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Extremely low secondary electron emission from metal/dielectric particulate coatings

Isabel Montero  
*Instituto de Ciencia de Materiales de Madrid*

L Aguilera  
*Instituto de Ciencia de Materiales de Madrid*

Leandro Olano  
*Instituto de Ciencia de Materiales de Madrid*

María E. Dávila  
*Instituto de Ciencia de Materiales de Madrid*

Luis Galán  
*Instituto de Ciencia de Materiales de Madrid*

JR Dennison  
*Utah State University*

*See next page for additional authors*

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Extremely low secondary electron emission from metal/dielectric particulate coatings

I. Montero, L. Aguilera, L. Olano, M. E. Dávila,
Instituto de Ciencia de Materiales de Madrid. CSIC. 28049-Madrid. Spain

V. Nistor, L. Galán
Applied Physics Dep., UAM

J. R. Dennison, G. Wilson
Materials Physics Group, Utah State University, Logan, Utah, 84322, USA
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
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 occurring under vacuum conditions
- Threatening any RF component
- Can cause disturbances/degradation of on-board satellite equipment and even total loss of the mission
\[ I_p = I_\sigma + I_s \quad I_\sigma > 0, \quad I_p < 0 \]

- \( I_s \) is measured in the sample
- \( I_p \) is measured in the Faraday cup

**Diagram:**
- \( V_g \) (e-gun cathode)
- \( V_c \)
- Collector connected to ground,
- Electrometers

Introduction
Development of coatings with low secondary electron emission yield (SEY)
Main objectives:

**Very low SEY**
- Like Au / roughAg
- \( \sigma_{\text{max}} < 1.5 \)
- \( E_1 > 200 \text{ eV} \)

**Very low RF surface resistance**
- Close to Ag
- \(< 1.5 \times R_{\text{surf}}(\text{Ag}) \)

**Very slow aging in air**
- > one year

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Secondary Emission Suppression by Surface Roughness of High Aspect Ratio

- Low SEY
- High $E_1$ value
- High stability in air  Ag, Au, ...
- High conductivity  Ag

Roughness: aspect ratio porosity
Anti-Multipactor Coatings Deposition Methods

- **Physical Vapor Deposition**
  - Evaporation
  - Ion implantation and/or reaction
  - Sputtering

- **Chemical Methods**
  - Chemical Etching or Growth
  - Anodization

- **Solid Particles Deposition**
ANTI MULTIPACTOR COATINGS

Different kinds tested:

- Aluminium
- Nickel
- Silver etched
- Gold-coated etched silver
- NEG-coated etched Al

Introduction

\[ \Delta \approx 1 \mu m \quad \frac{R_r}{R_s} = 2.4 \ @ \ 12 \ GHz \]

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**ANTI MULTIPACTOR COATINGS**

**DIFFERENT KINDS TESTED**

- Ag microstructured
- Nanoporous templates
- CuO nanowires

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Introduction

CuO nanowires

\[ T = 500\,^\circ\text{C}, \]

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DEFINITION OF SAMPLES

Harmonic low-pass corrugated filters = Multipactor samples

for low-power RF behaviour and multipactor threshold tests

K band 10.9 - 36.0 GHz

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Microstructured silver
Antimultipactor coatings for ESA

THE CHEMICAL TECHNIQUE

DETAIL OF THE STRUCTURE OF THE SURFACE

800 nm

800 nm

Ag

Antimultipactor coating, >10 μ

Ni(P) alloy, 10 μ

Al alloy device

PATENT CSIC, TESAT, ESA

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Antimultipactor coatings for ESA

SEY curves of treated filter

PATENT CSIC, TESAT, ESA

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Micrometrical \( \text{Al}_2\text{O}_3 \) Particles Coating

From suspension of nanometrical \( \text{Al}_2\text{O}_3 \) particles

Indentation of micrometrical ceramic particles

Aluminum alloy substrate

Al\(\text{2} \)O\(\text{3} \)

SEE coefficient

Primary Electron Energy [eV]

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Metallic/Dielectric MicroParticle Mixture

Irregular shape

25% $\text{Al}_2\text{O}_3$

50% $\text{Al}_2\text{O}_3$

75% $\text{Al}_2\text{O}_3$

Surface top view

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Extremely low secondary electron emission from metal/dielectric particulate coatings

SEY values close to 0

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SEY Theoretical Model

a simple attempt for explaining
Secondary electron emission yield (SEY)

\[ \text{SEY} = - \frac{I_\sigma}{I_p} \]

\[ I_\sigma = I_\delta + I_\eta + I_\epsilon \]

EDC, Energy Distribution Curves

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Sample current technique for SEY test

\[ \sigma_{\text{eff}} = \frac{I_\sigma}{I_o} = 1 - \frac{I_m}{I_o} \]

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

The apparent primary energy is:
\[ E_p = V_b - V_{e-gun} \]
(in units of eV and V)

The real primary energy is:
\[ E_o = V_s - V_{e-gun} \cdot \]

In a perfect conductive sample \(V_s = V_b\)

\[ \sigma_{\text{eff}}(E_o, V_s) = \delta_{\text{eff}}(E_o, V_s) + \eta_{\text{eff}}(E_o, V_s) + \epsilon(E_o) \]

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The Cumulative Probability Functions (MEST)

For the true secondary electron emission:

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

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

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

For the inelastically backscattered secondary electron emission:

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

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

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The condition of stationary or \textit{dc} SEY measurement is:

\[
\sigma_{\text{eff}}(V_s) - 1 = \frac{I_m}{|I_o|} = \left(\frac{|I_o| \cdot R_o}{|I_o|}\right)^{-1} \cdot (1 + \alpha \cdot V_{\text{sample}}^2) \cdot V_{\text{sample}}
\]

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

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

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

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

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

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

Evolution of effective SEY in an iterative procedure with

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

Convergence to $\sigma_{\text{eff}} < 1$ in a energy range 210 – 850 eV.
The **atypical** solution with $\sigma_{\text{eff}} < 1$, $V_s < 0$, and $E_o$ decreasing from $E_1$ to values close to 0

Evolution of effective SEY in an iterative procedure with

$$\Delta V_{\text{sample}} = -k \cdot (\sigma_{\text{eff}} - 1 - (I_m/I_0))$$

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

Above this wide energy range with two solutions, only the normal one, $\sigma_{\text{eff}} = 1+$, is always possible.
Real primary energy and surface potential of the high resistance coating as determined by Solver of Excel
Energy Distribution Curves, EDC

EDC conductor

Elastic peak determined by e-gun energy
Secondary electron peak shifted by bias voltage

Energy Distribution Curves, EDC
Energy Distribution Curves, EDC

EDC normal dielectric

- Elastic peak determined by e-gun energy
- Secondary electron peak shifted below cero by sample charging voltage
- Part of secondary electron peak suppressed

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Energy Distribution Curves, EDC

EDC atypical dielectric

Elastic peak determined by e-gun energy
Secondary electron peak shifted by sample charging voltage

Elastic peak determined by e-gun energy
Secondary electron peak shifted by sample charging voltage

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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