Electrostatic discharges on spacecrafts solar panels: coupled model of a cathode spot and flash-over propagation in vacuum

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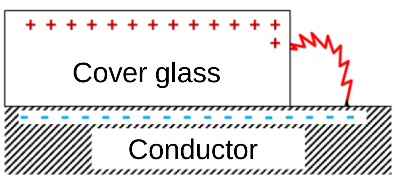
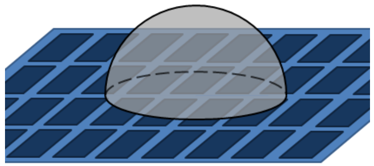
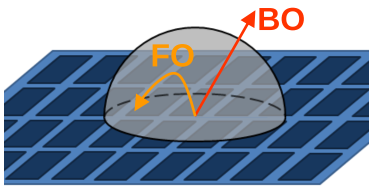
9th International Workshop on Mechanisms of Vacuum Arcs (MeVArc 2021)

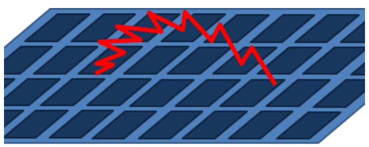
Context

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

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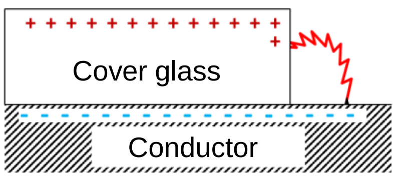

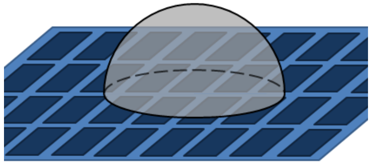

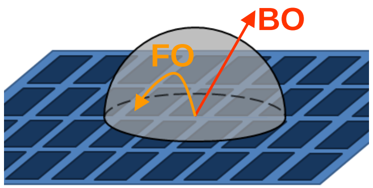

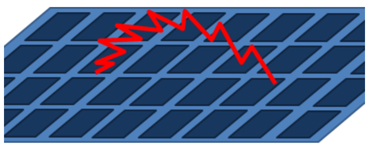

Our objective is to study the evolution of the FO over the SP from the plasma creation at the cathode spot to the extinction

Context

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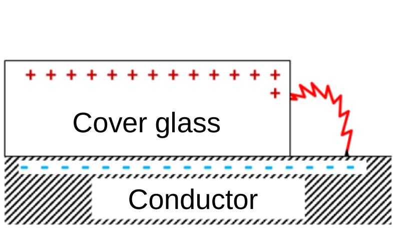
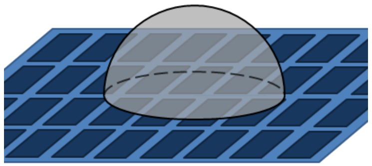
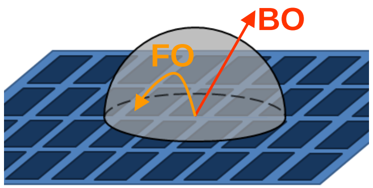
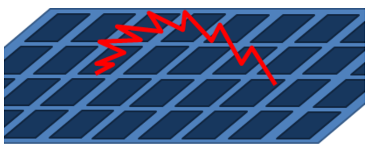
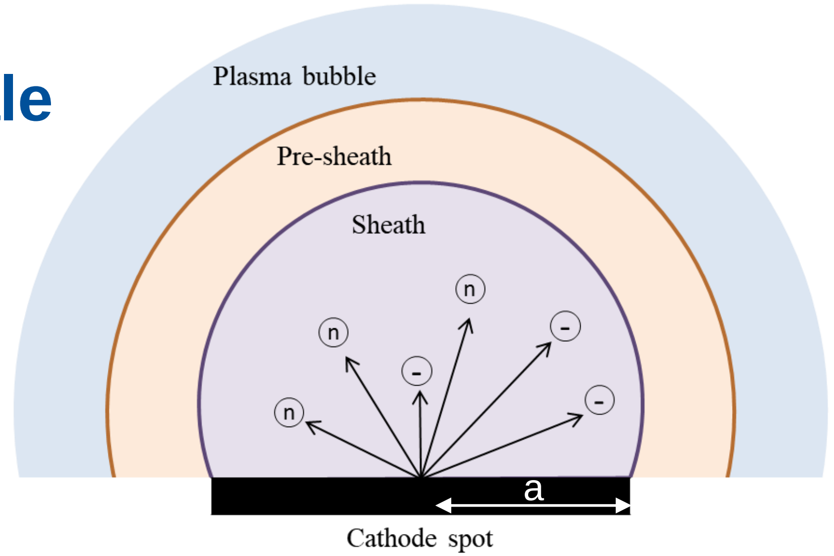
			
A cathodic spot is created	The plasma bubble expands over the SP	Two currents are carried by the plasma	Cause permanent dammage

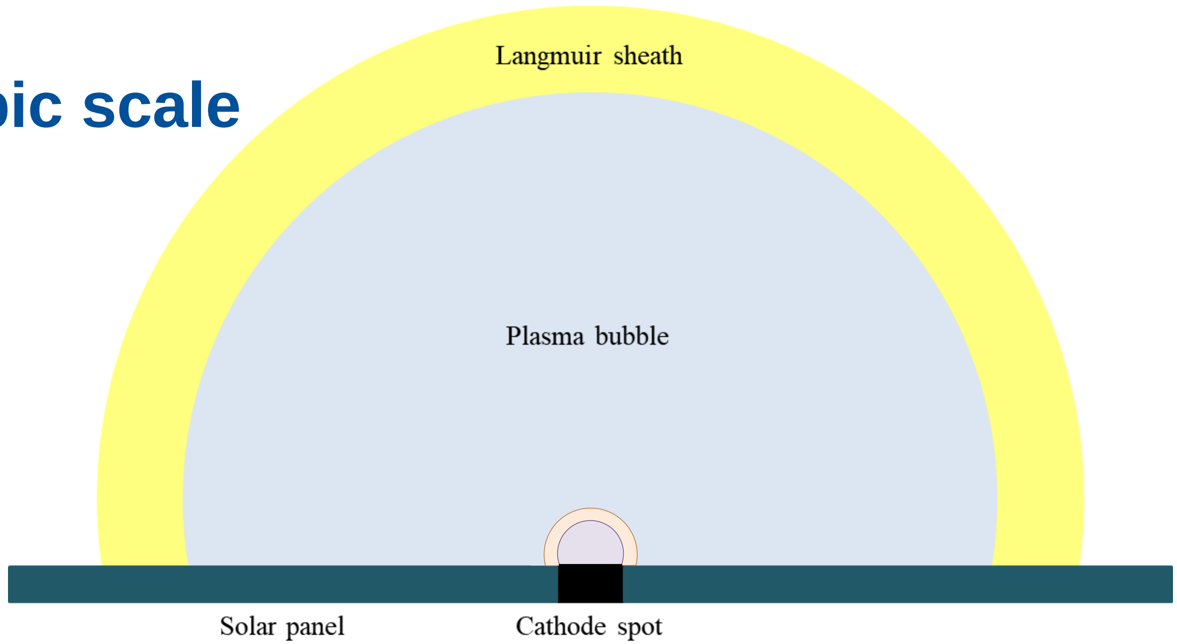
- System in ultra-high vacuum (mass and charge conservation)
- Diffuse anode
- Axial geometry : particles emitted in every directions and spherical plasma
- Cathode material : <u>silver</u>, aluminium or silicon (+ <u>copper</u>)

