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Extremely low secondary electron emission from metal/dielectric particulate coatings

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14th Spacecraft Charging Technology Conference
Space Research and Technology Centre of the European Space Agency (ESA/ESTEC)
Noordwijk, The Netherlands
April 4-8, 2016

Extremely low secondary electron emission from metal/dielectric particulate coatings

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UTAH STATE UNIVERSITY MATERIALS PHYSICS GROUP

CSIC Consejo Superior de Investigaciones Científicas
INSTITUTO DE CIENCIA DE MATERIALES DE MADRID (ICMM)

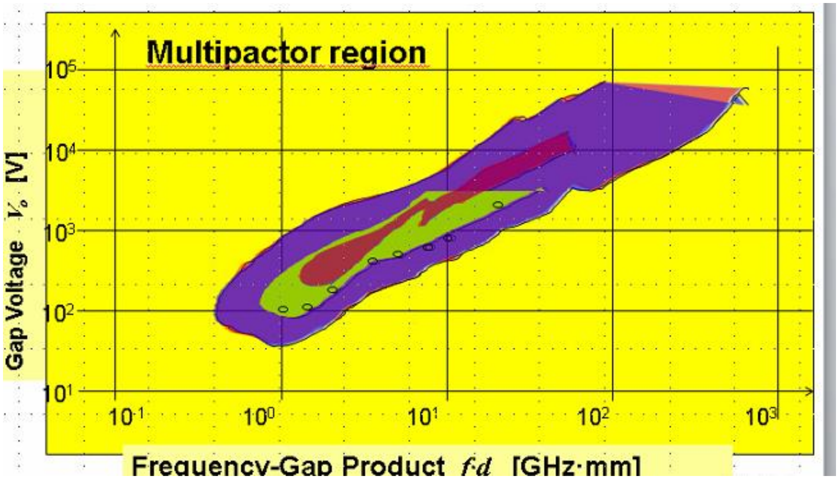
CONTENT

- Main goals
- Introduction: Antimultipactor coatings
- Antimultipactor coatings for ESA
- Micrometric dielectric particulate coatings
- Extremely low secondary electron emission from metal/dielectric particulate coatings
    - SEY simple theoretical model
- Conclusions

UAM

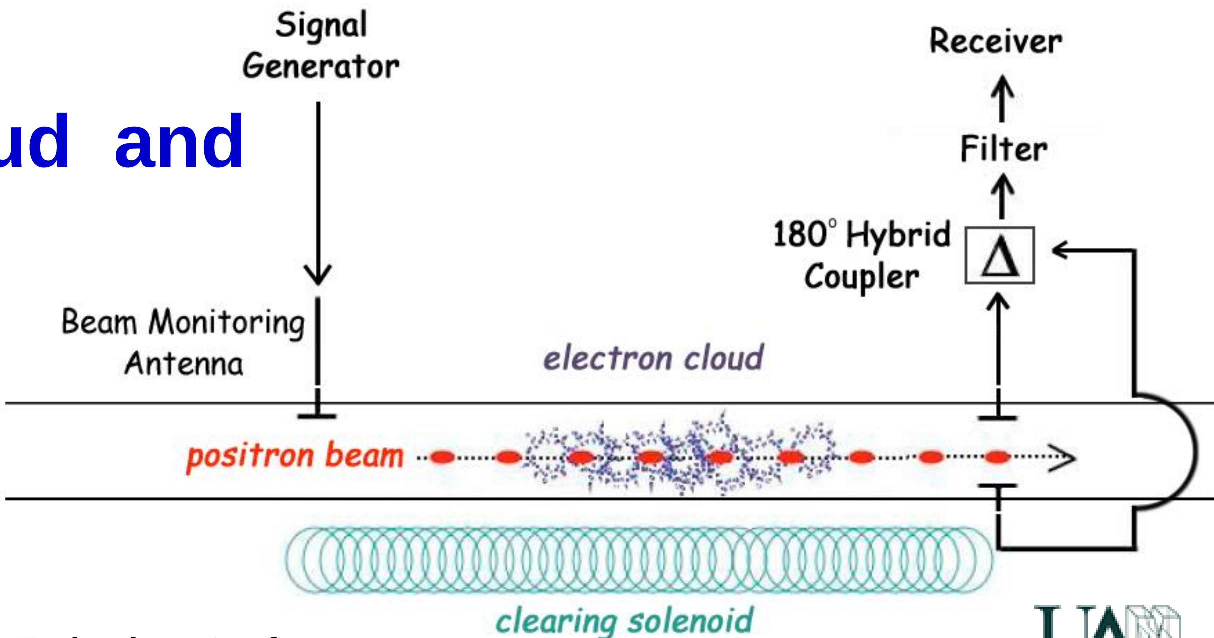
Main goals

To mitigate:



1.The multipactor effect in space-relate high-power RF hardware

2.The electron cloud and its adverse consequences



Multipactor phenomenon characteristics

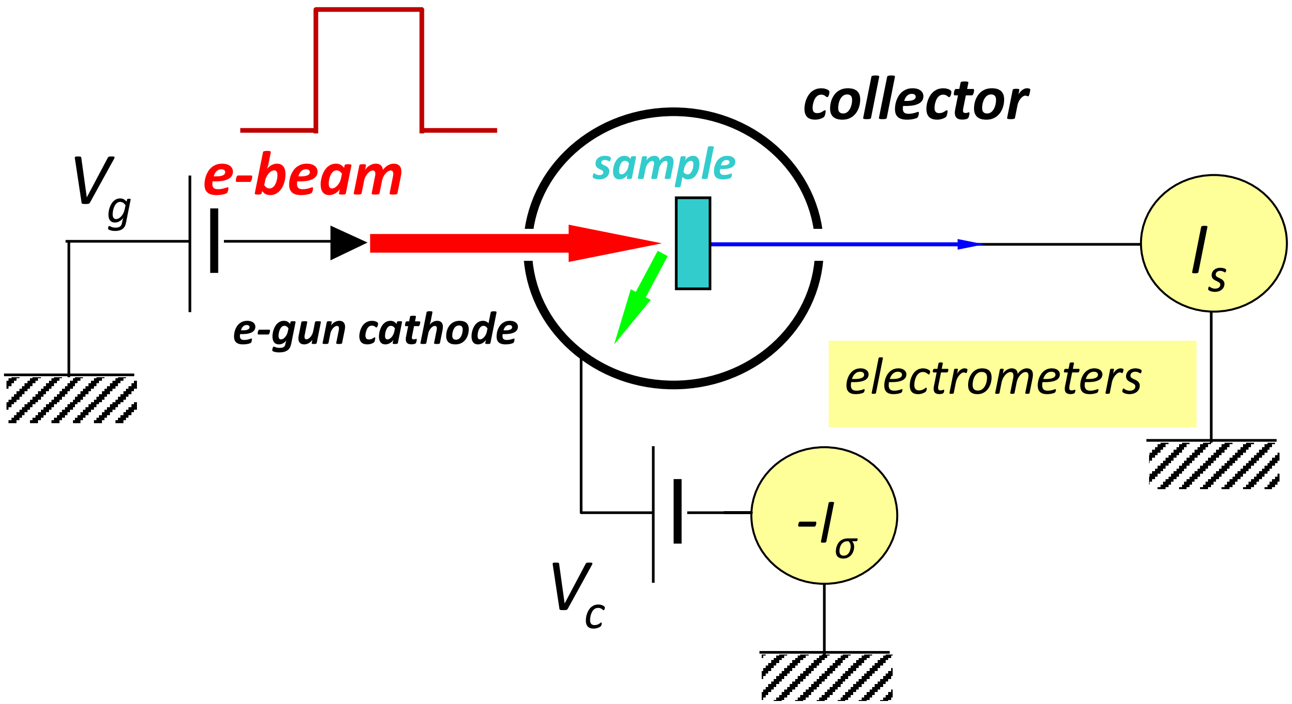
- Weak discharge
- Secondary electron emission seed and feedback (avalanche)
- Only ocurring under vacuum conditions
- Threatening any RF component
- Can cause disturbances/degradation of on-board satellite equipment and even total loss of the mission

Introduction

$$I_p = I_\sigma + I_s \qquad I_\sigma > 0\,,\ I_p < 0$$

I_s is measured in the sample

I_p is measured in the Faraday cup



collector connected to ground,

Development of coatings with low secondary electron emission yield (SEY)

Main objectives:

Very low SEY

like Au / roughAg
$\sigma_{max} < 1.5$
$E_1 > 200$ eV

Very low RF surface resistance

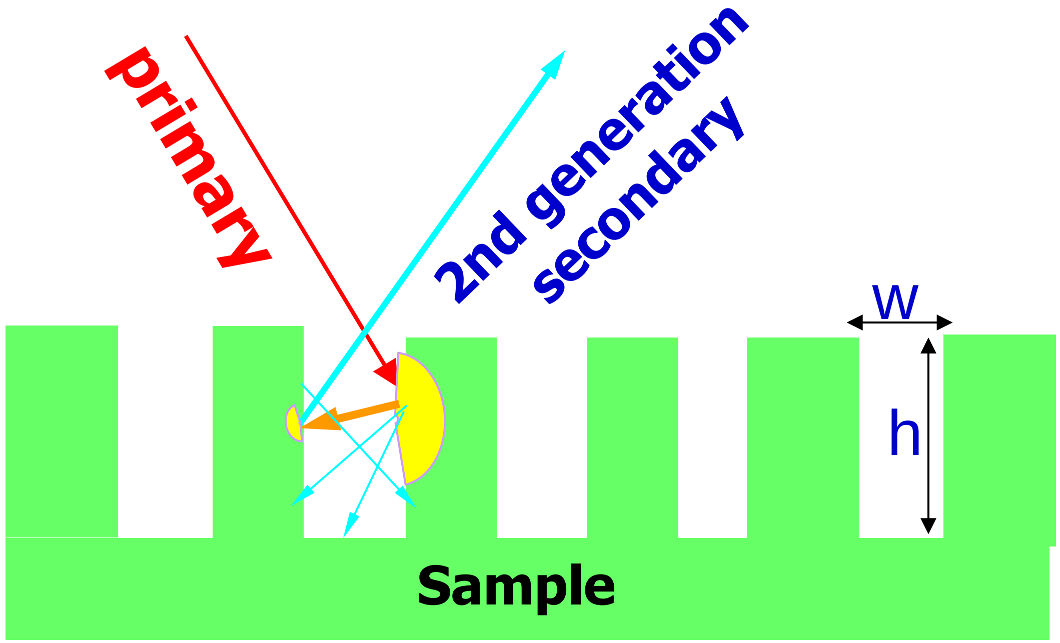
close to Ag
$< 1.5 \times R_{surf}(Ag)$

Tesat en ITI

Very slow aging in air

> one year

Secondary Emission Suppression by Surface Roughness of High Aspect Ratio



Roughness:
aspect ratio
porosity

in each generation secondary energy decreases

- **Low SEY**
- **High E_1 value**
- **High stability in air   Ag, Au, …**
- **High conductivity   Ag**

