SECONDARY EMISSION FROM INTERPLANETARY DUST GRAINS

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ABSTRACT. Secondary emission can play an important role in the charging of dust grains. This process is very sensitive to their size and to the physical properties of the solid. It is particulary important in the case of insulators in which an intense electric field is present at the surface and can accelerate the excited electrons.

As a consequence, the secondary emission yield δ does not depend on the energy of primaries and multiple solutions of the potential due to the usual non-monotonic form of δ versus the energy of primaries disappear.

1. INTRODUCTION.

When an electron impinges upon the surface of a metallic or dielectric material, it will suffer elastic reflection or be scattered by electrons in the material; it may also induce an excitation of the inner electrons which are ejected out. This last mechanism is known as the "true secondary emission".

In this paper, we present a specific new aspect of the true secondary emission taking place in porous dielectric materials such as those present in the interplanetary medium.

2. MAIN FEATURES OF THE ORDINARY TRUE SECONDARY EMISSION

In this mechanism, electrons excited to energies greater than the ionization energy, can escape through the potential barrier of the material.

The secondary yield δ - the number of secondary electrons induced by one primary electron - has a maximum value ranging from 1 (for metals and semi conductors) to 20 and more for insulators.

This ratio depends upon three factors: the energy of primaries, their angle of incidence and the nature of the material (Whipple, 1981).

The shape of the secondary yield curve as a function of primary energy is an universal curve when normalized to the maximum yield δ_m and the primary energy at this maximum E_m (Dekker, 1958).

After averaging w.r.t. the angle of incidence, the resulting analytic formula

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$$\delta(E) = 7,5\ \delta_m\ \ E/E_m\ \ \exp\left[-2(E/E_m)^{1/2}\right]$$

is in good agreement with experimental data. (Sternglass, 1954). Some typical values are given in the following table.

	δ_m	E_m (eV)
Fe	1,3	350
C	1	250
SiO_2	2,1 - 4	400
Al_2O_3	2 - 9	350 - 1300
MGo	3 - 25	400 - 1500

Secondary electrons are emitted with a Maxwellian velocity distribution having thermal energy $E_S = KT_S \simeq 3$eV. (Chung-Everhart, 1974).

3. THE CASE OF POROUS MATERIALS : FIELD DEPENDENT SECONDARY EMISSION (FDSE)

In a first paper, Jacobs (1951) noticed that high secondary emission (ie, 1000 to 1) were due to positive ions formed at the surface of the material by electron bombardment.

Experiments on insulators, (Jacobs, Friely, Brand, 1952) showed that this mechanism is sensitive to the structure of the material and the most porous, the largest the secondary yield. Due to the high resistivity of the material, positive charges stay at the surface for a long time and so, high fields exist and electrons can be liberated by field emission. This electric field affects the secondary emission in such a way that the yield is independent of bombarding energies and is exponentially dependent upon the field across the dielectric during bombardment.

This led Jacobs et al. (1952) to the hypothesis that the FDSE process is similar to the pre-sparking mechanism in gas-discharge.

Porosity allows bombarding electrons to penetrate inside the material. Secondary electrons released within the material are now accelerated toward the surface under the influence of the high field; they travel freely through these pores and gain sufficient energy to create further electrons and so on.

From the Townsend equation, we have; $\delta = e^{\alpha x}$ where α is the number of electrons generated along a unit path by electron and x, the depth within the material at which the initial secondary electrons are excited. α is related to the mean free path L_e, the strenght E of the electric field and the work function V_i fo the bulk material by

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$$\alpha = \frac{2.4}{\pi} \;.\; 10^3 \; p \; L_e \; E \; \exp(-\,16V_i/\pi^2 L_e E) \;\; (1 + 16V_i/\pi^2 L_e E)$$

where p is the equivalent pressure of colliding centers in the material leading to the same mean free path in gases. For example, to $L_e = 10^{-5}$cm corresponds $p = 4 \,.\, 10^5$mm Hg.

This mechanism appears if excited electrons gain between each collision an energy greater than the ionization energy; that is $E\,L_e > V_i$. In common cases, $V_i \sim 5$V and $E > 10^6$ V cm^{-1}, and the application of this mechanism is limited to grain with radius $R > L_e > 0{,}5$ µm.

The statistical properties of such electrons are the same than that of gas-discharge: the energy distribution is Maxwellian, with a temperature T_s related to the mean free path L_e on which electrons can be accelerated without collisions (0,1µ) by $T_s = e\,L_e\,E/1{,}64\,R$. Typical values are $\delta \sim 300 - 1000$ and $T_s \sim 10 - 20$ eV.

4. THE POTENTIAL OF THE GRAIN

The determination of the grain potential when immersed in a plasma (H_{II} regions, stellar wind) is completely solved by Lafon et al. (1982) in the case of species of ionized particles originally independent.

An approximation which balances the total flux of particles impinging and leaving the surface of the grain has been used previously by Feuerbacher et al. (1973).

In the case of secondary emission the flux of particles leaving the surface is dependent upon the energy of the primaries. Prokopenko et al. (1980) and Meyer - Vernet (1982) used the following expressions for the secondary current.

$$\Phi < o \qquad I_{sec} = \int_{-e\Phi}^{\infty} (1+e\Phi/E)\;\; 2\pi E/m_e^{\,2}\;\; n_e\;\; (m_e/2\pi KT_e)^{3/2}\;\; \exp(-E/KT_e)\;\; \delta\,(E+e\Phi)\,dE$$

$$\Phi < o \qquad I_{sec} = I_s\;\exp(e\;/KT_s)\;\;\;(1\;+\;e\;/KT_s)$$

where n_e, m_e, T_e are the density, mass, mean temperature of the primaries, Φ the grain potential, e the absolute value of the electron charge and

$$I_s = \int_{0}^{\infty} (1+e\Phi/E)\;\; 2\pi E/m_e^{\,2}\;\; n_e\;\; (m_e/2\pi KT_e)^{3/2}\;\; \exp(-E/KT_e)\;\; \delta\;(E+e\Phi)\;dE$$

Using the above approximation, Meyer - Vernet (1982) obtained the floating potential of interplanetary grains by solving for the zeros of the function

$$I_t\;(\Phi) = I_i + I_{sec} - I_e$$

I_e and I_i are the electronic and ionic currents driven from the plasma to the grain. She showed (her figure 2) that the potential is not unique and that the charge of grain can oscillate (flip-flop) under appropriate conditions.

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In the case of real grains with porous surface, the yield of secondary emission does not depend upon the energy of primaries and so, multiple roots do not appear. On other hand, the secondary emission being enhanced, the total current $I_T(\Phi)$ cannot zeroed wathever .

The approximation which balances the fluxes is not applicable and we have to numerically calculate the sheath (Lafon et al, 1981) which limits the currents from the grain or to introduce other process able to limit the high voltage such as disruption.

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