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Study on Characteristics of Constricted DC Plasma Using Particle-In-Cell Simulator

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1. Introduction

In dc glow discharge, when anode size is smaller than cathode, very small and bright plasma ball occurs in front of anode [1]. This plasma is called constricted dc plasma and characterized by a high plasma density in positive glow, so called plasma ball, compared to the conventional dc plasma [2-3]. For the reason, this plasma is utilized to ion or electron beam sources since the beam currents are enhanced by the dense anode glow. However, correlations between characteristics of the plasma (plasma density, electron temperature and space potential) and discharge conditions (anode size, discharge voltage, discharge current, pressure) have been a little investigated definitely clear in previous study because of the trouble of a diagnosis. The plasma ball which is the most essential part of the constricted plasma is too small to diagnose precisely without disturbing plasma. Therefore, we tried to analyze the constricted plasma through computer simulation with Particle-In-Cell (PIC) code. In this study, simulation result of constricted dc plasma as well as conventional dc glow discharge will be addressed and compared with each others.

2. Methods and Results

2.1 Numerical simulation with PIC code

OOPIC Pro [4] known as one of PIC codes is used to simulate the conventional dc plasma and constricted dc plasma. Simulation was performed in azimuthally symmetric cylindrical geometry. Simulation region is defined as broken lines as shown in Fig. 1. Radial and axial direction is denoted by r, z respectively.

Conditions are same at dc plasma and constricted plasma except size of anode. A dielectric cylinder (0.01 m in radius and 0.05 m in length) is used to confine the

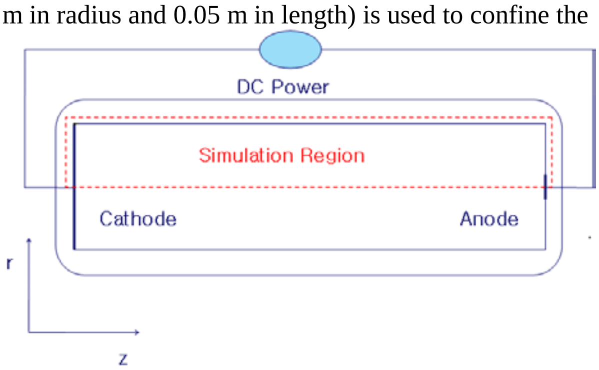

Fig. 1. Schematic of constricted plasma discharge geometry

plasma. Two electrodes (anode and cathode) place at the ends of the plasma chamber as shown in Fig. 1. Area of the anode at constricted dc plasma is set 100 times smaller than in case of normal dc plasma. Supplied voltage is 500 V in both plasma cases. Secondary electron coefficient is 0.2 for both anode and cathode and 0.3 for dielectric. 0.05, 0.5 Torr argon was used as discharge gas. The number of cells is 30 both in radial and axial direction in conventional dc plasma, while the constricted plasma has 60 axial and 40 radial cells. Time-step of dc plasma and constricted plasma is set for $3\times10^{-10}s$ and $5\times10^{-11}s$ respectively. In case of simulating constricted plasma, more precise calculation compared to dc plasma was needed to simulate high density, small-sized plasma ball through increasing the number of cells and reducing time-step.

2.2 Simulation results

First of all, we simulated the conventional dc plasma, whose anode and cathode has same area, in order to confirm that the OOPIC operates well. Fig. 2 shows successfully with a form of electrons of dc plasma in space at 0.05 Torr. Points indicate electrons. A dark section near the cathode (left side in the figure), wide and bright section with many electrons, and dark section near the anode (right side) appears. These regions represent cathode dark space, positive column, anode dark space respectively, as well known in conventional dc plasma [5]. Besides the electron distribution, other characteristics such as space potential and electric field are corresponding to the physical fact of dc plasma, as well. As a result, it is successfully performed to simulate conventional dc plasma with OOPIC code.

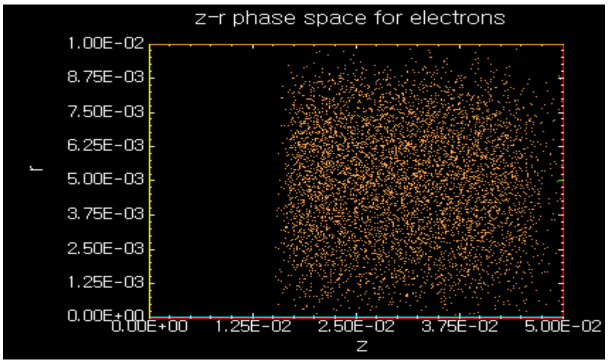

Fig. 2. Electrons of dc plasma in r–z space. Operating conditions: pressure p = 0.05 Torr and voltage V = 500 V.

