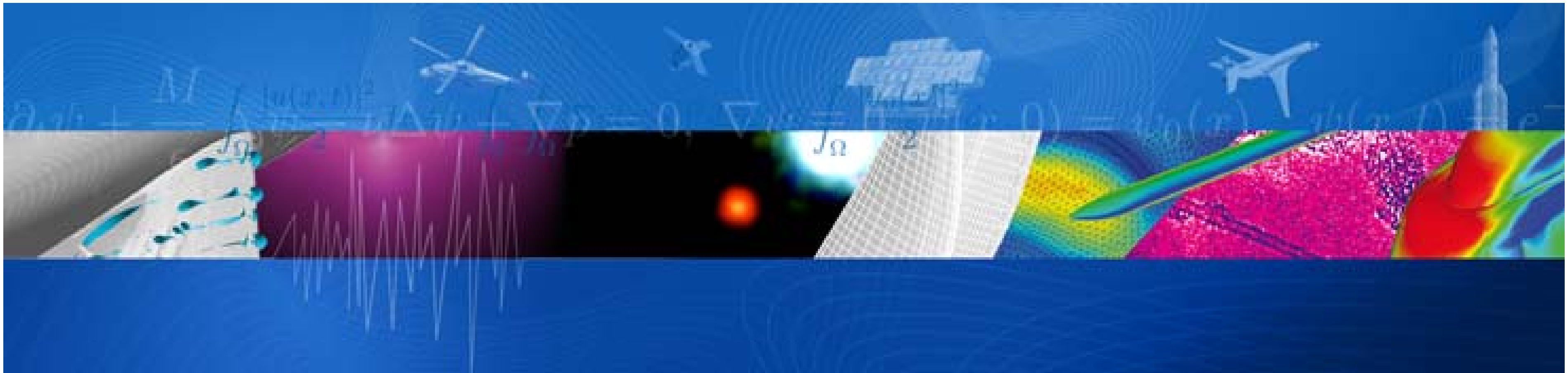

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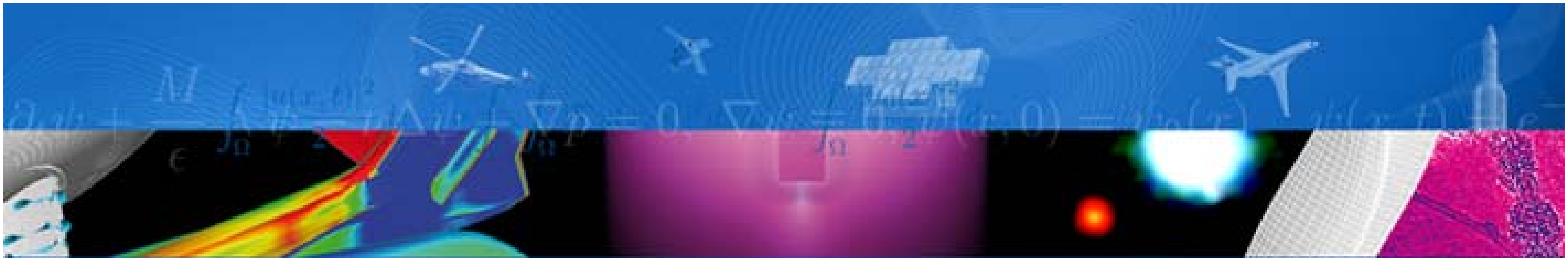

Comparison of numerical and experimental investigations on the ESD onset in the Inverted Potential Gradient situation in GEO

11th Spacecraft Charging Technology Conference, Albuquerque, NM, September 20-24, 2010

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Outline

- General overview on the ESD risk
- Experimental setup
- SPIS ESD tool
- Parametric study: comparison experimental/numerical results

General overview on the ESD risk

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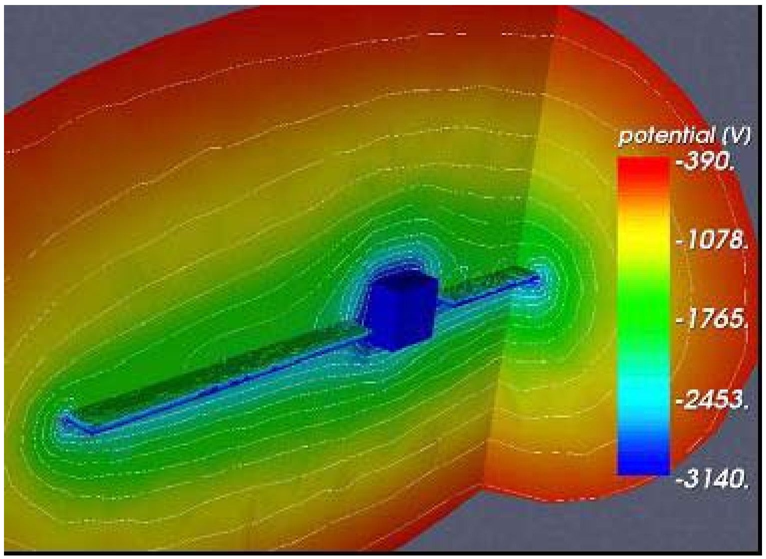
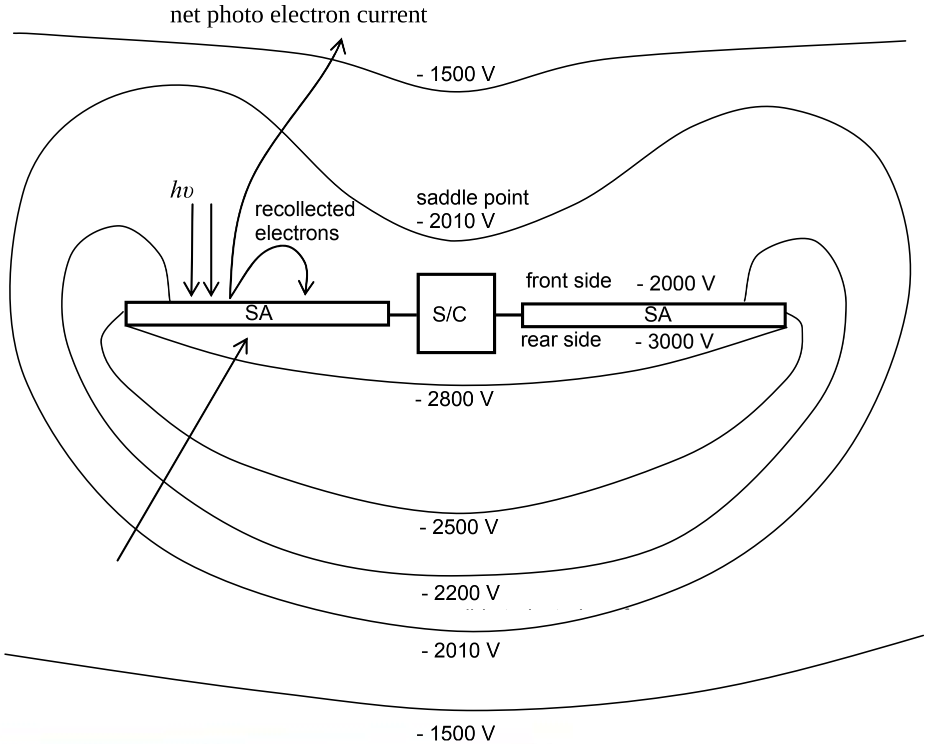
Spacecraft Charging at GEO in sunlight

- S/C structure at a negative potential several kV due to electron collection
- Photoemission on solar cell cover glass:
  - Dielectrics in sunlight more positive than S/C structure
  - Barrier of potential on the front side due to rear side negative potential
- This situation is the Inverted Potential Gradient (IPG)