Varias pequeñas modificaciones

Introduction

Anti-Multipactor Coatings
Deposition Methods

Gas (UHV)

Physical Vapor Deposition

Evaporation

Ion implantation and/or reaction

Sputtering

Liquid

Chemical Methods

Chemical Etching or Growth

Anodization

Solid

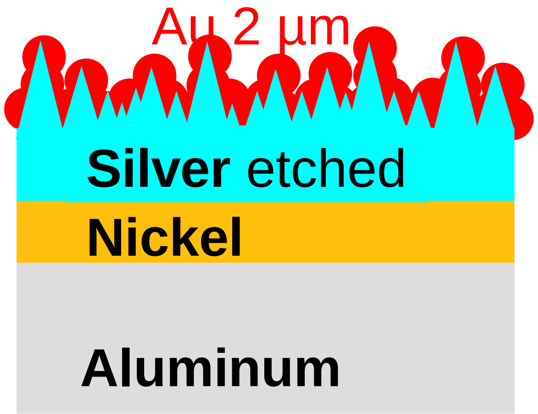
Particles Deposition

Varias pequeñas modificaciones

ANTI MULTIPACTOR COATINGS

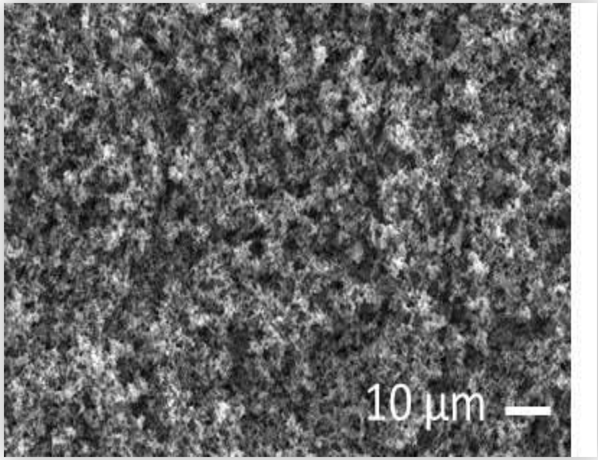
DIFFERENT KINDS TESTED

CHEMICAL ETCHING

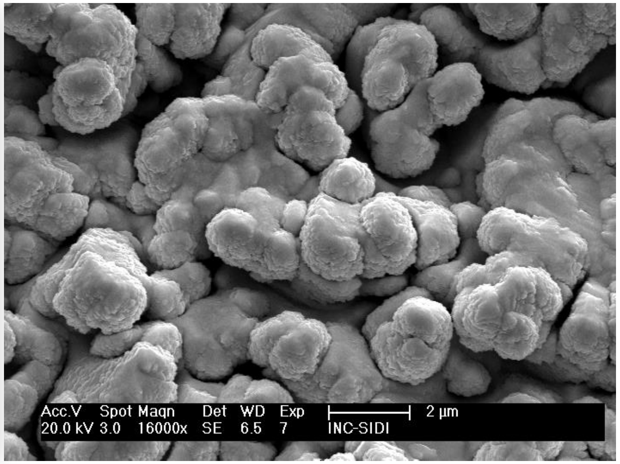


ROUGH NEG

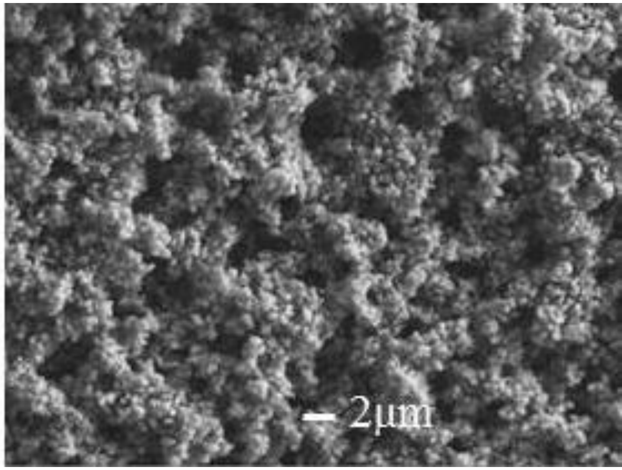
Etched aluminium



Gold-coated etched silver



NEG-coated etched Al

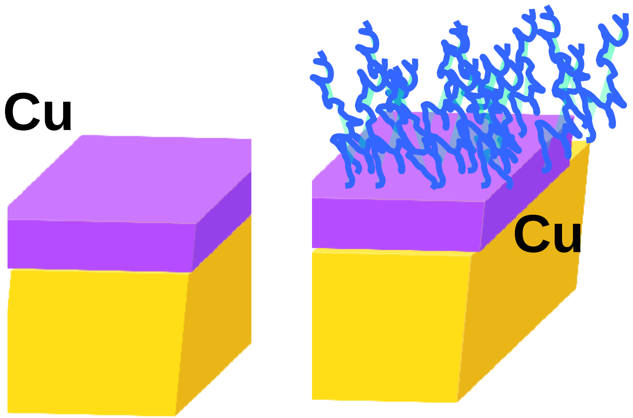


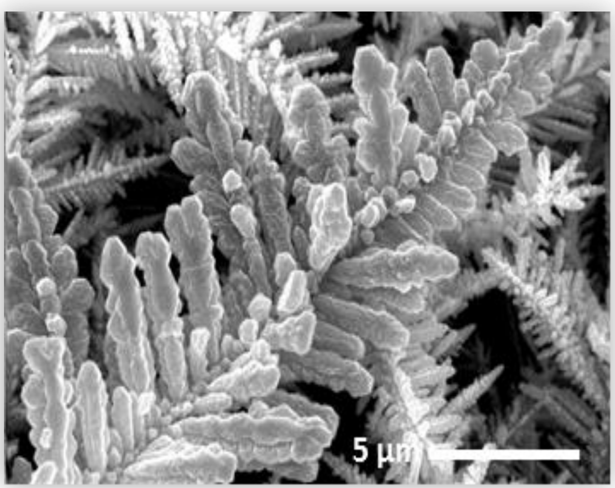
$\Delta \approx 1\mu m$ $R_r/R_s = 2.4$ @ 12 GHz

