MEASUREMENT OF NEGATIVE-ION IN SHEET PLASMA BY PHOTODETACHED METHOD

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Abstract

We demonstrated the measurement of the density of O^- , O_2^-, and H^- in an argon sheet plasma crossed with vertical gas flow of O_2 or H_2 gas by laser photodetachment techniques. It is found that both O^- and O_2^- are localized in the outer region of the sheet plasma and its profiles are unsymmetrical on both upper and lower sides (T_e = 0.5 - 1 eV) against the width of sheet plasma. Also, the step of the formation of O^- or H^- is dissociative electron attachment after O_2 or H_2 gas flows through the plasma column.

1. Introduction

Negative ions play an important role in reaction mechanisms between plasma and neutral gas molecules mainly because of their outstanding physical properties in relation to fields of application, such as plasma processing, environmental problems, and fusion plasma. Although a lot of work has been done in order to understand the basic properties of negative ions by microwave, dc, rf, and afterglow discharges, very little is known about the mechanism of the production of the negative ions. Negative ions in commonly used plasma devices exhibit complex characteristics because the cascade-type collisional process takes place in the plasma column. Therefore, control of the parameters affecting the formation of negative ions is difficult. For a better understanding of the relationship between plasma parameters and formation of negative ions, a development of system with extensive plasma diagnostics is necessary.

We have proposed a newly designed system of a magnetized sheet plasma crossed with a vertical gas-flow system [1,2]. The geometry of this system is estimated to be nearly one-dimensional (1-D) based on the scale of plasma thickness. Parameters affecting the interaction between negative ions and the plasma, such as reactive gas flow rate, plasma density, and electron temperature, are easily controlled for this device by selecting the experimental conditions. Contact phenomena between gas and plasma are analyzed using laser photodetachment techniques and an electrical probe. Laser photodetachment technique is a highly sensitive method for detecting negative ions [3]. Therefore, a quantitative analysis of negative ions based on a simple model can be achieved in the magnetized sheet plasma crossed with the vertical gas-flow system.

In this paper we demonstrated the measurement of the number density of O^- and O_2^- in the magnetized sheet plasma of argon crossed with vertical gas flow of O_2 gas. These negative ions are the important species from the view point of plasma processing and environment studies. Our results can be useful todetermine the optimum conditions for negative ion production as well as to explain the complex phenomena involved in the collisions between neutral gas molecules and plasma in relation to various plasma parameters.

2. A magnetized Sheet Plasma Crossed with Vertical Gas-Flow System

The magnetized sheet plasma crossed with the vertical gas-flow system is shown in Fig. 1. The reactive gas of O_2 or H_2 was fed perpendicularly to the argon sheet plasma through the rectangular slit with three small pipes (∅1 mm x 300 mm) in the low-pressure experimental region (~ 10^{-4} Torr). This gas feeder was placed in the gas contact chamber located in front of the anode at a distance of 40 cm and below the sheet plasma at a distance of 2.0 cm. When the reactive gas is vertically fed to the sheet plasma, the negative ions are produced by flowing the plasma whose thickness in the direction perpendicular to the dc magnetic field is equal to twice the mean ion Larmor radius.

The advantages of the magnetized sheet plasma crossed with the vertical gas-flow system are as follows: (i) the plasma parameters and conditions of the reactive gas can be controlled independently because this system is separated into the part consisting of the plasma source and the part consisting of radical production; (ii) the plasma density and electron temperature can be widely varied by changing both current and gas flow rate during the discharge, independently; (iii) since the geometry of this system is estimated to be nearly 1-D based on the scale of plasma thickness, the experimental results can be compared with the result determined based on the 1-D model; (iv) free radicals and ionized charged particles can be separated because the reactive gas is vertically fed to the magnetized sheet plasma; and (v) the influence of the processes of ion collision in addition to those of electron collision on molecules can be examined in the plasma, such as charge exchange. Therefore, this system is capable of creating some complex phenomena between the plasma and neutral gas species as the simple model.

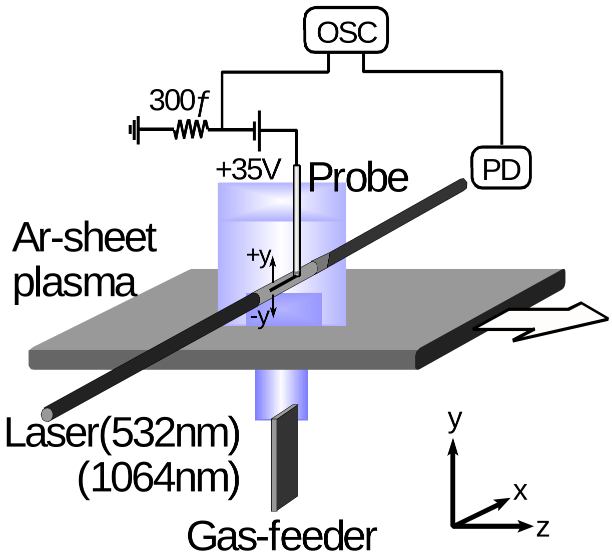

Fig. 1. Schematic diagram of the magnetized sheet plasma crossed with the vertical gas-flow system.

