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Electron emission from insulators in the context of spacecraft research

M. Belhaj

e-CLOUD & GWD Vac'22 , 28th September La Biodola Bay – Isola d'Elba

In collaboration with my colleagues: Sarah Dadouch, Christophe Inguimbert, Quentin Gibaru, Julie Belfio, Quentin Peyson, Pierre Sarrailh

And with the support of

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

Content

- Spacecraft and SEY, the context
- SEY and charging effect
  - External charging effects
  - Internal charging effects

- Measuring the SEY of insulators using a Kevin Probe
- Can electrons neutralize the electrostatic charge on test mass mirrors in gravitational wave detectors?

  L. Spallino, M. Angelucci, G. Mazzitelli, R. Musenich, S. Farinon, A. Chincarini, F. Sorrentino, A. Pasqualetti, G. Gemme, and R. Cimino
  Phys. Rev. D **105**, 042003 – Published 17 February 2022

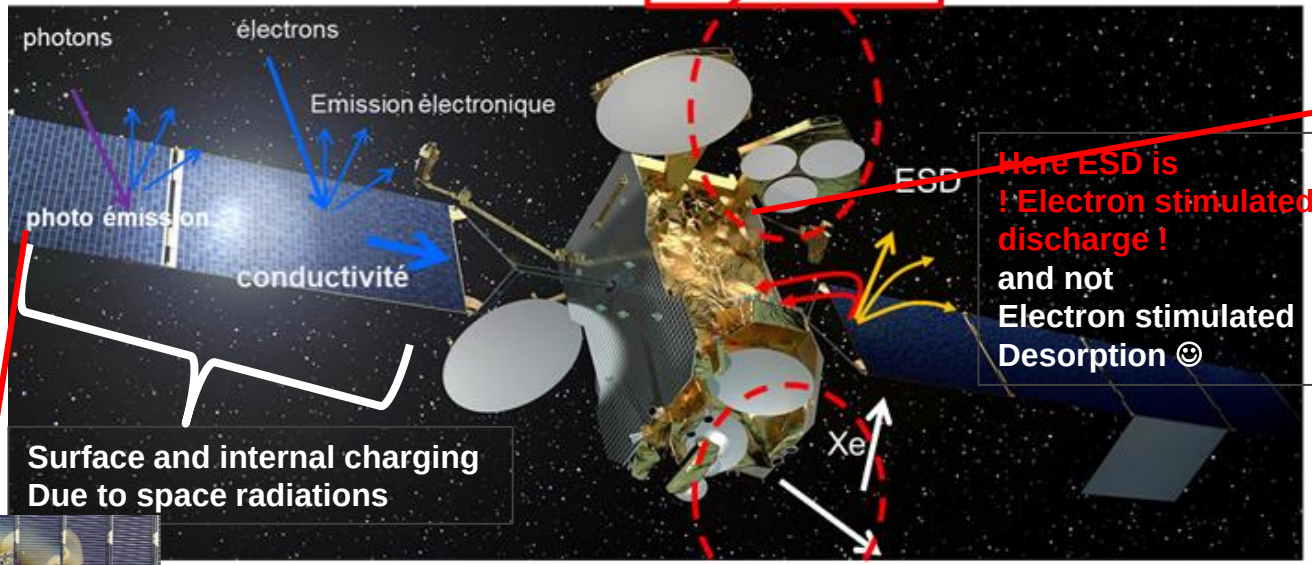
Some new supporting experiments

Spacecraft and SEY, the context

Spacecraft and SEY, the context (1/3)

Systèmes RF
- Effet multipactor

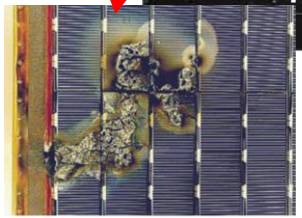
Multipactor effect
On RF systems wave guides, filters, …)



Here ESD is
! Electron stimulated discharge !
and not
Electron stimulated Desorption ☺

Kapton window (*)

Surface and internal charging
Due to space radiations



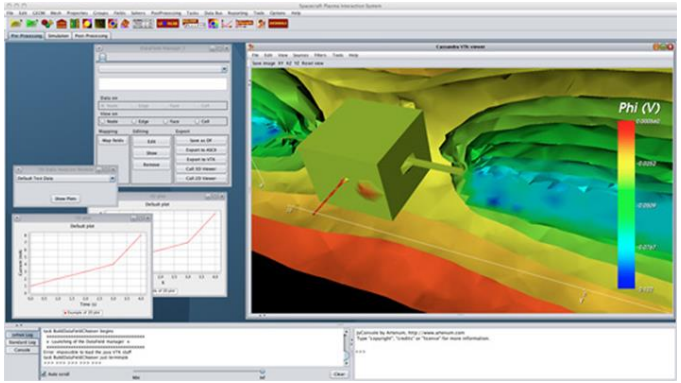
ESA EURECA satellite solar array sustained arc damage.
Credits: ESA

Propulsion
- Erosion
- Interaction plasma- propulseur

Plasma propulsion

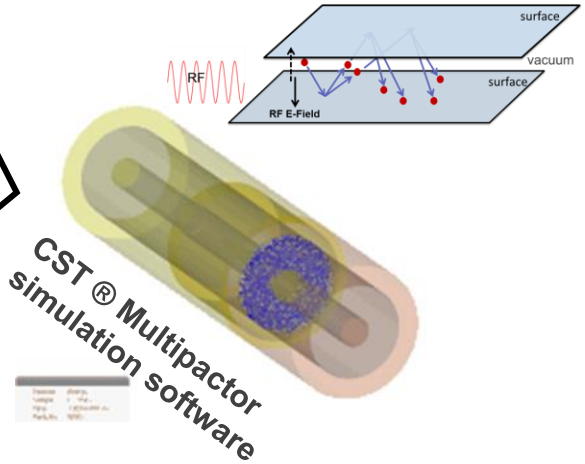
(*) Photos extracted from Benito Gimeno Martínez, Daniel González-Iglesias CALIFES Workshop 2016, CERN, October, 10-12

