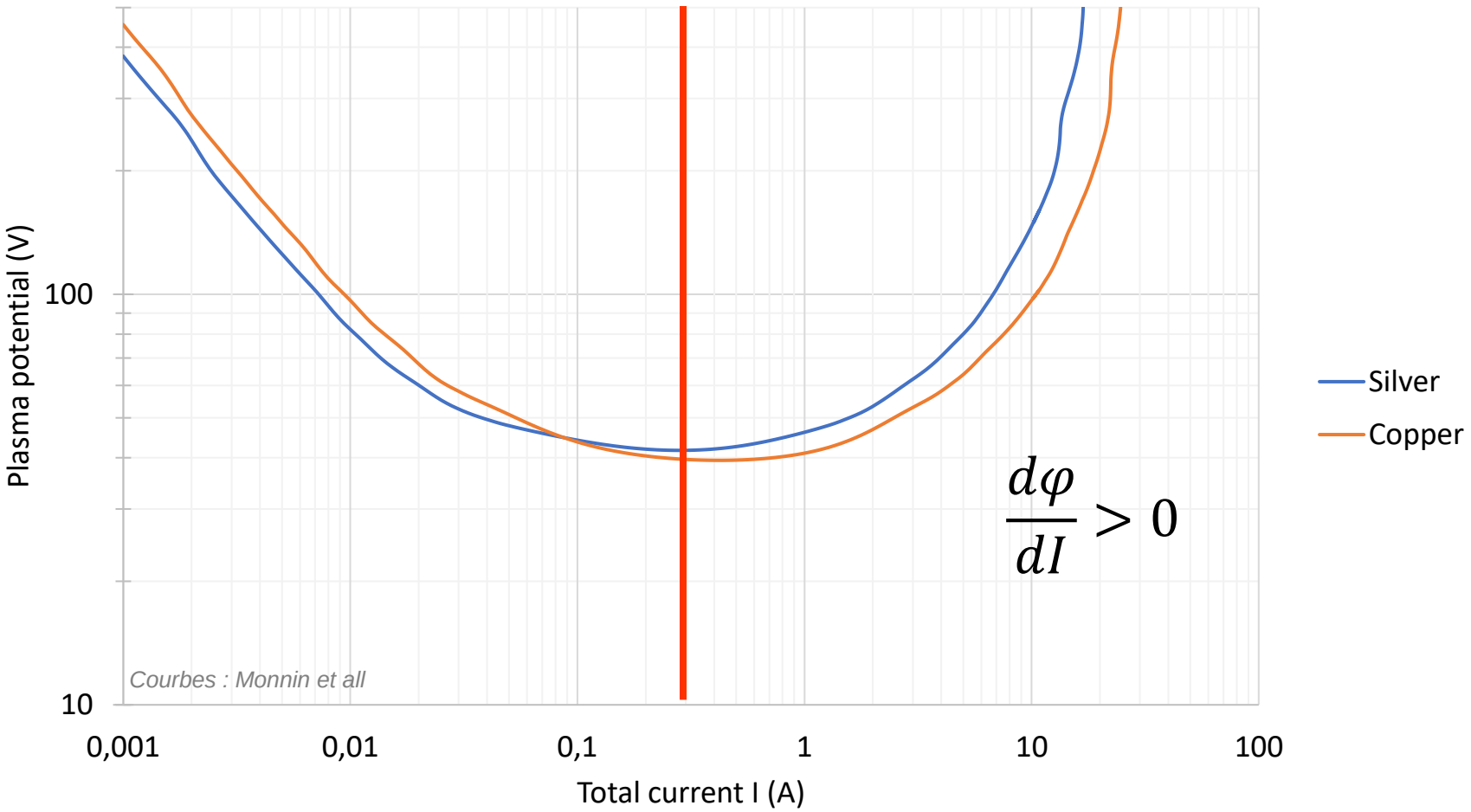
Only unknown = plasma potential

Spot characteristic time smaller than expansion time step = Instantaneous current conservation

