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Numerical simulation of a direct current glow discharge with gas flow at atmosphere pressure
微細希ガス流を用いた大気圧グロー放電の数値シミュレーション

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We carried out two-dimensional numerical simulation of atmospheric pressure dc glow discharge between nozzle and plate electrodes. Since helium is injected from the nozzle into atmospheric pressure nitrogen, the discharge is generated along the helium flow. That is, the spatial distribution of helium is very important for determining the discharge property. The purpose of this work is to clarify the relationship between the glow discharge property and helium mole fraction distribution. We found that the discharge is generated in the region with helium mole fraction larger than 99 %.

1. Introduction

In recent years, non-equilibrium plasmas at atmospheric pressure attract much attention because they can be irradiated easily to liquids [1-2], fine particles [3] at relatively low temperature and without vacuum unit. Yokoyama *et al.* developed a method to generate an atmospheric pressure dc glow discharge with a miniature helium flow in air between nozzle and plane electrodes [4]. In these discharges, the spatial distribution of helium is very important for determining the shape of the discharge because swarm parameters of charged species are strongly influenced by the local gas composition.

In this work, we carried out two-dimensional numerical simulation of atmospheric pressure dc glow discharge between nozzle and plate electrodes with miniature helium flow in nitrogen, following our previous report [5]. Discussion is focused on the relation between the discharge shape and the helium mole fraction distribution.

2. Simulation method

Simulation model in this work is shown in Fig. 1. The dc glow discharge is generated between nozzle and plate electrodes with gap distance of 1 mm. The inner diameter of the nozzle is 250 µm. Helium gas is injected from the nozzle with flow velocity of 10 m/s into atmospheric pressure nitrogen. Positive dc voltage of 500 V is applied to the nozzle or plate electrode while the counter electrode is grounded. We used the axisymmetric two-dimensional model in cylindrical coordinates. The calculation region is 1 mm in a longitudinal direction and 5 mm in a radial direction.

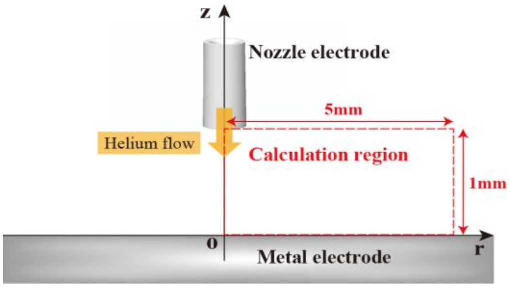

Fig.1 Simulation model

The simulation is divided into two parts, the gas flow simulation and the gas discharge simulation. The gas flow simulation provides the spatial distributions of helium and nitrogen densities based on a two-component compressible fluid model. The calculation was carried out by commercial software CFD2000 by Adaptive Research. The gas discharge simulation was carried out by a two-dimensional fluid approximation model. The densities of charged and neutral species are calculated by solving continuity equations for all species and conservation equation of electron energy coupled with Poisson's equation. In the present simulation, we considered electron, He^+, He_2^+, N_2^+, N_4^+, $He(2^1S)$ and $He(2^3S)$. We considered 26 chemical reactions. The rate coefficient for helium-nitrogen mixed reactions was taken from ref. [6]. Electron's swarm parameters were prepared by solving Boltzmann equation using Bolsig+ [7]. The mobility of each ion in helium and in nitrogen was taken from the ref. [8].

3. Results and discussion

3.1. Gas flow simulation

Figure 2 shows the calculated mole fraction of helium at steady state in helium-nitrogen mixtures. The helium mole fraction is very high within radial distance of 250 μm from the central axis. After the helium flow along the central axis reaches the plate electrode, it flows radially over the plate electrode. Therefore, the mole fraction of nitrogen is about 1% or less near the plate electrode near the central axis.

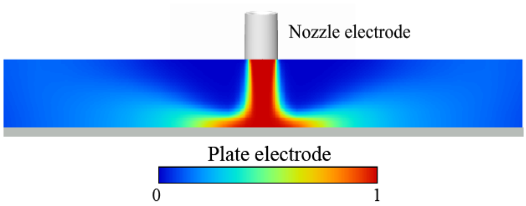

Fig. 2 Helium mole fraction in calculation region.