ANTI MULTIPACTOR COATINGS

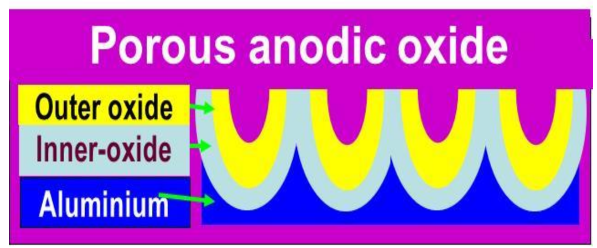
DIFFERENT KINDS TESTED

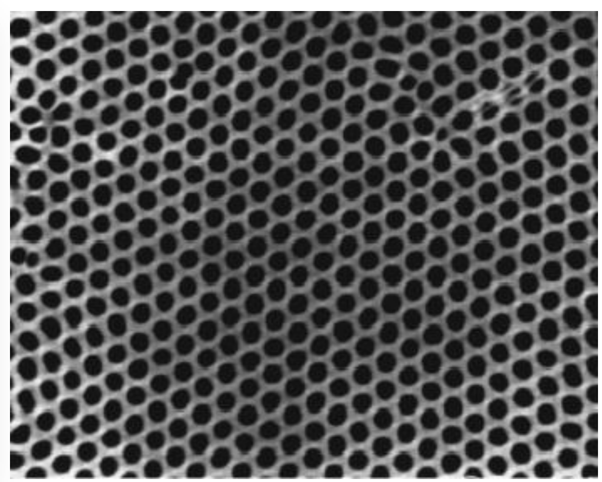
Ag microstructured



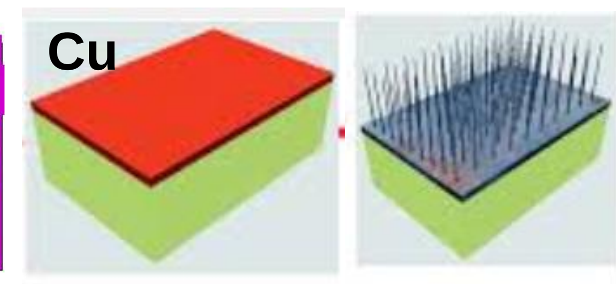


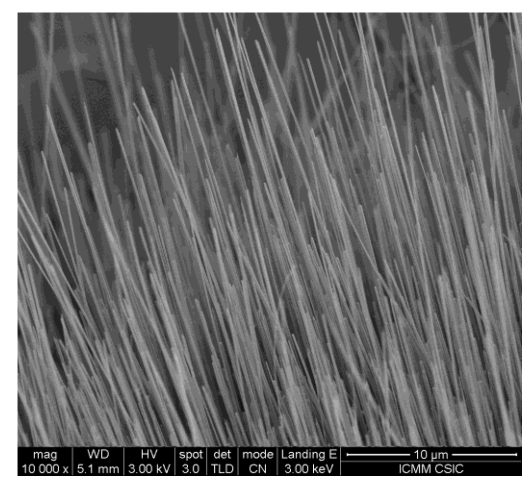
Nanoporous templates



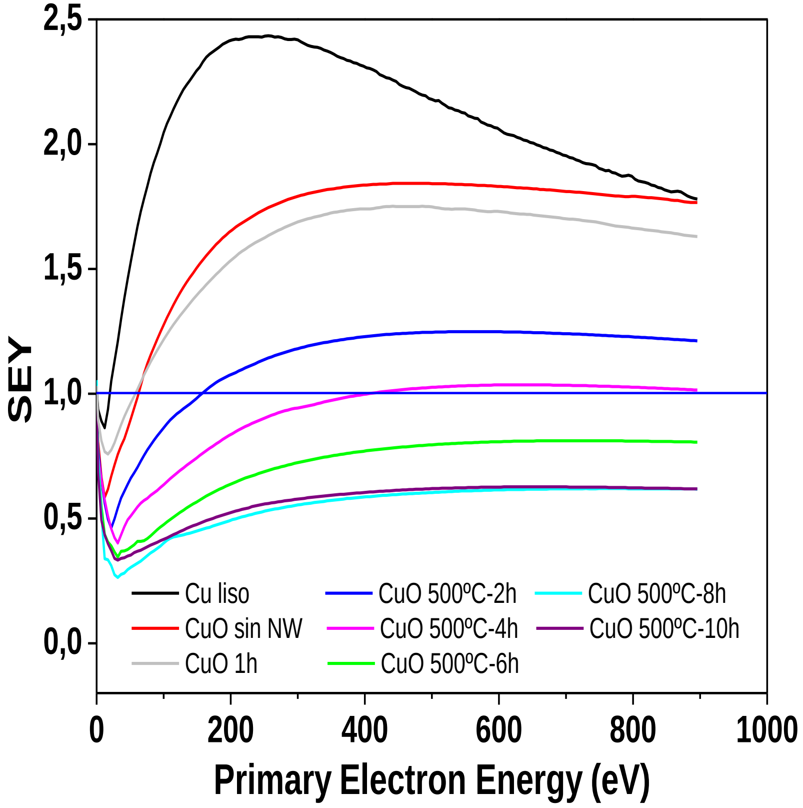


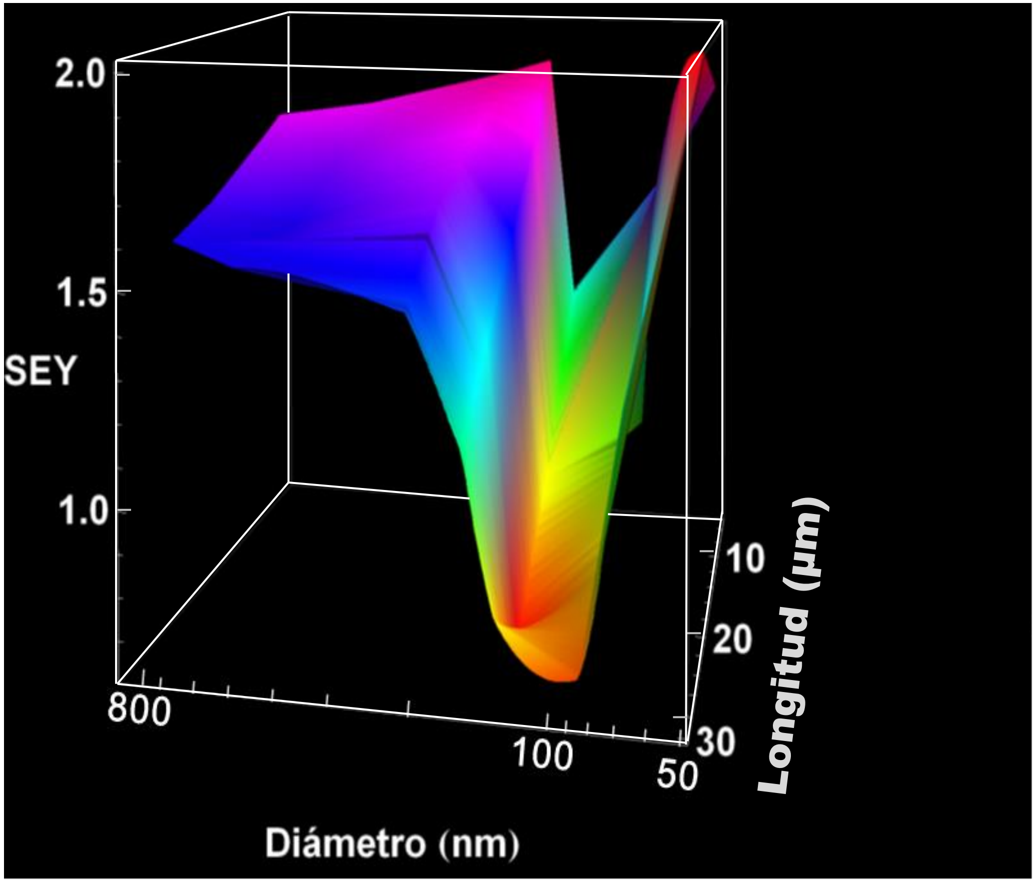
CuO nanowires





CuO nanowires





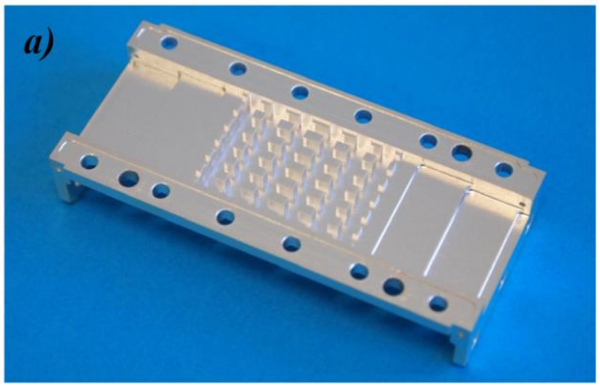
T= 500°C,

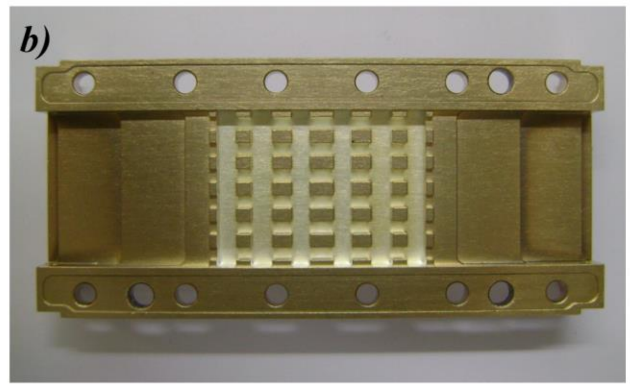
DEFINITION OF SAMPLES

Harmonic low-pass corrugated filters = Multipactor samples

for low-power RF behaviour and multipactor threshold tests

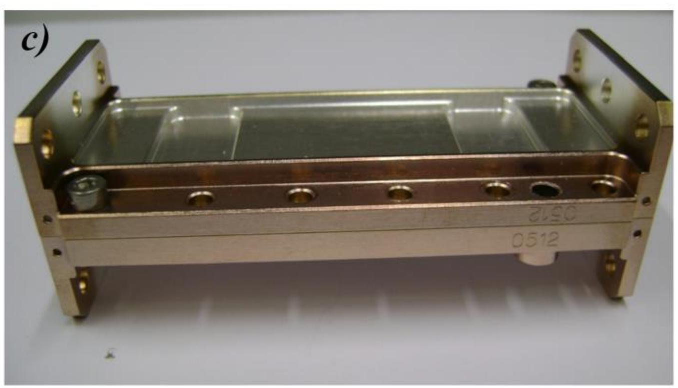