Model presentation

Microscopic scale

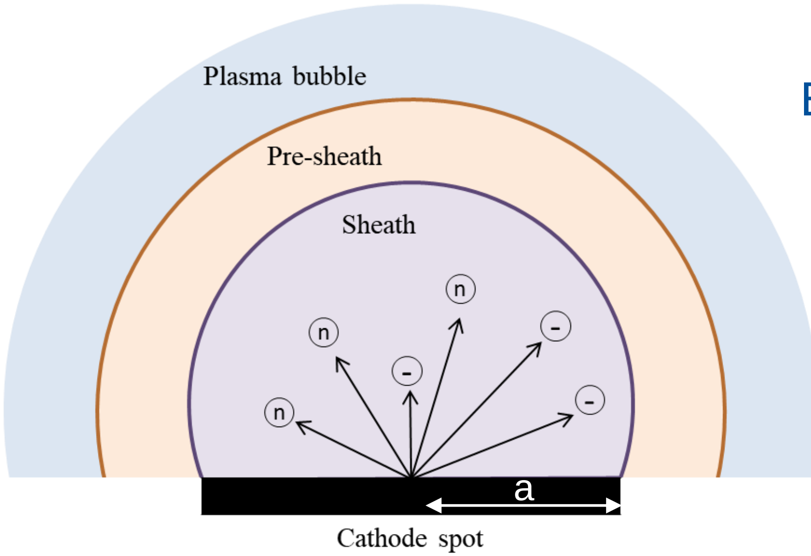


Macroscopic scale



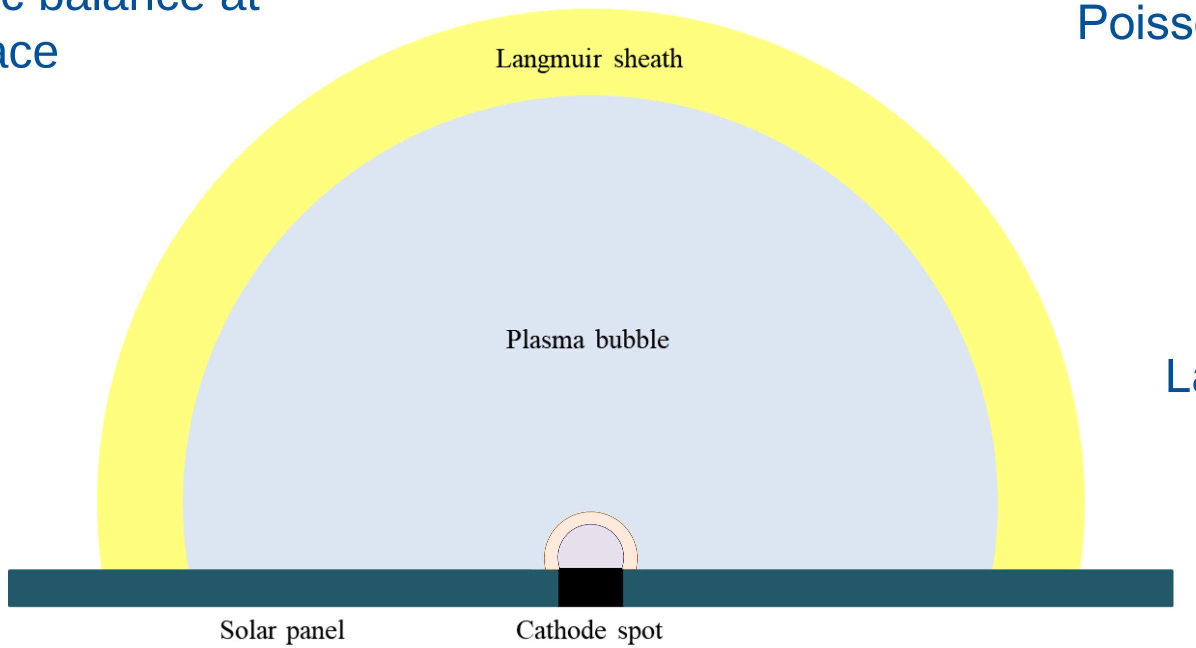
Current conservation

Energetic balance in the pre-sheath



Energetic balance at the surface

Poisson’s law



Langmuir current

Current conservation

Secondary electrons

Incoming ions

Emitted electrons

Electrons coming back from the plasma

$$J = \underbrace{J_{cat} + J_{sec} + J_i - J_{bk}}_{\text{Current density at the spot surface}} = \underbrace{J_{ep} - J_{ip}}_{\text{Current density in the plasma}}$$

Total current density

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

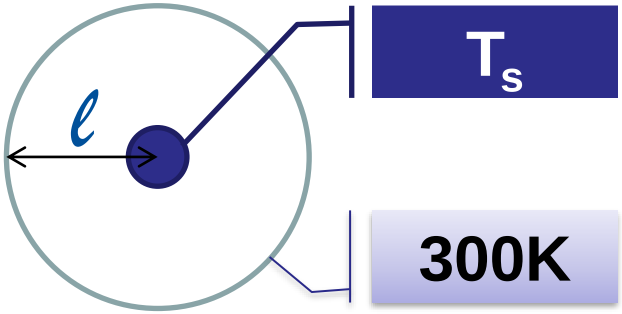
$$S_i + S_{bk} + S_{jle} = S_n + S_{cat} + S_{sec} + S_{cd}$$

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

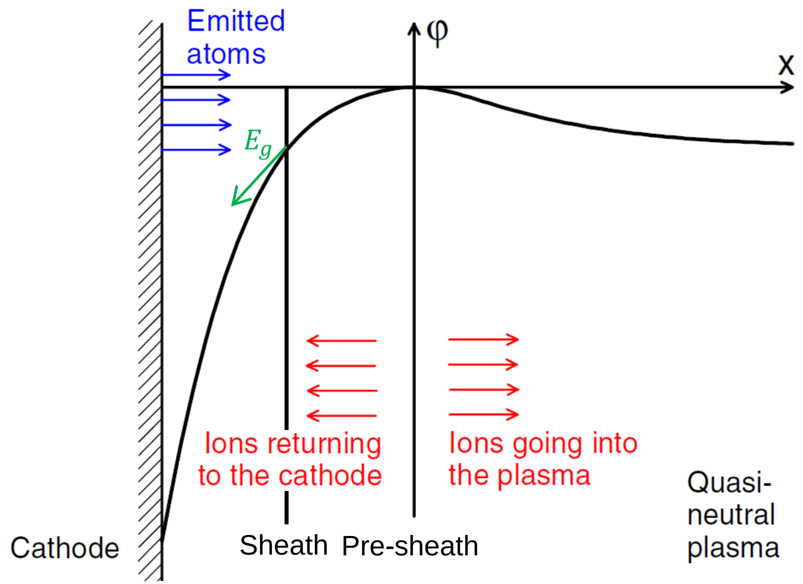
$$\nabla\varphi = -\frac{dE}{dx} = -\frac{e}{\varepsilon_0}(Zn_i - n_e)$$

