Journal of Modern Physics, **2014, 5, 89-91**
Published Online January 2014 (http://www.scirp.org/journal/jmp)
http://dx.doi.org/10.4236/jmp.2014.52014

High Density Fluorine Negative-Ion Source Generated by Utilizing Magnetized SF_6

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Received November 25, 2013; revised December 23, 2013; accepted January 16, 2014

ABSTRACT

In a magnetized plasma column generated from an electronegative gas, negative-ions accumulate around the plasma column via radial diffusion. In this study, a dc discharge is applied in SF_6 gas to produce a plasma column, and the radial density profile of negative-ions is measured by Langmuir probes using the modified Bohm criterion. The gas pressure and discharge current dependences of negative-ion density are also measured. It is found that the negative-ion density of 8.0×10^{17} m^{-3} is obtained around the plasma column at r = 1.0 cm when SF_6 pressure is 0.13 Pa and discharge current is 0.50 A. The negative-ion density has radial gradient, and the electron density is much lower in this region.

KEYWORDS

Fluorine Negative-Ion; Ion Source; String-Type Plasma; Radial Diffusion; Langmuir Probe; Magnetized Plasma; Sulfur Hexafluoride

1. Introduction

It is already known that negative-ions can be produced by magnetized plasmas, in which discharge of electronegative gas such as CF_4 gas makes fluorine negative-ions and they accumulate around a magnetized plasma column via radial diffusion [1-4]. Higher-density and stable fluorine negative-ion sources have potential to make fine silicon etching, because the negative-ions could reduce the charging-up damage and abnormal etching on the etching surfaces in case of LSI fabrications [5-10].

In this study, in order to obtain higher density fluorine negative-ions, on the standpoint of future application to negative-ion etching, SF_6 is used as a source gas of the magnetized plasma because this gas has high electron affinity, particularly at low electron temperatures [11]. The pressure and discharge current dependences of negative-ion density are also studied.

Though multiple negative-ion species (F^-, SF_6^-, SF_5^-) may have contributed to negative charges around the SF_6 plasma column via nondissociative attachment and dissociative attachment reaction schemes, F^- ions have the highest density [12], similarly to the case of CF_4 plasmas [13].

2. Experimental Setup

Figure 1 shows a schematic diagram of the experimental setup. A metal chamber of 2.0 m length and 21 cm diameter is set across eight solenoid coils producing a magnetic field of 0 - 0.15 T. An electron beam of 20 mm diameter is injected by an electron-beam source (placed at the axial center about 85 cm from the chamber end), which has a beam energy of Ψ_{BE} = 100 eV and a current of I_{BE} = 0 - 1.0 A. The anode of the beam source (20 cm in diameter), which has a gridded hole of 20 mm diameter on the center, is grounded. At about 77 cm from the anode, an electrically grounded metal end-plate of 20 cm diameter is placed. Hot-wire-type Langmuir probes made of Ta wire of 0.2 mm diameter, shaped as semicircle of 1.5 mm diameter, are used for the diagnosis of the plasma. Here, results are obtained using the probe placed at 25 cm from the end plate.

In the dc-discharge plasma, thermal electrons in the

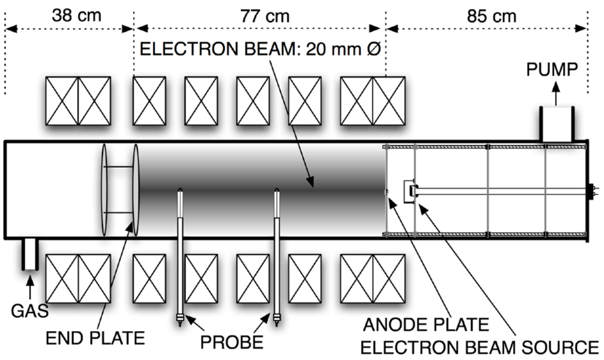


Figure 1. Schematic diagram of the experimental setup.

