EFFECTIVE SECONDARY EMISSION COEFFICIENT FOR "ROUGH" CATHODE SURFACES

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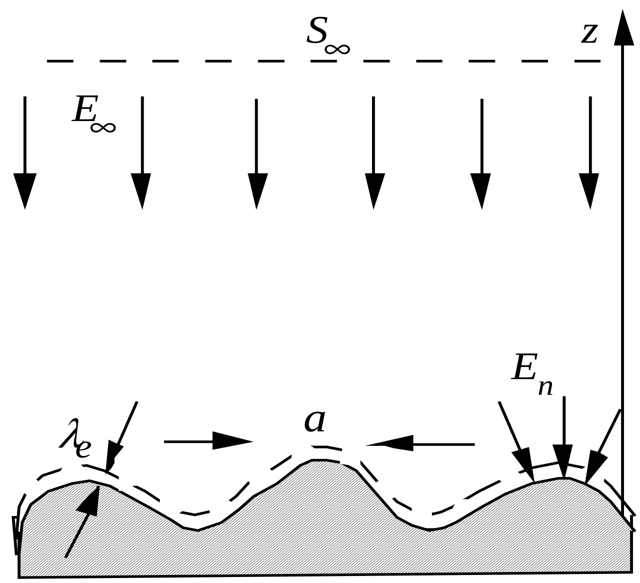
In the theory of gas breakdown, an important role is played by the effective secondary emission coefficient (ESEC) γ : the number of electrons leaving the cathode surface per one impinging ion [1]. Since long ago, it has been known that at low E/p values (where E is the electric field and p is a gas pressure) the so defined γ depends linearly on E/p , reaching a constant value only at high E/p . The mechanism responsible for this dependence was identified as a reflection of a part of the secondary electrons from the gas atoms back to the cathode surface [see Refs. 1 - 4] .

In the present communication, we point out a new important factor that can affect γ at high p : this is a "roughness" of the cathode surface, with a scale a of the humps and dips exceeding the electron mean free path. Note, that at atmospheric pressure the new effect becomes important even for very fine surfaces, with the size of the non-uniformities exceeding only $0.3 - 0.4 \mu m$. Qualitatively, the effect of the surface roughness can be explained as follows. Electric field that has only a normal component near the conducting surface, varies along the surface, being stronger at the humps and weaker in the dips. At $a \gg \lambda_e$, it is possible to divide the surface into small elements which are almost planar and have a size much larger than λ_e , with the electric field varying from one element to another. Then, γ will also vary from one element to another and, generally speaking, its average value will differ from that of a flat surface.

Another important phenomenon that enhances this effect, is a non-uniform distribution of the ion current over the surface. As the ion mean free path is usually even smaller than the electron mean free path, the ion current in the vicinity of the surface can be described by the usual mobility formula $j_i = en_i\mu_i E$, from which it is clear that the distribution of the ion current will follow the distribution of the electric field and the regions with a larger local values of γ also have larger ion current densities. Obviously, for "rough" cathodes the value of the ESEC should be obtained by some averaging procedure. Let us consider a planar gap with the axis z directed from the cathode toward the anode. We assume that the roughness of the surface can be characterized by a single parameter a , which stands both for the height of the non-uniformities and the distance between them, as shown in Figure. We limit ourselves to the early stages of the discharges, when the charge density is small and the electric field corresponds to the vacuum problem. In this case, at $z \gg a$, electric field in the planar gap is uniform. We denote its value by E_∞ and the area it intercepts by S_∞ . At the cathode the electric field is non-uniform, causing



corresponding nonuniformities of the ion current.