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

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

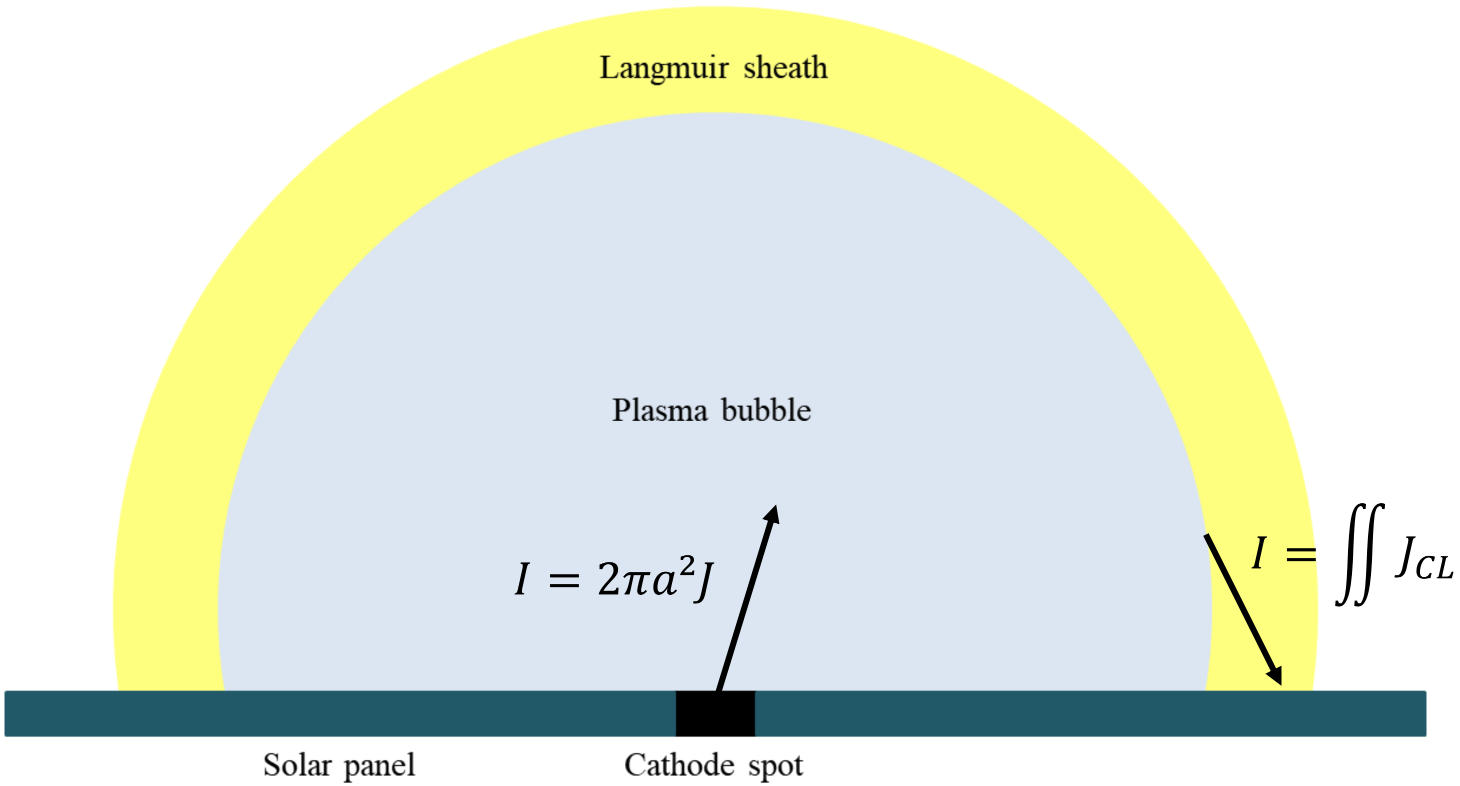
$$\varphi(0) = 0 \qquad E(0) = E_s$$

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



Benilov - Space-charge sheath with ions accelerated into the plasma

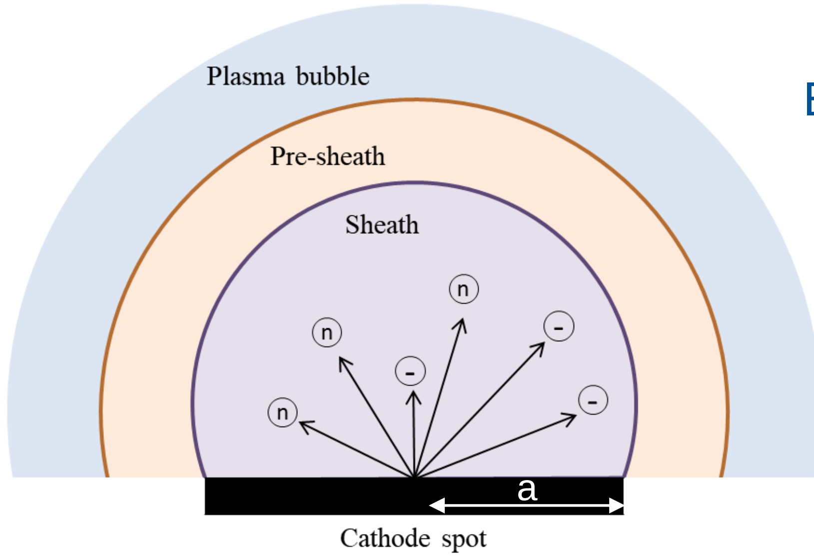
Child-Langmuir law



Spot characteristic time << expansion time step → Instantaneous current conservation