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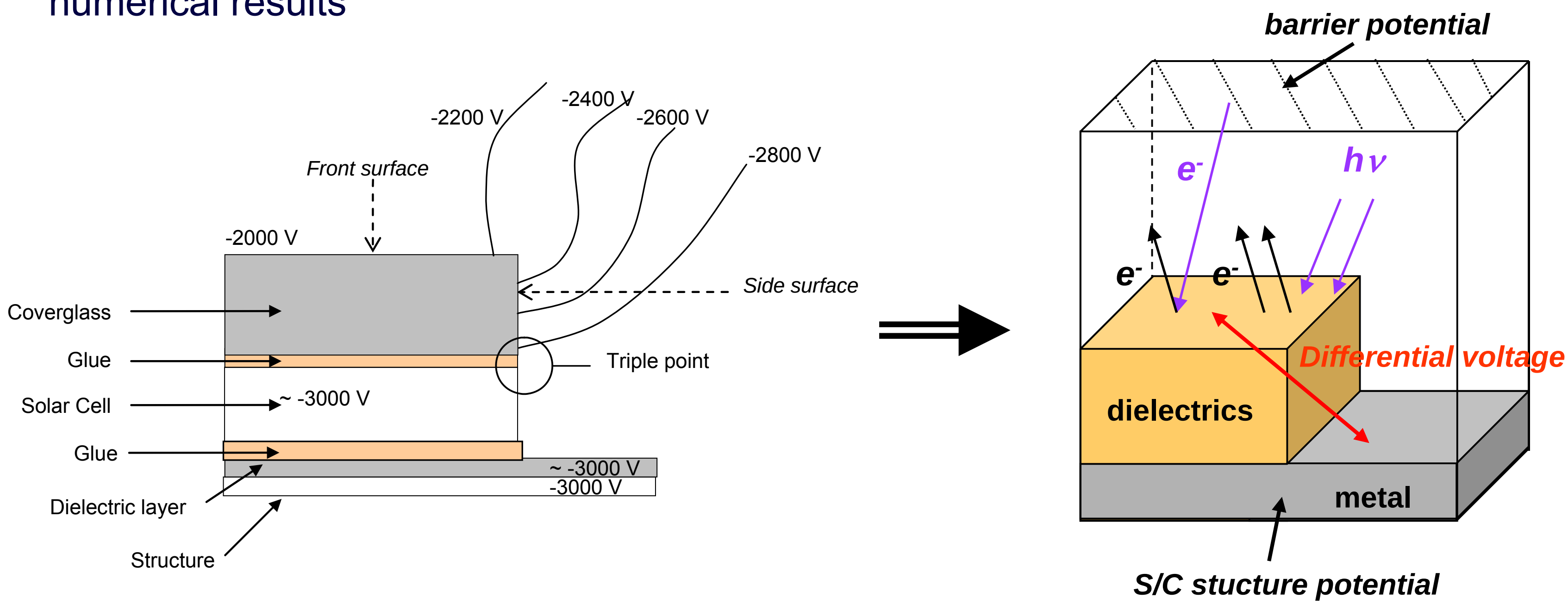
IPG situation at the solar cell scale

- At the solar cell edge:
  - Gap surface covered with (photoconductive) kapton = S/C structure voltage
  - Solar cell voltage ~ S/C structure voltage (strings voltage ~100 V)
  - Cover Glass top surface is more positive than solar cell = differential voltage
- Triple point between conductor, dielectric and vacuum

- Uses of a simplified geometry (valid for interconnects) to compare experimental and numerical results



Microscopic structure and electron avalanche

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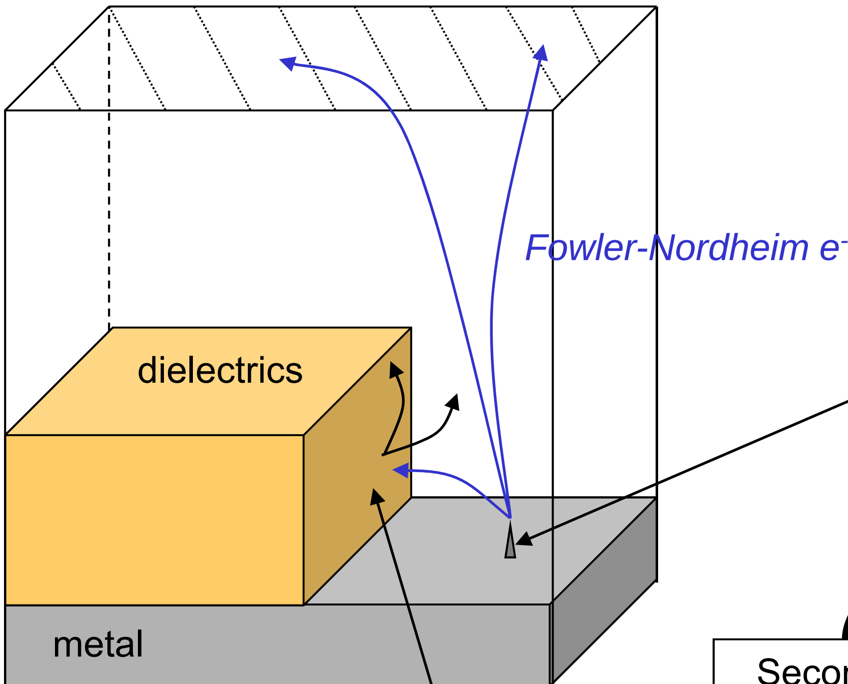
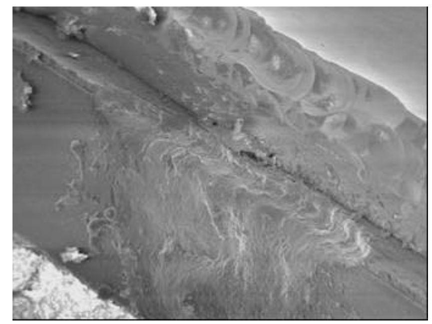
Simulation at mesoscopic scale



Secondary emission by electron impact + recollection

Microscopic scale model



β electric field amplification due to micron tip

Differential potential

Electric field on the tip

Fowler-Nordheim electron emission

Secondary emission > 1

Electron avalanche
+
Cathode spot creation

=> ESD

Tip geometry and field enhancement factor

- Field enhancement factor from 300 to 800
- Tip length: 1 μm
- Tip radius (from emitting area): 1 - 10 nm

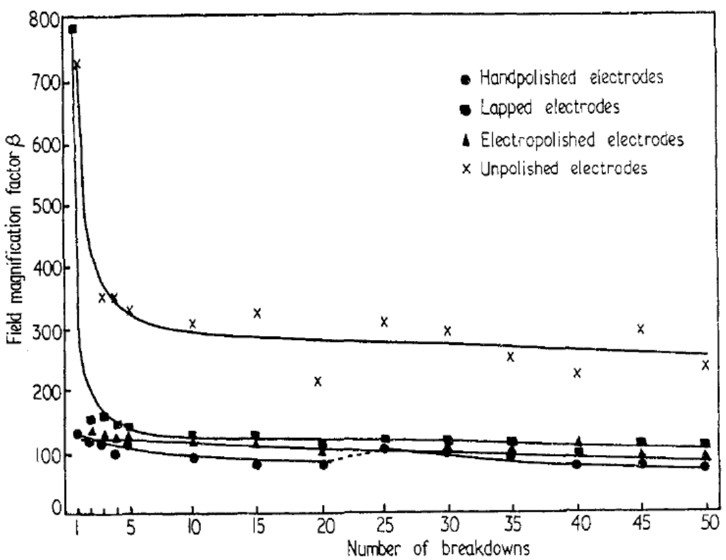


Figure 5. Variation of field magnification factor with number of breakdowns for different sets of electrodes.

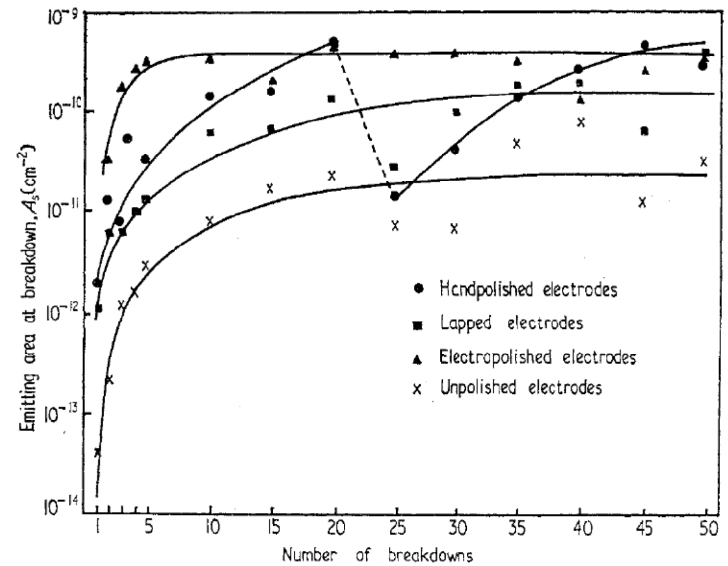
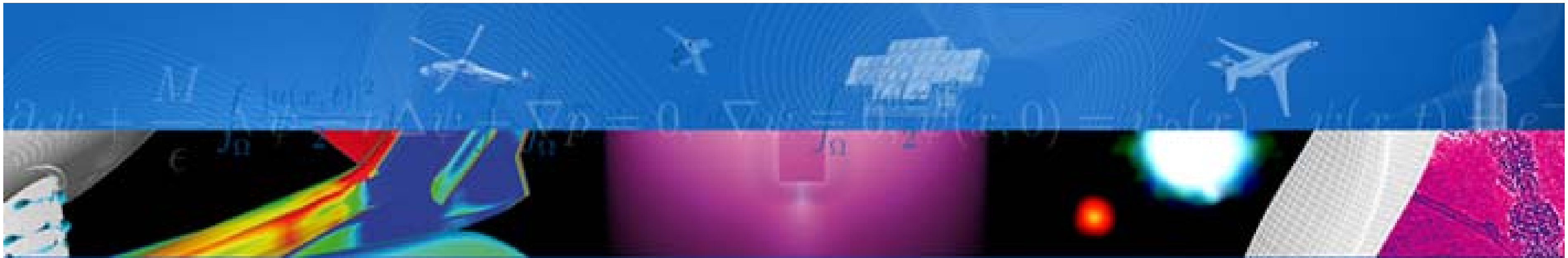


