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DYNAMIC SECONDARY ELECTRON EMISSION IN DIELECTRIC/CONDUCTOR MIXED COATINGS

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INTRODUCTION

Secondary Emission Yield (SEY) of dielectric materials is of great importance for prediction and testing of the Multipaction discharge in RF components for space applications. An atypical behavior of the SEY of coatings composed by a mixture of conductor and dielectric microparticles was reported and modeled in [1]; in this original model, the interactions between dielectric and conductor particles were not taken into account, but an effective action of the surface voltage generated within the sample was included. The aim of the present contribution is to more accurately model the effect the electric fields between dielectric and conductor particles have on secondary electrons emitted by the sample. One of the most prominent features of the coatings is their roughness, so a model is proposed here that takes into account both the roughness and the charging of the dielectric particles to explain the unusual charging behavior of these coatings.

EXPERIMENTAL RESULTS

Two different coatings were selected to produce composite materials with low yields: (i) a mixture of polyimide thermosetting resin (dielectric) and aluminum microparticles (referred to as Type 1 samples) and (ii) zeolites coated by gold nanoparticles (referred to as Type 2 samples). Results for Type 1 coatings were reported in [1]. The surface roughness of Type 1 coatings is due to the irregular shape and different sizes of both dielectric and conductor microparticles. The mixture of dielectric and aluminum particles was deposited on an aluminum substrate using a conductive-adhesive graphite tape layer. This procedure was also used to affix the zeolite nanoparticles to the aluminum substrate in Type 2 samples. For Type 2 samples, gold nanoparticles were subsequently deposited over the zeolites using a standard sputtering method resulting in a ~2nm thick gold layer. The roughness of Type 2 samples is due only to that of the zeolites.

Type 1 samples are therefore composed of a mixture of dielectric particles and conducting particles (which are grounded through the tape/substrate). Type 2 samples have an isolating material—the zeolite particles—which are intermittently covered by a gold layer (see **Fig. 1**). The gold layer in this sample can also be considered a grounded surface.

The SEY (which here refers to all emitted electrons at all energies) was measured as a function of the primary electron energy using both pulsed and continuous measurement methods. Pulsed methods used a pulse duration of 180 ns and a pulse dose of 1fC/mm^2. The continuous method linearly increases the energy of the primary electrons as a function of time and typically uses a total dose of 40nC/mm^2. All measurements were taken in an ultra-high vacuum (UHV) chamber with pressure of 10^{-9} hPa.

When the continuous method was used to obtain the SEY curves, both types of samples showed an unusually large first cross-over energy (the lowest primary energy at which SEY = 1), named E1C, where C stands for 'charged'. Type 1SEY curves had E1C > 1000eV [1], while those of Type 2 had E1C ~ 300eV. By contrast, when SEY was measured using the pulse method, Type 2 SEY curves exhibited a more typical E1 < 100 eV (see **Fig. 2**). However, E1 of the Type 1 samples was the same when measured with both continuous and pulse methods. For both Type 1 and 2 coatings, the SEY decreased to values close to 0.2 for primary energies smaller than E1C when measured with a continuous method. However, for Type 2 samples, such extremely low SEY values were not observed using the pulsed method. These findings are summarized in **Table 1.**

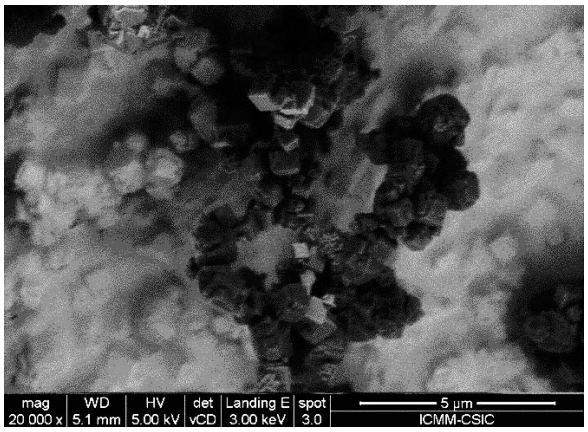

Fig. 1. Scanning electron microscopy (SEM) image (backscatter mode) of a Type 2 sample. Bright areas are gold coated regions of the sample and darker areas are uncoated zeolite regions. This confirms that there are sample regions that are not gold coated.

Table 1. Secondary emission yield parameters for the Type 1 and 2 samples.