SF_6 plasma are produced by injecting an electron beam with an energy of 100 eV along the magnetic field. Some of the thermal electrons are lost at the end electrodes by diffusion along the magnetic field and by attachment to neutral molecules. On the other hand, the produced negative ions are well confined along the magnetic field by sheath potentials at the end plates, and are partially lost by recombination with positive ions. Around the column-type plasma, the radial-diffusion speeds of electrons and negative ions are very different, which can cause high negative-ion accumulation around the plasma column.

3. Results and Discussion

The negative-ion density in the SF_6 plasma is evaluated from the probe measurement utilizing the modified Bohm condition [1,14]. At slightly outside the electron-beam region, negative ion density $n_- \approx 8 \times 10^{17}\ m^{-3}$ at r = 1.0 cm for the typical conditions of B = 0.030 T, p = 0.13 Pa, and I_d = 0.50 A is obtained. **Figure 2** shows radial profiles of n_- evaluated using the modified Bohm condition across the plasma column. The results from the normal Bohm condition is also plotted for comparison.

Radial profiles of the negative-ion density, n_- and electron density, n_e are shown in **Figure 3** under the typical conditions of B = 0.030 T, p = 0.13 Pa, and I_d = 0.50 A. From this figure, it is evident that the density ratio of n_- to n_e monotonically increases with the increase in radial distance and it is more than 1000 at r > 3.0 cm.

Figure 4 shows radial profile of electron temperature T_e. $T_e \approx 1$ eV outside the beam region and $T_e \approx 2$ eV within the electron-beam region are obtained. The produced SF_6 plasma is a typical low-temperature plasma.

Radial profiles of n_- across the magnetic field are measured for several discharge currents and pressures and are shown in **Figure 5**, where profiles of the discharge current dependence at p = 0.13 Pa (a) and the pressure dependence at I_d = 0.30 A (b) are shown. From these figures, it can be understood that n_- always has radial gradient. In these experiments, maximum value of

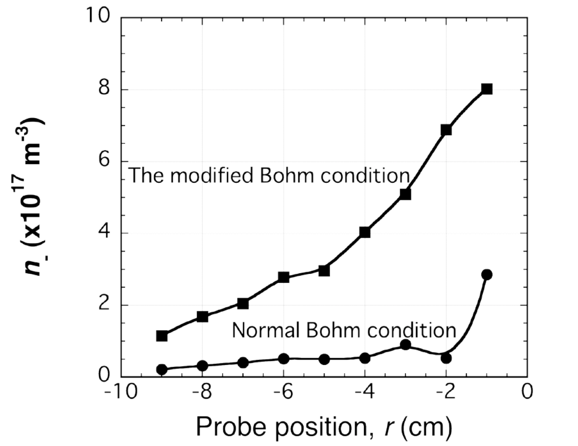


Figure 2. Radial profiles of n_- across the plasma column evaluated by the two methods. B = 0.030 T, p = 0.13 Pa, and I_d = 0.50 A.

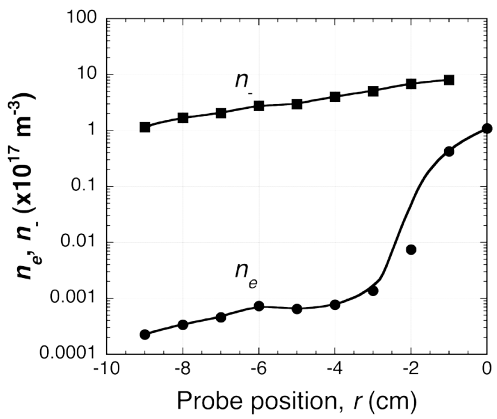


Figure 3. Radial profiles of n_- and n_e evaluated using the modified Bohm criterion. B = 0.030 T, p = 0.13 Pa, and I_d = 0.50 A.