Spacecraft and SEY, the context (2/3)



SPIS: Spacecraft Plasma Interaction Software (ESA-ONERA)

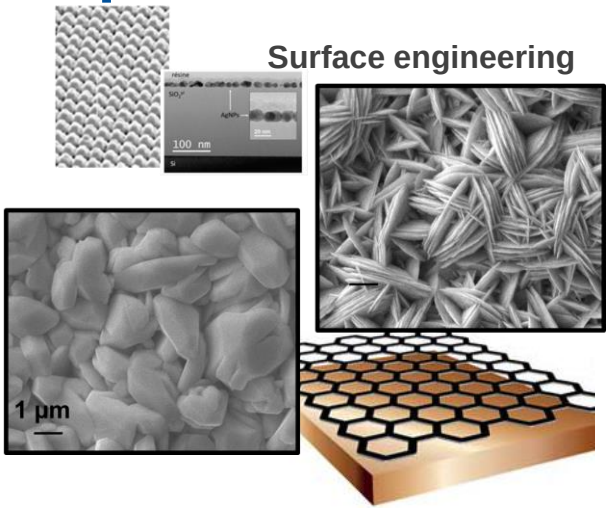
SEY data and models



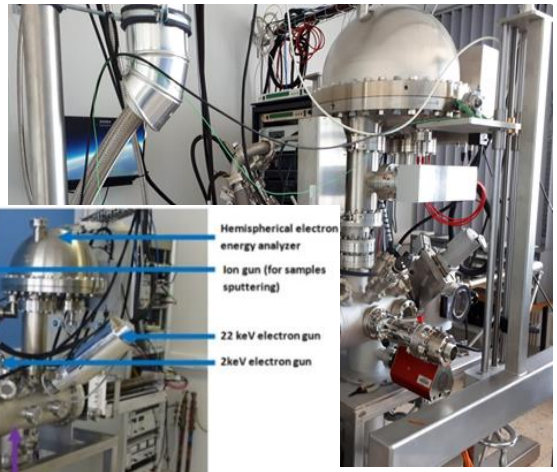
Optimisation of plasma thruster for satellites

Spacecraft and SEY, the context (3/3)

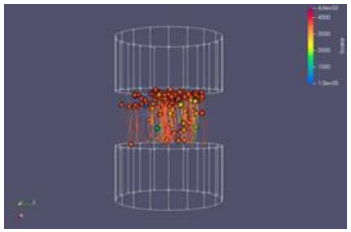
Surface engineering

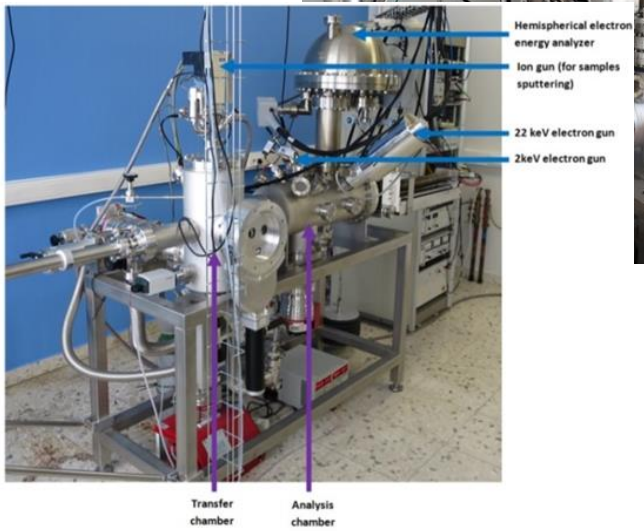


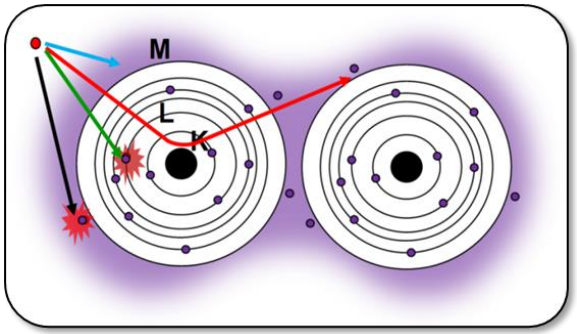
Développement of SEY and XPS facilities



Development of PIC Multipactor codes

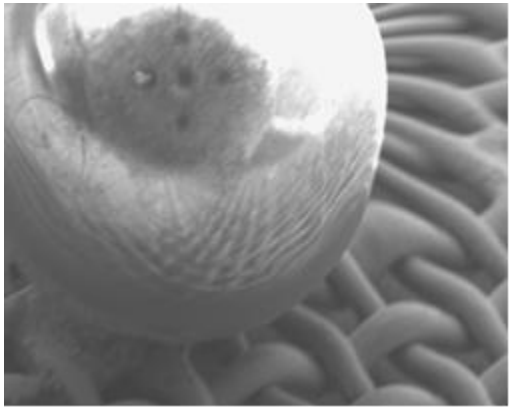






Development of SEY Monte-Carlo codes
MicroElec code (CEA/ONERA/CNES)