Current conservation

I

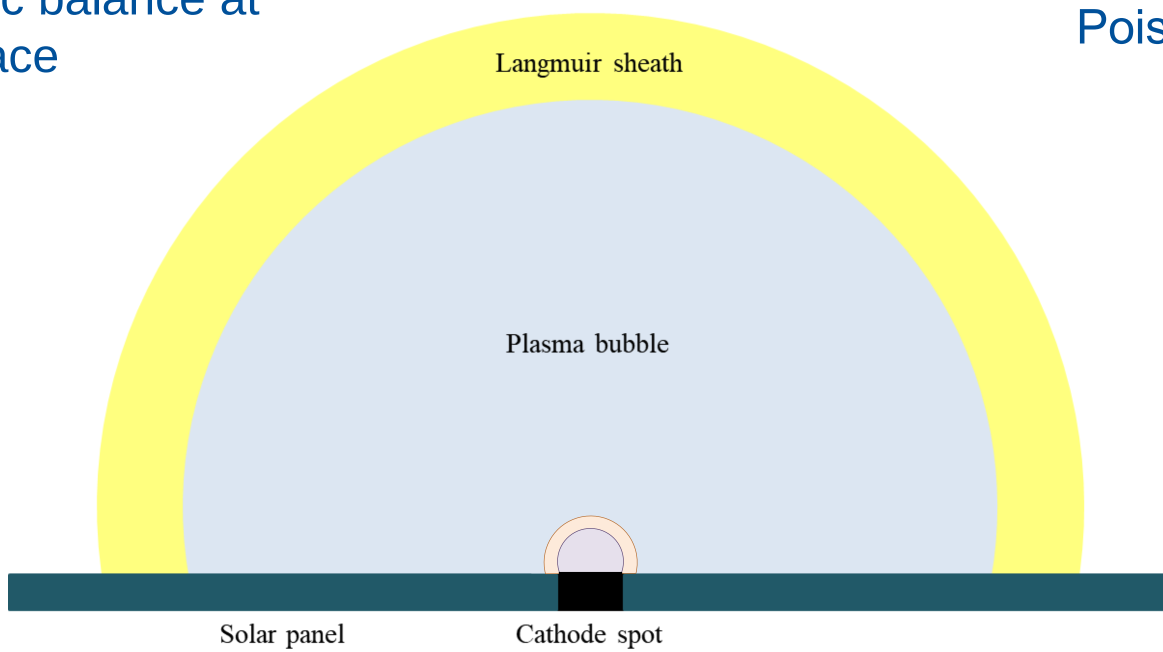


Energetic balance in the pre-sheath

T_e

Energetic balance at the surface

T_s



Poisson's law

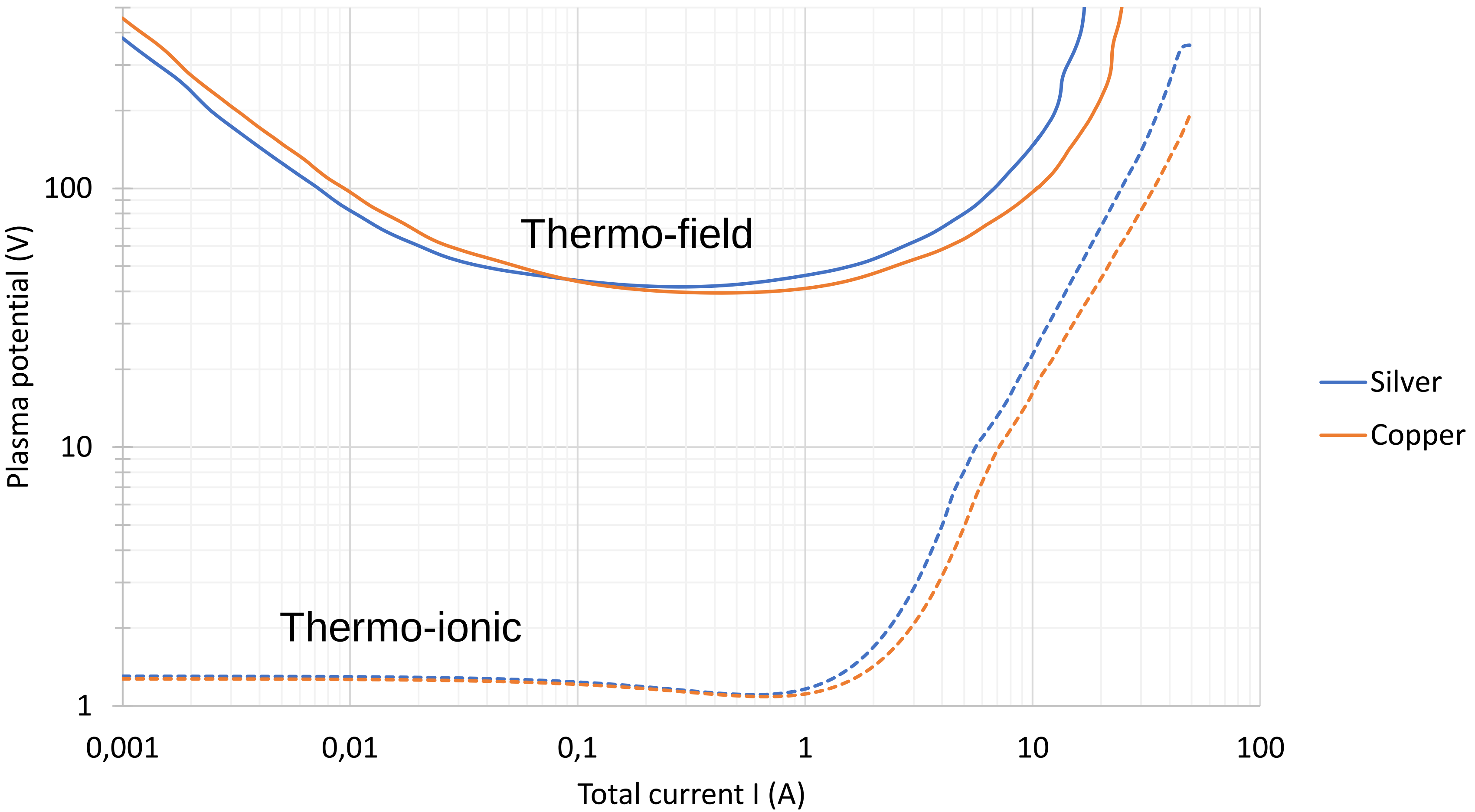
E_s

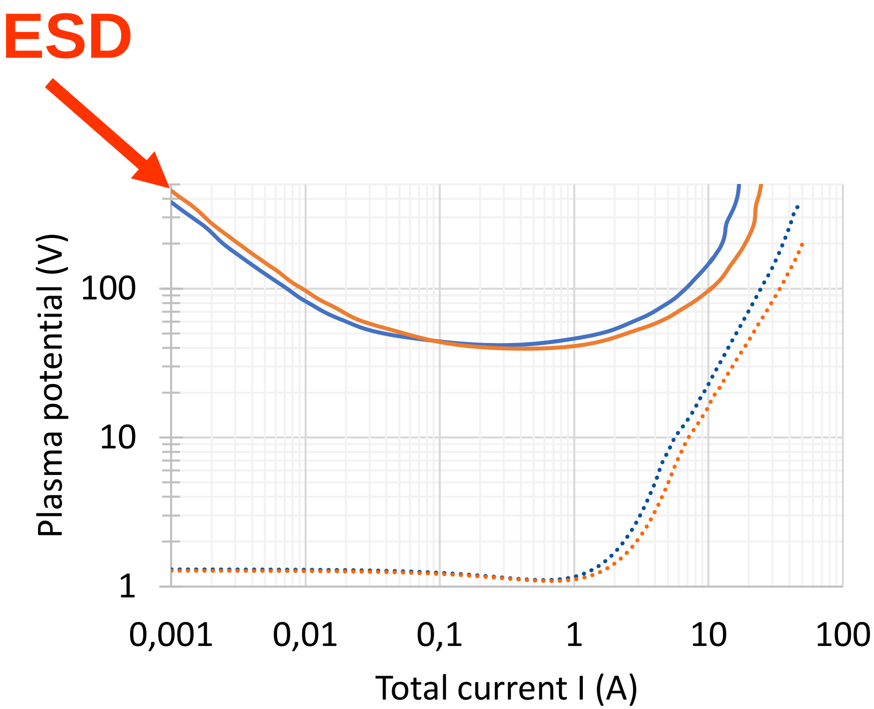
