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Estimation of Secondary Electron Emission Coefficient in Dielectric Barrier Discharges
誘電体バリア放電における二次電子放出係数の評価法

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A Monte Carlo simulation is applied to the narrow-gap argon dielectric barrier discharges (DBD) to investigate the relationship between the secondary electron emission coefficient (γ) and the Townsend's second ionization coefficient. Since the flux of ions, metastable species and photons onto the anode surface differently depend on the pd conditions, evaluation of γ for each of such species would be possible by measuring the breakdown voltage.

1. Introduction

Secondary electron emission is an important mechanism in discharge devices. It affects the electron yield significantly especially under the low electron density conditions before breakdown. The secondary electron emission coefficient (γ) is therefore a quite important parameter since the breakdown voltage (V_{bd}) is strongly influenced by γ. In dielectric barrier discharges (DBDs) breakdown occurs repetitively since they are usually driven by pulsed or alternating power feedings. γ of dielectric materials are crucial for DBD devices.

A practical value of γ has been evaluated by measuring V_{bd} in the narrow-gap DBDs [1,2]. This method is based on the Townsend's breakdown criterion which gives the condition for the electron multiplication in the discharge gap

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

Here, γ' is called as the Townsend's "second ionization coefficient", while α is the Townsend's first ionization coefficient and d is the gap distance. Since α is often given as a function of the reduced electric field (V_{bd}/pd), γ' also depends on the discharge conditions (p represents the gas pressure). This γ' appears to be different from the exact γ defined as the flux ratio, since γ should depend only on the bombarding particles and facing materials and not on the electric field or gas pressure.

The difference would arise partly because of the secondary electron emission by the species other than ions. A one-dimensional fluid model simulation on argon DBD suggested the importance of metastable species (γ_{m}) and photons (γ_{p}) as well as ions (γ_{i}) [3]. Fig. 1 shows the characteristics of γ' with some sets of γ. It appears that γ_{m} and γ_{p} are necessary to achieve the experimental characteristics of γ', which decrease rapidly with lower reduced electric field ($V_{\text{bd}}/pd \lesssim$ 200 V cm^{-1} Torr^{-1}) [1,2].

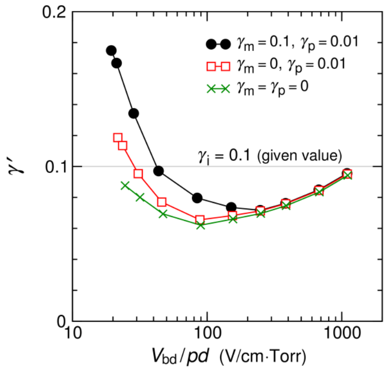

Fig. 1. γ' characteristics with and without γ_{m} and γ_{p} (γ_{i} is fixed at 0.1).

The objective of the present study is to investigate the relationship between the values of γ and γ'. If it can be made clear the estimation of consistent set of γ_{i}, γ_{m} and γ_{p} might be possible by measuring V_{bd} under some pd conditions.

2. Model and results

A Monte Carlo simulation is applied to trace the trajectories of the 10^4 test electrons in a narrow gap (d = 0.1 cm) argon DBD. Fig. 2 shows the average number of collisions per one electron under pd = 1 Torr·cm and 10 Torr·cm. The inelastic collision types are sorted into four categories (ions, metastable states, resonance states and other higher

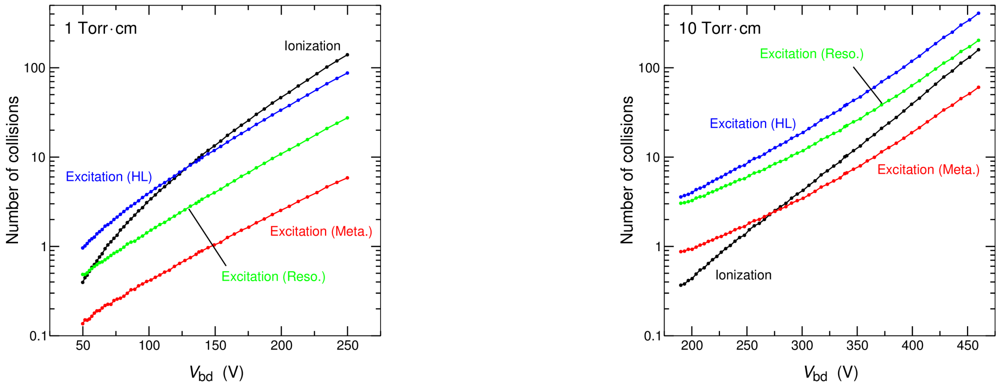

Fig. 2. Number of collisions per one electron.