as received Ag plating

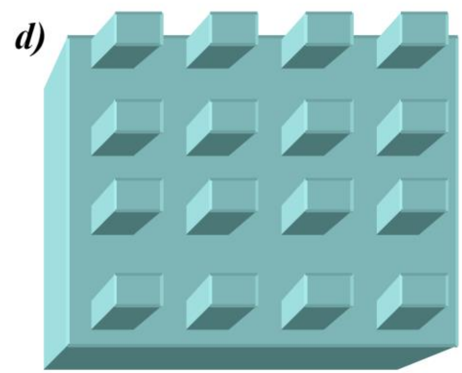




treated filter

RF filter

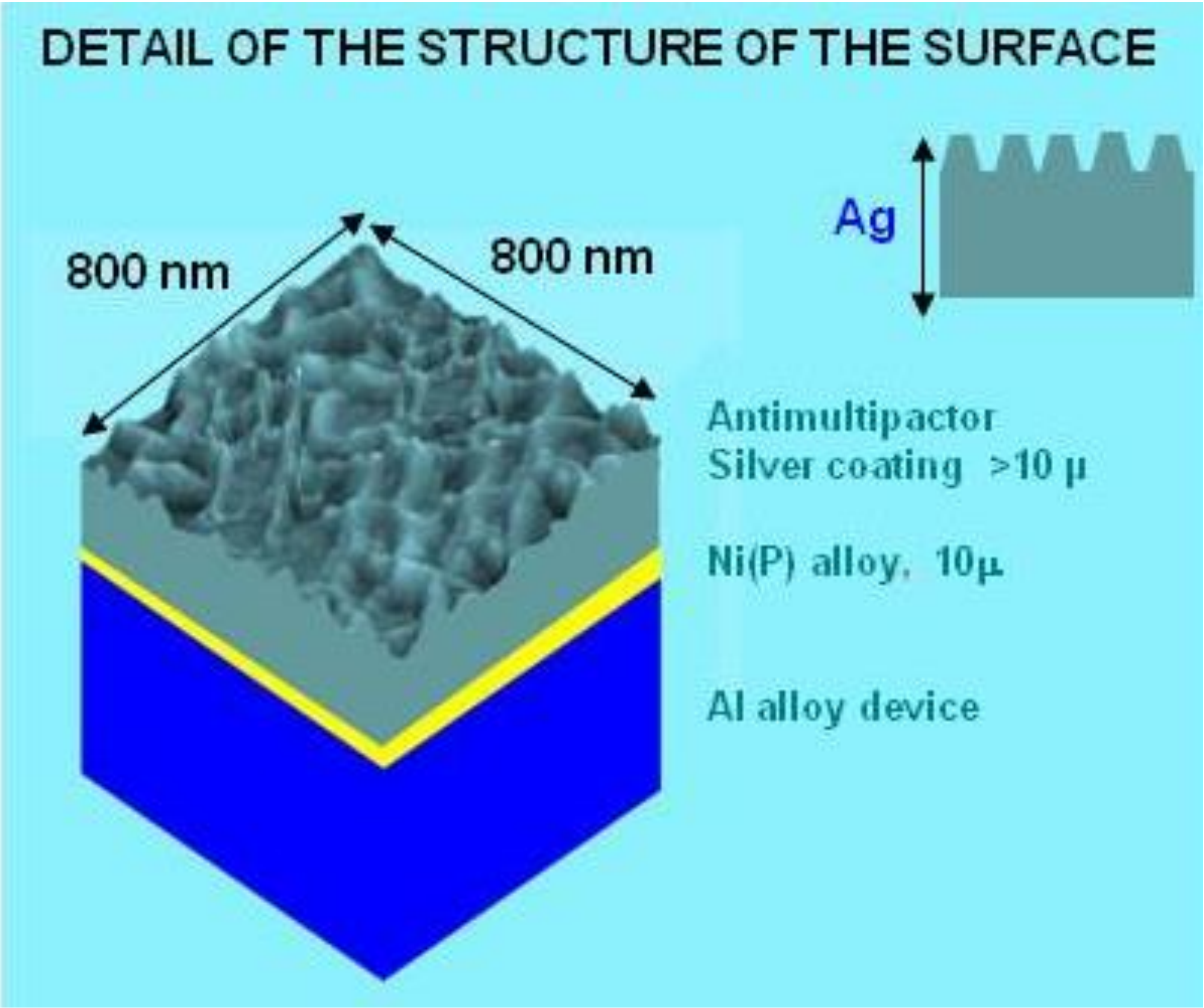




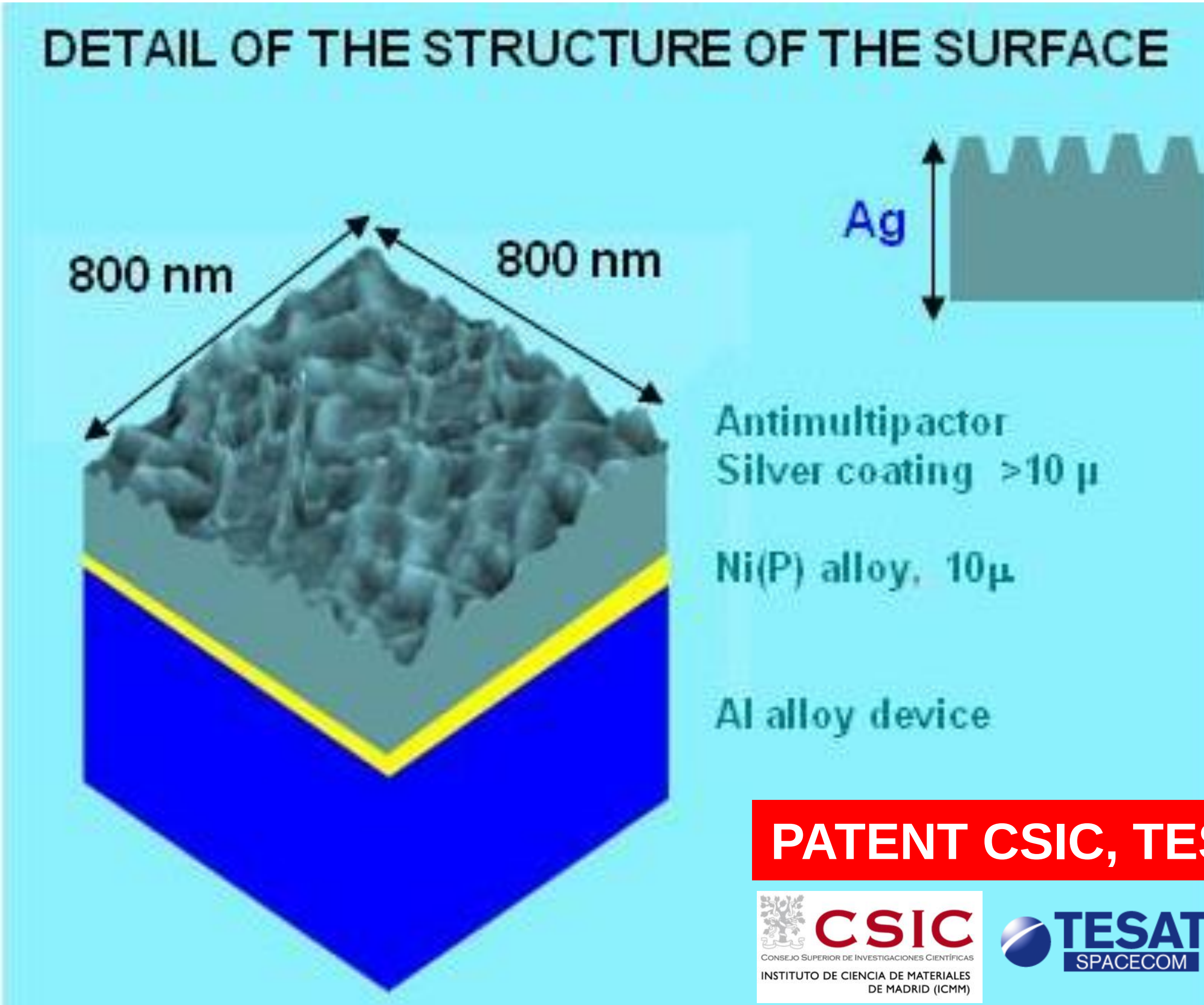
rectangular crossing grooves in corrugated central part

K band 10.9 - 36.0 GHz

Microstructured silver



THE CHEMICAL TECHNIQUE



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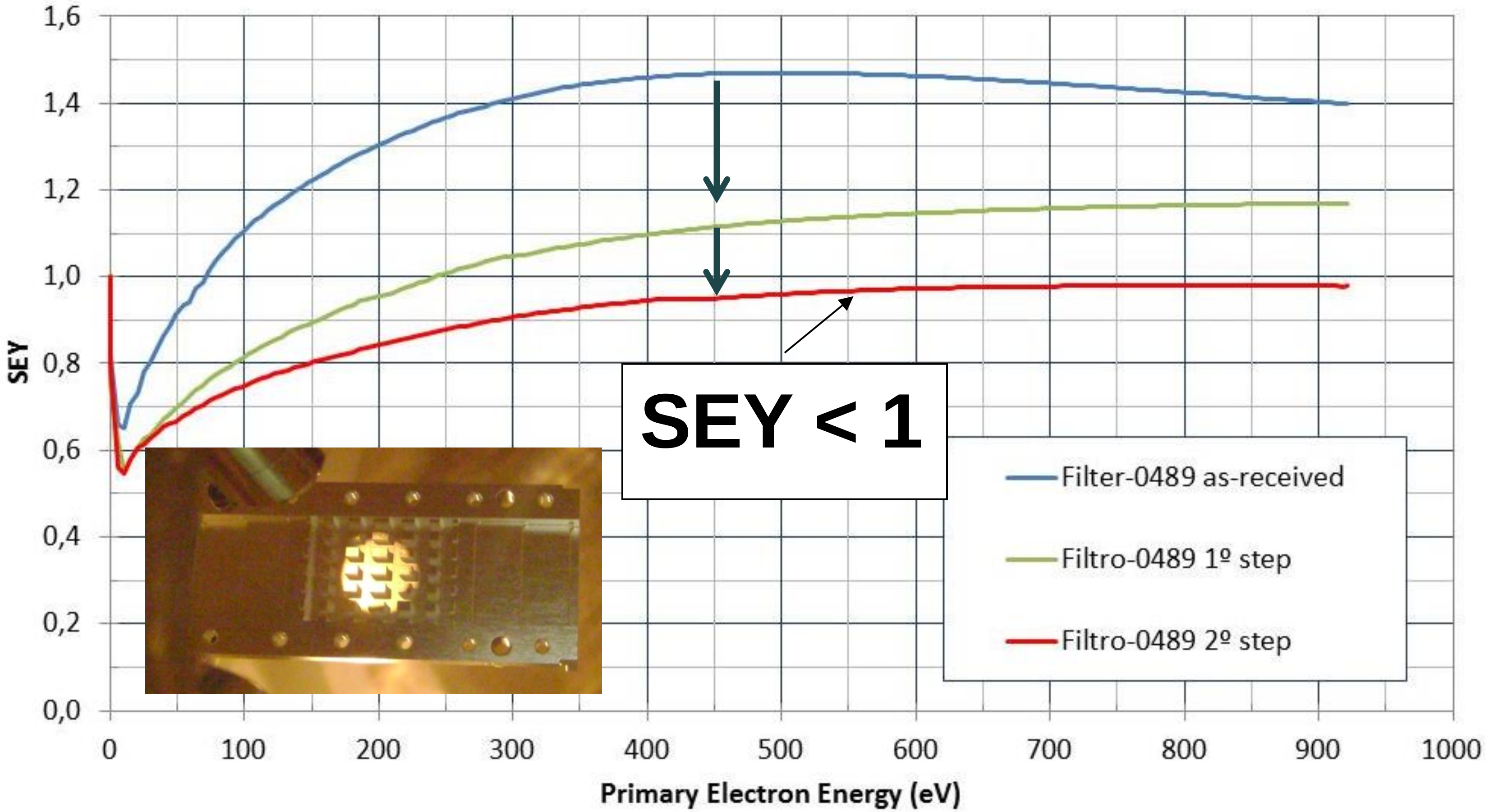
SEY curves of treated filter



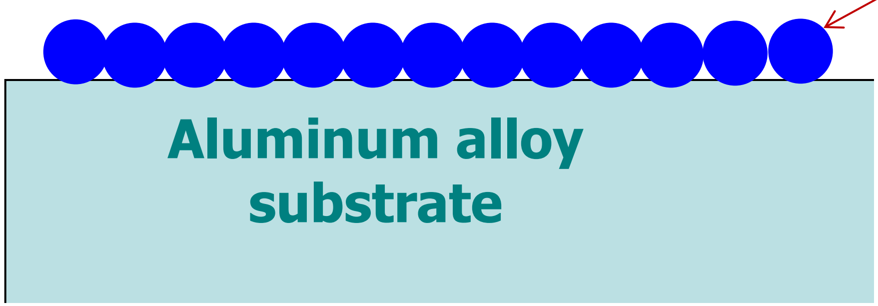
PATENT CSIC, TESAT , ESA

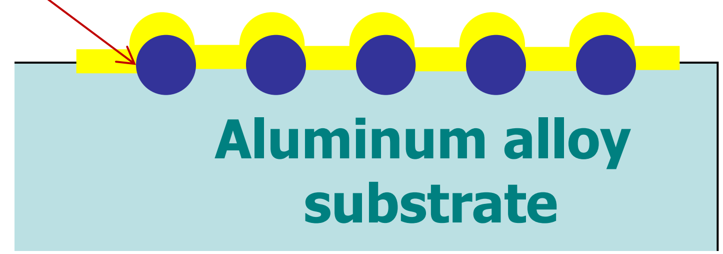
Micrometrical Al_2O_3 Particles Coating

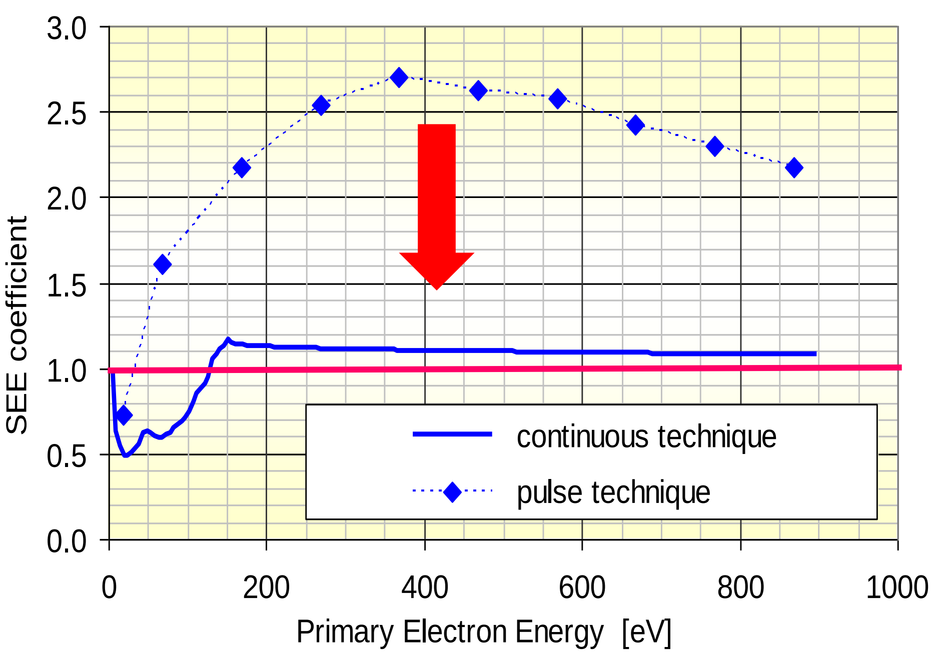
From suspension of nano-metrical Al_2O_3 particles

