Analysis of secondary electron emission coefficients from Paschen curves using Monte Carlo simulations

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A Monte Carlo simulation and a simple one-dimensional analysis are applied to explore the possibility to evaluate the secondary electron emission coefficients for ions (γ_i) and photons (γ_p) concurrently. On the assumption that γ_i and γ_p are independent of the reduced field, those values are evaluated to reproduce the experimental Paschen curves for Ar and Ne. The effects of the initial electrons' energy and the reflection coefficient of the cathode are also studied. The values of γ_i and γ_p which reproduces the experimental Paschen curves in good agreement are obtained when the initial energy of Maxwellian distribution at 3.2 eV and the lower reflection coefficients at 0 or 0.1 are assumed.

Secondary Electron Emission (SEE) coefficient (γ) is one of the most important parameters in discharge phenomena since it determines the breakdown voltage (V_{bd}). A commonly used method to evaluate γ is based on the Townsend discharge criterion [1],

$$\gamma \cdot [\exp(\alpha d) - 1] = 1. \quad (1)$$

Here, α is the first Townsend coefficient which is derived from V_{bd}, and d is the gap distance between the parallel plane electrodes. Since α is essentially a function of the reduced electric field (E/p), γ also depends on the discharge conditions. The SEE effects of other particles than ions would originate the dependency as well as the backward diffusion [2].

The purpose of the present study is to explore the possibility to derive γ for ions (γ_i) and photons (γ_p) concurrently from the experimentally obtained Paschen curves. A Monte Carlo (MC) simulation is applied to calculate the number of collision events for ionization (S_i), excitation to metastable states (S_{ms}) and to other permitted states (S_{ex}) per initial electron emitted from the cathode. From a simple one-dimensional analysis, which assumes no recombination and no reabsorption of photons, the particle fluxes of ions (Γ_i), photons (Γ_p) and metastable species (Γ_m) are estimated as follows,

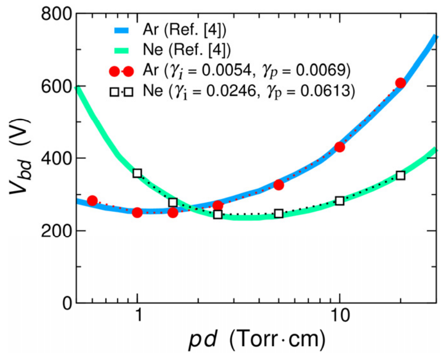

Fig. 1. Paschen curves of Ar and Ne. Ar: $f_{refl} = 0$ at 3.2 eV. Ne: $f_{refl} = 0.1$ at 3.2 eV

$$\Gamma_i = S_i = f_{eff} \cdot [\exp(\alpha d) - 1],$$
$$\Gamma_p = S_{ex}/2,$$
$$\Gamma_m = S_{ms} \cdot [1/\alpha d - f_{eff}/S_i].$$

f_{eff} is the fraction of initial electrons which escaped from the backward diffusion and penetrates into the discharge space. Instead of Eq. (1) the breakdown condition can be expressed as,

$$\gamma_i \Gamma_i + \gamma_p \Gamma_p + \gamma_m \Gamma_m = 1. \quad (2)$$

Here, γ_m corresponds to the SEE coefficient for metastable species. Eight types of collision cross sections are included in the MC simulations [3].

The values of γ_i and γ_p are evaluated to reproduce the experimental Paschen curves of Argon and Neon [4] on the assumption that they are independent of E/p and that γ_m is equal to γ_i. The effect of γ_m is small compared with that of γ_i since Γ_m is less than 10 % of Γ_i. The effects of the initial electron energy distribution, which is assumed as the Maxwell distribution at 0.1, 0.32, 1.0, 3.2, and 10 eV, are considered as well as the reflection coefficient (f_{refl}) of the cathode at 0, 0.1, 0.2, 0.5, and 1.0. As a result, 3.2 eV produced the least square errors for both Ar and Ne, while f_{refl} at 0 and 0.1 produced the least square errors for Ar and Ne, respectively. Both of the fitted curves agree well with the experimental values as shown in Fig. 1. This result suggests that the consideration of γ_p in addition to γ_i can reproduce the V_{bd} characteristics. The concurrent estimation of γ_i and γ_p which are independent of the external discharge conditions such as E/p might be possible.

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