DYNAMIC SECONDARY ELECTRON EMISSION IN DIELECTRIC/CONDUCTOR MIXED COATINGS

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INTRODUCTION

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

EXPERIMENTAL RESULTS

Two different coatings were selected: a mixture of polyimide thermosetting resin (dielectric) and aluminum microparticles (named Type 1 samples), and zeolites coated by gold nanoparticles (named Type 2 samples). Type 1 coatings are the ones 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 dielectric and aluminum particles mixture were deposited on the aluminum substrate through a conductive graphite tape layer. This procedure was also used to fix the zeolite nanoparticles to the aluminum substrate in Type 2 samples. In these samples, gold nanoparticles were deposited over the zeolites by sputtering method making a 2nm thick gold layer. The roughness of these samples is only due to that of the zeolites.

Type 1 samples are therefore composed by the dielectric and the conducting particles, which are grounded through the substrate. Type 2 samples have as isolating material the zeolite particles, which are randomly covered by a gold layer as can be seen in Fig. 1.The gold layer in this sample can also be considered a grounded surface.

The SEY was measured as a function of the primary electron energy using pulsed and continuous measurement methods. Pulsed method have a pulse duration of 180 ns and a pulse dose of 1fC/mm2. The continuous method linearly increases the energy of the primary electrons as a function of time and it typically uses a total dose of 40nC/mm2. All measurements were taken in an ultra-high vacuum (UHV) chamber with pressure of 10-9 hPa.

When the continuous method was selected to obtain the SEY curves, both Type of samples showed an unusually large first cross-over energy (first primary energy at which SEY = 1), named E1C, where C stands for ‘charged’. SEY curves of Type 1 has E1C > 1000eV and those of Type 2 had E1C ~ 300eV. However, when SEY is measured using the pulse method, the SEY curve of Type 2 samples exhibited a more usual E1 < 100 eV, Fig. 2. However, E1 of the Type 1 samples did not change respect to the SEY results measured with the continuous method. For both coatings Type 1 and 2, the SEY decreased to values close to 0.2 for primary energies smaller than E1C when continuously measured. However, for the case of Type 2 samples, such extremely low value for the SEY was not observed by the pulsed method.

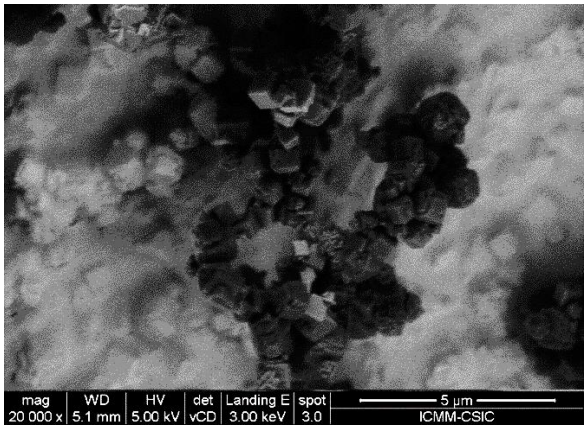

Fig. 1. SEM image (backscatter mode) of the Type 2 sample. Bright areas are gold coated areas of the sample and darker are zeolite (non-gold coated) areas. We can see how there are areas that are not gold coated.

Additionally, the SEY transients were registered when Type 2 samples were irradiated at a fixed primary energy and 100 µs-wide pulses with a frequency of 100 Hz, Fig. 3. For primary energies E < E1C, the SEY values decreased from the one measured by the single pulse method to the SEY measured with the normal dose (continuous method). Conversely, it was also observed for an energy primary larger than E1C that the SEY increased with the deposited charge by this train of pulses. In all cases, the behavior of the SEY did not approach to one as the charge built up, as it should do in a usual isolating material [2-4]. In addition, ~100s after the electron irradiation was stopped, the sample had recovered its initial SEY.

RESULTS

To simulate such SEY behavior we propose a model based in both surface roughness and charging of the dielectric particles. We consider a geometry where the conductor and dielectric particles are triangular and consecutively placed one next to another. An aspect ratio of 1/2 is selected with a distance between particles set to 1µm.

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

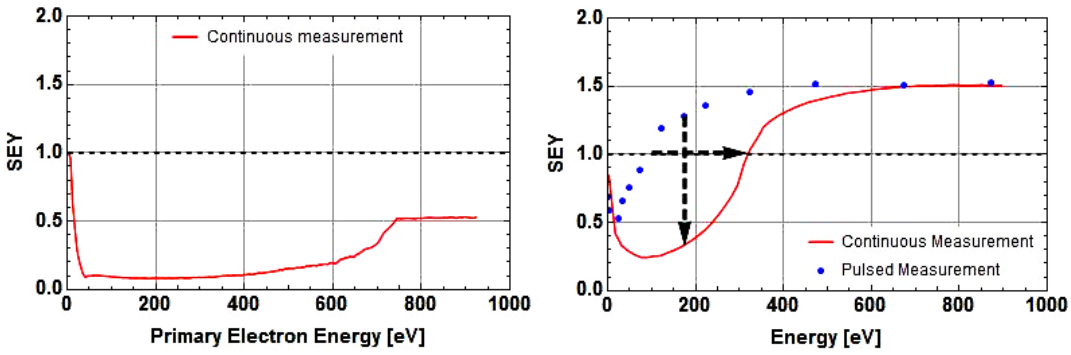

Fig. 2. SEY curves obtained by the continuous measurement method (red lines), Type 1 (left) and Type 2 (right). SEY measured by the pulse method of Type 2 (blue dots). The cross over energy of Type 2 sample shifts toward high energies and its SEY for E<E1c decreased toward low values.