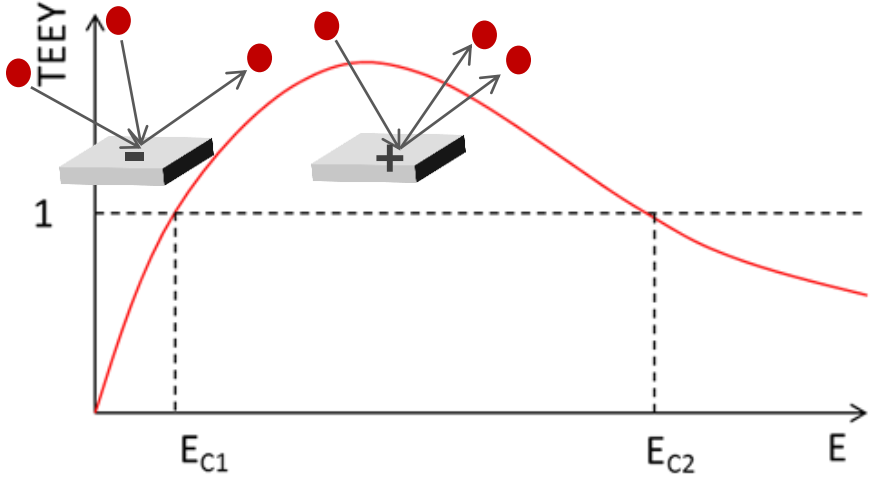
SEY and charging effect

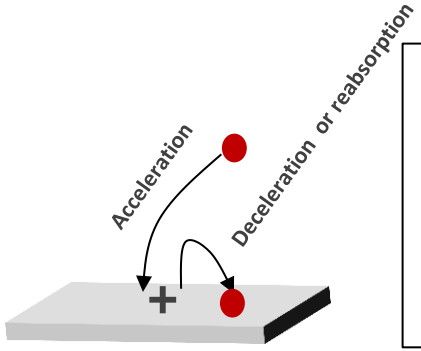


Electrostatic mirror effect in SEM
A2O3 sphere on palladium grid

SEY and charging effect (1/5)
External effects

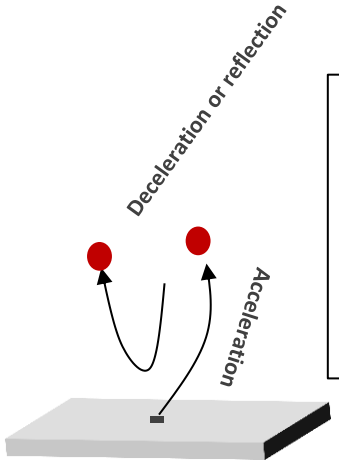
! TEEY=SEY !





Positif charging artefacts:

- **Underestimation of the beam impact energy**
- **Underestimation of the SEY**

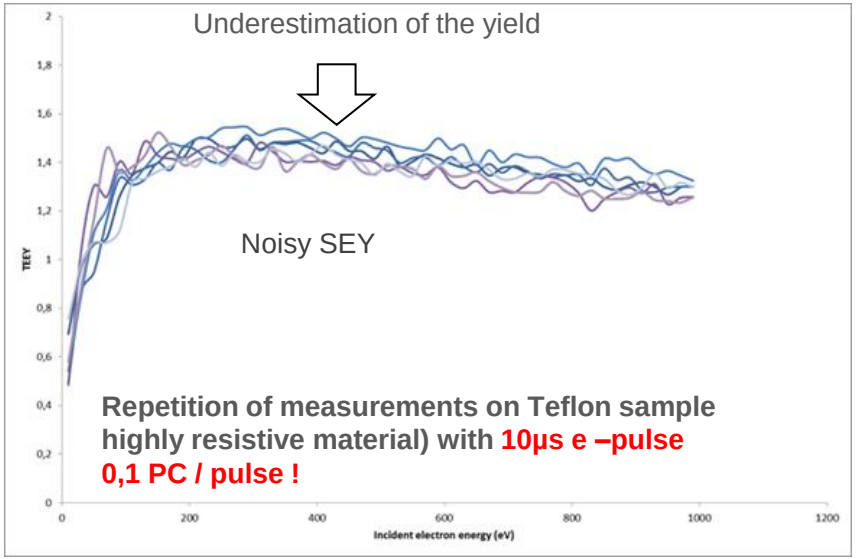


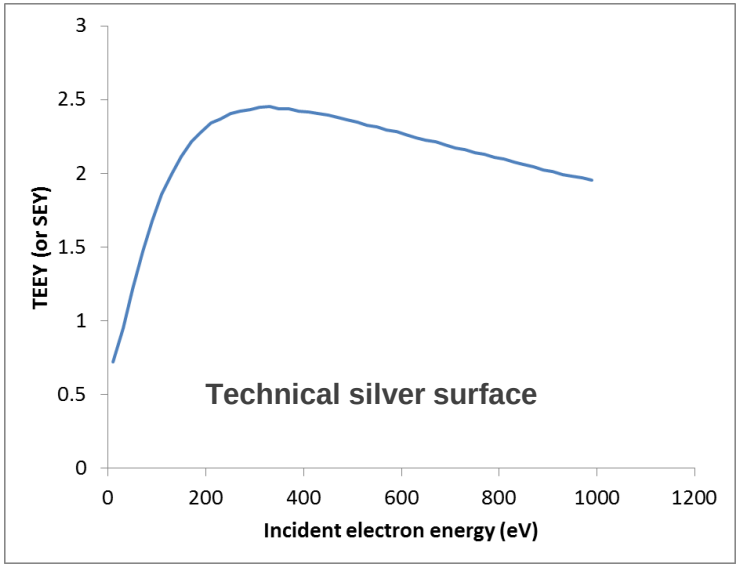
Negative charging artefacts:

- **Overestimation of the beam impact energy**
- **Sporadic electrostatic discharges in some cases**

SEY and charging effect (2/5)

External effects



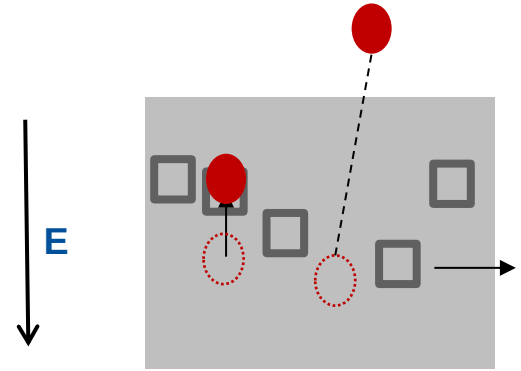


SEY and charging effect (3/5)