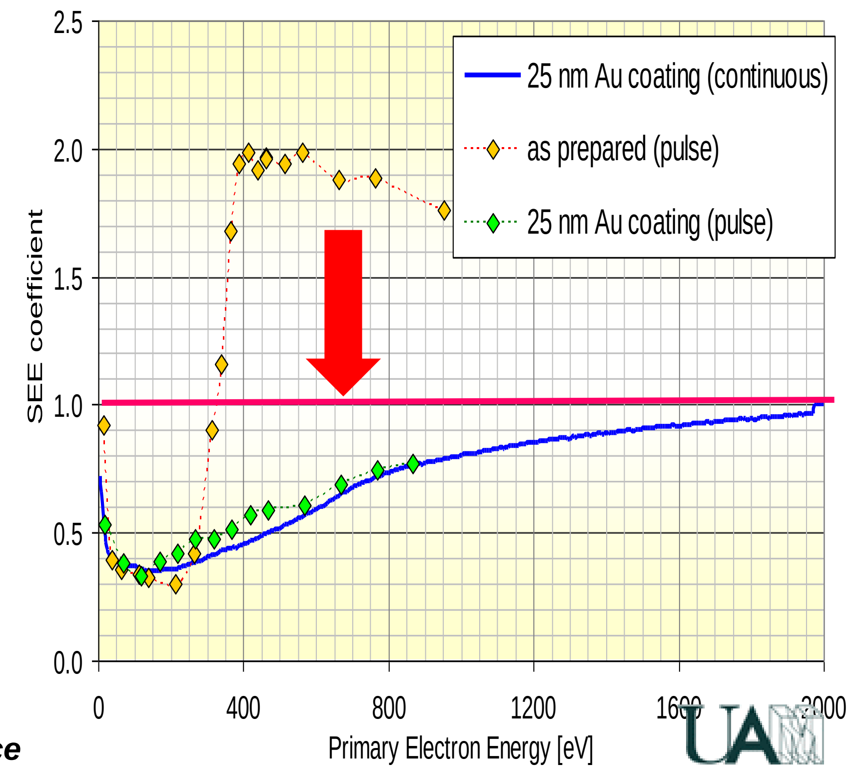
Indentation of micro-metrical ceramic particles

Al_2O_3





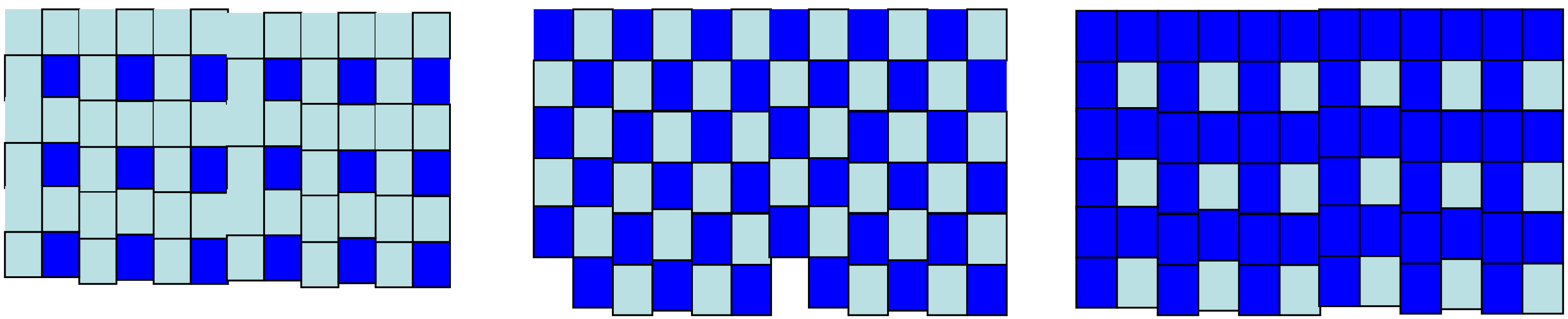




Extremely low secondary electron emission from metal/dielectric particulate coatings

Metallic/Dielectric MicroParticle Mixture

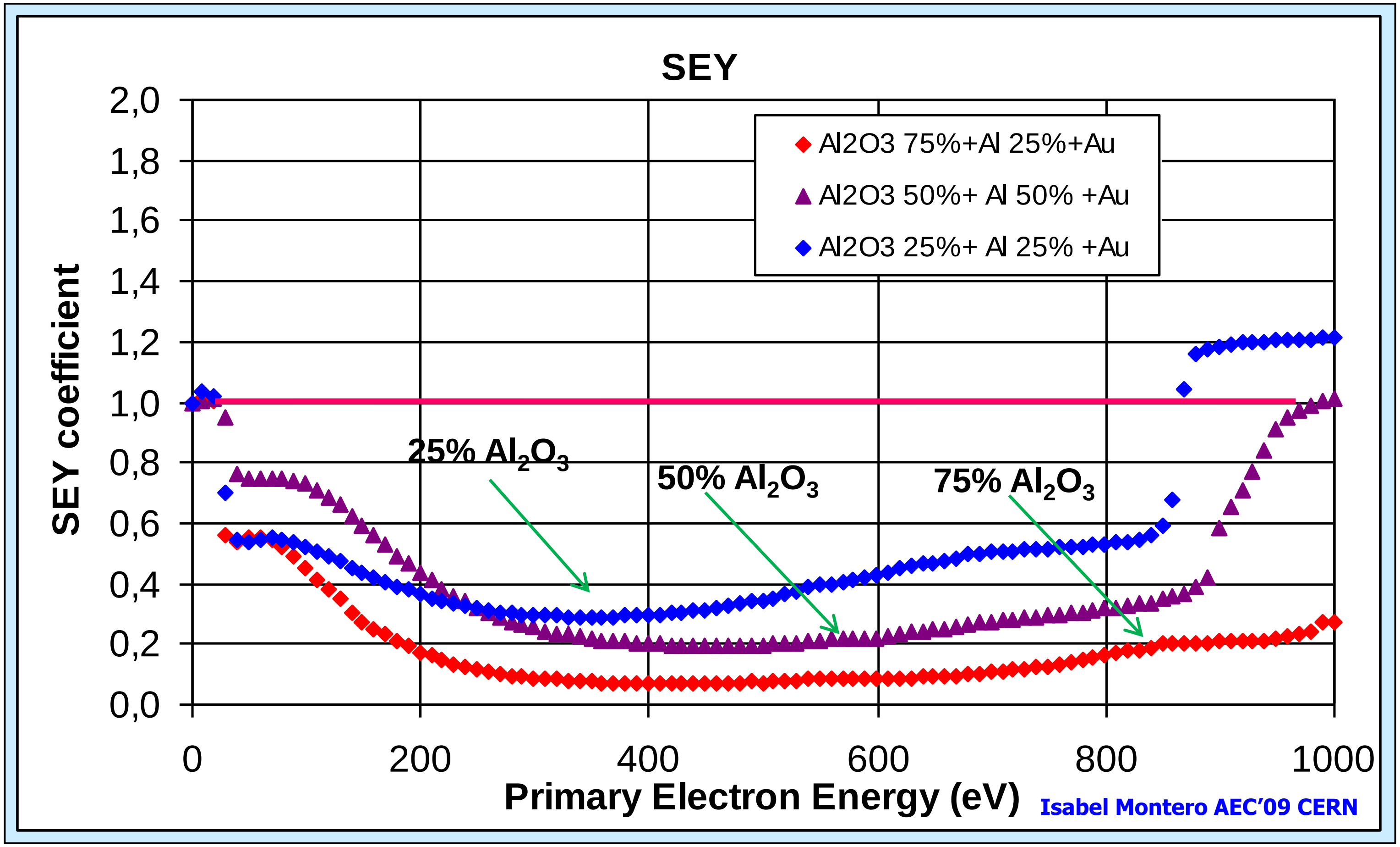
Irregular shape **Al particle** **Al_2O_3 particle**



25% Al_2O_3 **50% Al_2O_3** **75% Al_2O_3**

Surface top view

Extremely low secondary electron emission from metal/dielectric particulate coatings



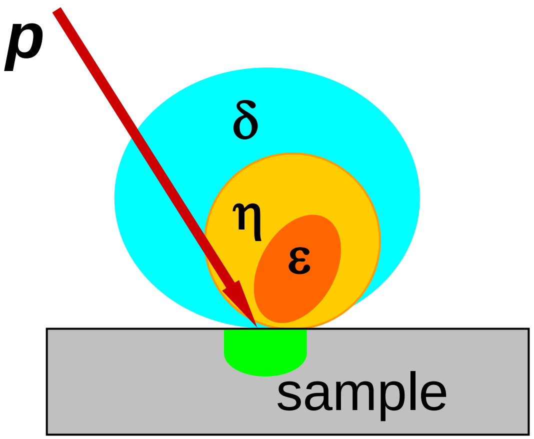
SEY values close to 0

Extremely low secondary electron emission from metal/dielectric particulate coatings

SEY Theoretical Model

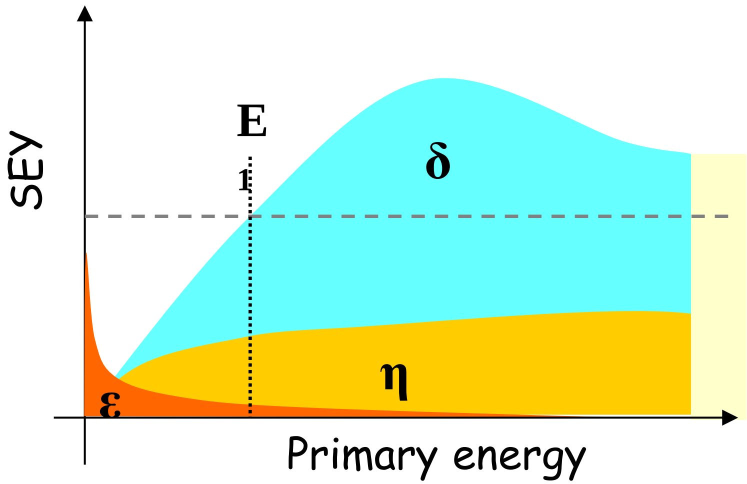
a simple atempt for explaining

Secondary electron emission yield (SEY)