The density of O^-, O_2^- and H^- were measured by photodetached techniques. The Q-switch YAG laser was driven at a pulse repetition rate of 10 Hz. The maximum powers of fundamental (1.06 nm) and second harmonic (0.53 nm) radiation were 65 mJ and 25 mJ, respectively. The laser width was about 10 ns and the diameter of laser beam was 3 mm. A cylindrical probe (0.4 x 2 cm) is used to measure the spatial profiles of the negative ion density by a probe-assisted laser photodetachment method. The plasma parameters (electron density, electron temperature) in the gas contact region were measured by a Langmuir plane probe.

3. Experimental Results

Figure 2 shows that the spatial profiles of (a) O^- and (b) O_2^- are plotted against the Y-direction of the width of the sheet plasma. The experimental parameters are as follows: the discharge current I_d between the anode and the cathode of the argon sheet plasma is 12 A, the magnetic field B_z is 0.7 kG, and the gas flow rate of Ar for the discharge is 20 sccm. The gas flow rates of O_2, which was fed perpendicularly to the sheet plasma, was kept constant at 20 sccm. The half width of the electron density of the sheet plasma is 1 cm. In the sheet plasma, it is observed that O^- and O_2^- are localized in the outer region and its profiles are unsymmetrical on both upper and lower sides against the width of sheet plasma. The density of O^- has a peak value of 2.3×10^{16} m^{-3} at Y = 3 cm in the upper side. On the other hand, the density of O_2^- has that of 1.0×10^{16} m^{-3} at Y = -3 cm in the lower side near the gas feeder. It is found that the step which lead to O^- when O_2 gas flows through the plasma column of the sheet plasma is dissociative electron attachment and that of O_2^- is electron attachment.

The spatial profiles of (a) the electron temperature T_e, (b) the electron density n_e, (c) the density of O^- are plotted against the y-direction of width of the sheet plasma as shown in Fig.3. The gas flow rate of argon sheet plasma Q_{Ar} changes from 8 to 20 sccm. The experimental parameters are as follows: the discharge current I_d is 14 A, and the magnetic field B_z is 0.7 kG. In case of Fig.

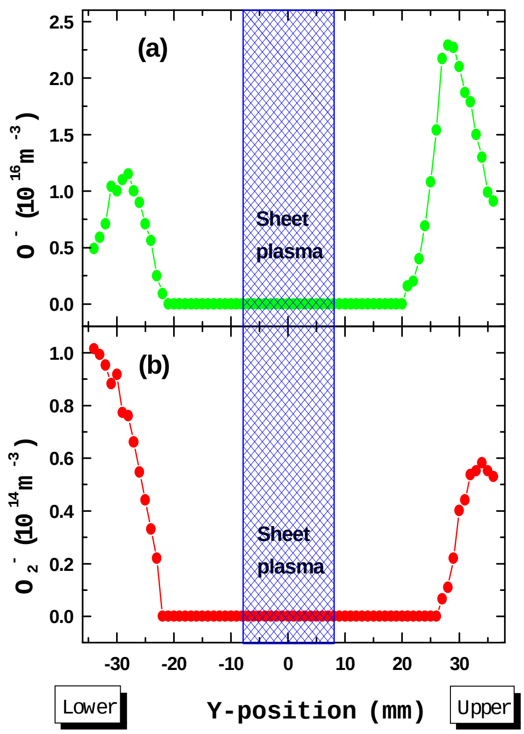

Fig. 2 The spatial profiles of (a) O^- and (b) O_2^- is plotted against the y-direction of the width of the sheet plasma.