Langmuir current

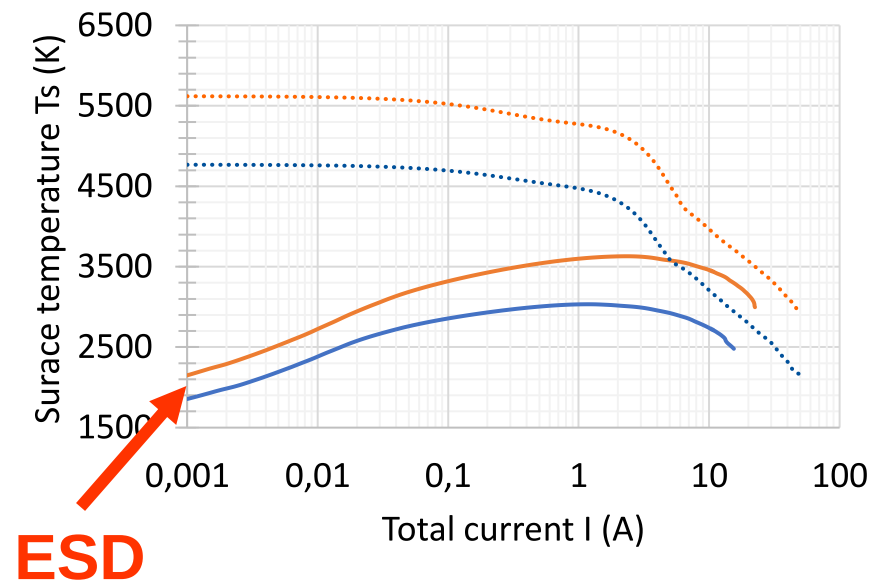
φ_B

Results

Plasma potential

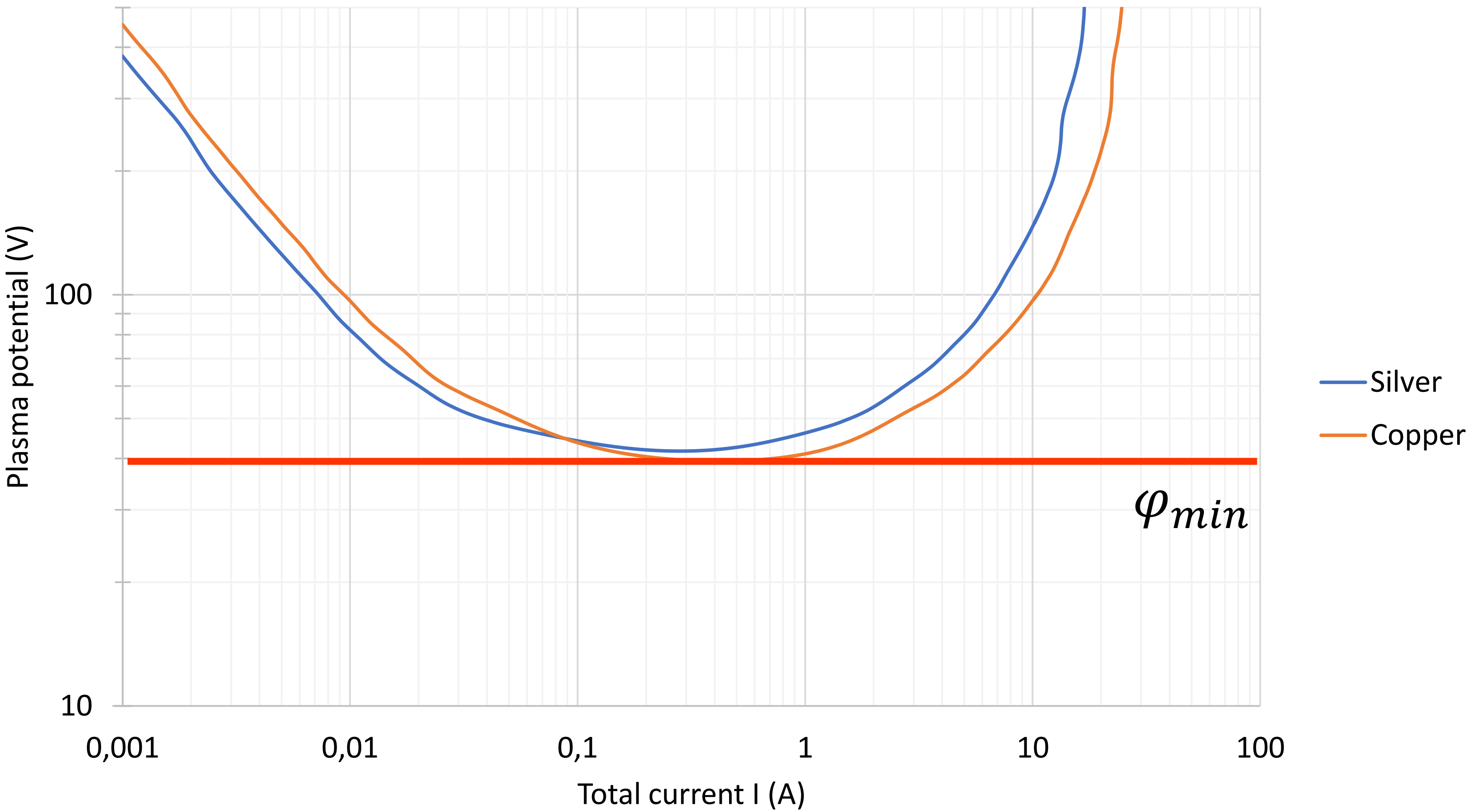




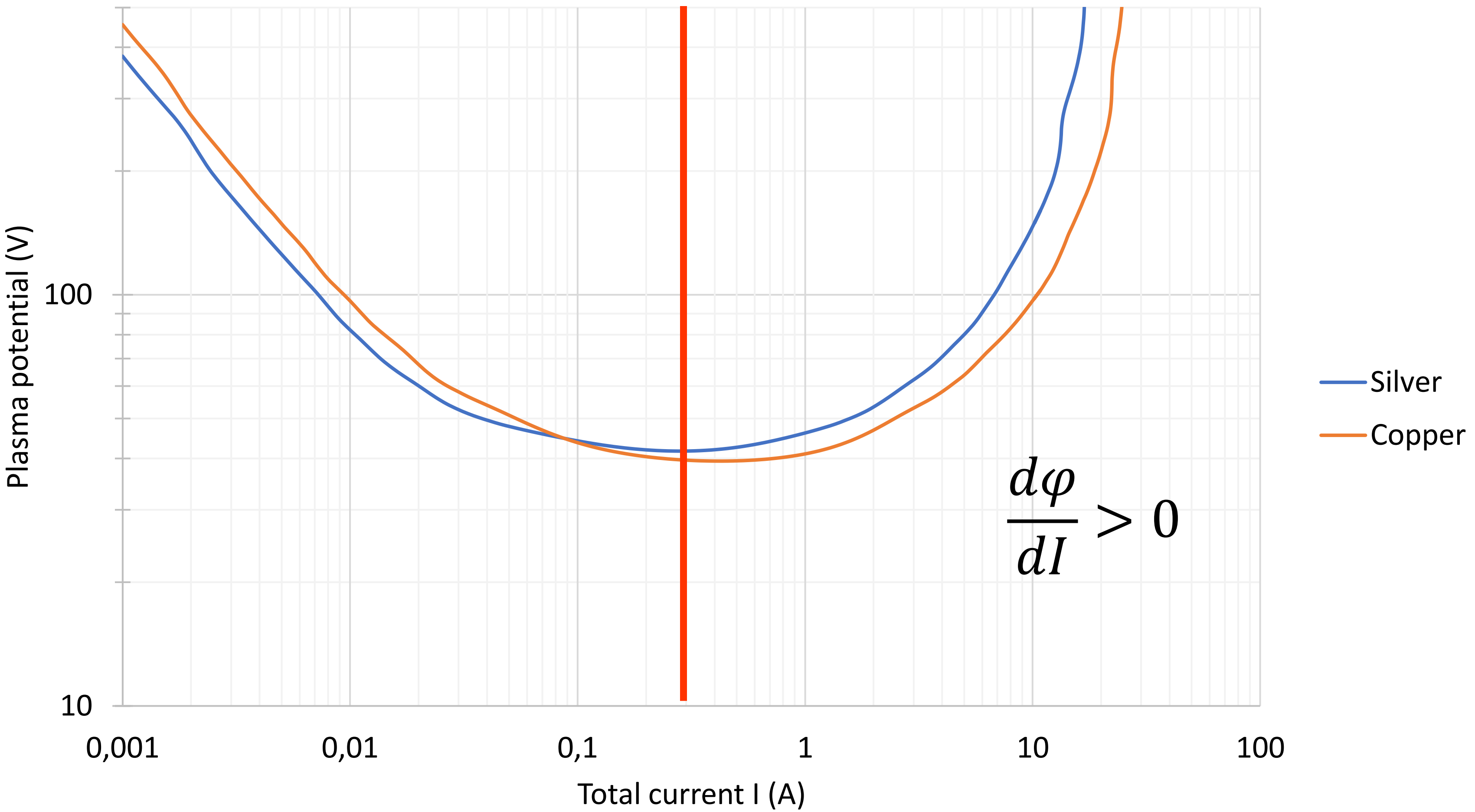


Electric field ≈ 10^9 V/m

Plasma potential