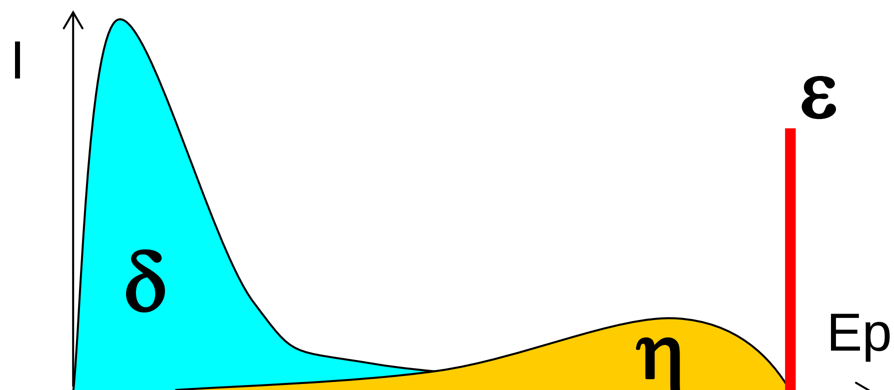


$$SEY = -I_\sigma/I_p$$

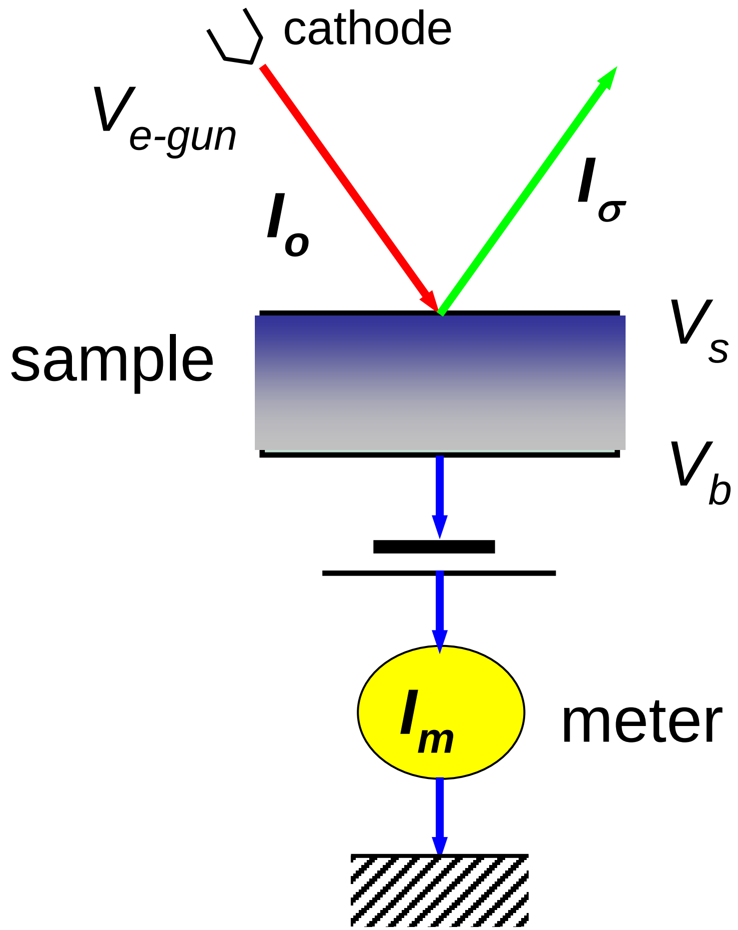
$$I_\sigma = I_\delta + I_\eta + I_\varepsilon$$



EDC, Energy Distribution Curves



Sample current technique for SEY test



$$\sigma_{eff} = \frac{I_\sigma}{I_o} = 1 - \frac{I_m}{I_o}$$

$$I_o = I_\sigma + I_m$$

During calibration with a Faraday cup ($I_\sigma = 0$),
I_o is measured in the pico-amp meter.

The apparent primary energy is:

$$E_p = V_b - V_{e\text{-}gun}$$

(in units of eV and V)

The real primary energy is:

$$E_o = V_s - V_{e\text{-}gun}\ .$$

In a perfect conductive sample $V_s = V_b$

$$\sigma_{eff}(E_o, V_s) = \delta_{eff}(E_o, V_s) + \eta_{eff}(E_o, V_s) + \varepsilon(E_o)$$

The Cumulative Probability Functions (MEST)

For the true secondary electron emission:

$$F_s(X) = \frac{2}{\pi}\arctan\left(\frac{\tan^2\left(\frac{\pi}{2}X^{n_s}\right)}{\tan(\frac{\pi}{2}\cdot X_s)}\right)$$

where $$X_s = 1.5\cdot\min\{\frac{\phi}{E_o}, 0.3\}\cdot\frac{\phi}{\phi+(E_o/75)}$$

and n_s = 0.65, ϕ = 5 eV are material *dependent constants* ($X_{max} \approx \phi/E_o$).

For the inelastically backscattered secondary electron emission:

$$F_b(X) = \frac{1-\cos\left(\pi\cdot X_b^{n_b}\cdot X^{n_b}\right)}{1-\cos\left(\pi\cdot X_b^{n_b}\right)}$$

where n_b = 1.5 and $X_b = (2^{1/nb}\cdot X_{max}) = 0.85$ are material dependent constants

The condition of stationary or *dc* SEY measurement is:

$$\sigma_{eff}(V_s) - 1 = I_m / |I_o| = (|I_o| \cdot R_o)^{-1} \cdot (1 + \alpha \cdot V_{sample}^{2}) \cdot V_{sample}$$

Explain atypical SEY: to solve this equation, i.e.,

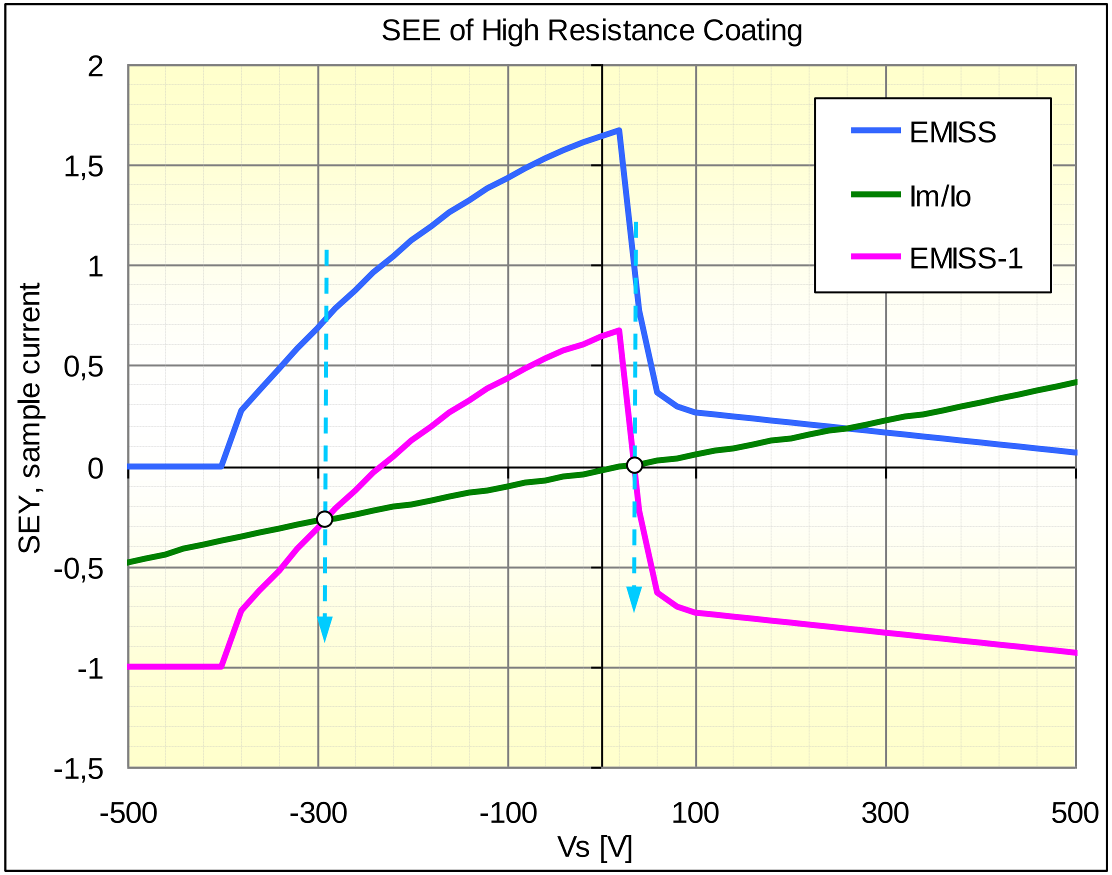
to find the possible values of E_p and V_{sample} solutions of this equation,

with $\sigma_{eff} - 1 < 0$, $I_m < 0$, and $V_{sample} < 0$

($V_{sample} > 0$ and $I_m < 0$ is not possible)

Two solutions for a certain wide primary energy (E_p) range above the first cross-over energy E_1

ATYPICAL

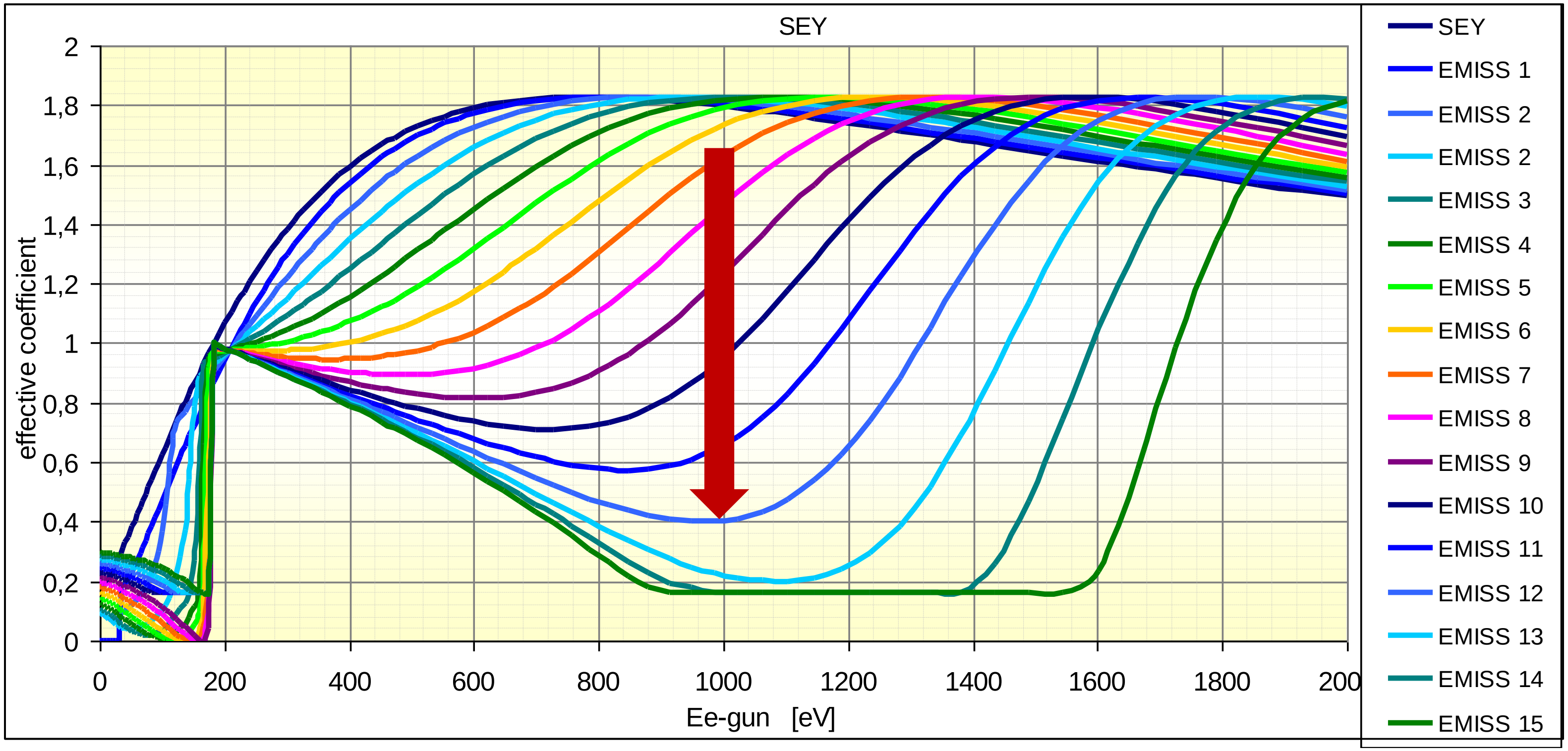


NORMAL

Secondary electron emission as a function of sample voltage, for E_p = 400 eV. EMISS = σ_{eff}