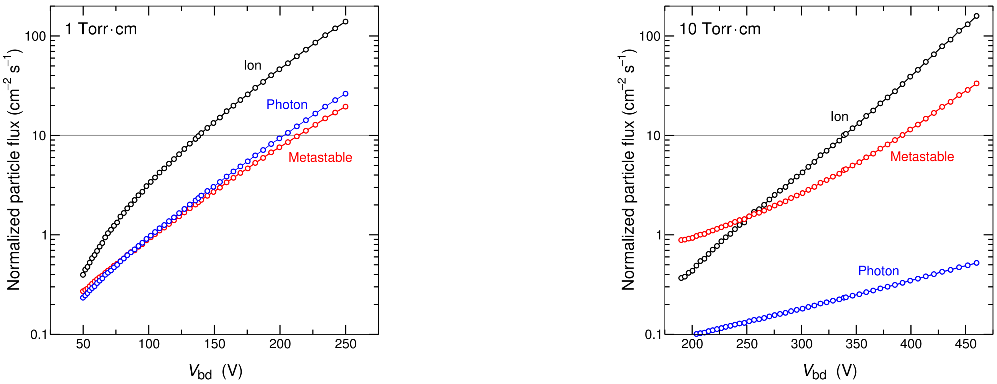

Fig. 3. Particle flux of product species per one electron.

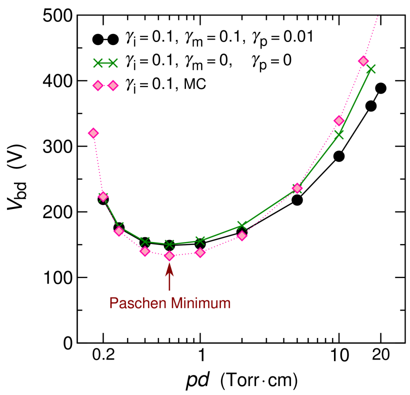

Fig. 4. V_{bd} characteristics deduced from the fluid model and Monte Carlo model.

levels) according to the product species [4]. By ignoring the effects of the acceleration regions near the electrodes and assuming uniform α, the fluxes (Γ) of product species onto the anode in steady state are roughly estimated as,

$$\Gamma_i = \exp(\alpha_i d) - 1, \cdots\cdots\cdots\cdots\cdots\cdots\cdots (2)$$

$$\Gamma_m = \frac{\alpha_m}{\alpha_i}[(\exp(\alpha_i d) - 1)/\alpha_i d - 1], \cdots (3)$$

$$\Gamma_p = \frac{\alpha_{ex}}{2(\alpha_i - \mu)}[\exp\{(\alpha_i - \mu)d\} - 1]. \cdots\cdots (4)$$

Here, μ is the light absorption coefficient. Since the reabsorption becomes significant and Γ_p drops rapidly as pd increases as shown in Fig. 3, V_{bd} under lower pd condition (e.g. 1 Torr·cm) is crucial to evaluate γ_p. On the other hand, it would be advantageous to measure V_{bd} under higher pd conditions (e.g. 10 Torr·cm) to evaluate γ_m since Γ_m becomes relatively large. As shown in Fig. 4 the V_{bd} characteristics estimated by assuming $\gamma_i =$ 0.1 ($\gamma_m = \gamma_p = 0$) in Monte Carlo simulation agrees roughly with the fluid model. Under higher pd condition, however, V_{bd} tends to be higher than expected from the fluid model. It would be necessary to consider the indirect ionization processes such as cumulative or metastable-metastable ionization, which are not included in the present flux estimation.

References

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