18PB-034

Ion Mass Analysis and Separation Oriented to Generation of Paired Hydrogen-Ion Plasma

水素ペアイオンプラズマ生成に向けたイオン質量の分析と分離

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For generation of a paired hydrogen-ion plasma consisting of positive and negative ions of atomic hydrogen, negative ions are produced by the plasma-assisted catalytic ionization using a plasma grid with nine apertures. Positive ions and electrons passing through the plasma grid and negative ions flow to the downstream section. Current ratio of negative and positive saturation currents of a probe decreases as the plasma grid is negatively biased, electrons are electrostatically reflected, thus, an ionic plasma is attained to be generated here.

1. Introduction

Pair plasmas consisting of only positively and negatively charged particles of equal mass have the special characteristics of space-time symmetry in collective phenomena, in contrast to ordinary electron-ion plasmas. A pair plasma in electron system consisting of electron and positron, which is antimatter of electron, has been tried to be generated experimentally in laboratories, but it is not easy to maintain a steady-state electron-positron plasma. So a pair plasma in ionic system consisting of positive and negative ions of equal mass, has been generated, where the ionic pair plasma is called a paired ion plasma [1]. Collective phenomena in a paired fullerene-ion plasma consisting of C_{60}^{+} and C_{60}^{-} ions have been investigated experimentally. The frequency of interesting collective phenomena is limited in low frequency range because of massive ions. Therefore we are trying to generate a paired hydrogen-ion plasma consisting of H^+ and H^- ions, which are the lightest ions and have high response frequencies to electromagnetic fields. Production of negative ions, H^-, which is the most important element in the generation process of the paired hydrogen-ion plasma, is performed by a plasma-assisted catalytic ionization method [2].

2. Experimental Apparatus

Figure 1 shows a schematic diagram of the experimental setup. A hydrogen plasma is generated by a dc arc discharge with the line-cusp magnetic fields. The electron density at the plasma core is 3×10^{10} cm^{-3}, where the hydrogen pressure in the discharge section during operation is about 0.04 Pa. A plasma grid (PG) with nine extraction apertures

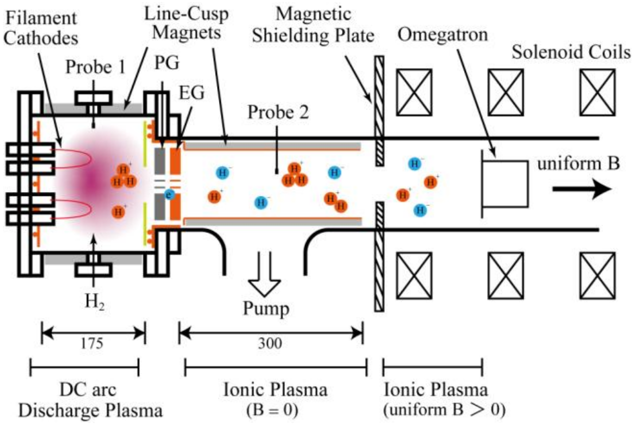

Fig. 1. Diagram of experimental setup.

negatively biased at a dc voltage of V_{PG} is irradiated with positive ions. Since there is a tendency in our previous works that the production quantity of negative ions increases in the case of using a grid made of Al, the PG is made of Al. Negative hydrogen ions are produced inside the extraction apertures of 13 mm diameter and 10 mm thickness by the plasma-assisted catalytic ionization. An extraction grid (EG) made of Cu is biased at a dc voltage of V_{EG}, which has the same geometric structure as the Al-PG but 13 mm thickness. The EG is located at a distance 10 mm from the Al-PG and controls the ion energy in the aperture of the Al-PG. Magnetic fields for electron deflection are applied in the vertical axis of the extraction aperture of ions by permanent magnets. The ions passing through the EG are directed into a copper cylinder with line-cusp magnetic fields. Molecular positive ions are produced by collision of H^+ ions and neutral gas particles, the production quantity is suppressed by evacuation in the cylinder. The ions in the cylinder pass through a magnetic shielding plate set between the cylinder and a uniform magnetic region, where the uniform magnetic field is applied by solenoid coils. If molecular positive ions are only eliminated, the paired hydrogen-ion plasma generation will be realized, but the elimination is not performed at the present stage. The plasma parameters are measured by Langmuir probes located at the discharge plasma (Probe 1) and the cylinder with line-cusp magnetic fields (Probe 2), as shown in Fig. 1. An omegatron mass spectrometer situated at the end of the plasma in the uniform magnetic fields is conventionally used for mass/charge determination.