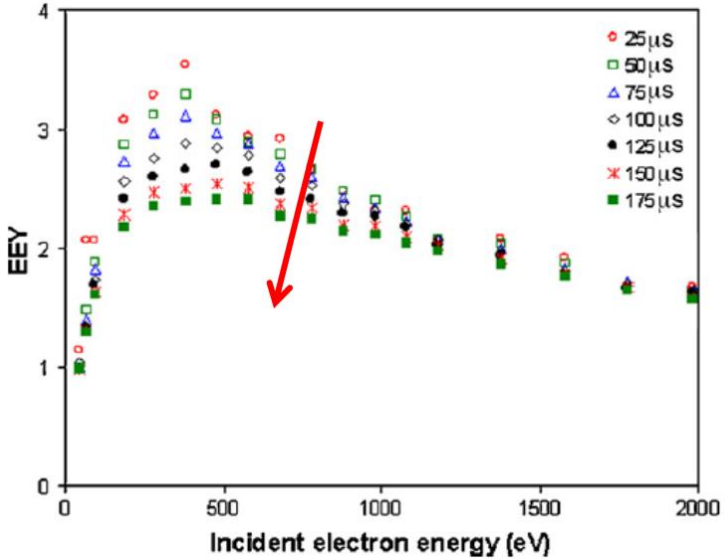
Internal effects

Holes

Electrons



e- thermalisation due to extra interactions (E and holes)
→ recombination : SEY ↓

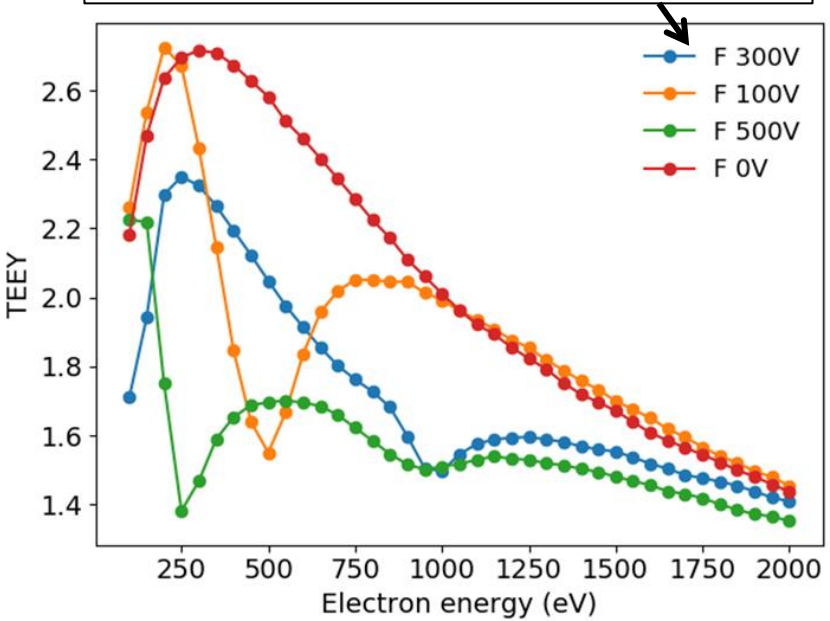


M. Belhaj, et al : Effect of the incident electron fluence on the electron emission yield of polycrystalline Al 2O 3. Applied Surface Science 03/2011; 257(10)

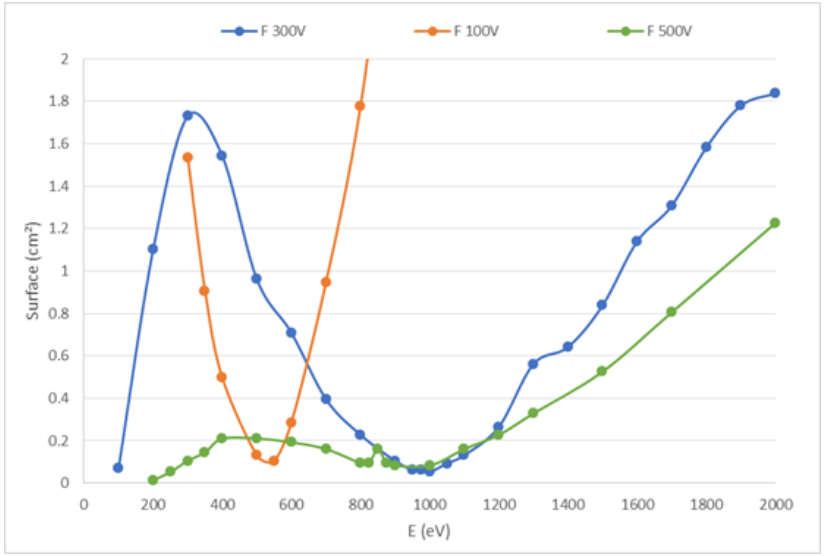
SEY and charging effect (3/5)

