EXTREMELY LOW SECONDARY ELECTRON EMISSION FROM METAL/DIELECTRIC PARTICULATE COATINGS

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ABSTRACT

We have studied the SEY behaviour of a particulate coating composed of a mixture of a metal (aluminum) in solid state contact with a particulate dielectric material (polyimide thermosetting resin). Surface charging, roughness, and volume fraction are utilized as the main parameters to characterize the electron emission behaviour. Apart from the important role played by surface composition in the SEY, the influence of the dielectric volume fraction has demonstrated to be critical to achieve a significant reduction of SEY. it was found that E_1 of the particulate sample increased with increasing dielectric volume fraction. An extremely high first crossover energy, E_1>1000eV, was obtained after the gold metallization of the metal/dielectric coatings of 0.75 dielectric volume fraction. It is also remarkable that SEY was ~0.2 for E<1000 eV, the true secondaries appear to be reabsorbed.

1. INTRODUCTION

Research on low secondary electron emission coatings is essential for the design and manufacture of space high-power RF devices without Multipactor discharge [1]. This electron avalanche phenomenon appears for a determined power, frequency and electrode or wall distance and may destroy a RF equipment working in vacuum. Research on low secondary electron emission coatings is essential for the design and manufacture of space high-power RF devices without multipactor discharge. This paper discusses some of the factors that reduce secondary electron emission for metal-dielectric films. With the field of coatings to avoid electron discharges or Multipaction effect in high-power RF devices in space growing in recent years, there have been strong interests in finding suitable surface treatments to decrease the secondary electron emission. However, the list of candidates is restricted mostly to silver and gold, with a promise seen in rough surfaces [2]. In addition, the effects on spacecraft charging from varying material properties by exposure to the space plasma environment can also have profound effects on spacecraft charging [3]. This paper discusses some of the factors that reduce secondary electron emission for metal-dielectric surfaces.

2. EXPERIMENTAL PART

We have prepared particulate coatings composed of a mixture of a metal (aluminium particles) in solid state contact with a particulate dielectric material (polyimide thermosetting resin). This paper presents the SEY results and also specifies the measurement procedure of secondary electron emission for insulators and conductive samples in an ultra-high vacuum system, Figure 1. The secondary electron emission coefficients were determined on defined test samples under the same experimental conditions. All equipments for measuring were calibrated devices. Emission current of the electron gun was set to its calibration routine before tests start. The SEY experiments were performed in CSIC [1]. SEY (σ) was defined as $\sigma = (I_0 - I_s)/I_0$, where I_0 is the primary current and I_s is the sample current to ground. The current I_0 is always negative, while I_s can be positive or negative depending on the primary energy and SEY values of the sample. Low primary electron current (I_0 <5nA) were used to avoid surface contamination or modification. SEY can effectively be determined by continuous (total dose 42.5 nC/mm^2) and pulsed (1.1 fC/mm^2/pulse) electron irradiation methods. In this pulsed method one single pulse is used for each primary energy. The pulse time is 180 ns.

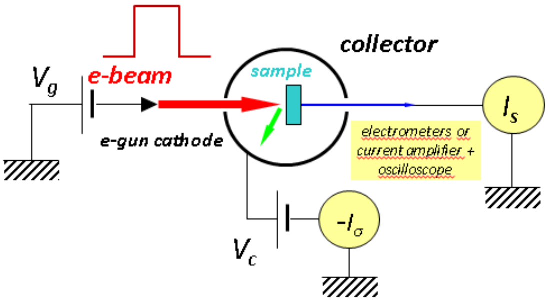


Figure 1. SEY general test

3. RESULTS

Figure 2 shows the SEY as a function of the primary energy of the metal particulate coatings composed of the following dielectric particles volume fractions: 0.25, 0.50 and 0.75.

In a metal/dielectric particulate coating the resulting properties can depend on the mass or volume fraction on the characteristics of the two types of components and on the way in which the particles are interconnected.

The connectivity of these coatings can be defined as the number of dimensions in which each component "phase" is continuous. Three connectivity patterns of biphasic coating were studied, connectivity 1-0 for 25% dielectric, 0-0 for 50% dielectric and 0-1 for 75% dielectric, Fig. 2.