Micrometric metal/dielectric particles coatings

The atypical solution with $\sigma_{eff} < 1$, $V_s < 0$, and E_o decreasing from E_1 to values close to 0



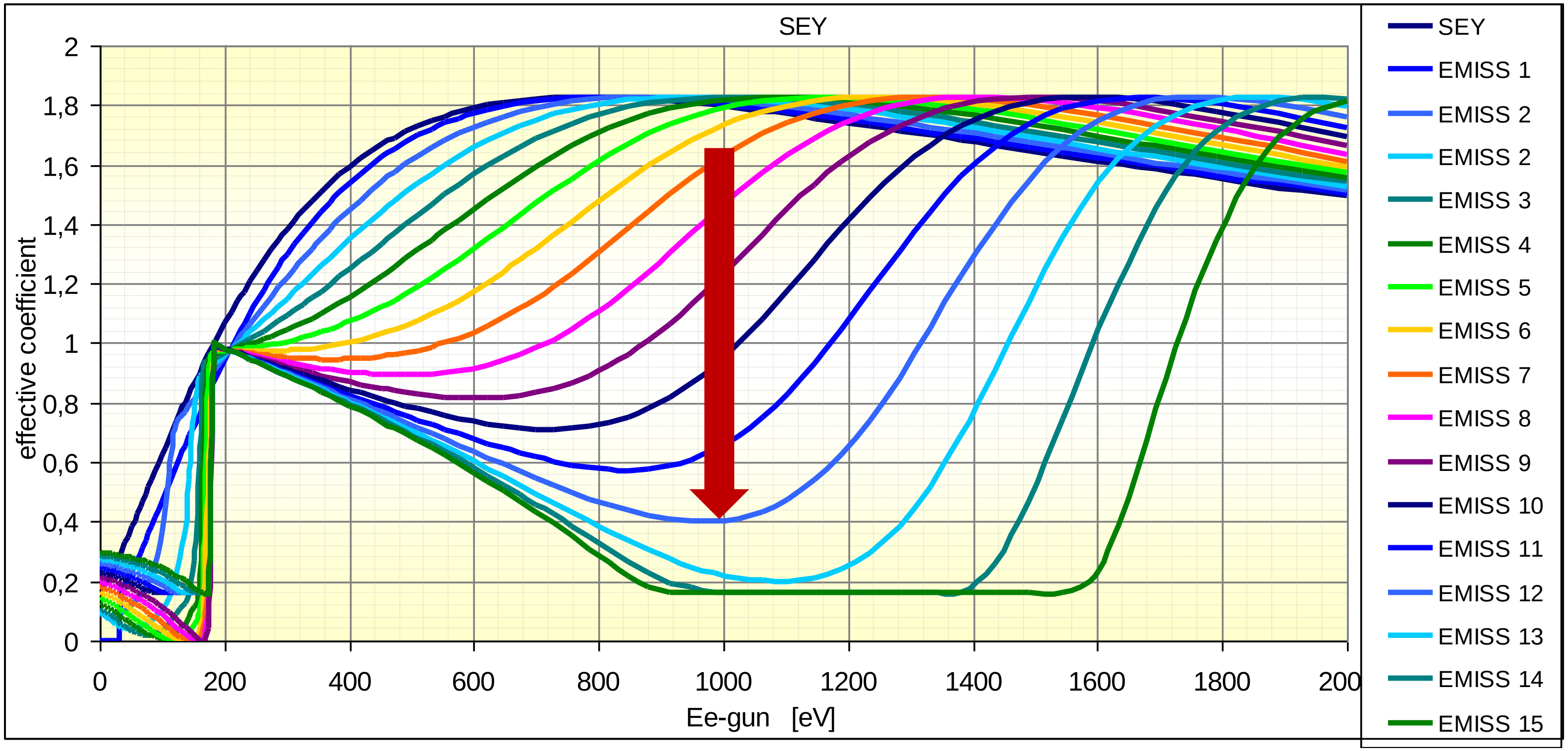
Evolution of effective SEY in an iterative procedure with

$$\Delta V_{sample} = -k\cdot(\sigma_{eff} - 1 - (I_m/|I_o|))$$

Convergence to $\sigma_{eff} < 1$ in a energy range 210 – 850 eV.

Micrometric metal/dielectric particles coatings

The **atypical** solution with $\sigma_{eff} < 1$, $V_s < 0$, and E_o decreasing from E_1 to values close to 0



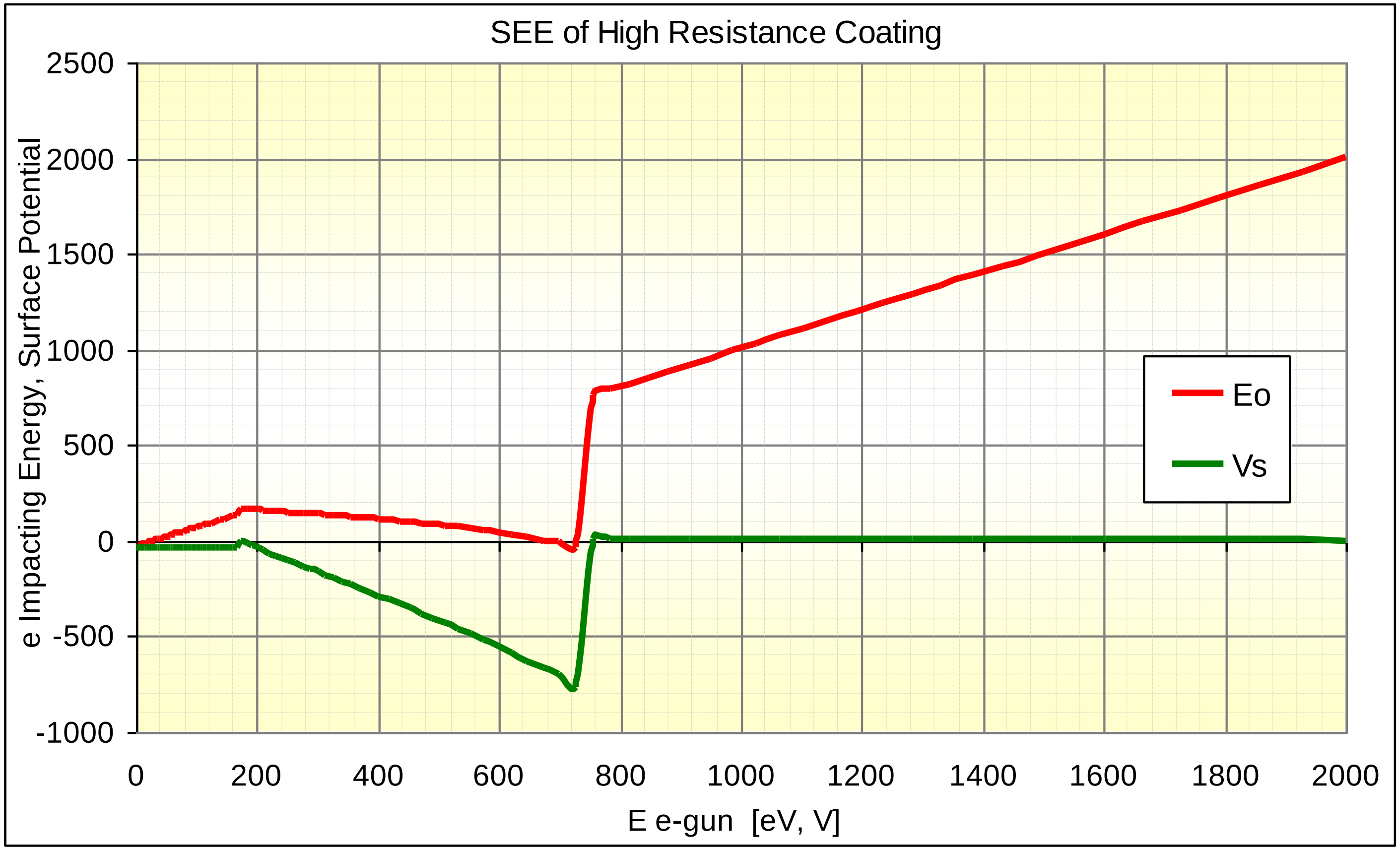
Evolution of effective SEY in an iterative procedure with

$$\Delta V_{sample} = -k\cdot(\sigma_{eff} - 1 - (I_m/|I_o|))$$

Convergence to $\sigma_{eff} < 1$ in a energy range 210 – 850 eV.