Fig. 3. Electrons of constricted plasma in r–z space. Operating conditions: pressure p = 0.05 Torr and voltage V = 500 V.

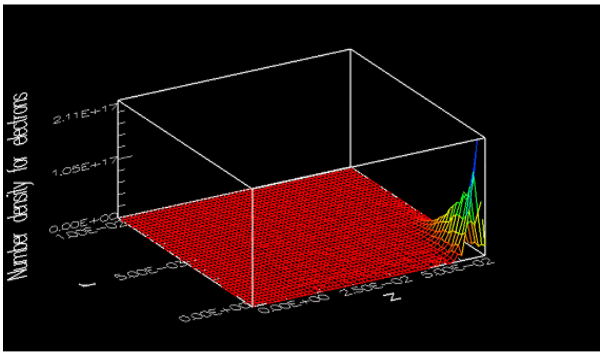

Fig. 4. Number density for electrons.

Constricted dc plasma with reduced anode whose area is 1/100 of cathode has different characteristics from normal dc plasma. The distribution and number density of electrons for 500 V and 0.05 Torr are shown in Fig. 3 and Fig. 4, respectively. The bright plasma ball occurs near the anode and has very high density. Also high degree of ionization in the plasma ball is observed through neutral gas density and electron number density. The plasma ball consists of a lot of electrons and ions and the maximum density is $2.11\times10^{17}m^{-3}$ at the center of plasma ball. This is much larger than conventional dc plasma of $6.47\times10^{15}m^{-3}$ at same condition except anode area. It seems that the electron number density doesn't have the maximum value at r=0 in Fig. 3. It is because the Fig. 3 shows number of electrons summarized along the cylinder chamber azimuthally in rectangular space. Meanwhile, Fig. 4 shows the density of electron with respect to radial and axial position. It is clarified that population of electrons is maximized at the center of plasma ball with the Fig. 4.

Effect of operating pressure upon the characteristics of constricted dc plasma is investigated. Fig. 5 shows electron distribution of constricted plasma at 0.5 Torr. Difference from 0.05 Torr in Fig. 3 is the increase in electrons next to cathode dark space. Dark and luminous regions: cathode dark space, negative glow faraday dark space and positive column which is small plasma ball, are distinguished more clearly than 0.05 Torr. These arrangements of dark and luminous regions agree to constricted plasma structure reported in the previous study [1]. Also Fig. 3 and Fig. 5 show a deviation in

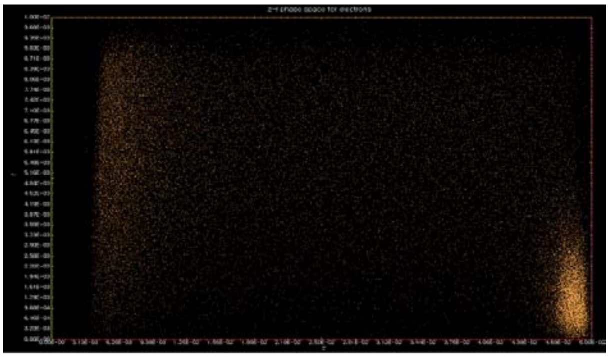

Fig. 5. Electrons of constricted plasma in r–z space. Operating conditions: pressure p = 0.5 Torr and voltage V = 500 V.

length of cathode dark space. At 0.5 Torr, a length of cathode dark space is shorter than 0.05 Torr. A low pressure glow discharge will adjust the axial length of its cathode dark space d_c, so that a minimum value of the product of pressure and the discharge chamber length pd is established $pd_c = (pd)_{\min}$ [5]. Therefore, results of simulation that cathode region length is decreased with pressure are valid.

3. Conclusions

As a result of simulating constricted plasma through OOPIC, the plasma ball was simulated successfully in the situations that operating conditions except pressure are fixed. Higher density property than normal dc plasma and effect of operating pressure upon plasma structure was observed. To investigate correlations between characteristics of plasma ball and operating conditions (especially anode size and discharge voltage), further analysis are being done.

REFERENCES

[1] V. I. Miljevic, *J. Appl. Phys.* **60** (1986) 4109.
[2] A. Anders and M. Kuhm, *Rev. Sci. Instrum.* **69**(1998) 1340.
[3] A. Anders and S. Anders, *Plasma Sources Sci. Technol.* **4**(1995) 571-575.
[4] OOPIC Pro User's guide Version 1.0, Tech-X Corporation.
[5] J. R. Roth, *Industrial Plasma Engineering Volume 1: Principles*, IOP Publishing, London, pp.283-350, 1995.