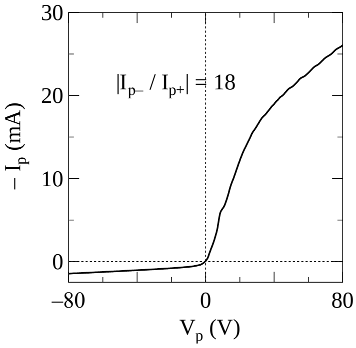

Fig. 2. Typical probe characteristics of Probe 1 in the discharge plasma.

3. Results

No negative ions exist in the discharge plasma because of high temperature of electrons for negative ions. A typical characteristics of probe current I_p and voltage V_p is measured by Probe 1, as shown in Fig. 2. The current ratio of $|I_{p-}/I_{p+}|$ is obtained from the characteristics, where I_{p+} and I_{p-} are the positive and negative saturation currents of the probe at $V_p = -80$ V and +80 V, respectively. $|I_{p-}/I_{p+}|$ is about 18, and this current ratio is a reference value without negative ions.

In order to investigate the existence of negative ions in the cylinder with line-cusp magnetic fields, the I_p – V_p characteristics depending on V_{PG} are measured by Probe 2, as shown in Fig. 3(a), where the bias voltage of the EG is constant at $V_{EG} = 0$ V. When the Al-PG is negatively biased, electrons in the discharge plasma are electrostatically reflected in the sheath in front of the Al-PG and the negative current decreases. Positive ions passing through the Al-PG, that is, the positive current also decreases. The current ratios of $|I_{p-}/I_{p+}|$ obtained from Fig. 3(a) as a function of V_{PG} are shown in Fig. 3(b), where I_{p+} and I_{p-} are the positive and negative saturation currents of the probe at $V_p = -500$ V and +500 V, respectively. The current ratio without negative ions is indicated by a dashed line. The current ratio, decreasing as V_{PG} is negatively high, approaches to one which is an ideal value in the paired hydrogen-ion plasma. Therefore negative ions are considered to be produced at the Al-PG. It is necessary to eliminate completely electrons for realization of the paired ion plasma. The deflection magnetic fields are applied at the apertures of the EG, electrons passing through the Al-PG are expected to be eliminated by the fields. But electrons pass through the EG from Fig. 3(b) at $V_{PG} > -200$ V at least. The current ratio is considered to decrease, because electrons passing through the Al-PG are suppressed by the electrostatic reflection in the sheath as V_{PG} is negatively high. It becomes clear that electrons across the magnetic field lines, the same as the plasma diffusion perpendicular to the lines, when positive ions and electrons coexist in harmony in the deflection magnetic fields. The magnetic fields, which eliminate secondary electrons by ion impact, only need to be applied. Electrons seem to be completely reflected at $V_{PG} = -500$ V, but the current ratio is higher than one. Molecular positive ions, H_2^+ and H_3^+, have been found to exist abundantly in the discharge plasma from the omegatron mass spectrometry. Even if the negative current consists of only negative ions, the current ratio becomes higher than one because the positive current of molecular positive ions is low, compared with that of H^+.

To generate the paired ion plasma, the production of equal quantities of positive and negative ions with an equal mass and the elimination of molecular positive ions of impurities are both required, where the latter is our future work. The results of the omegatron mass spectrometry in the uniform magnetic fields will be reported with relation to the former.

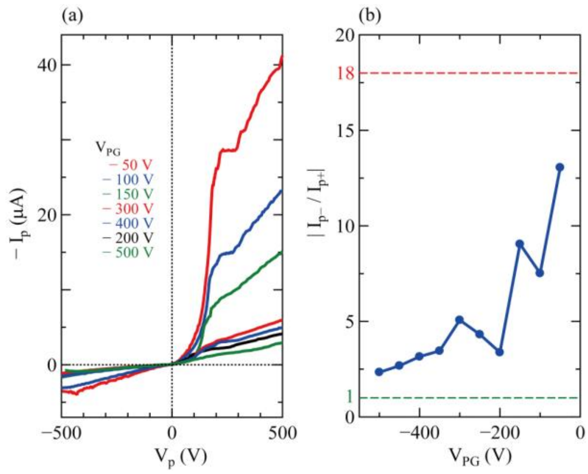

Fig. 3. (a) Probe characteristics of Probe 2 in ionic plasma ($B = 0$) depending on V_{PG}. (b) Current ratios of positive and negative saturation currents obtained from (a) as function of V_{PG}.

References

[1] W. Oohara, R. Hatakeyama, Phys. Rev. Lett, **91**, 205005 (2003).

[2] W. Oohara, K. Kawata, T. Hibino, Phys. Plasma **21**, 063514 (2014).