Internal effects : current density effect

Focus parameters of the electron gun = spot size



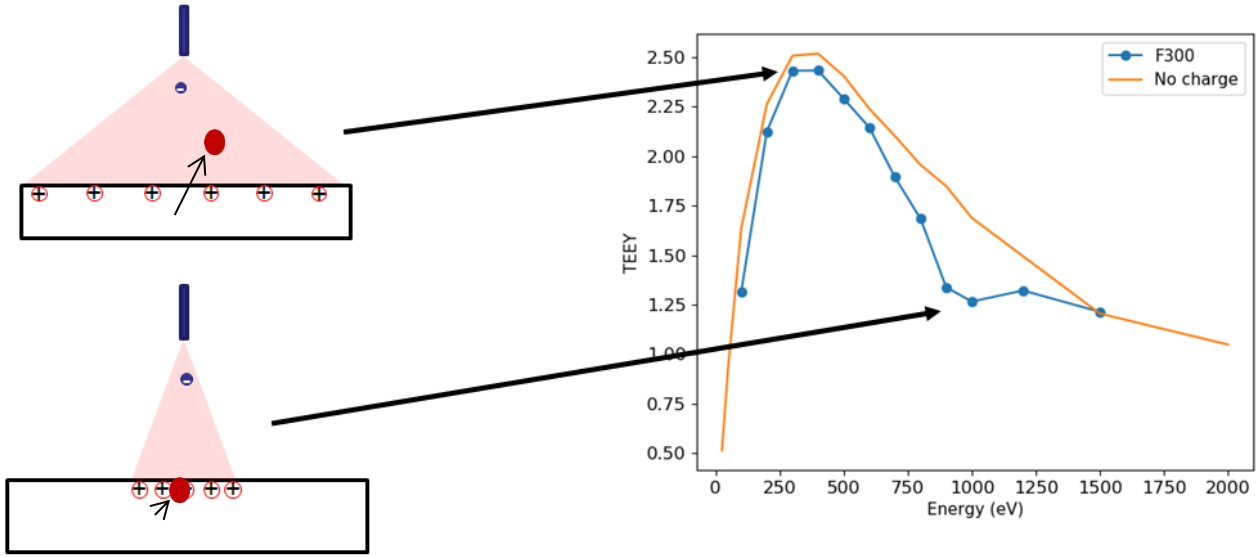
spot size



SEY of 20 nm plasma deposited SiO_2 on Si

! Results obtained in the framework of Quentin Gibaru (ONERA-CNES-CEA) thesis. Results submitted to publications

SEY and charging effect (4/5)



We should minimize not only the electron dose (pulse duration) but also the current density (flux)

! Results obtained in the framework of Quentin Gibaru (ONERA-CNES-CEA) thesis. Results submitted to publications

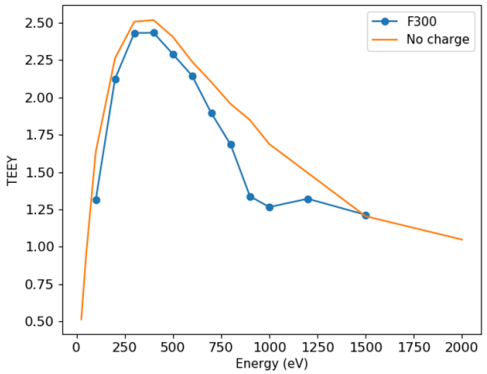
SEY and charging effect (5/5)

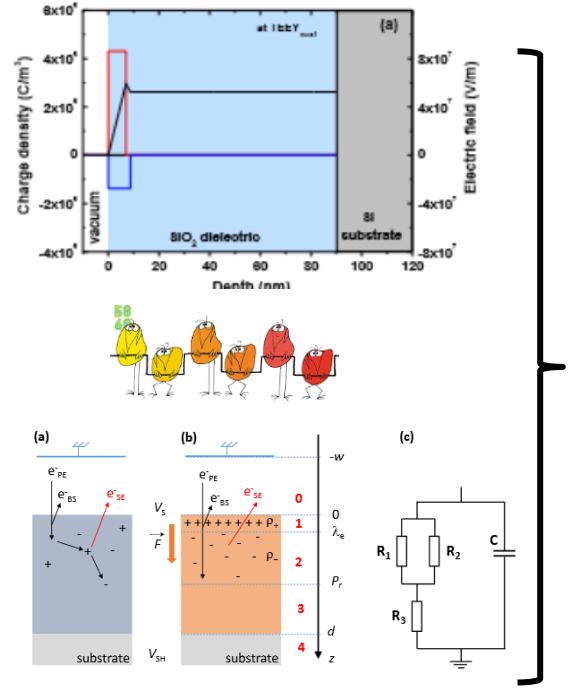
How to develop a nice physical model to explain in fact just an experimental artefact ☺

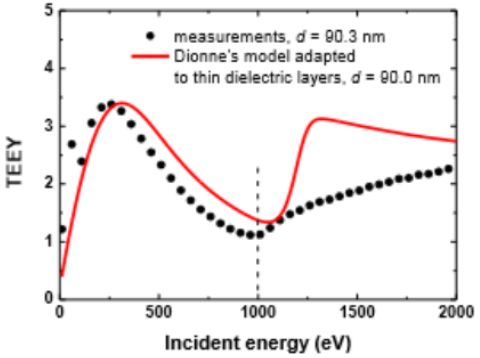
Atypical secondary electron emission yield curves of very thin SiO_2 layers: Experiments and modeling