Figure 8. Variation of emitting area at breakdown with number of breakdowns for different sets of electrodes.

- Figure 5 and figure 8 extracted from:

Effect of electrode surface finish on electrical breakdown in vacuum, D W Williams and W T Williams, J. Phys. D: Appl. Phys. (5), 1972.



Experimental setup

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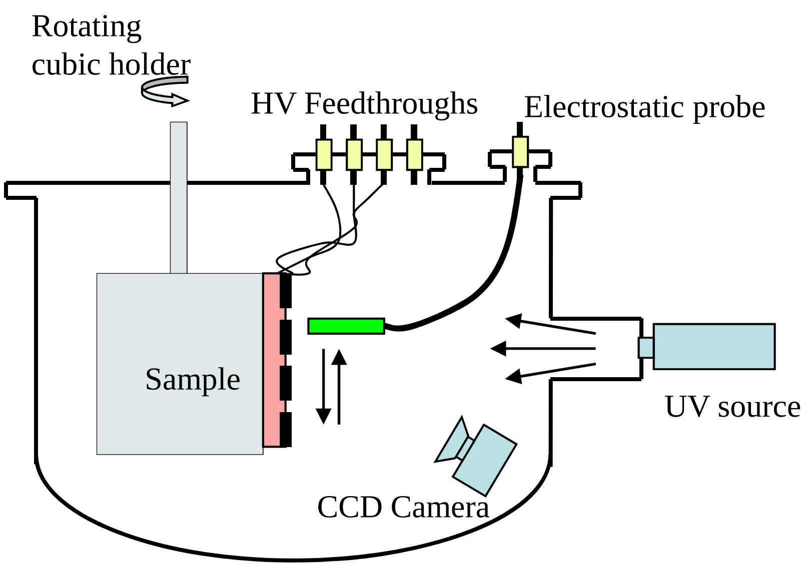
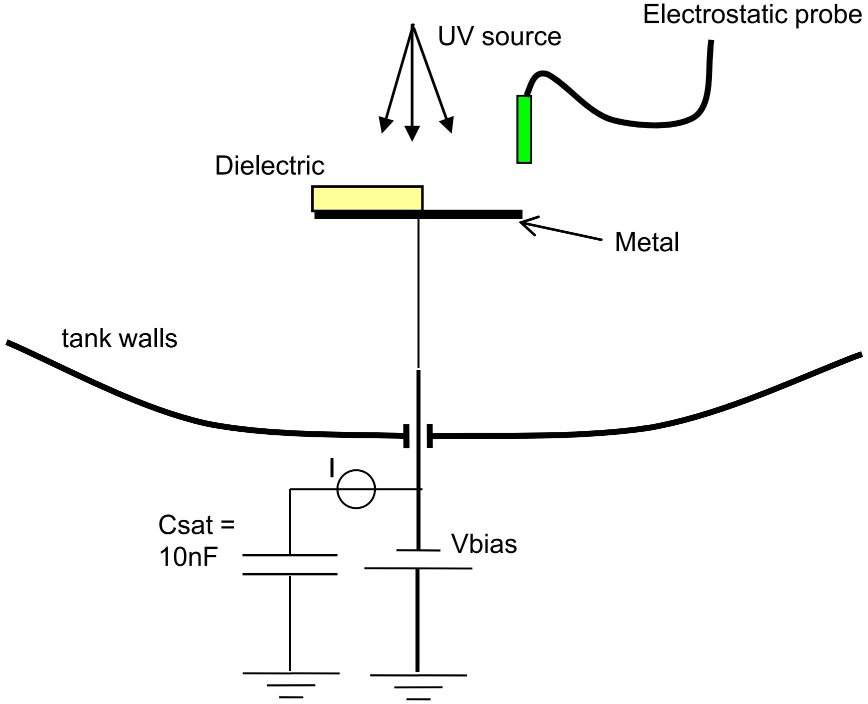
Experimental Setup

- ONERA CEDRE vacuum chamber
  - Pressure: 3.10^{-6}mbar
  - Barrier potential controlled by V_{bias}
  - Differential voltage by photoemission (as in flight)