We can observe in Fig.3 the metal/dielectric particulate coatings present extremely low SEY and the dielectric volume fraction is critical to achieve a significant reduction of SEY.

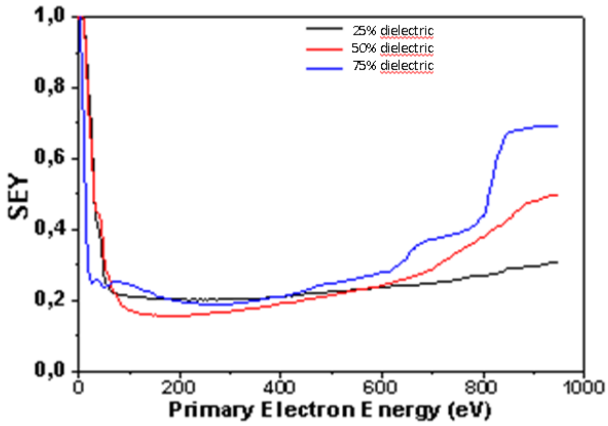
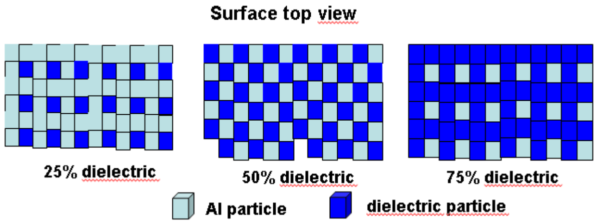


Figure 2. Total SEY of the metal/dielectric particulate coatings of Fig.2 as a function of the primary electron energy.

Thus, the first crossover energy for SEY = 1, E_1 of the particulate coating increased with increasing dielectric volume fraction. It is remarkable the very high E_1 after the gold metallization, being higher than 1000eV for 0.75 volume fraction. It is also remarkable that SEY was 0.2 for E<1000 eV.



.Figure 3. Three possible connectivity patterns of "diphasic" particulated coating.

Another remarkable fact is that SEY curves measured by using either the continuous or the pulsed methods coincide in the whole primary energy range, despite the much larger electron dose of the continuous method as compared to the very low dose of the pulsed method; this result is usually understood as an indication of minimal influence of charging on SEY.

An investigation on the possible explanation of the extremely low SEY was performed. The atypical behaviour of the SEY of a metal-dielectric composite coating which we attempt to explain is the observed effective total secondary electron emission yield less than one ($\sigma_{eff} < 1$) in a supposed or apparent range of primary energies where the real or intrinsic yield is expected to be greater than one, $\sigma > 1$, Eq.1. More expressly, in the SEY test technique based on the measurement of the sample current to ground, see Figure 4.

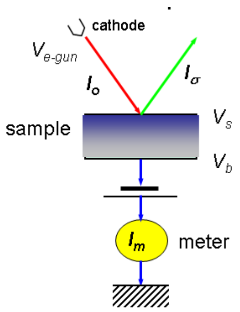


Figure 4. SEY setup. V_b= bias voltage, V_s= surface voltage, I_o = primary curreent, I_σ = secondary current, I_m = sample current.

$$\sigma_{eff} = \frac{I_\sigma}{|I_o|} = 1 - \frac{I_m}{I_o} \qquad (1)$$

where the emission current I_σ is defined as positive and the primary current is negative as measured in the pico-amp meter during calibration with a Faraday cup (I_σ = 0). It is assumed a stationary, or *dc*, measurement: the sample current $I_m = I_\sigma + I_o$.

The apparent primary energy is: $E_p = V_b - V_{e\text{-}gun}$ (in units of eV and V); while the real primary energy is: $E_o = V_s - V_{e\text{-}gun}$. In a perfect conductive sample $V_s = V_b$, and both energies are equal. Usually, a sample bias is used $V_b \approx -30$ V for avoiding secondary electrons from other parts of the analysis chamber. However, in this simple preliminary analysis, we will assume that for any $V_s < 0$, the total intrinsic secondary current $I_\sigma = \sigma \cdot |I_o|$ is emitted.