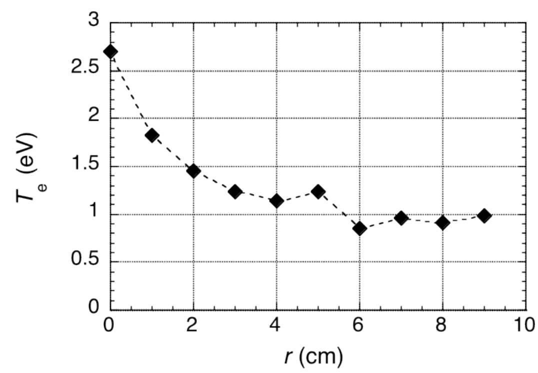
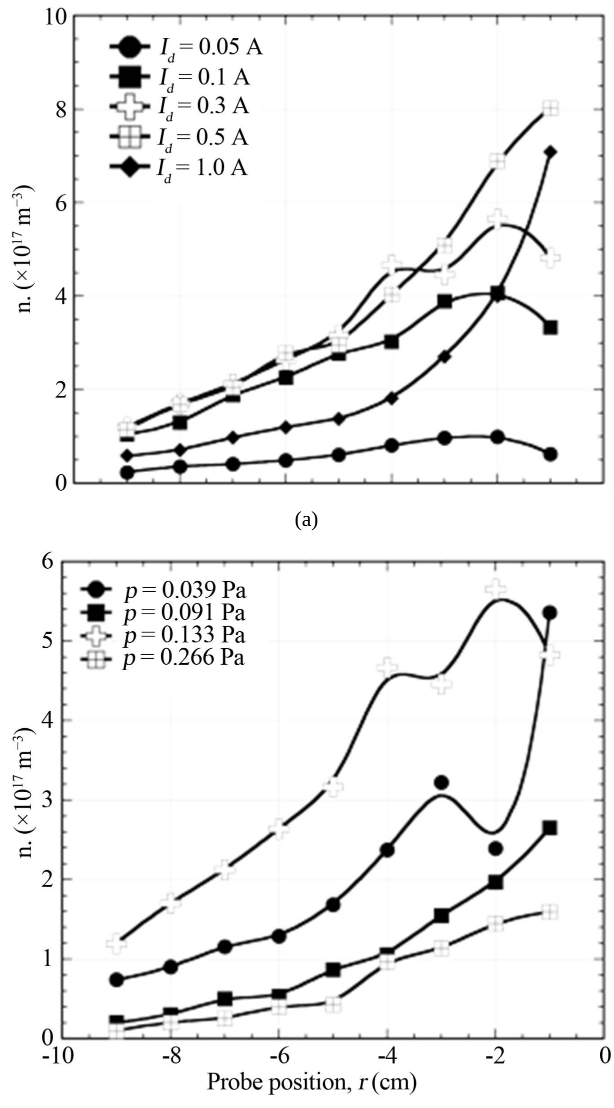


Figure 4. Radial profile of T_e across the plasma column. B = 0.030 T, p = 0.13 Pa, and I_d = 0.50 A.

n_- is $8.0 \times 10^{17}\ m^{-3}$ at r = 1.0 cm, I_d = 0.50 A and p = 0.13 Pa under B = 0.030 T.

The radial profiles of n_- obtained in the present study for SF_6 across the magnetic field are compared with those for CF_4 obtained in earlier studies [1,11]. Both re-



(b)

Figure 5. **Discharge current dependence at p = 0.13 Pa (a) and pressure dependence at I_d = 0.30 A (b) of radial profiles of n_-. B = 0.030 T.**

sults have such a radial density gradient. Outside the electron-beam region, the negative-ion density for SF_6 gas is on the order of 10^{17} m^{-3}, whereas for CF_4 gas it is on the order of $\approx 10^{16}$ m^{-3}.

4. Conclusions

Radial profiles of negative-ion density across the magnetic field are measured in SF_6 plasma under various experimental conditions, where the major ion species is F^-. The modified Bohm condition is utilized for the calculation of n_-. It is found that in the series of experiments, n_- is maximum of 8.0×10^{17} m^{-3} at p = 0.15 Pa, r = 1.0 cm, and B = 0.030 T, which is larger than the results of CF_4 gas.

The control of the radial density profile should be studied, and now it is under study by changing the magnetic field and other experimental conditions.

Acknowledgements

This study was supported by The True-Nano Project of Shizuoka University (2009) and JASSO Follow-up Research Fellowship (2010).

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