Journal of Applied Physics 130, 135305 (2021); https://doi.org/10.1063/5.0056218

C. Rigoudy[1,2], K. Makasheva[1], M. Belhaj[2], S. Dadouch[2], G. Teyssedre[1], *and* L. Boudou[1,a)]

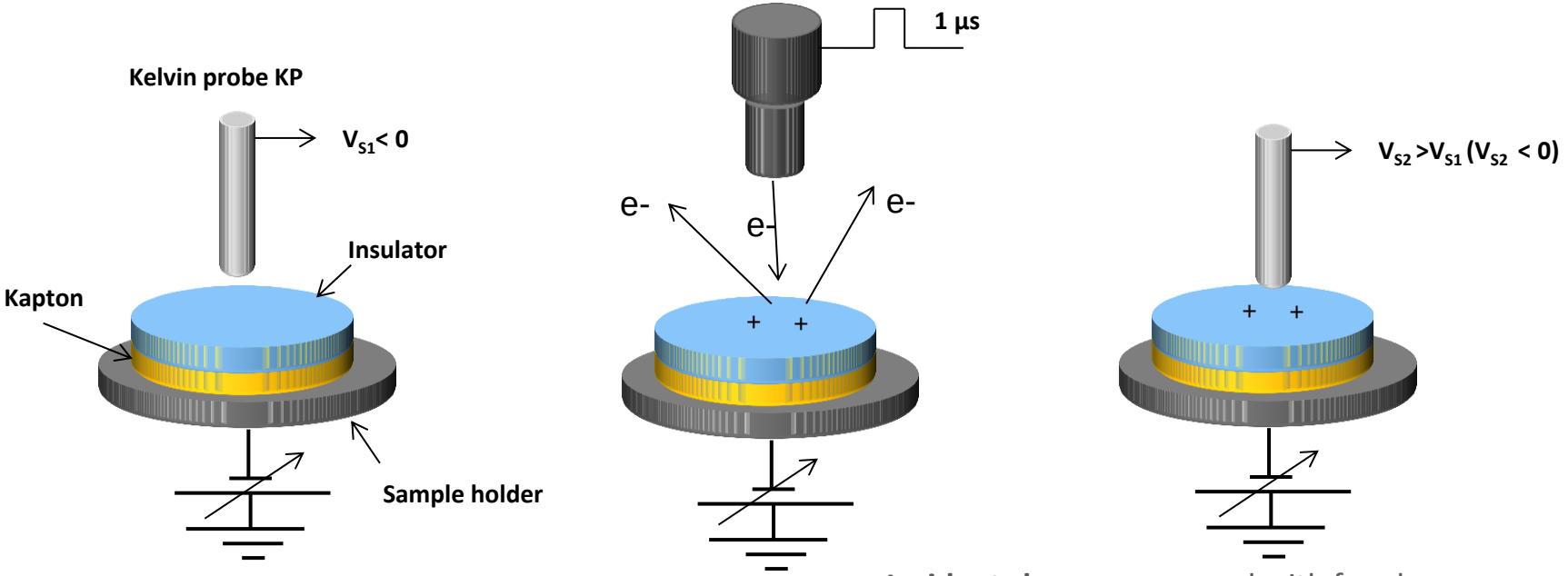






Measuring the SEY of insulators using a Kevin Probe

Measuring the SEY of insulators using a Kevin Probe (1/2)



$$SEY = 1 - \frac{Emited\ charge}{incident\ charge}$$

Incident charge: measured with faraday cup Faraday

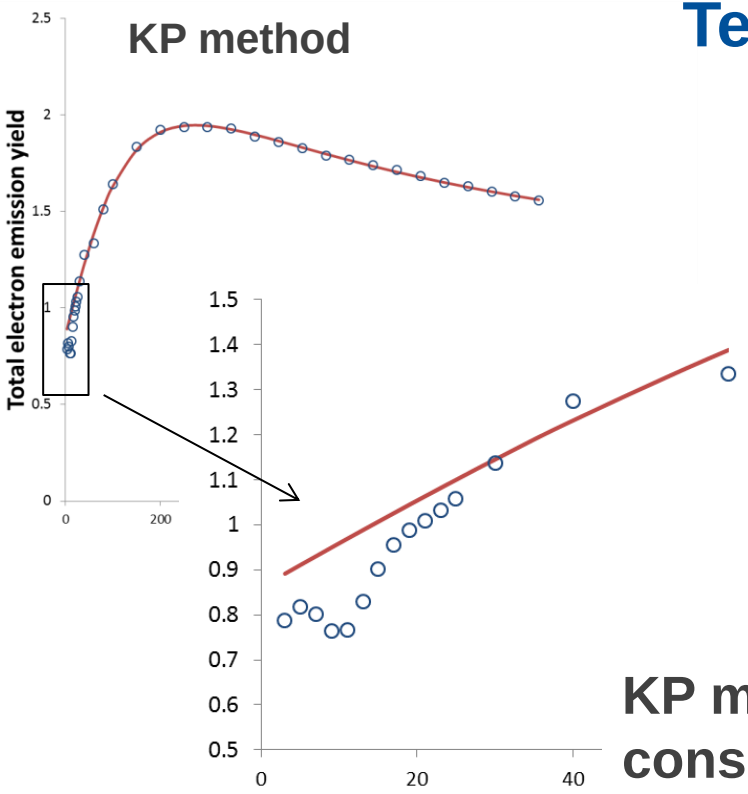
C: capacitance of the sample holder+ sample+ measured in situ

$$Emitted\ charge\ = C\ (VS_1 - VS_2)$$

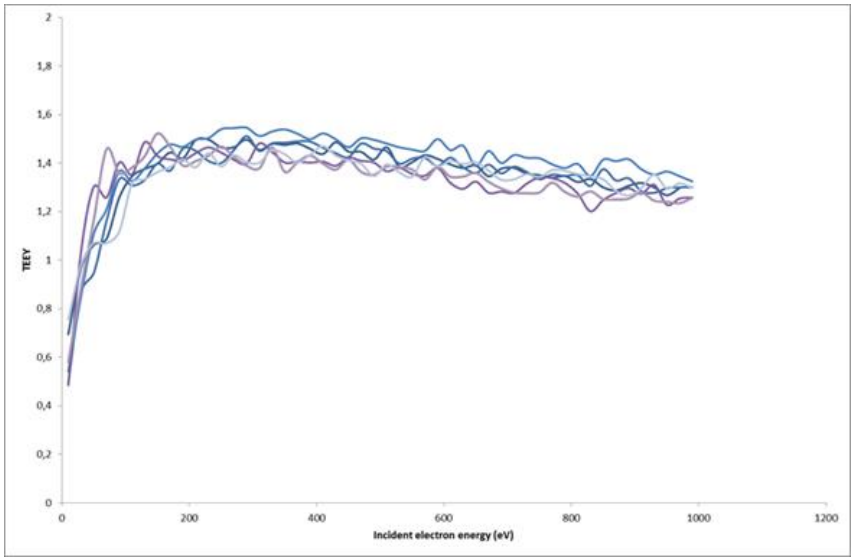
Measuring the SEY of insulators using a Kevin Probe (2/2)

Teflon

KP method



Conventional method



KP method : fastidious and time consuming

Can electrons neutralize the electrostatic charge on test mass mirrors in gravitational wave detectors?