Sample	E_1^C (eV)	E_1 (eV)	E_{max} (eV)	σ_{max}
Type 1	> 1000	-	-	< 1
Type 2	320	90	~800	1.5

Additionally, SEY transients were registered when Type 2 samples were irradiated at a fixed primary energy with 100 µs-wide pulses (~500 fC/mm2 per pulse) at a pulse frequency of 100 Hz (see
Fig. 3). For primary energies E < E1C, the SEY values decreased from the yield measured at low accumulated charge (for low flux using the single pulse method) to the SEY measured at accumulated charge (for high flux using the continuous method). By contrast, SEY transients were also registered for primary energies larger than E1C. In this case, the SEY increased with increasing accumulated charge from sequential pulses. For both E < E1C and E > E1C, the SEY did not reach unity with many subsequent pulses, as happens for typical insulating material or isolated conductors (For negative charging at E < E1, electrons are stopped before they reach the surface due to the negative potential that arises at the surface after charging. For positive charging at E > E1, emitted electrons are reattracted to achieve an equilibrium positive surface potential and unity yield) [2-4]. In addition, ~100s after the electron irradiation was stopped, the sample had recovered its initial (low charge) SEY value. We interpret this transient behavior as partial charging of isolated insulators or conductors, which randomly discharge prior to their reaching an equilibrium surface potential and unity yield. Such electrostatic discharge would occur at lower potentials than for smooth surfaces, due to enhanced fields from the rough surface.

MODEL RESULTS

To simulate such SEY behavior, a model based on both surface roughness and charging of the dielectric particles is proposed. We consider a 1D-geometry where the conductor and dielectric particles are equal and triangular with angles 45º-90º-45º and consecutively placed one next to another. An aspect ratio of 1/2 was selected, with a distance between triangles of 1µm, as a reasonable model of the surface shown in Fig. 1.

Total charge in the dielectric is computed sequentially after each pulse of primary electrons. First the charging due to the incident electrons and second the discharge of the dielectric particles with an RC ~ 100s as measured. The external electric field due to evolving accumulated charge on the dielectric particles affects the number and energy of emitted electrons, which have to overcome the field in order to escape to vacuum. In this model, SEY is computed as a function of the charge evolution in the dielectric particles. We take into account modifications in the SEY due to the different landing energy at which the primary electrons hit the dielectric particles due to its evolving surface potential.

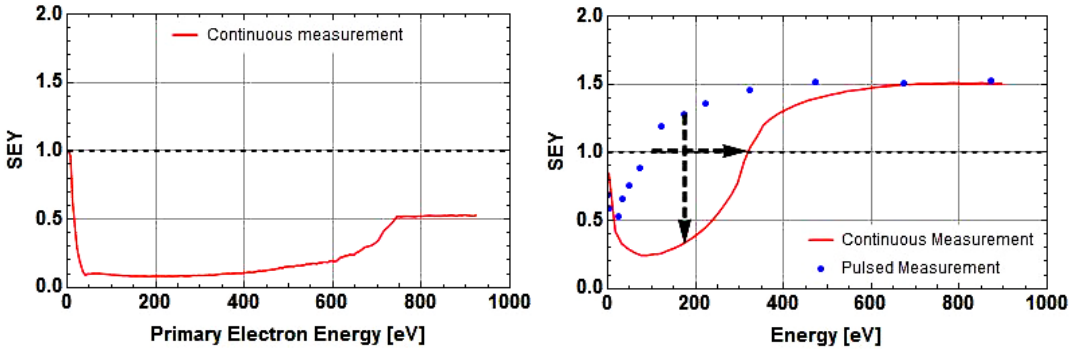

Fig. 2. SEY curves measured with the continuous beam method (red lines) for Type 1 (left) and Type 2 (right) samples. SEY curve measured with the pulse method for a Type 2 sample (blue dots). The crossover energy of the Type 2 sample shifted to higher energies and its SEY for E< E_1^C decreased to low values, as indicated by the arrows.

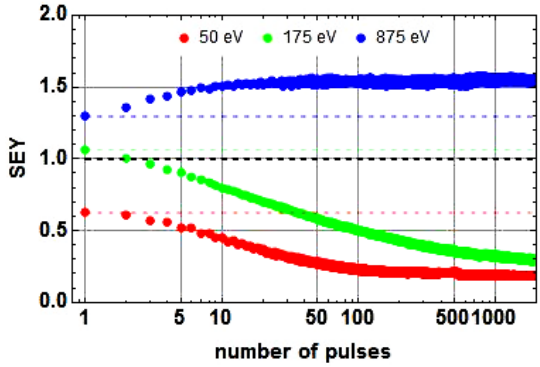

Fig. 3. SEY evolution as a function of the number of pulses (charge per pulse 1pC/mm^2) of Type 2 sample for three different energies (red 50eV< $\mathbf{E_1}$, green E_1<175eV<$\mathbf{E_1^C}$, blue 875eV> $\mathbf{E_1^C}$**)**.