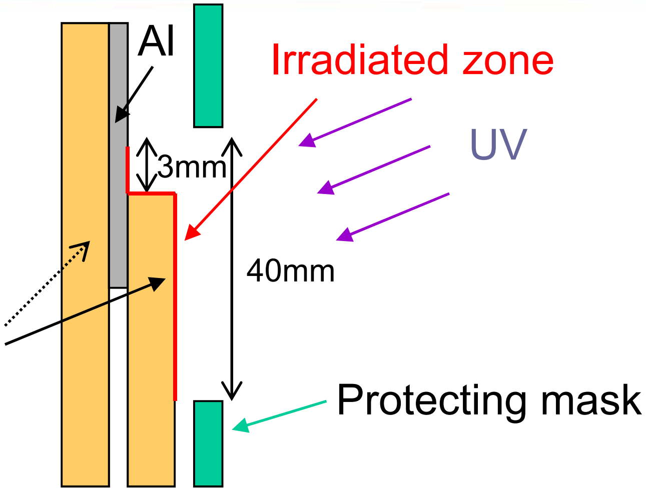


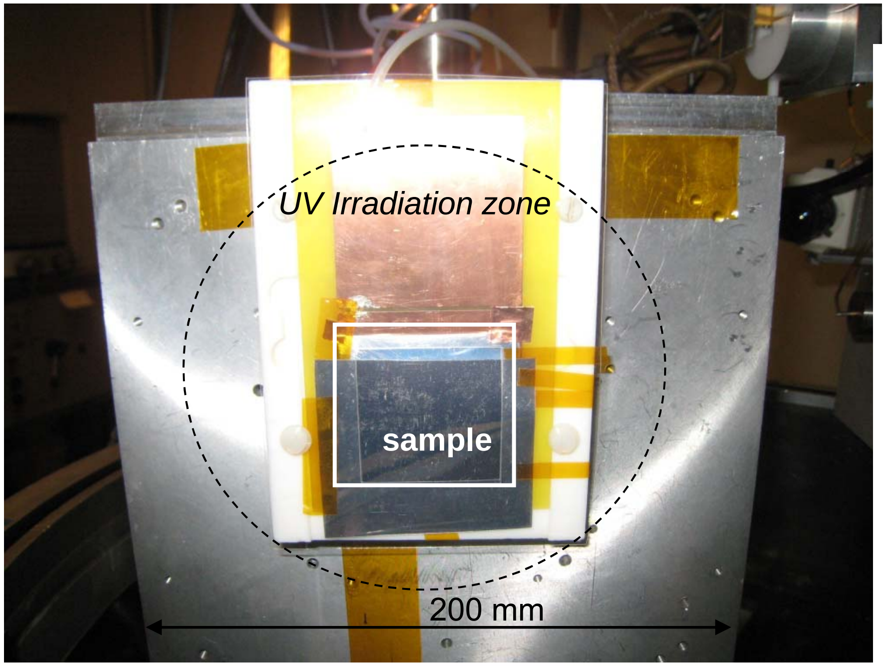
CEDRE chamber

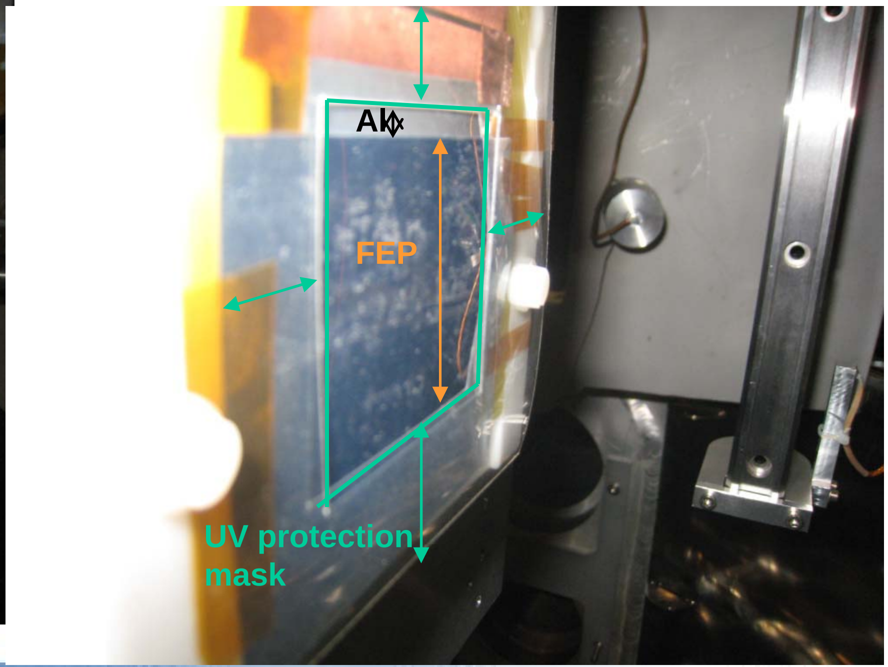


Nominal case – Perpendicular TP with Aluminum and Teflon

- The triple point is irradiated by the UV source
- Only the chosen triple point line can generate ESDs thanks to a protecting mask

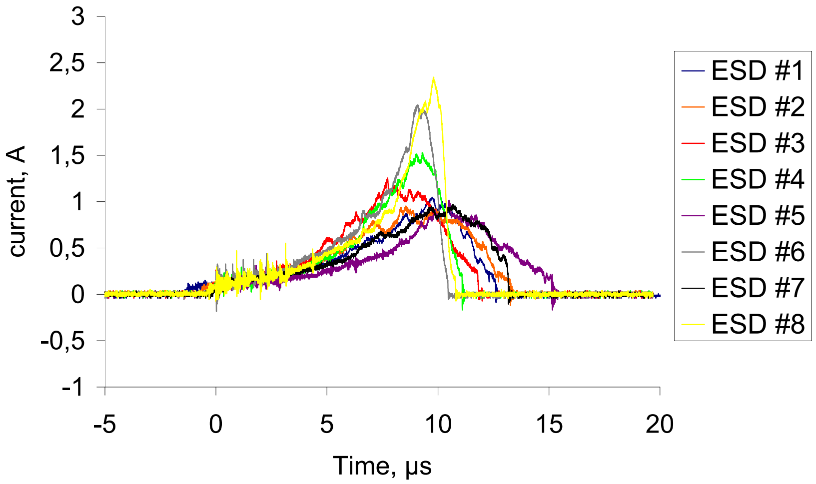


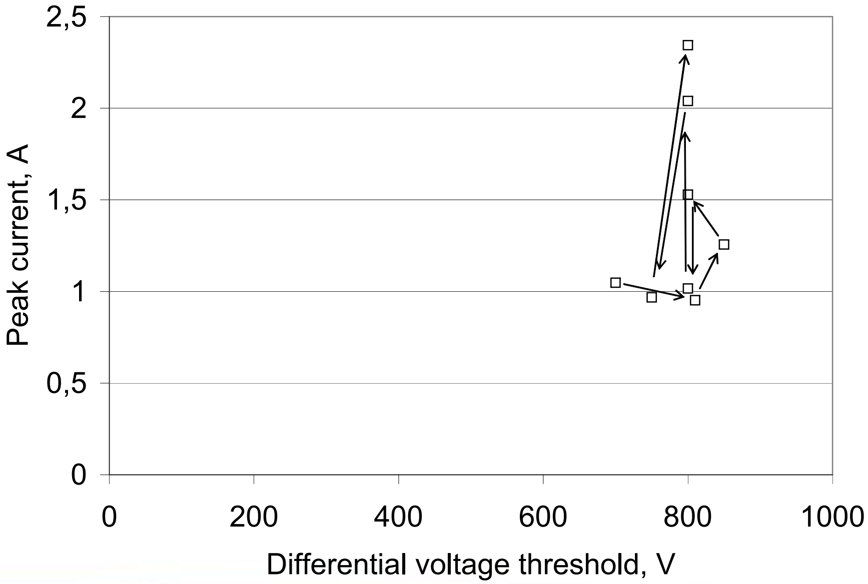




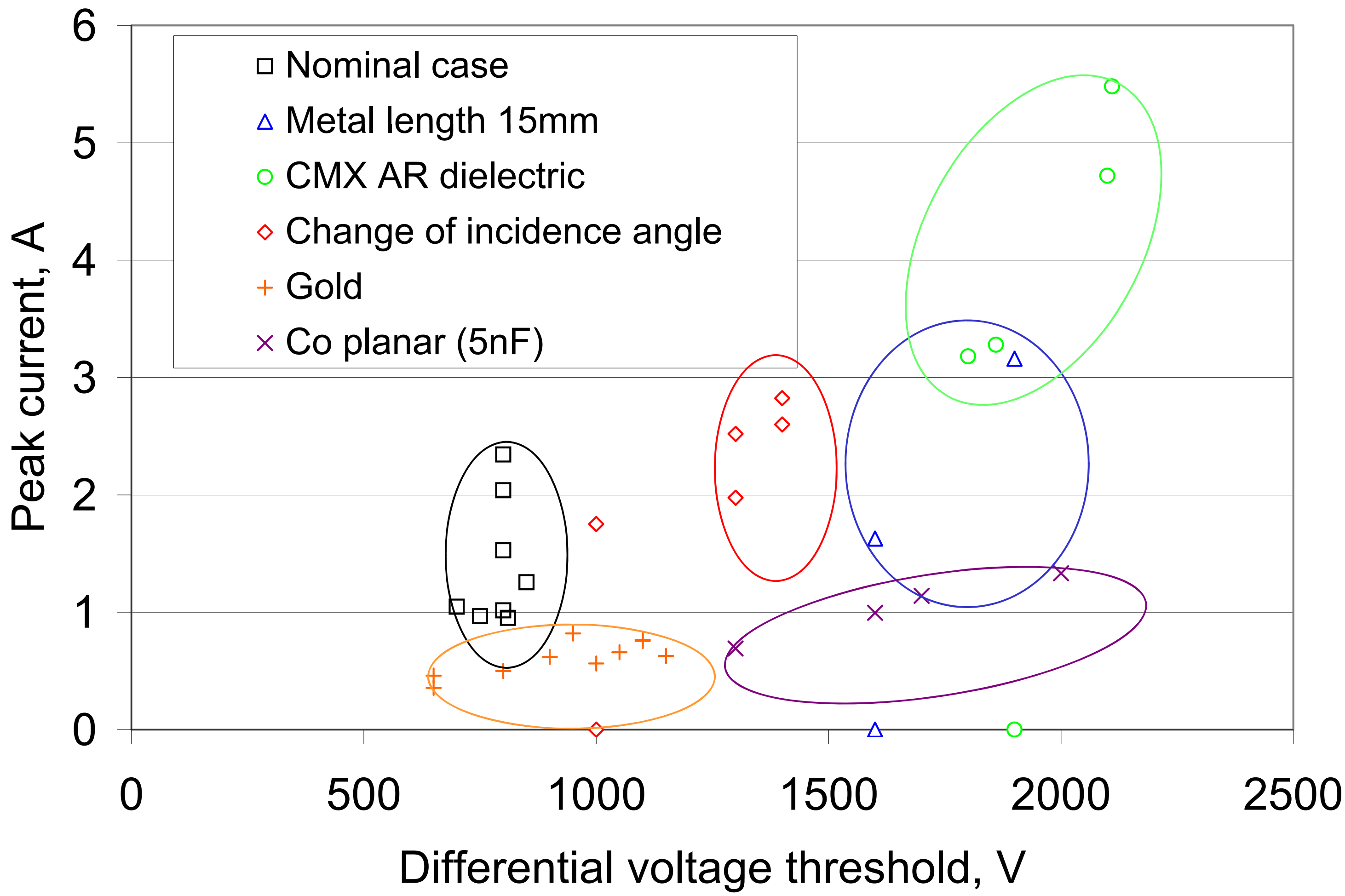
Nominal case – Perpendicular TP with Aluminum and Teflon