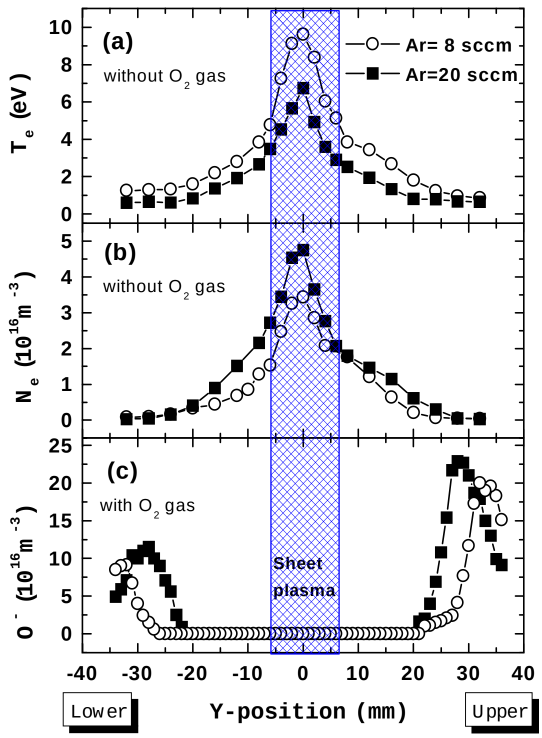

Fig. 3 The spatial profiles of (a) the electron temperature T_e, (b) the electron density n_e, and (c) the density of O^- are plotted against the y-direction of width of the sheet plasma.

3(c), the gas flow rate of O_2 was kept constant at 20 sccm. In the sheet plasma, both T_e and n_e have hill-shape profiles. The thin plasma area with high density (n_e= 5 x 10^{16} m^{-3}) and high temperature (T_e = 10 eV) is produced in the plasma column (Y = 1cm). On the other hand, the low density (n_e = 1 x 10^{15} m^{-3}) and low temperature (T_e =0.5-1eV) is formed in the outer region in the sheet plasma. The density of O^- increases with decreasing T_e in the plasma column when the gas flow rate of argon sheet plasma Q_{Ar} increase from 8 to 20 sccm.

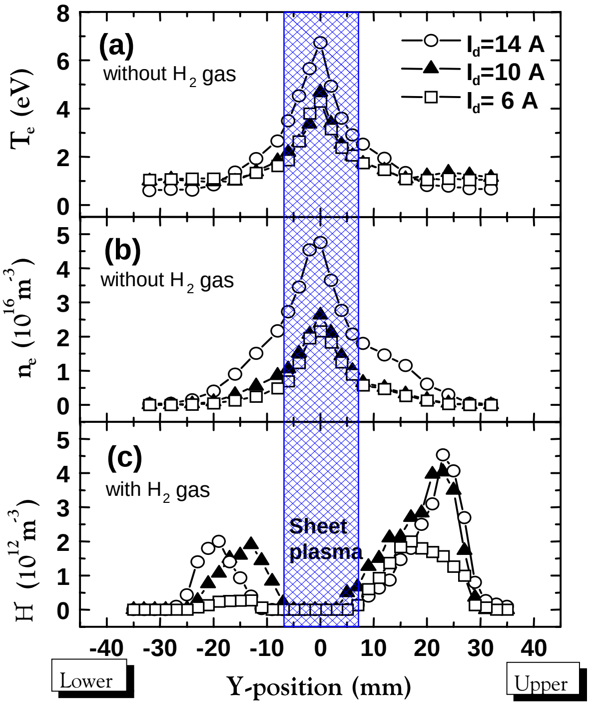

Fig. 4. The spatial profiles of (a) the electron temperature T_e, (b) the electron density n_e, and (c) the density of H^- are plotted against the y-direction of width of the sheet plasma.

In Figure 4, the spatial profiles of (a) the electron temperature T_e, (b) the electron density n_e, (c) the density of H^- are plotted against the y-direction of width of the sheet plasma. Each discharge current I_d is selected as 6,10 and 14 A. The experimental parameters are as follows: the gas flow rate of argon sheet plasma Q_{Ar} is 20 sccm, and the magnetic field B_z is 0.7 kG. In case of fig4-(c), the gas flow rate of H_2 was kept constant at 20 sccm. The density of H^- has a peak value of 4.5x$10^{12}m^{-3}$ at Y = 2 cm in the upper side and the density profiles of H^- are unsymmetrical against the width of sheet plasma. The peak value of H^- increases with increasing the discharge current. When the gas flow rate of argon sheet plasma Q_{ar} is 20 sccm, H^- increases on upper side in spite of low value of T_e in the plasma column below 10 eV.

4. Conclusions

We demonstrated the formation of negative ions (O^-, O_2^-, and H^-)in the magnetized sheet plasma crossed with a vertical gas-flow of O_2 or H_2 gas. Both O^- and O_2^- are localized in the outer region of the sheet plasma and its profiles are unsymmetrical on upper and lower sides against the width of sheet plasma. The peak value of both O^- and H^- is formed in the outer region where is the low density (n_e= 1 x 10^{15} m^{-3}) and low temperature (T_e = 0.5 - 1 eV) in the sheet plasma. It is found that the step of the formation of O^- or H^- is dissociative electron attachment after O_2 or H_2 gas flows through the plasma column.

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