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Distribution of hydrocarbon negative ion by DC-laser photodetachment method

半導体レーザを用いた光脱離計測による炭化水素負イオンの分布

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Production of carbon and hydrocarbon negative ions in a plasma sustained by high temperature carbon cathode has been investigated by DC-laser potodetachment method. High temperature carbon ribbons performed as the cathode producing 20 mA discharge current in 0.6 Pa Ar environment. The distribution of plasma concentrated in the center of discharge chamber due to the influence of confinement magnetic field. Langmuir probe measurement suggests the existence of negative ions in plasma, and we have initiated the experimental study to measure how carbon and hydrocarbon negative ions are transported in process plasma through the photodetachment method.

1. Introduction

Measurement of negative ions is indispensable to monitor and control process plasma. In a reactive plasma, negative ions interact with ions, and alter particles transport toward the container wall. Takahashi et al have firstly reported that the hydro negative ions can be quantitatively analyzed by DC-laser photodetachment method introducing plasma transport velocity[1]. Matsuda et al have adapted the DC-laser photodetachment method to verify diffusion process in an oxygen plasma[4]. Carbon forms another typed of reactive plasma, but concentrated of carbon negative ions in plasma has never been determined yet. When advanced containing hydrocarbons new materials like DLC coating, carbon foil, and graphene are manufactured, process plasma containing hydrocarbons are used. The role of carbon and hydrocarbon negative ions on the performance of synthesized material should be evaluated to improve the process plasma characteristics. Therefore, we attempt to measure how carbon and hydrocarbon negative ions are transported in process plasma through the photodetachment method.

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2. Measurement method of hydrocarbon negative ions by DC-laser photodetachment

The following photodetachment reaction releases an electron for a negative ion to generate photodetachment signal.

$$A^- + h\nu \rightarrow A + e^- \quad (2.1)$$

;where A^- is the negative ion, h is the Planck constant, and ν is frequency, e^- is the electron, and A is the neutral particle.

3. Plasma parameter measurement with a Langmuir probe

In this experiment, plasma parameters are obtained by inserting a single electrode into a plasma. Probe current (I_p) is changed by controlling a voltage (V_p) to the probe, and this *I-V* characteristic shown in Fig. 3.1 allows one to determine plasma parameters. When probe voltage (V_p) is equal to or greater than plasma potential (V_s), an ion sheath is no longer formed around the probe, and electron current flows into the probe up to a saturation point due to thermal motion of electrons. In electron saturation region, the probe saturation current is expressed by the following equation.

$$I_{es} = \frac{1}{4} e n_e S_p \left(\frac{8\kappa T_e}{\pi m} \right)^{1/2} \quad (3.1)$$

; where n_e is electron density, S_p is probe surface area, and T_e is electron temperture, κ is the Boltzmann constant, and m is electron mass. When negative ions exist, negative probe saturation current I_{-s} equation (3.1) is rewritten in the following equation.

$$I_{-s} = eS_p \left(n_e \sqrt{\frac{\kappa T_e}{2\pi m}} + n_n \sqrt{\frac{\kappa T_n}{2\pi M_n}} \right) \quad (3.2)$$

; where n_n is negative ion density, T_n is negative ion temperature, and M_n is negative ion mass.

When probe voltage (V_p) is more negative with respect to the plasma potential (V_s), ion sound velocity determines the ion saturation current.

$$I_{is} = eZn_p S_p \exp\left(-1/2\right) \sqrt{\frac{\kappa T_e}{M_p}} \quad (3.3)$$

; where M_p is ion mass, n_p is ion density, and Z is charge number of ions. In negative ion containing plasma, I_{es}, I_{-s}, and I_{is} give information of negative ion density.

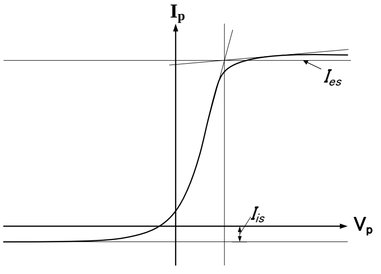
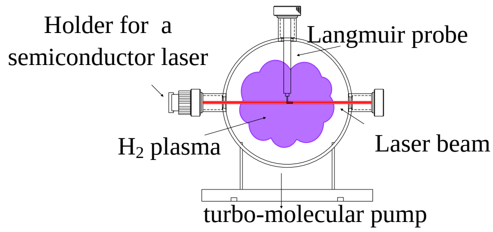


Fig. 3.1 Typical probe *I-V* characteristics.

4. Experimental apparatus



Cross sectional view from the top

Fig. 4.1. The schematic illustration of the ion source used for carbon cathode experiment

The schematic illustration of the ion source used in the photodetachment experiment is given in Fig. 4.1. This plasma source has the 105 mm inside diameter, and 120 mm depth. To produce carbon negative ions, two carbon ribbons (0.5 mm in diameter, 60 mm in length) serve as the cathode of discharge. The filaments are mounted in the middle of an ion source evacuated by a turbomolecular pump coupled to an oil rotary pump, and a DC-laser beam passes through between two filaments. To produce negative ions stably, the structure of plasma source has electron confinement. The ion source in this experiment has twelve permanent magnets from side to top. In this configuration, thermionic electrons are confined to remain at the center of plasma and they are capable of creating a denser plasma. For measurement of photodetachment, we use semiconductor laser with the wavelength at 790 nm with the output power of 3 W. To measure plasma parameters, and photodetachment signals, the Langmuir probe which has 5.0 mm diameter, 70 mm length is used. This Langmuir probe is movable and has coaxial cable geometry. The tip of probe which is immersed in plasma has 0.3 mm diameter, 5.0 mm length, and has a right-angle bend with the end 4.5 mm parallel to a laser beam. Increase of electron density caused by photodetachment reaction enlarges the electric current signal of a Langmuir probe inserted into the plasma region adjacent to the laser path. In this experiment, the laser power is amplitude-modulated to make phase-sensitive detection possible to remove noise from the plasma.

5. Confirming existence of negative ions

From equation (3.1) and equation (3.2), I_{es}/I_{is} takes the figure,

$$\frac{I_{es}}{I_{is}} = \frac{1}{Z} exp\left(\frac{1}{2}\right)\sqrt{\frac{M_+}{2\pi m}} \qquad (5.1)$$

Provided no negative ion exists in the plasma. The *I-V* curve in Fig.5.6 shows the ion saturation current does not surpass the electron saturation current, but the magnitude is comparable. The figure for eq. (5.1) is about 180, While Fig.5.6 indicates far much smaller value of I_{es}/I_{is}, corresponding to a sizable contribution of negative ion density in the plasma.

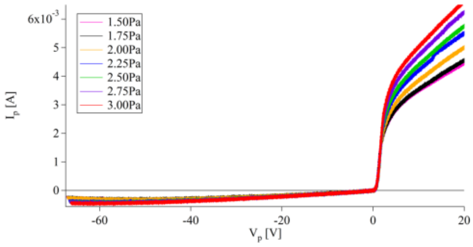


Fig. 5.6 The comparison from 1.5 Pa to 3.0 Pa in the characteristic of probe current with probe voltage

6. References

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