At $a \gg \lambda_e$, one can divide the cathode surface into the small almost planar elements much larger than λ_e, but still much smaller than a . Each of these elements can be characterized by its own ESEC, $\gamma = \gamma(E_n)$, which depends on the electric field near the surface. Here E_n is the normal component of the electric field on the surface. Also the ion current density is proportional to E_n. The averaged (over the surface area much larger than a^2) ESEC is, then equal to

$$\bar{\gamma} = \frac{\int \gamma(E_n) j_{in} dS_n}{\int j_{in} dS_n} = \frac{\int \gamma\left(E_n\right) E_n dS_n}{\int E_n dS_n} \tag{1}$$

where the integrations are carried out over the cathode surface and we used $j_{in} = en_i\mu_i E_n$.

One can introduce the distribution function $P(E_n)$, defined as a fraction of the total flux of the electric field intercepted by the cathode area ($\Phi_E = \int E_n dS_n = E_\infty S_\infty$), where the electric field strength lies in the range $(E_n, E_n + dE_n)$:

$$P\left(E_n\right) dE_n = E_n dS_n / (E_\infty S_\infty) \tag{2}$$

Obviously for this definition, $\int P(E_n) dE_n = 1$ and

$$\bar{\gamma} = \int \gamma(E_n) P(E_n) dE_n \tag{3}$$

If the probability distribution is known, then inserting into (3) $\gamma(E_n)$ for a perfectly flat surface, we find $\bar{\gamma}$.

To find the probability distribution, one should solve the Laplace equation for a given rough surface.

As an illustration we consider the model situation in which the electric field can acquire only two values: E_{n1} and E_{n2} , with the probabilities P_1 and P_2 . As for the $\gamma(E_n)$, we shall use expression [2-4]

$$\gamma(E_n) = \gamma_i E_n/(E_n + E_0), \quad (4)$$

where γ_i is the vacuum value of ESEC, and $E_0 \sim W_0/(e\lambda_e)$. Here W_0 is the kinetic energy of electron just emitted from the surface. One can find a more correct expression for $\gamma(E_n)$ in Ref. [4]. The normalization conditions in this case are reduced to

$$P_1 + P_2 = 1 \quad (5)$$

$E_{n1} > E_\infty$ (humps), and $E_{n12} < E_\infty$ (dips). If we introduce the enhancement factor $\alpha = E_{n1}/E_\infty$, and specify the value P_1 , then from (3) and (5) we find:

$$\bar{\gamma} = \gamma\left(E_{n1}\right)P_1 + \gamma\left(E_{n2}\right)\left(1 - P_1\right) \quad (6)$$

For the surface, covered by separate hemispheres, the enhancement reaches factor of 3 at the tips of the spheres. For more prolate humps, α can be larger than 3. For a numerical examples, we assume that *all* the electric flux is intercepted by the areas of enhanced electric field, so that $E_{n2} = 0$. In this case

$$\bar{\gamma} = \gamma\left(E_{n1}\right) = \gamma_i\left[\alpha E_\infty/\left(\alpha E_\infty + E_0\right)\right], \quad (7)$$

ESEC on the linear part ($E \ll E_0$) is larger than ESEC for the flat surface by a factor of α, being at the same time small compared to γ_i . If $E \gg E_0$, then $\bar{\gamma} = \gamma_i$. If $a \ll \lambda_e$, then the non-uniformities of the electric field vanish at the distances $\sim a$ from the surface, and the motion of the secondary electrons is virtually the same as for a perfectly flat surface. In this case, there is no considerable effect of the surface roughness on ESEC: $\bar{\gamma}$ remains the same as for the perfectly flat surface. One can observe a similar effect, although not as strong, when a gas does not contact directly the conducting electrodes, but contacts the insulating coating of the electrodes. However, on these surfaces the electric field may also have a tangential component E_τ . The electric field near the surface and consequently $\gamma(E_n, E_\tau)$, in this case depend not only on the shape of the conductor but also on the dielectric constant of the coating, thickness and topography of the insulator, etc. In some cases, with dielectrics, the ESEC can be even less than that of a flat electrode, while the roughness on a conductive surface always increases its value making it closer to the vacuum value.

References

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