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Phys. Rev. D **105**, 042003 – Published 17 February 2022

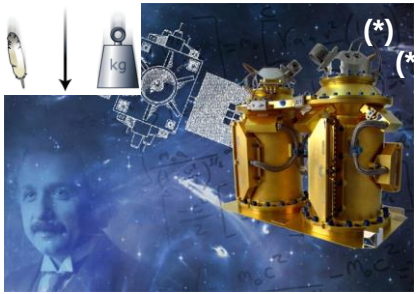
Some new supporting experiments

e- gun for discharging a electrically floating surface

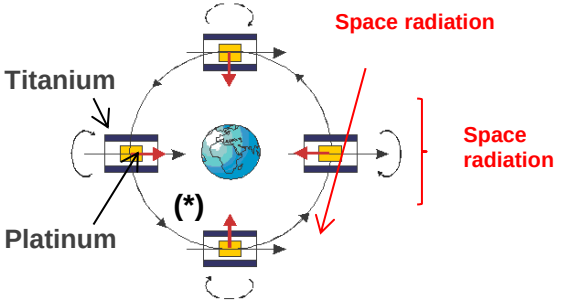
ONERA context : testing the equivalence principle at lower than 10^{-16} accuracy (future mission)

Is using e-gun too discharge the masses is an interesting and effective way ?

https://www.onera.fr/en/news/microscope-mission-first-results-confirm-albert-einsteins-theory-of-relativity



Past mission: µscope (10^{-15}) 2016-2018



GWD context

Can electrons neutralize the electrostatic charge on test mass mirrors in gravitational wave detectors?

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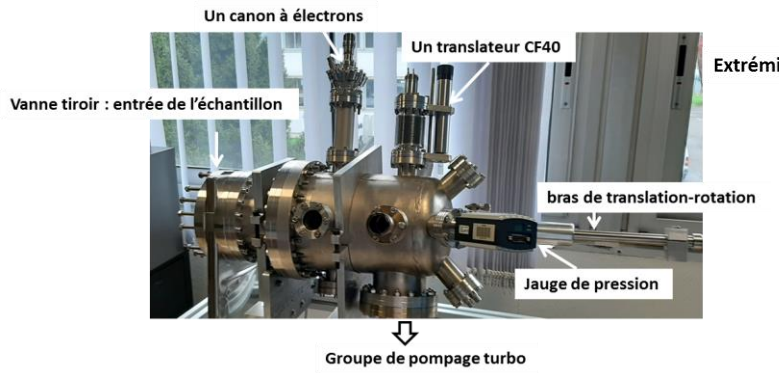
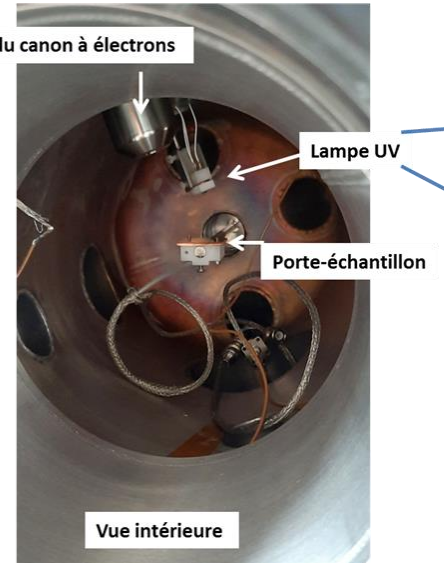
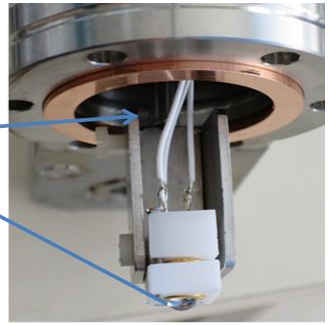
(*) figures extracted from : https://microscope.onera.fr/mission

e- gun for discharging a electrically floating surface

We developed a specific HV facility for the ONERA project internal project (2020-2025) equipped with e-gun and VUV LED

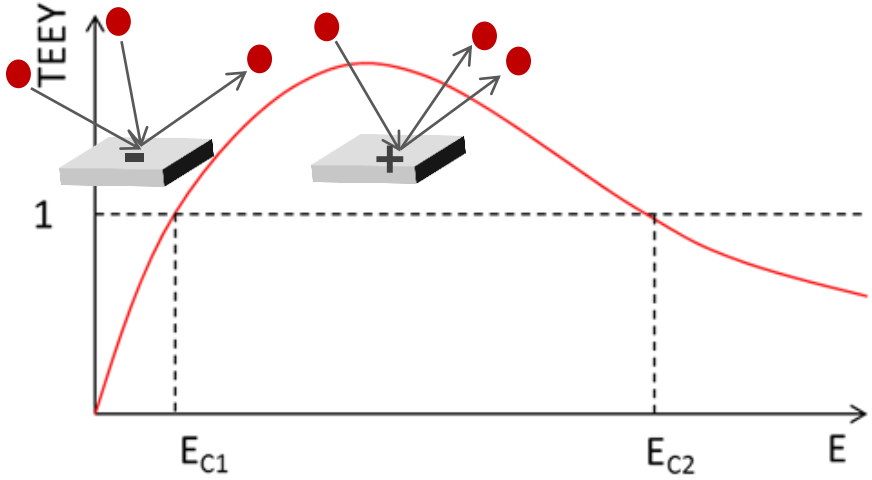






e- gun for discharging a electrically floating surface
Principle: relatively simple

! TEEY=SEY !