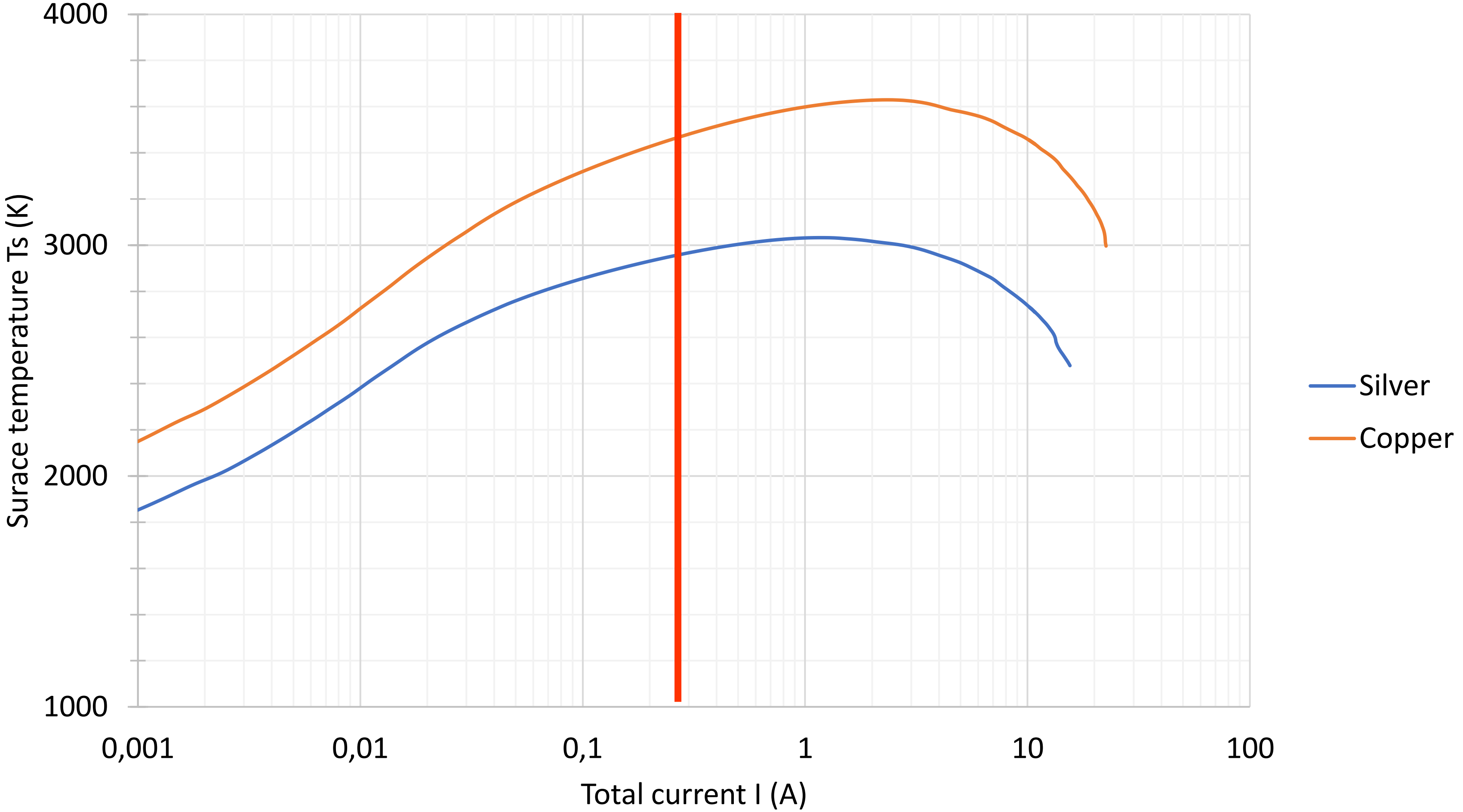


Plasma potential

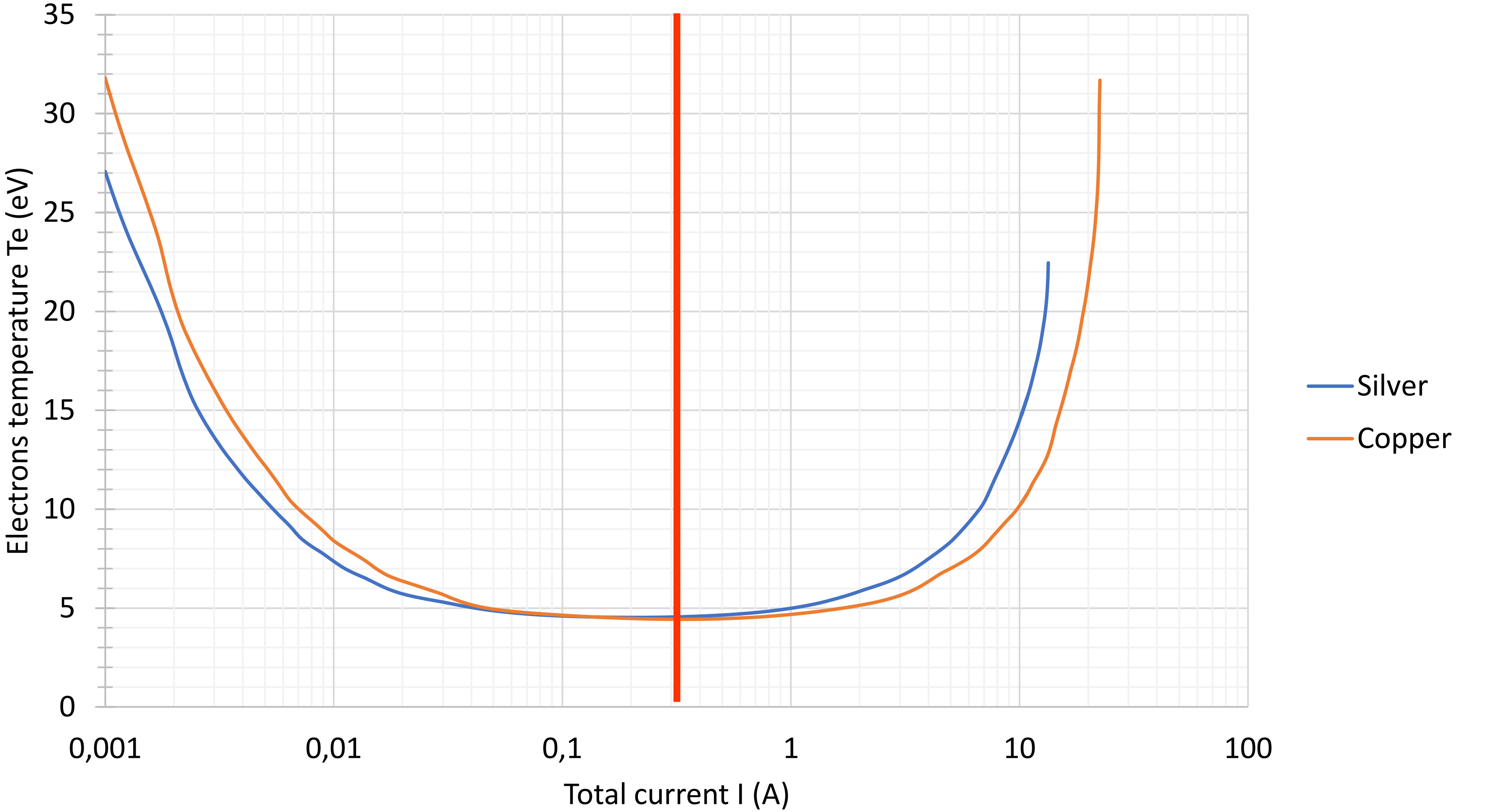


$$\frac{d\varphi}{dI} > 0$$

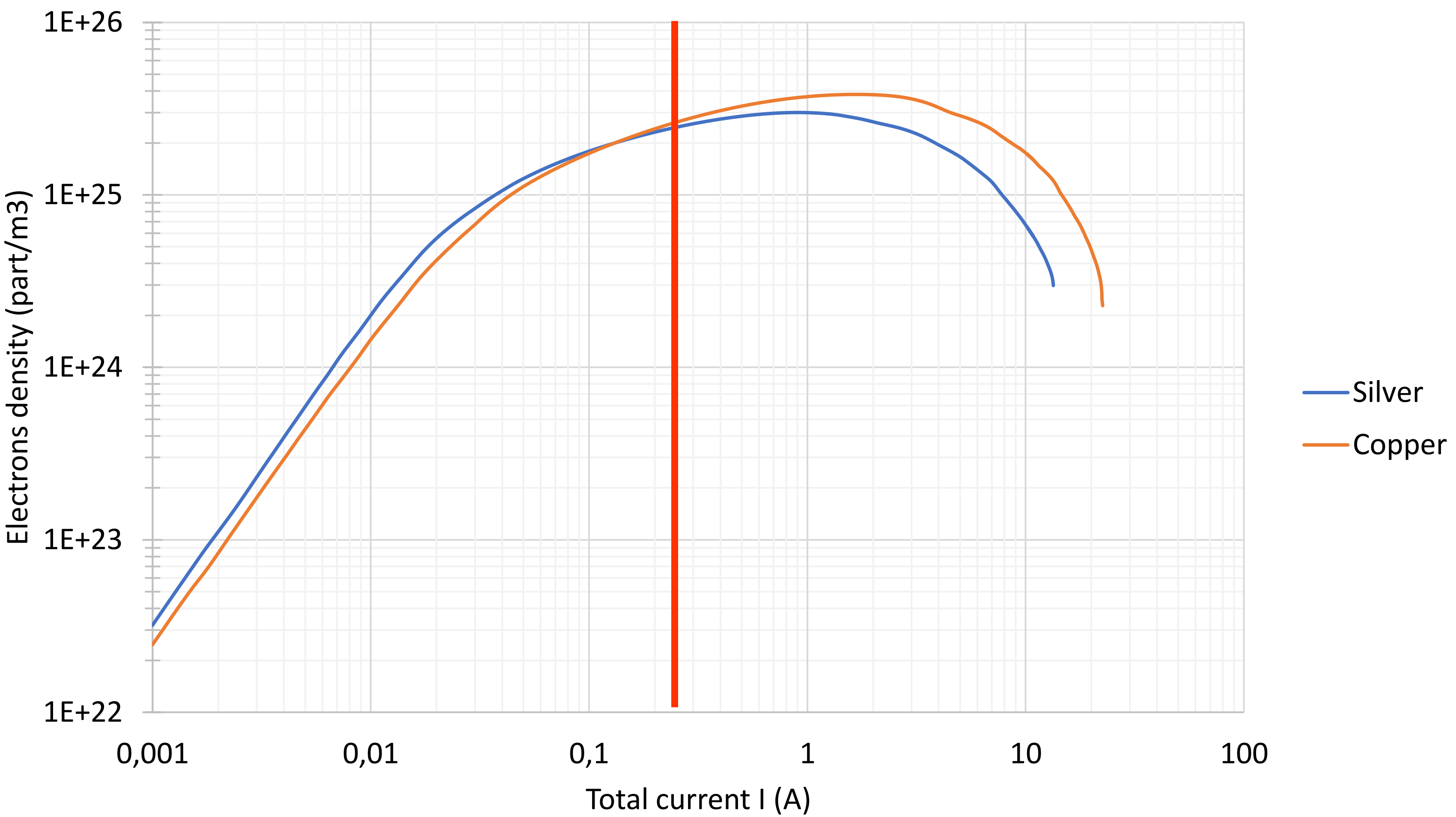
Surface temperature



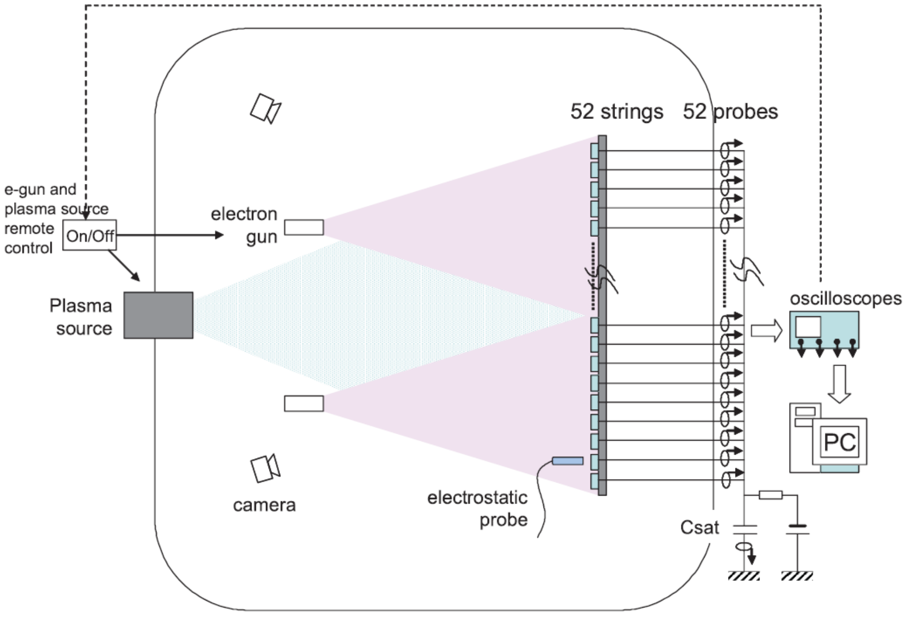
Electrons temperature