- The voltage on the FEP is close to 0V
- 8 ESDs have been obtained at different locations of the triple point edge
- The ESD threshold is about -800V





Results of the parametric study



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SPIS ESD tool

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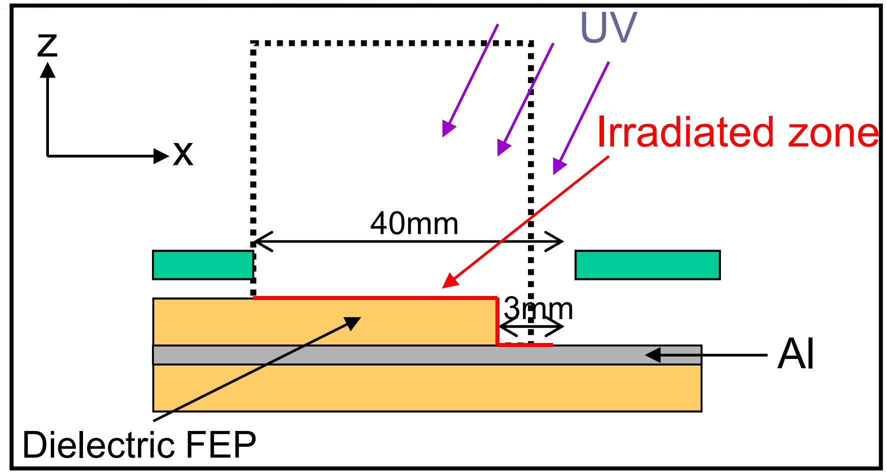
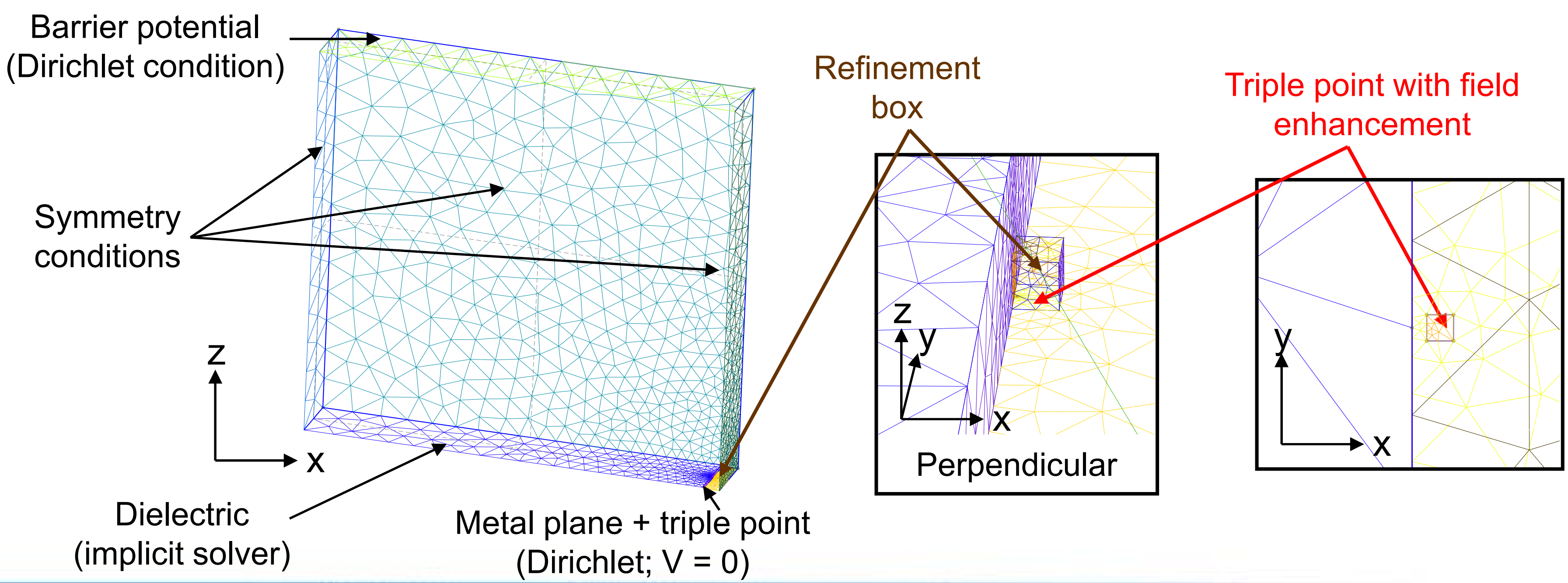
The mock-up geometry and the boundary conditions

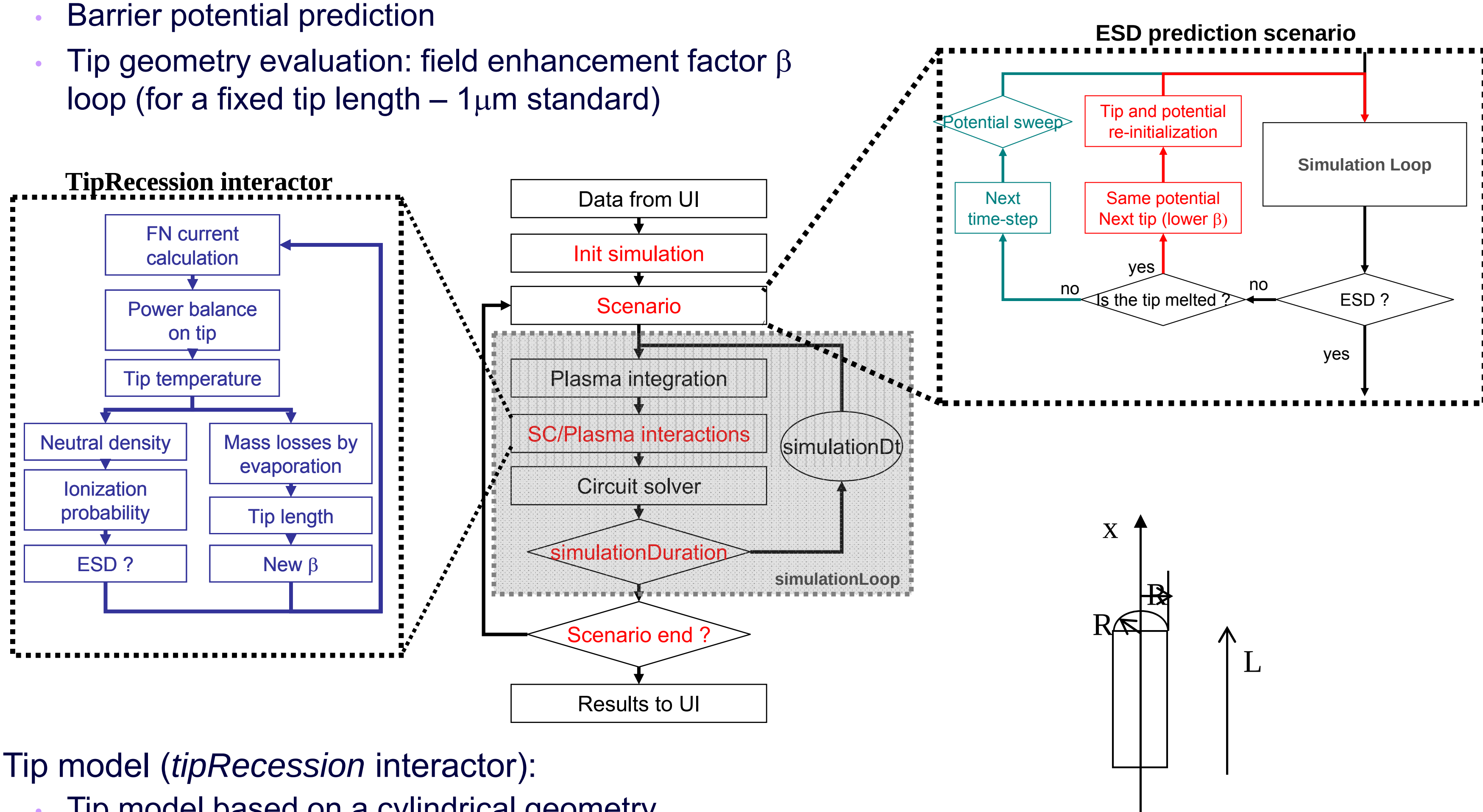
- Simulation conditions:
  - Teflon (127 µm) / aluminum (1.5 mm)
  - External box : 4 cm x 4 cm x 0.6 cm
  - TP zone : 1 µm
  - tip length = 1 µm
  - Barrier potential from 500 V to 2000V
  - β from 800 to 300;