3.2. Gas discharge simulation

Figure.3 shows the calculated spatial distributions of electron density and ionization rate at steady state under the nozzle anode condition. Solid and dashed lines in figures are the contour lines indicating the helium mole fraction of 0.99 and 0.999, respectively. Electron density is high in the region within approximately 250 μm from central axis where the helium mole fraction is higher than 99%. Therefore, it is found that the discharge plasma is formed along the helium flow. He^+ is mainly generated by the electron impact ionization of He in the cathode fall region because high electron energy is required. Penning ionization of N_2 is active in the cathode fall region and also at the side surface of positive column along the contour line indicating the helium mole fraction of 99.9%, where helium metastable atoms are generated a lot and moderate amount of N_2 exits. The highest electron density is located in the region with helium mole fraction of 99-99.9%, where Penning ionization of N_2 is active. These results indicate that the spatial distribution of helium is quite important in determining the discharge characteristics.

Next, calculated results under the nozzle cathode condition are shown in Fig. 4. The cathode fall region in nozzle cathode case is limited by the nozzle diameter while the cathode fall region in front of plate electrode is wider in nozzle anode case. Penning ionization of N_2 in the cathode fall region is also limited in nozzle cathode case because nitrogen density just beneath the nozzle is almost zero. As a result, the plasma density in the positive column becomes lower in comparison to the nozzle anode case.

4. Conclusion

In this work, we investigated the fundamental property of atmospheric pressure dc glow discharge along a miniature helium flow in nitrogen. In these discharge He spatial distribution of helium mole fraction plays a significant role in determining the characteristics of glow discharge.

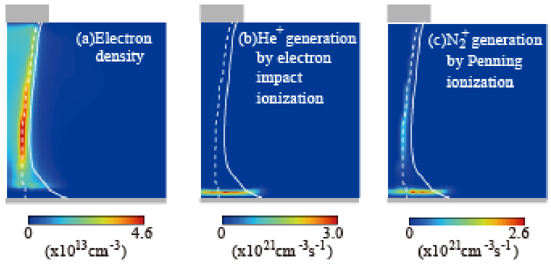

Fig. 3 Spatial distributions of (a) electron density, (b) electron impact ionization of He^+, (c) Penning ionization of N_2^+, respectively. Positive voltage of 500 V is applied to the nozzle electrode.

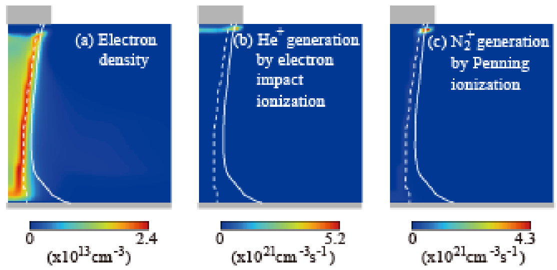

Fig. 4 Spatial distributions of (a) electron density, (b) electron impact ionization of He^+, (c) Penning ionization of N_2^+, respectively. Positive voltage of 500 V is applied to the plate electrode.

Acknowledgement

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References

[1] P. Bruggeman, C. Leys: J. Phys. D 42 (2009) 053001.
[2] N. Shirai, K. Ichinose, S. Uchida, F. Tochikubo, Plasma Sources Sci. Technol. 20 (2011) 034013.
[3] T. Nakajima, K. Tanaka, T. Inomata, M. Kogoma, Thin Solid Films 386 (2001) 208.
[4] T. Yokoyama, S. Hamada, S. Ibuka, K. Yasuoka, S. Ishii, J. Phys. D 38 (2005) 1684.
[5] F. Tochikubo, N. Shirai, S. Uchida, Appl. Phys. Express 4 (2011) 056001.
[6] G. M. Petrov, J. P. Matte, I. P´er`es, J. Margot, T. Sadi, J. Hubert, K. C. Tran, L. L. Alves, J. Loureiro, C. M. Ferreira,V. Guerra, and G. Gousset: Plasma Chem. Plasma Proc. 20(2000) 183.
[7] G. J. M. Hagelaar, L. C. Pitchford, Plasma Sources Sci. Technol. 14 (2005) 722.
[8] L. A. Viehland, E. A. Mason, Atom. Data Nucl. Data Tab. 60 (1995) 37.