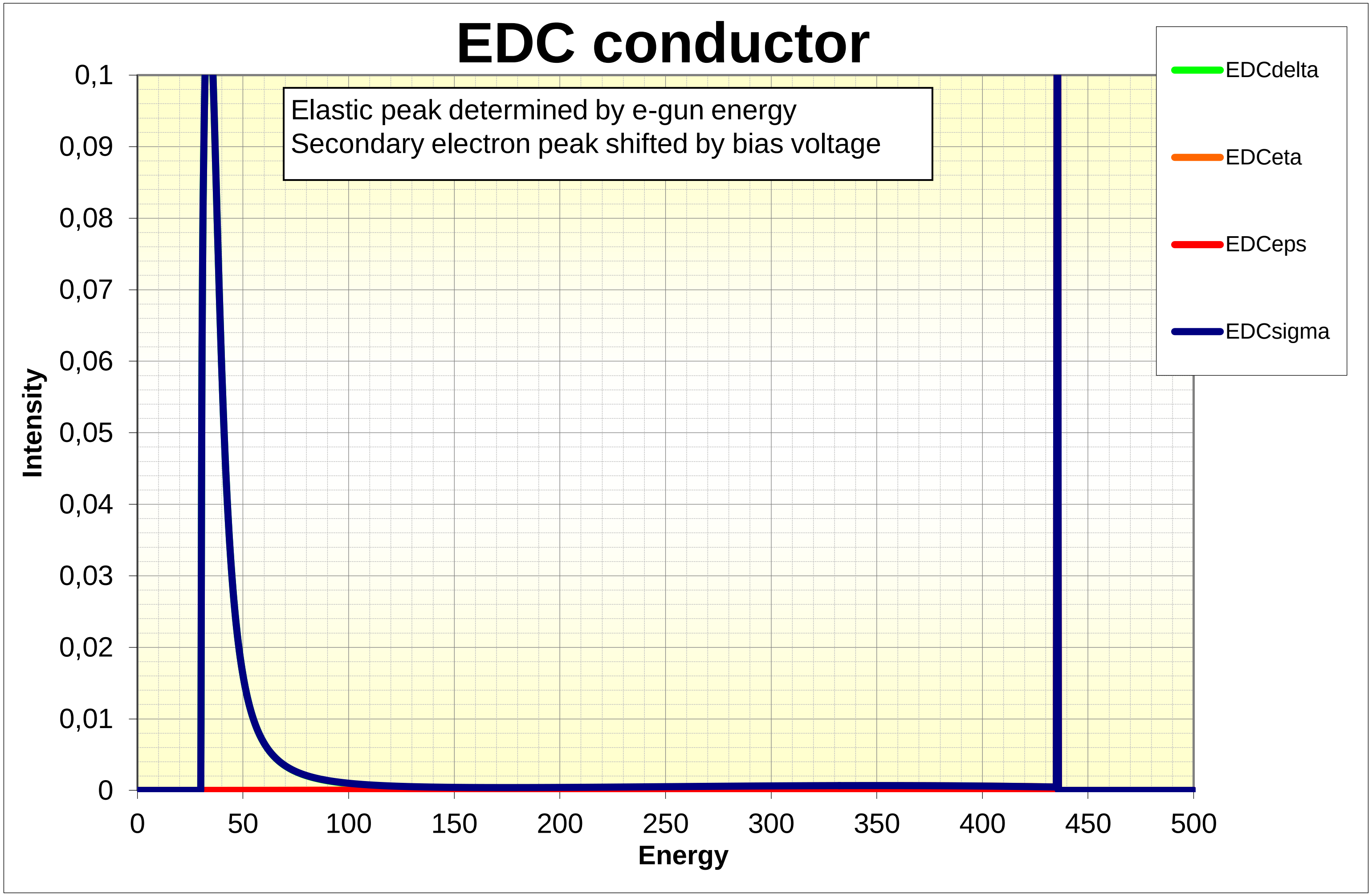
Above this wide energy range with two solutions, only the normal one, $\sigma_{eff} = 1+$, is always possible.

Micrometric metal/dielectric particles coatings

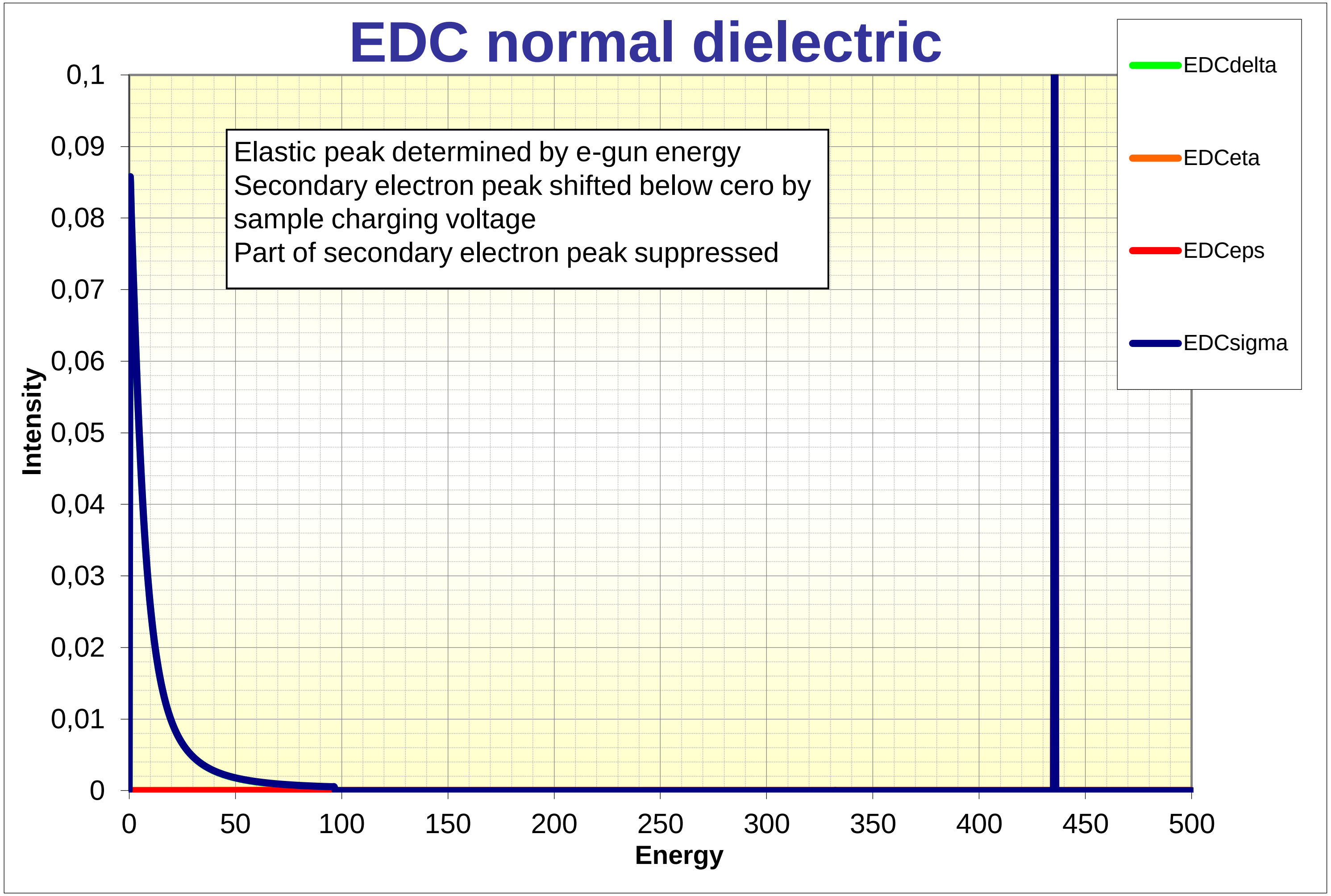


Real primary energy and surface potential of the high resistance coating
as determined by *Solver* of *Excel*

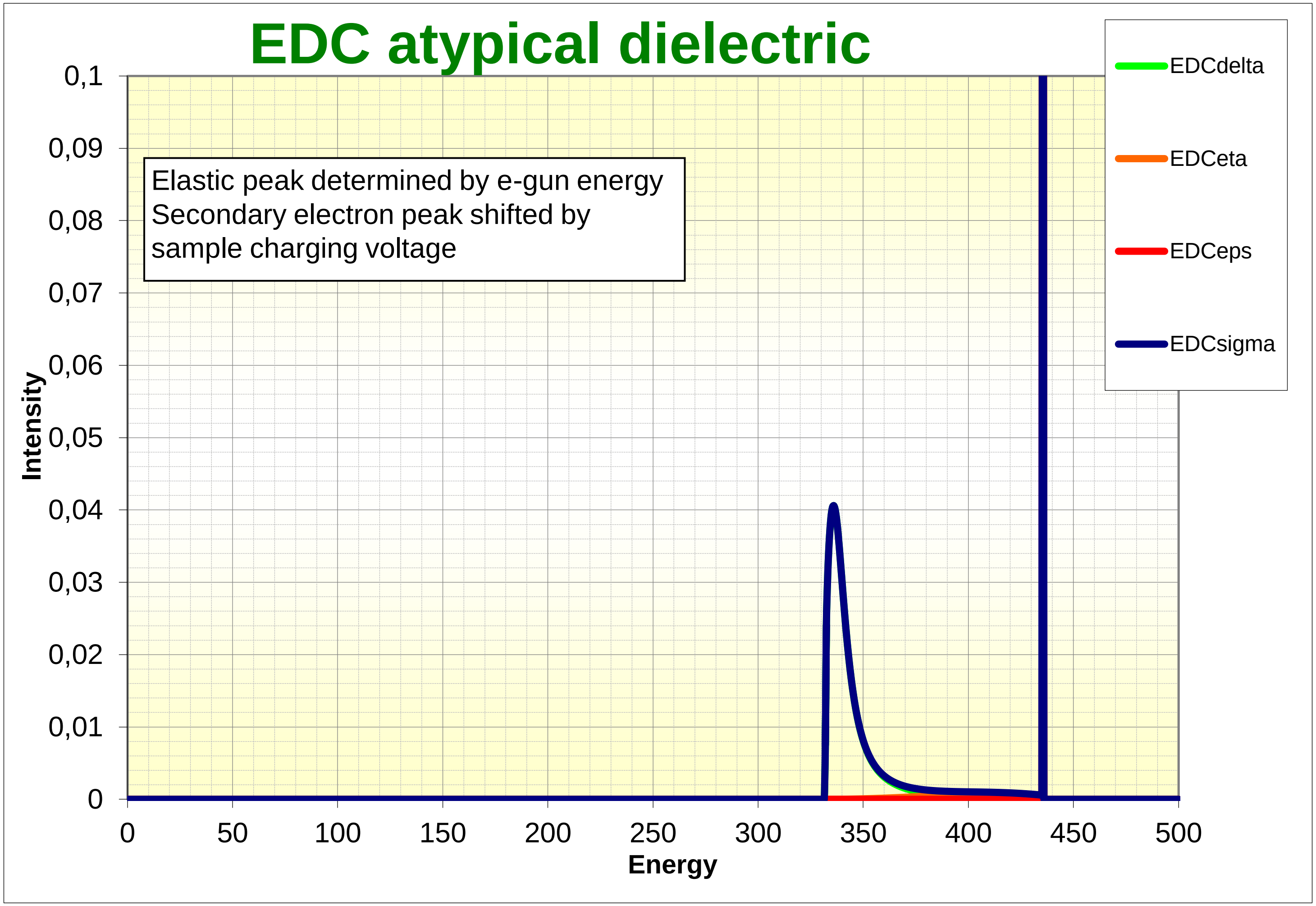
Energy Distribution Curves, EDC



Energy Distribution Curves, EDC



Energy Distribution Curves, EDC



Conclusions

MAIN CONCLUSIONS:

Coatings of micrometric surface roughness can avoid Multipactor effect.

SEY of metal/dielectric particulate coatings can be lower than 0.2 until Ep of the order of 1000 eV.

The extreme decrease of SEY of metal/dielectric particulate coatings could be explained by using a simple model:

Two different solutions were found:
the normal and the atypical one with extremely low-SEY values

Why the atypical one is chosen by metal/dielectric particulate coatings?

THANK YOU
FOR YOUR ATTENTION