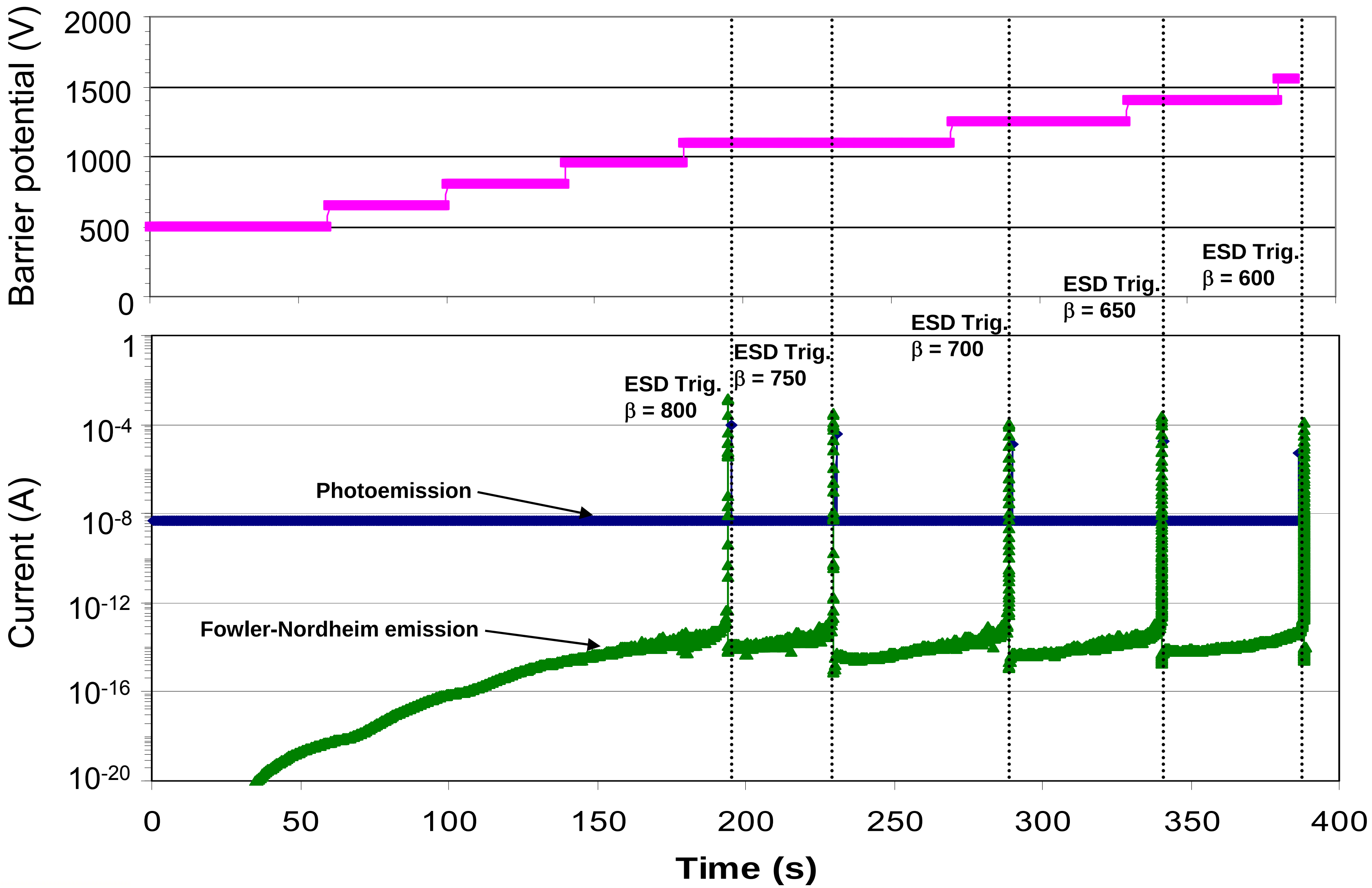
SPIS ESD tool

- ESD prediction scenario, two imbricate loops:
  - Barrier potential prediction
  - Tip geometry evaluation: field enhancement factor β loop (for a fixed tip length – 1μm standard)

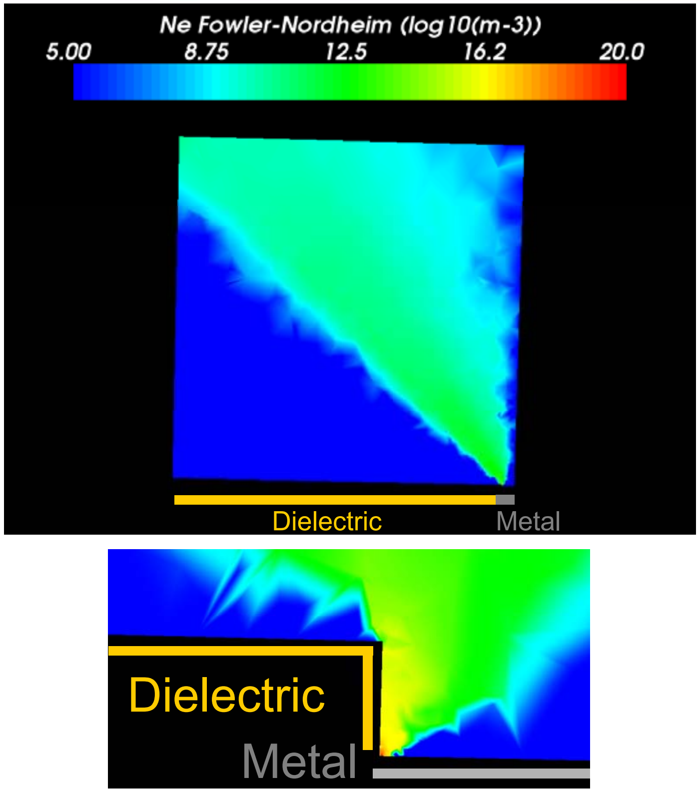


- Tip model (*tipRecession* interactor):
  - Tip model based on a cylindrical geometry
  - Zero dimensional thermal model (compared to Rossetti ….)

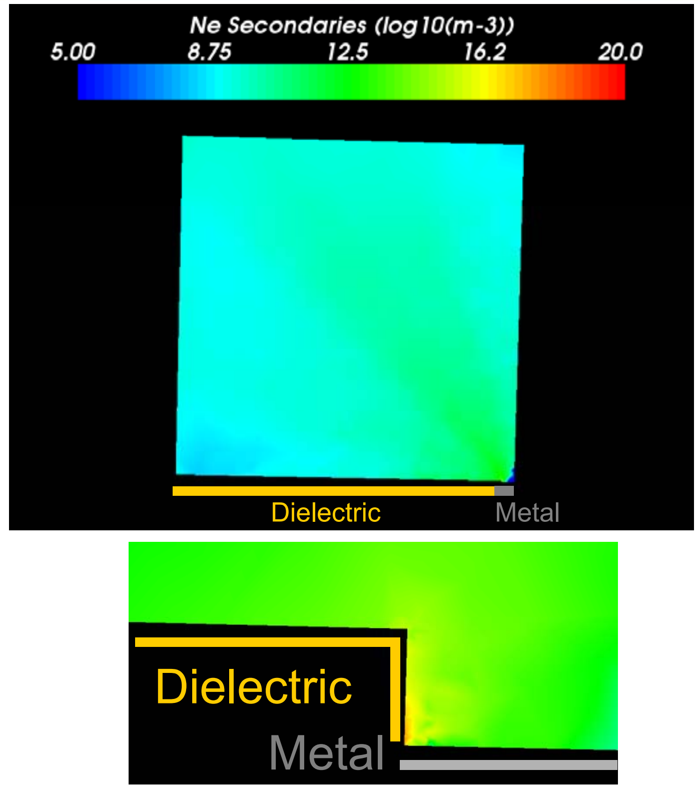
Barrier potential and emitted currents



Electron emission : densities in volume



Fowler-Nordheim electrons density



Secondary electrons density

- F-N primary electrons:
  - directed toward the barrier potential
  - Max density can reach 10^{20} m^{-3} (Space charge effect)
- Secondary electrons are present on the top side of the dielectric due to hoping