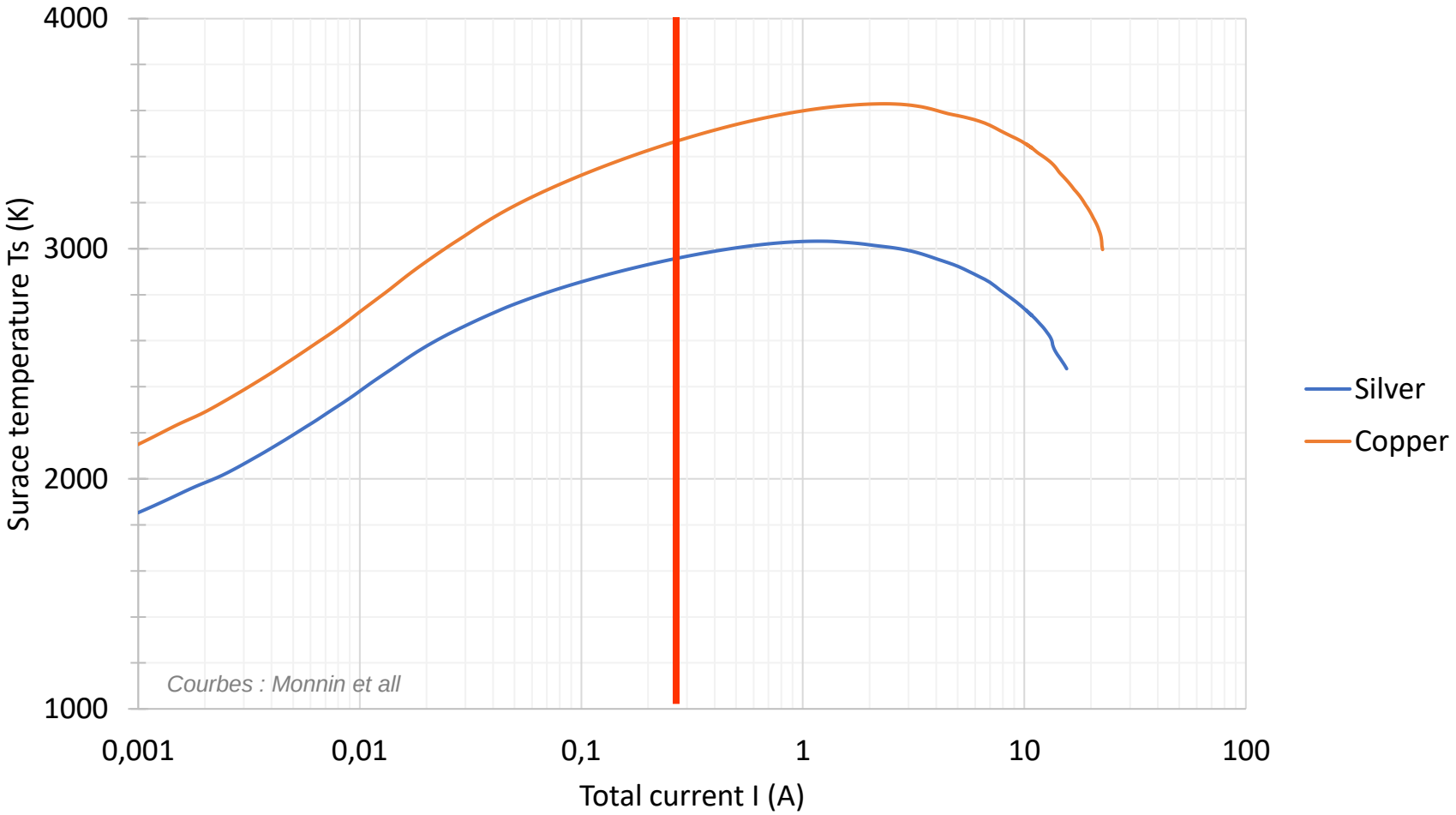
Plasma potential



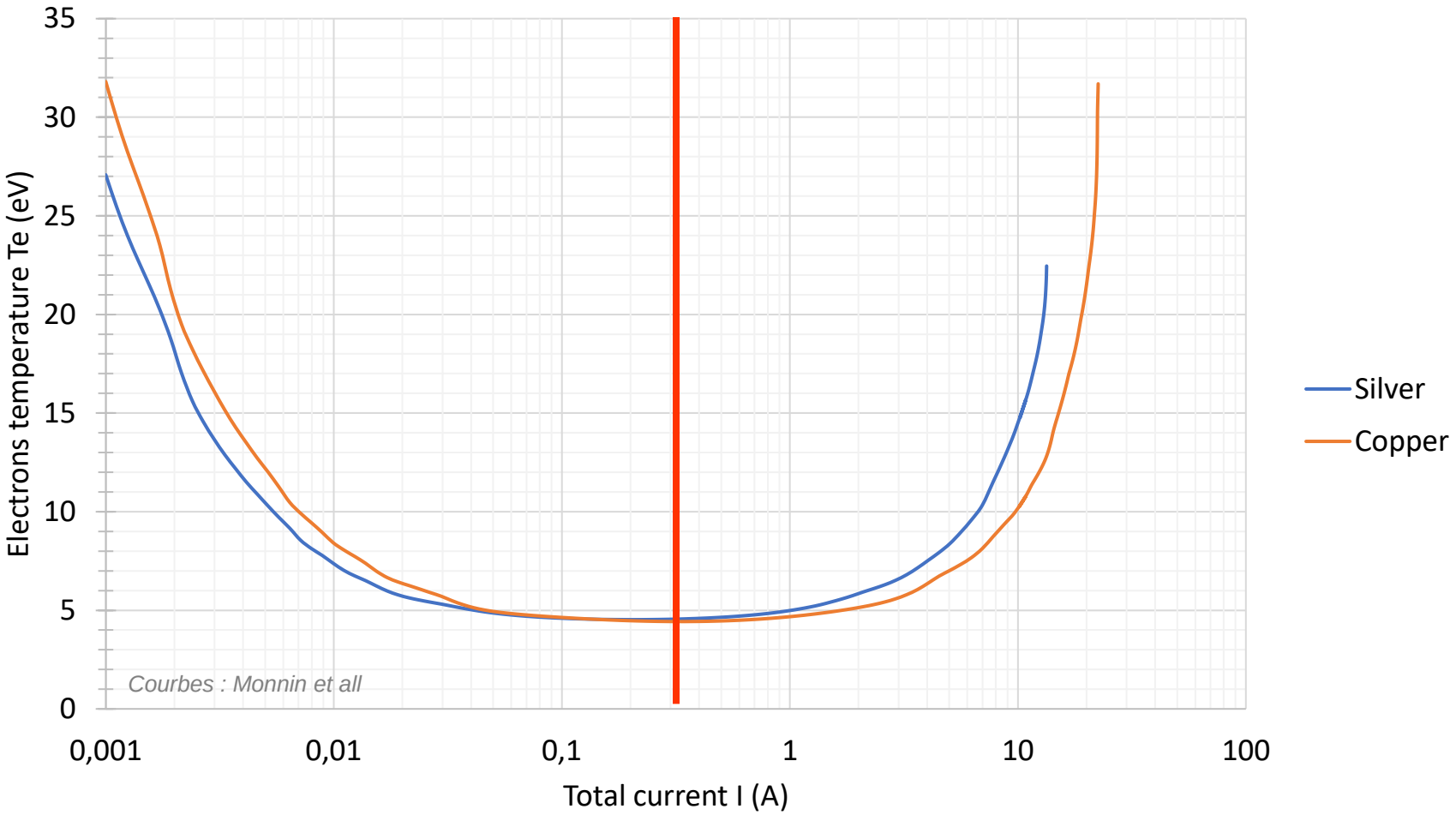
Plasma potential



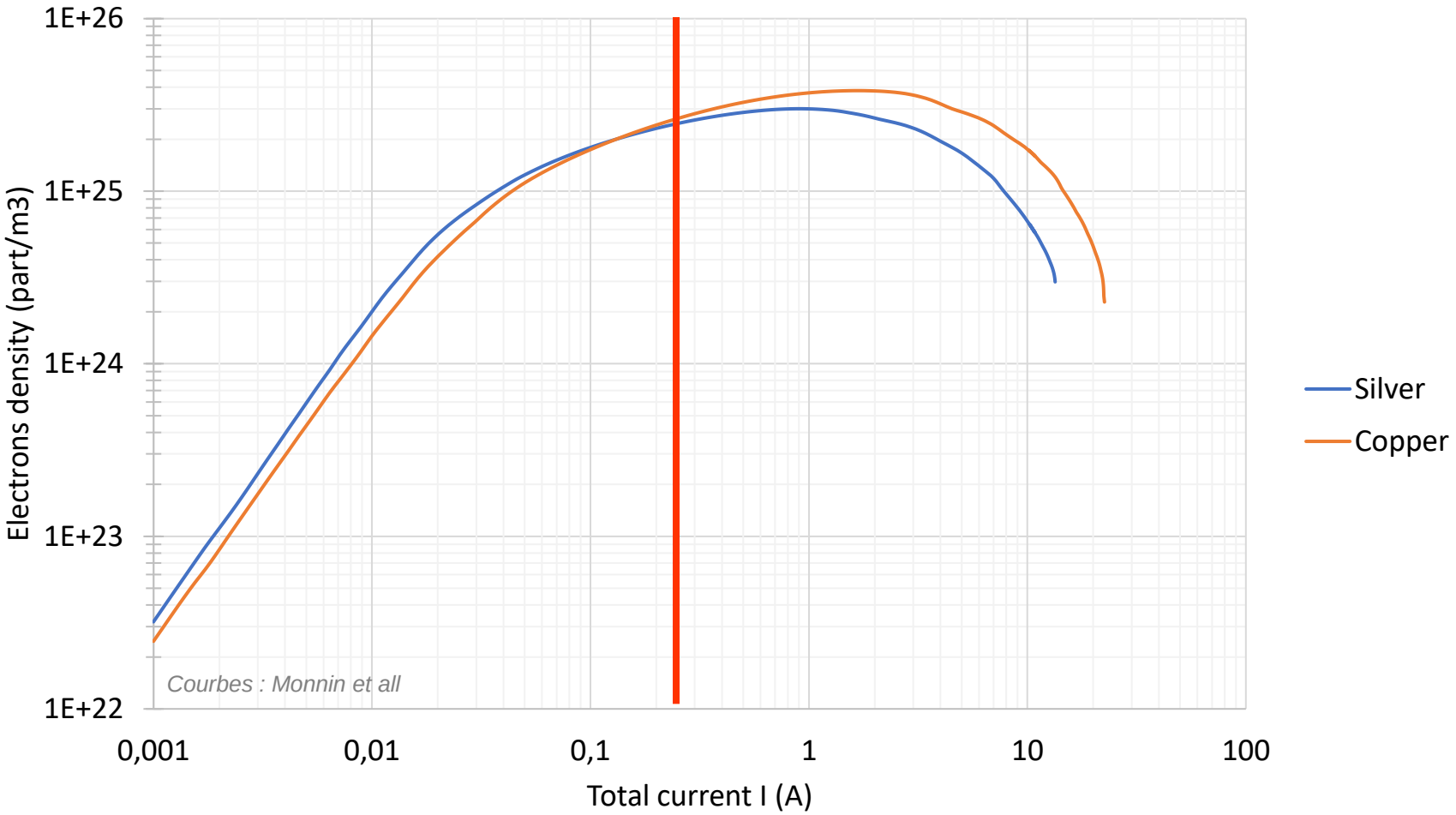
Surface temperature



Electrons temperature

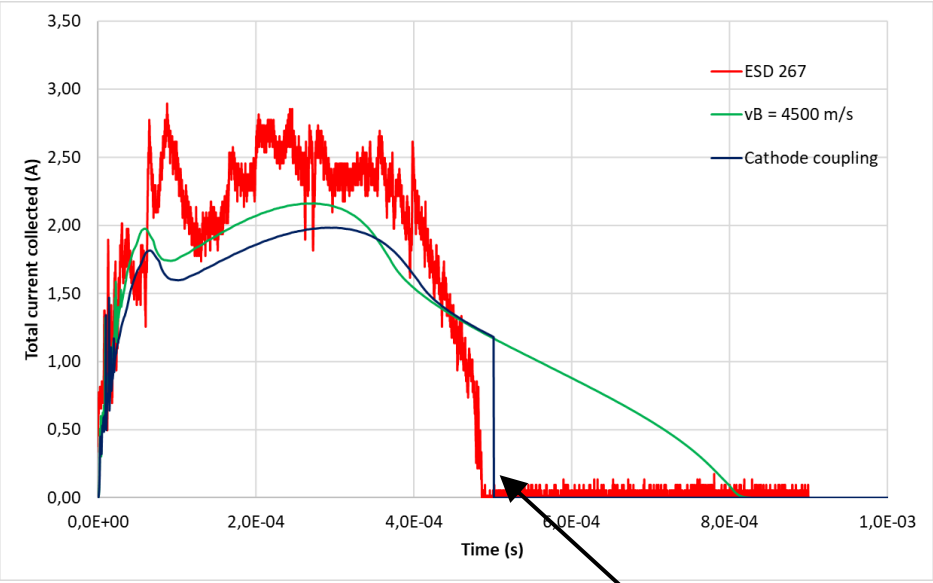