- Negative charging → irradiation between E_{C1} and E_{C2}

- Positive charging → irradiation above E_{C1}

For technical flat materials E_{C1} is typically In the range 18 eV to 45 eV

Similar principle than

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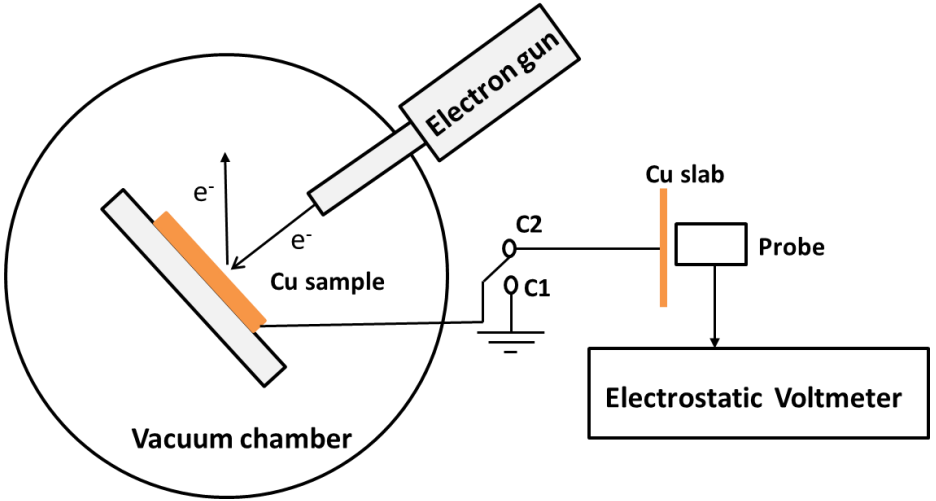
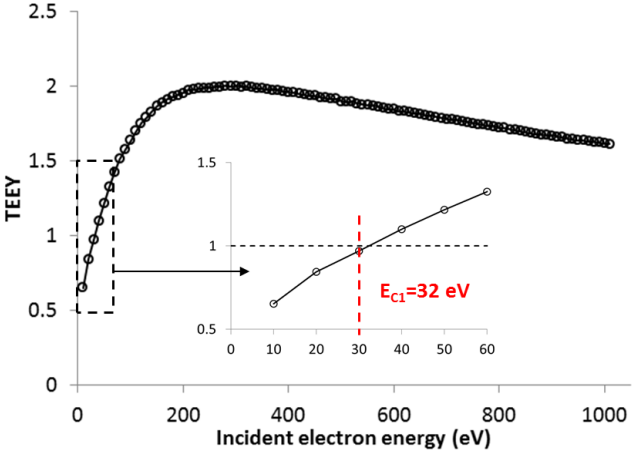
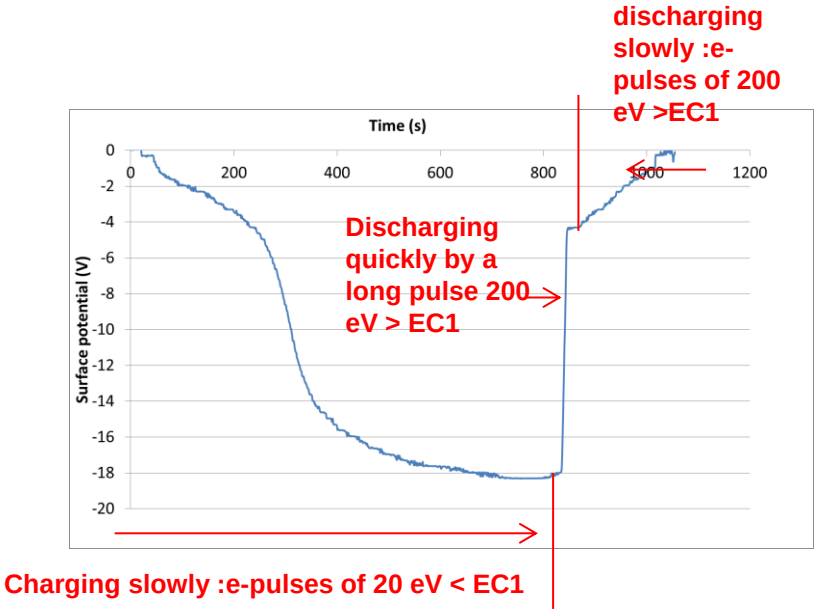
e- gun for discharging a electrically floating surface
The experimental arrengment



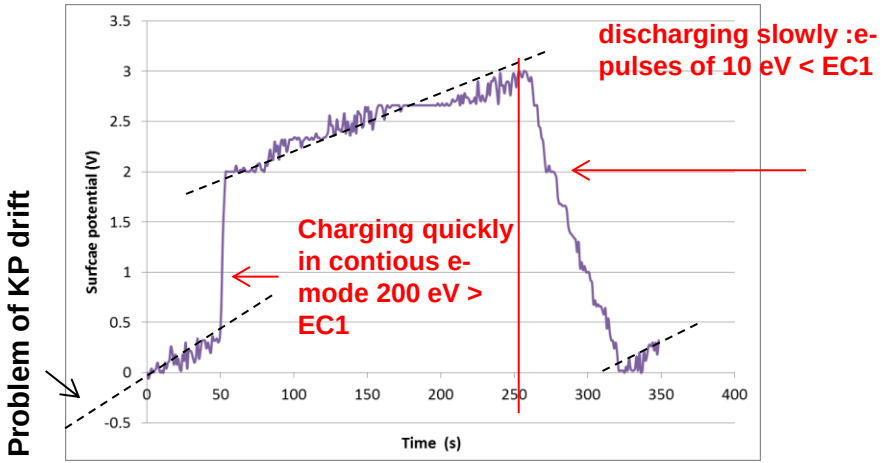


M. Belhaj and S. Dadouch Review of Scientific Instruments 92, 083301 (2021)

e- gun for discharging a electrically floating surface experiments : testing the concept



Discharging of negative charge



Discharging of positive charge

SEY of insulators conclusion and perspectives

Conclusion

- The effect of the charging on the SEY should be carefully analyzed and the experimental methods and protocols should be improved → Despite the effort we have been making for years, we do not have absolute confidence in our measurements: the charging artefact is never far away.

- If you have the opportunity to replace the **thick (> 100 nm)** insulator by higher conductivity material or thin film (few nm or tens of nm) : do it. If not, save money and time. You can roll the  the result should not be much less valid than that of the experiment,

Perspectives

- Monte-Carlo modeling of full process charge trapping, carriers drift, low secondary electron transport to define the limit of “optimal” experimental parameters

- Found projects : insulators free ☺

Discharging conclusion and perspectives

Conclusion

- The principle of discharging of floating conductor by electron beam is tested for both polarities and the results are interesting.

Perspectives

- Testing the combination of the VUV LED and e-gun (redundancy)
- Miniaturization a home made electron source (ONERA project undergoing)
- Study the effect of thermic radiation (hot cathode) on the instrument and design of the electrostatic optics
- Incorporation of the electrons sources and LEds on the instrument