Parametric study: comparison of the numerical and experimental results

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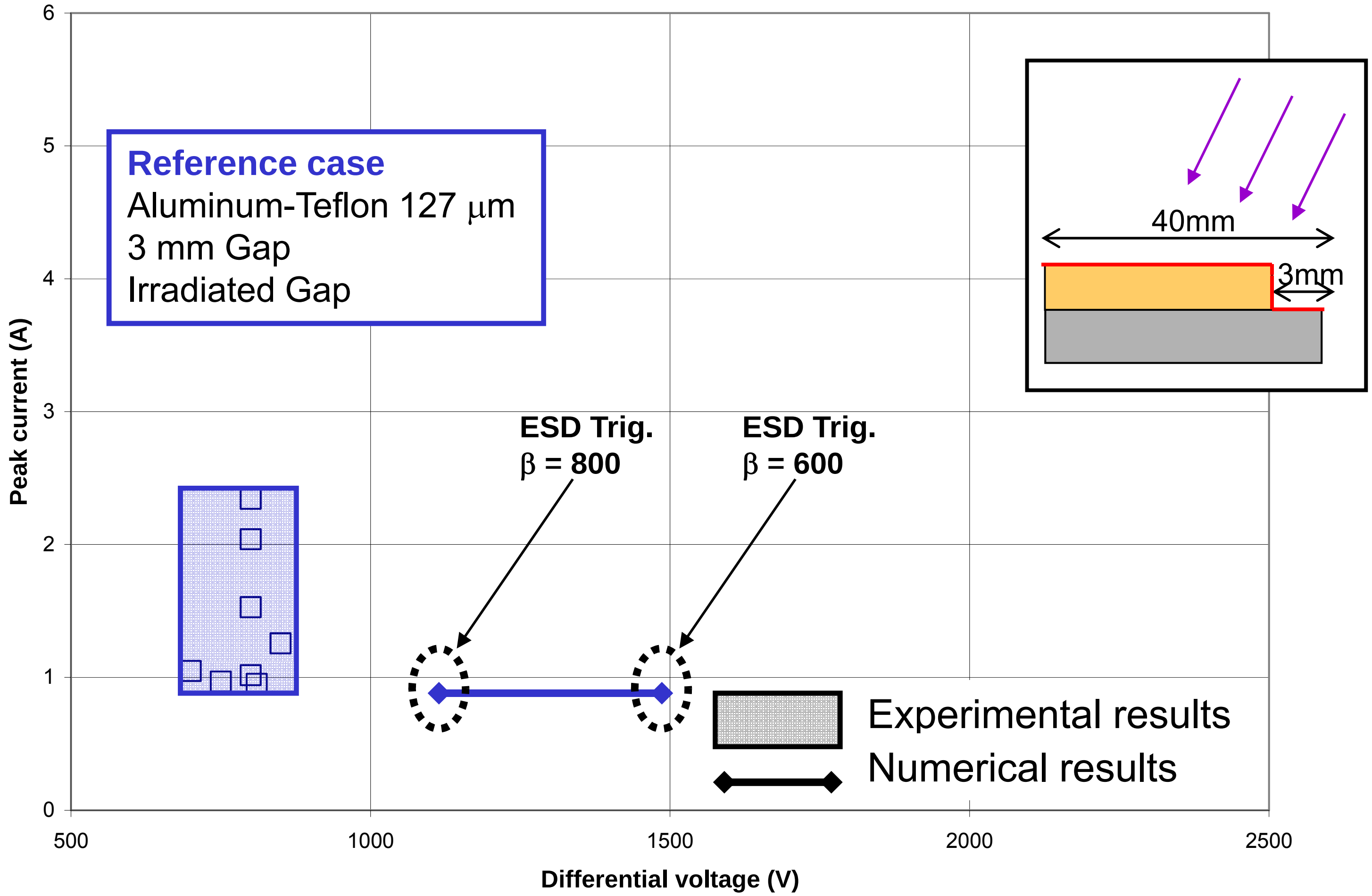
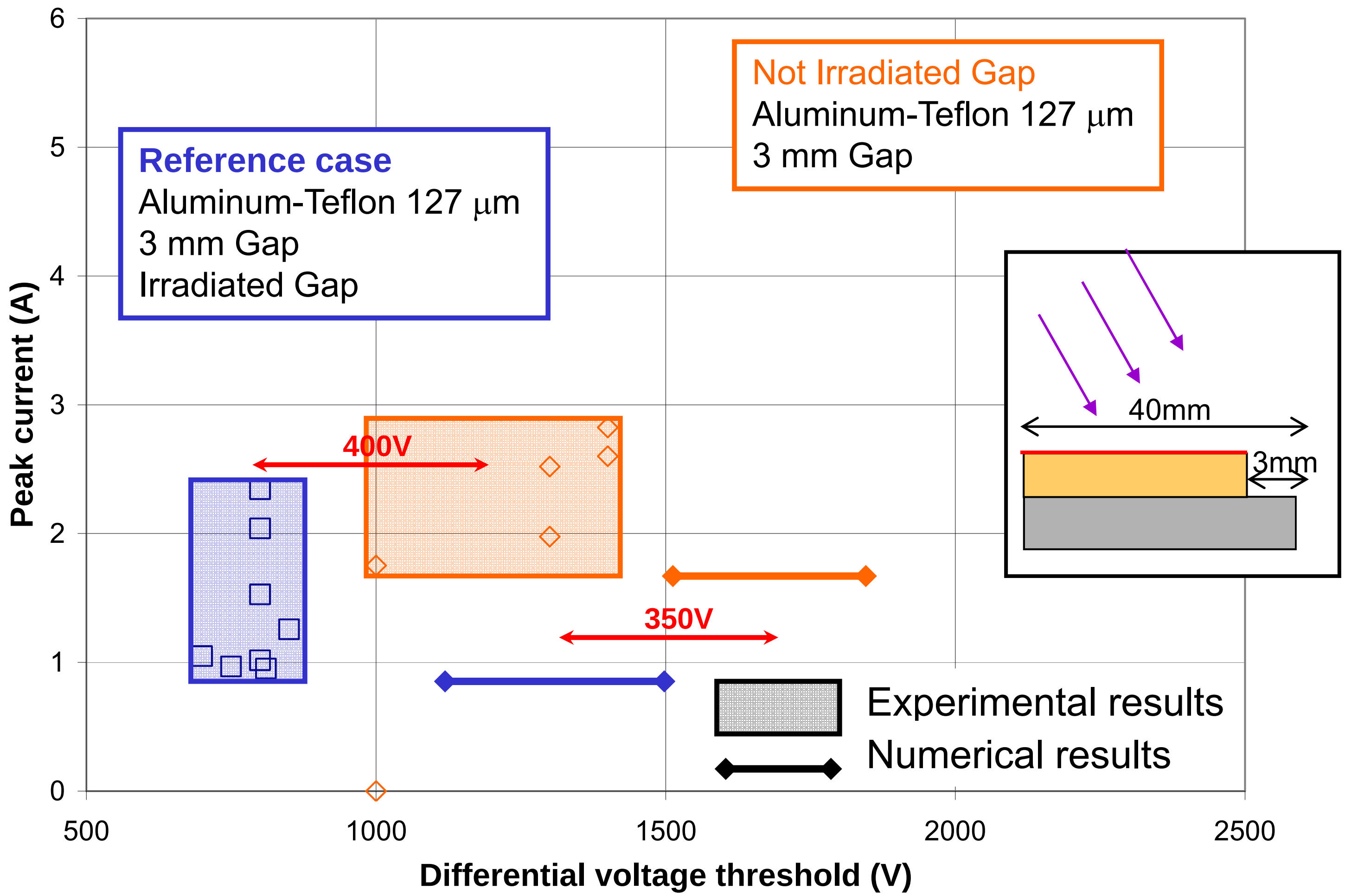
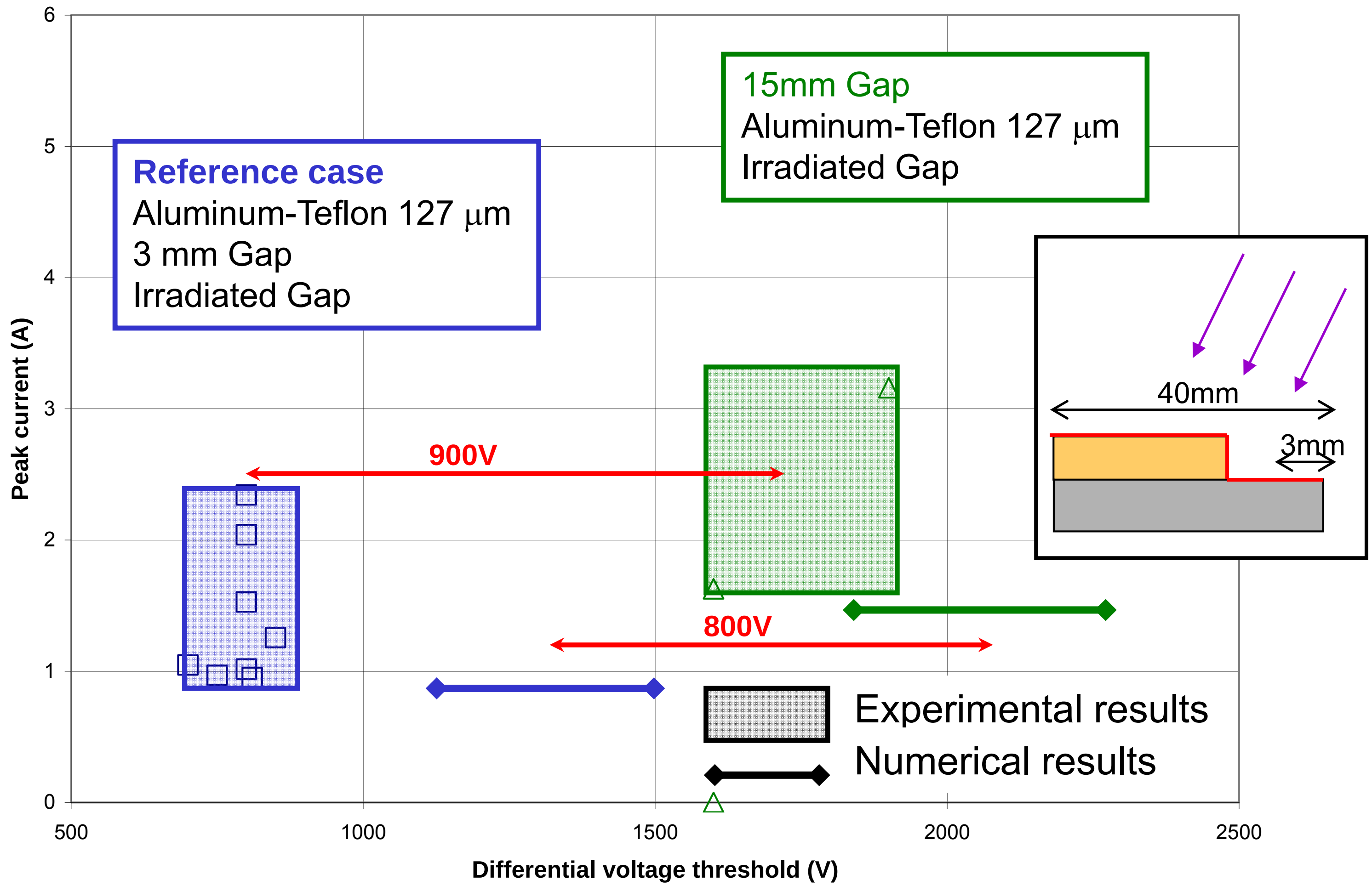
Parametric study – reference case