Plasma density

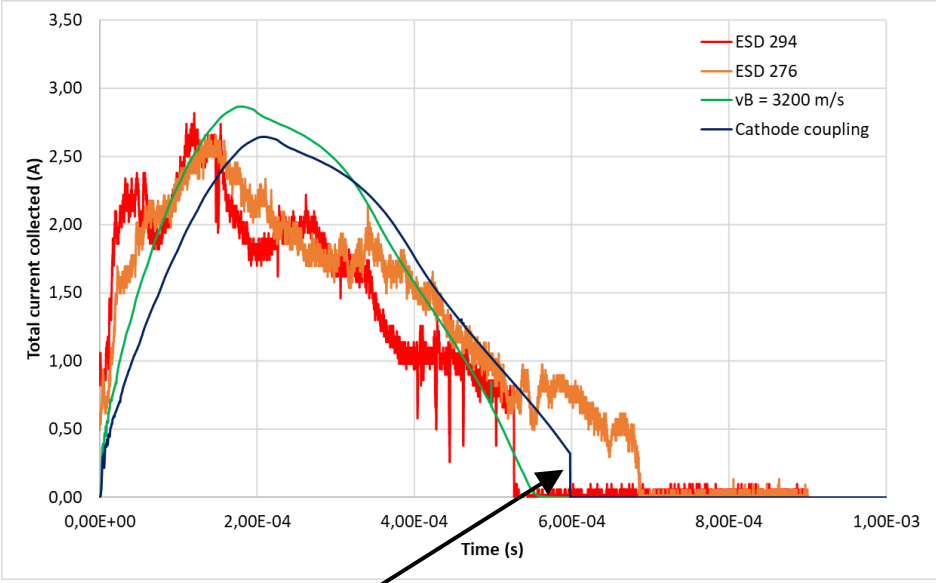


FOEBUS results

Triggering on a silicon cell



Triggering on a silver interconnector



$$\varphi_b < \varphi_{min}$$

Courbes : Monnin et all

Conclusion

- We have a Flash-over propagation model with creation and extinction of plasma
- Coupled model between cathode spot emission and current collection over solar panel
- Limiting conditions by the spot = limiting condition for the expansion
- No need for experimental data

Perspectives

- Evolution over large solar panels
  - Current limited by the solar panel size
  - Thermal effect on large scales
  - Density evolution in space

- Solar panel electric circuit
  - Secondary arcing
  - Link between the arc and the FO duration

Thank you!