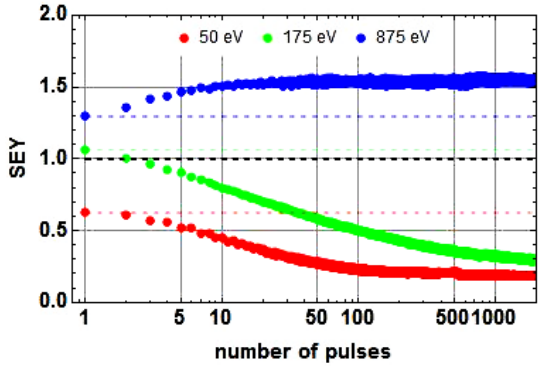

Fig. 3. SEY evolution as a function of the number of pulses (dose per pulse 1pC) of Type 2 sample for three different energies (red 50eV, green 175eV, blue 875eV. All three of them present an anomalous behavior.

Total charge in the dielectric is computed sequentially after each pulse of primary electrons. After every pulse, the evolution of the charge in the dielectric particles was evaluated. The external electric field due to the charged dielectric affects to the emitted secondary electrons, which have to climb it in order to escape to vacuum. In this model, the secondary electron emission is computed as a function of the charge evolution in the dielectric particles. We take into account the reduction of the energy at which the primary electrons hit the dielectric particles due to its surface potential.

Continuous and pulsed experimental SEY measurements were simulated with this model. As can be seen in Fig. 4, for an energy at which primary electrons should have a SEY > 1, the charging of the dielectric particles maintain SEY < 1. This is due to two facts: 1) the primary electrons are slowed down (SEY decreases) and 2) the secondary electrons, once emitted, cannot escape because of the external electric fields near the surface of the sample. It is important to notice that at energies < E1C, the SEY can be lower than the lowest SEY of these coatings when they are uncharged. This can be explained by the synergic effect of dielectric and conductive particles of the coatings. This model also explain the unusual behavior in which the SEY of the coating when irradiated by a train of pulses with constant energy, does not tend to SEY = 1. For a pure dielectric material that tendency is not possible but in the mixed coatings, the electric fields that arise in the space between conductor and dielectric particles, can evolve into highly effective electron traps, independently of the sign of the accumulated charge in the dielectric particles).

In this model, to simulate the increasing of the SEY as a function of the accumulated charge at high primary energies (Figs. 3 and 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 high energy the SEY > 1, and the number of emitted electrons increased.

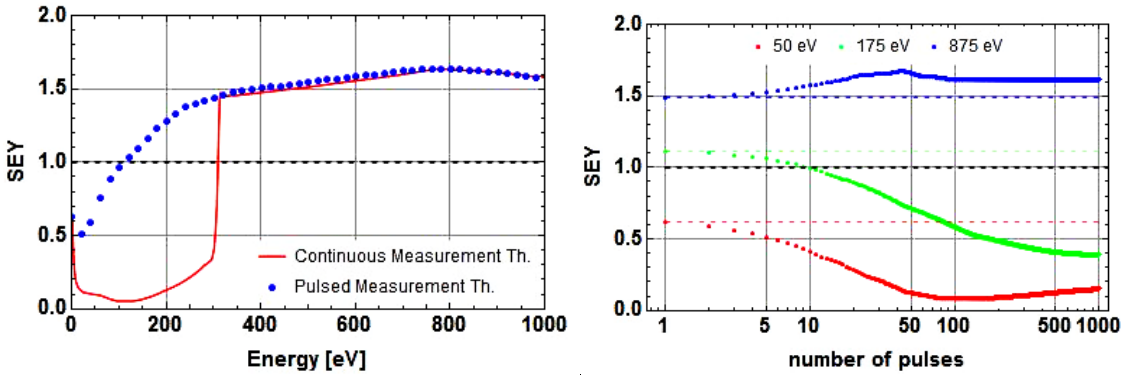

Fig. 4. Results of the simulation. We can observe this model simulated the SEY behavior of the experimental results. The first cross-over energy for SEY = 1 of the continuous measurements is displace toward higher energies (left panel) and the SEY of the charging curves does not tend one as a function of the accumulated charge (right panel).

As can be seen in Figs. 2-4, there exists a great resemblance between experiment and simulation results. The simulation results in Fig. 4 is for Type 2 samples. For insulating materials, as the polyimide thermosetting resin in Type 1 samples, the E1C is shifted towards higher energies with also higher values of the accumulated charge density in the dielectric particles.

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