In the case of $V_s > 0$, only secondary electrons with energy $E > V_s$ are emitted; others are absorbed back into the sample, because the chamber walls are grounded. We will use the following notation for that, Eq.2:

$$\sigma_{eff}(E_o, V_s) = \delta_{eff}(E_o, V_s) + \eta_{eff}(E_o, V_s) + \varepsilon(E_o) \qquad (2)$$

(elastically backscattered electrons are always emitted unless $E_o < V_s$ and then $\sigma_{eff}(E_o, V_s) = 0$), where:

$$\delta_{eff}(E_o, V_s) = \delta(E_o)\cdot[1- F_s((V_s/E_o), E_o)]$$

and

$$\eta_{eff}(E_o, V_s) = \eta(E_o)\cdot[1- F_b((V_s/E_o), E_o)] \qquad (3)$$

δ, η, ε are the real or intrinsic true secondary, inelastically, and elastically backscattered electron yields, respectively, of the sample surface (all positive).

The functions $F(X, E_o)$, $X = V_s/E_o$, $0 \le X \le 1$, are the corresponding cumulative probability functions for primary energy E_o ; which are easily obtained from the inverse cumulative probability functions defined and given in [1]. :

In present analysis, the current through the sample creates a voltage gradient, Eq. 4:

$$V_s - V_b = V_{sample}(I_m) \qquad (4)$$

the I-V characteristics of the metal-dielectric composite coating, and we will assume with some generality, Eq.5:

$$I_m = R_o^{-1}\cdot(1+ \alpha\cdot V_{sample}^{2})\cdot V_{sample} \qquad (5)$$

In fact, we found that, as far as α is small, it has no qualitative significance, we can do equally well without that degree of freedom.

This sample voltage gradient will affect to the primary energy: $E_o = E_p + V_{sample}$, and to the secondary electron emission $\sigma_{eff}(E_o = E_p+V_{sample}, V_s = V_b +V_{sample})$. The condition of stationary or *dc* SEY measurement is, Eq.6:

$$\sigma_{eff}(V_s) -1 = I_m / |I_o| \qquad (6)$$

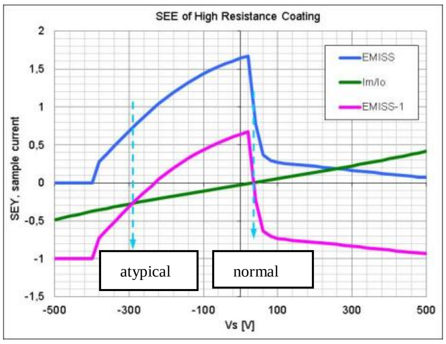


Figure 5. Secondary electron emission as a function sample voltage, for E_p = 400 eV. EMISS = σ_{eff} . Others, according to text.

Therefore, the proposed problem is 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 $V_{sample} < 0$.

We have found that in general, for highly resistive samples, there are two solutions for a certain wide primary energy (E_p) range above the first cross-over energy E_1, see Fig. 5, the normal one in dielectrics: $\sigma_{eff} = 1$ and $V_s \approx 5 - 7$ V positive; and a anomalous one with $\sigma_{eff} < 1$, $V_s < 0$, and E_o decreasing from E_1 to values close to 0.

The normal solution is reached in an iterative sequence if $\sigma_{eff} -1 > I_m /|I_o|$ produces a $dV_{sample} > 0$; if the opposite, the atypical solution is reached. Above this wide energy range with those two solutions, this simple model predict the normal one, $\sigma_{eff} = 1$.

4. CONCLUSIONS

SEY as a function of the primary electron energy of particulate metal/dielectric coatings were measured for three dielectric volume fractions: 0.25, 0.50 and 0.75.

We have found an extremely low SEY, ~0.2, up to $E_1 >$ 1000eV. A simple model is proposed to explain the atypical SEY curves as a function of the primary energy. In this analysis, it is assumed that for any $V_s <$ 0, the total intrinsic secondary current $I_\sigma = \sigma\cdot|I_o|$ is emitted, for $V_s > 0$, only secondary electrons with energy $E > V_s$ are emitted; others are absorbed back into the sample, because the chamber walls are grounded. The non-linear I(V) characteristic proposed predicts two different solutions: the low-SEY (atypical SEY curve) and the usual SEY = 1.

ACKNOWLEDGEMENTS

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