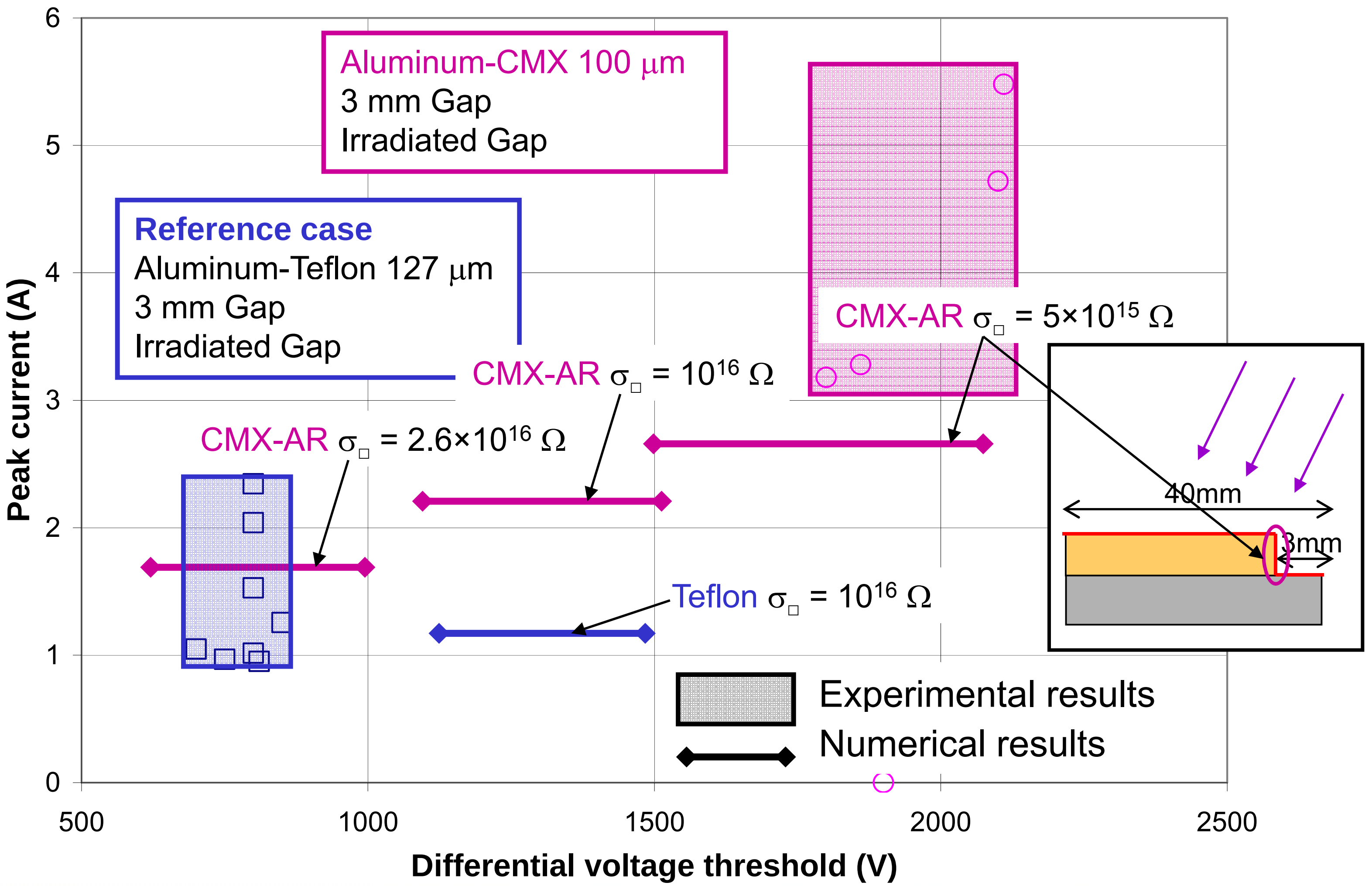
Parametric study – Sun incidence angle



Parametric study – Gap length



Parametric study – Dielectric material



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Lessons to be taken from the experiments and numerical simulations

- The numerical results qualitatively agree with the experiments
  - It is definitely more difficult to trig ESDs in the following cases
    - Low photon incidence angle
    - Longer metallic plate
    - Co-planar geometry
    - More conductive dielectric

- Strong effect of
  - surface resistivity of the front edge
  - Tip geometry (radius and shape)

- Need for complementary experimental data (surface resistivity measurement, surface distribution and type of microscopic structures)

Conclusion

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Conclusion

- Large experimental parametric study
- SPIS ESD tool:
  - Complete ESD scenario:
    - 3D Electron avalanche
    - Thermal model of the tip
    - ESD threshold estimation
  - Simulation of the charging and electron avalanche well described
    - Automatically adapted time steps: from 1s to 10^{-12}s
    - 3 length scales simulated
- Good qualitative agreement between experiments and numerical results
- Need of further experimental data to provide design engineers with quantitative/predictive ESD risk tool

Perspective

- Experimental investigation on surface resistivity to get more data
- Photo conductivity modeling improvement
- More complex geometry:
  - solar cell edge
  - here, it is close to the interconnects
- Effect of multiple tips (tip distribution on the surface)
- Emission from semi-conductors
- Model the plasma generation during the transition to arc

Questions ?

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