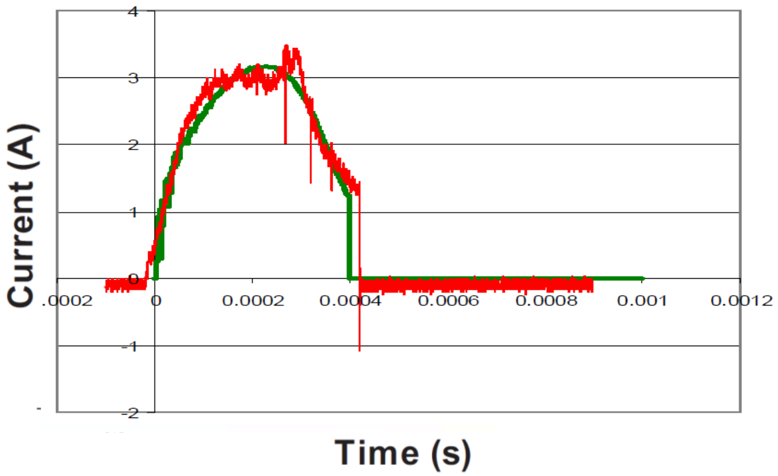


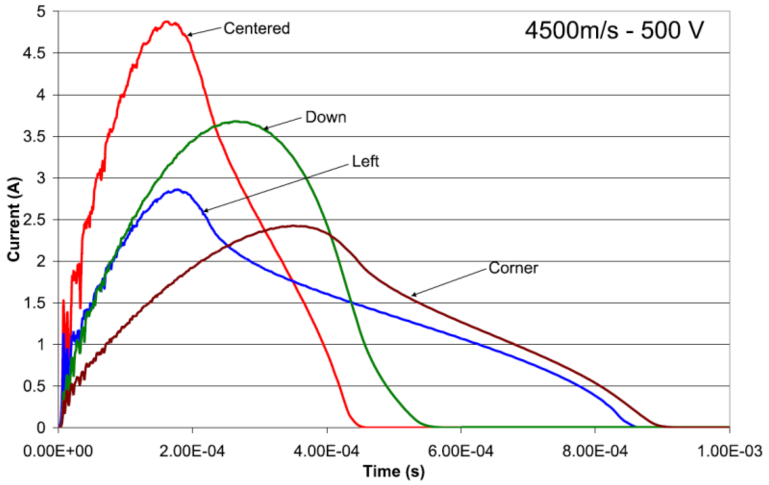
Plasma density



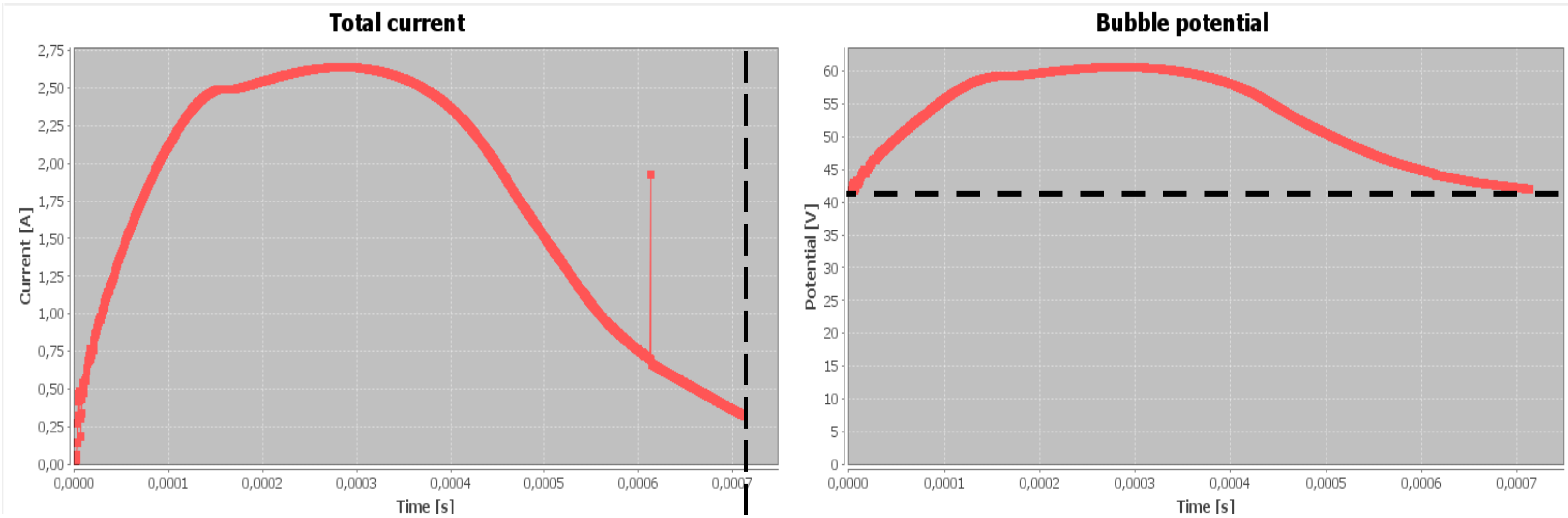
Presentation of EMAGS3 results

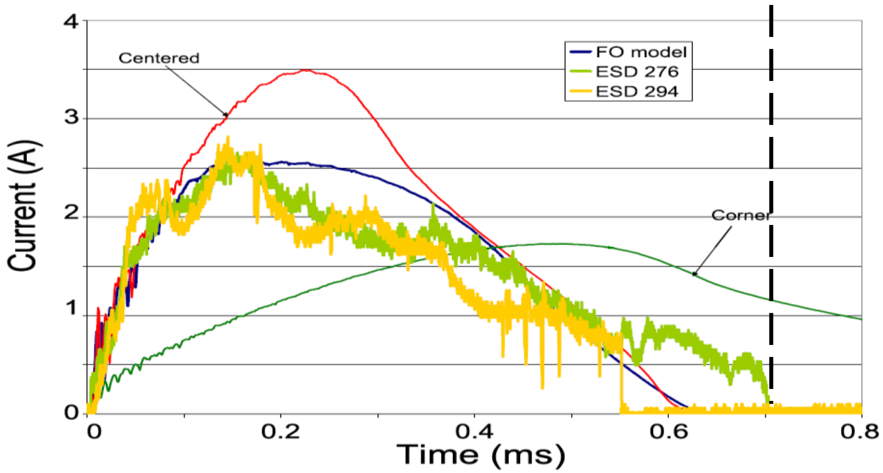






Flash-over propagation and extinction





Simulation stops when

$$\varphi_{Bubble} < \varphi_{min}$$

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
- Good agreement with 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
  - Dynamic effects
  - Secondary arcing

Thank you!