Continuous and pulsed experimental SEY measurements were simulated with this evolving SEY model. As can be seen in **Fig. 4** (left panel), the continuous method diminishes the SEY below the one measured by the pulsed method. This can be explained by the fact that the secondary electrons, once emitted, cannot escape because of the external electric field near the surface of the sample. This field pushes some of them towards the conductor particles when the accumulated charge in the dielectric is negative. It also, inhibits the emission of the secondary electrons from the conductor, as they have to climb up the potential that arises from the dielectric particles. Coupled with roughness, this potential acts as a highly effective electron trap, which is actually independent of the sign of the accumulated charge in the dielectric particles.

It can also be seen in **Fig. 4** (left panel) that the continuous method displaces the first cross over energy from E1~100eV of the uncharged sample to the one obtained by it, E1C~300eV. This is due to two facts: (i) the incident electrons on the dielectric are slowed down by the negative charge accumulated on them by previous lower energetic incident electrons. (ii) as the sample is negatively charged, when the incident electrons on the dielectric have an energy bigger than the E1 of the dielectric the emission of some of those secondary electrons is inhibited rendering an SEY smaller than 1. This electrons end up in the conductive particles, therefore, the dielectric particles are discharging at this point. This discharging process is leaded by the emission of electrons in the dielectric and not by the dissipation of electrons to earth.

This evolving SEY model also explains the unusual behavior in which the SEY of the coating when irradiated by a train of pulses with constant energy (50eV< E_1^C and $\mathbf{E_1}$<175eV<E_1^C) exhibit anomalous behavior, i.e. does not tend to SEY = 1 as it occurs for pure dielectric materials. In the mixed particle coatings this is explained by the electric fields that arise in the space between conductor and dielectric particles as explained above. However, for the case of 875eV> E_1^C, to simulate the increase of the SEY as a function of accumulated charge at high primary energies (Fig. 4, blue line); an initial negative surface density charge is required. This is in agreement with the fact that the SEY measured at the beginning of

the train of pulses was lower than SEY of the uncharged coating. The external electric field produced by the initial charge pulled some of the secondary electrons back to the sample. As the primary electrons impinged on the dielectric surface, such initial charge decreased because at that primary energy the SEY > 1, and the number of emitted electrons increased.

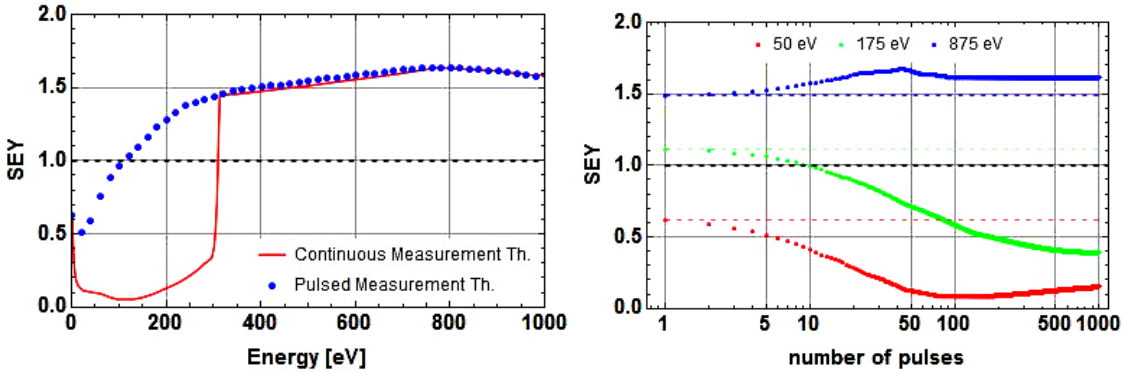

Fig. 4. Results of the SEY simulations as functions of primary energy and number of pulses.

As can be seen in Fig.2-4, there are many similarities between the experimental and simulation results. The simulation results in Fig. 4 for Type 2 samples Show that: (i) the first crossover energy for SEY = 1 of the continuous measurements is displaced toward higher energies (left panel) and (ii) the SEY of the charging curves do not tend to one as a function of the accumulated charge (right panel). For insulating materials, such as the Type 1 polyimide thermosetting resin samples studied in [1], E1C is shifted towards higher energies with higher values of the accumulated charge density in the dielectric particles also observed.

ACKNOWLEDGEMENTS

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