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Production of Hydrogen Pair Ions using DuoPIGatron
DuoPIGatronを用いた水素ペアイオン生成

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In order to generate hydrogen pair-ion plasma for investigating collective properties of pair plasmas, hydrogen atomic positive and negative ions are produced by a plasma-assisted catalytic ionization method using a porous nickel plate or cylinder and a DuoPIGatron. Production quantities of positive and negative ions depend on irradiation current and incident angle of positive ions irradiated.

1. Introduction

Pair plasmas consisting of only positively and negatively charged particles of equal mass have the characteristics of space-time symmetry in collective phenomena, in contrast to ordinary electron-ion plasmas [1]. Electron-system pair plasmas consisting of electron and positron of antimatter electron have been tried to be generated experimentally in laboratories [2], but it is not easy to maintain a steady-state electron-positron plasma. So an ionic-system pair plasma (pair-ion plasma), consisting of positive and negative ions of equal mass, has been generated [3]. Collective phenomena in a pair-ion plasma consisting of C_{60}^+ and C_{60}^- ions have been investigated experimentally. Since the frequency range of interesting collective phenomena is limited to low frequencies in the massive C_{60} pair-ion plasma, our attention is concentrated on the generation of a hydrogen pair-ion plasma consisting of H^+ and H^- ions, which are the lightest ions and have high response frequencies to electromagnetic fields. It is difficult to generate the hydrogen pair-ion plasma by ordinary production methods of H^+ and H^- ions. We have proposed a new production mechanism of the ions as a plasma-assisted catalytic ionization method [4,5].

2. Experimental Apparatus

The apparatus for producing the pair ions mainly consists of a DuoPIGatron and an ion production part. The DuoPIGatron consists of a sub PIG discharge part and a main PIG discharge part, and the two parts are connected tandem. In the sub PIG part, two cathodes are located on opposite sides of a cylindrical anode with an inner diameter of 6.4 cm and a length of 10 cm, which is placed in a uniform magnetic field (100 mT), and a tungsten ring filament of 0.5 mm diameter, grounded at the same voltage as the cathodes, is set in front of the cathode at $z = -48$ cm to supply thermionic electrons. The anode is positively biased at V_{as} relative to ground voltage. The electrons are accelerated in a sheath formed in front of the filament cathode and injected into the space between the two cathodes, and most electrons accelerated are reflected in the sheath in front of the opposite cathode (anticathode) at $z = -26$ cm because the cathode voltages are the same. Since the accelerated electrons are electrostatically confined between the two cathodes along the magnetic-field lines, neutral particles can be efficiently ionized by electron impact, generating a hydrogen plasma (sub plasma) in this region. The anticathode at $z = -26$ cm has a center aperture with an inner diameter of 2.2 cm, a part of electrons in the sub plasma enter the main PIG part through the aperture and are accelerated. A cylindrical anode with an inner diameter of 5 cm and a length of 10 cm is biased at V_{am}. The cathode in the main plasma is used a porous plate or a porous cylinder at $z = 0$ cm. The porous-plate cathode grounded can be rotated, the angle θ to the magnetic field lines can be varied. On the other hand, the cylindrical porous cathode, in the case of $\theta = 180^{\circ}$, can be biased at V_{pc}. The porous cylinder with an inner diameter of 2 cm and a length of 6 cm is capped for preventing the plasma passage. A schematic diagram of the experimental setup in the case of using the cylindrical porous cathode is illustrated in Fig. 1.

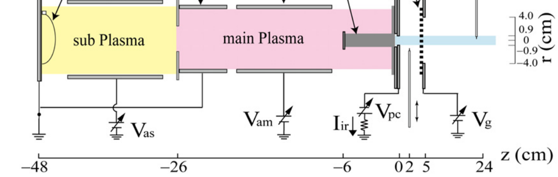

Fig.1. Schematic diagram of experimental apparatus.

A grid for electrostatic-wave excitation (z = 5 cm) is grounded here. The hydrogen pressure in the source during operation is about 5×10^{-2} Pa. The porous plate is made of nickel with a pore size of 0.5 mm, a thickness of 3.2 mm, a specific surface area of 3,570 m^2/m^3, and a porosity of 94.8 %. The porous cylinder, on the other hand, is made of a porous nickel plate rolled with a pore size of 0.45 mm, a thickness of 1.4 mm, a specific surface area of 5,800 m^2/m^3, and a porosity of 96.6 %. Plasma parameters are measured using a Langmuir probe at z = 2 cm.

3. Results

Positive ions produced by the PIG discharge are irradiated to the porous-plate cathode grounded in a direction perpendicular to the porous surface and the irradiation current I_{ir} is measured. Positive and negative ions are produced by the plasma-assisted catalytic ionization from the back of the irradiation plane. Positive- and negative-saturation currents of the probe, I_+ and I_-, are obtained at probe bias voltages of −200 V and +200 V, respectively. I_{ir} can be varied by adjusting the discharge power. The dependences of I_+ and I_- on I_{ir} are shown in Fig. 2. Both I_+ and I_- increase with I_{ir}, that is, the production quantities of positive and negative ions increase with the irradiation flux. I_+ is almost the same as I_-, indicating the property of ionic plasmas.

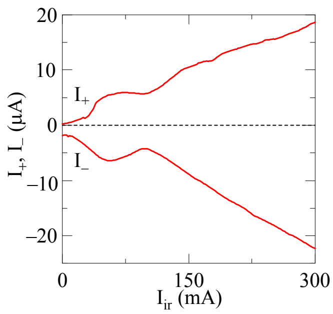

Fig. 2. Probe saturation currents of positive and negative ions as function of the irradiation current of positive ions.

The radial profiles of I_+ and I_- are shown in Fig. 3, where dashed lines indicate the diameter of plasma limiter. The porous plate can be rotated, the angle θ to the magnetic field lines can be varied. When positive ions are irradiated to the porous plate in a direction perpendicular to the plate surface, $\theta = 90^{\circ}$, the production quantities of positive and negative ions are large. However, the production quantities drastically decrease when positive ions are irradiated in an oblique direction, $\theta > 90^{\circ}$. This seems to be the reason that the thickness of the porous cylinder is equivalently increased.

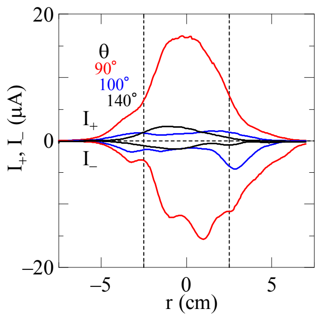

Fig. 3. Radial profiles of the ionic plasma depending on the incident angle to the magnetic field lines.

Positive ions produced are irradiated to the cylindrical porous cathode biased negatively at V_{pc} in an oblique direction close to a parallel direction to the magnetic field lines. Probe characteristics are measured at z = 2 cm, as shown in Fig. 4. The negative current is much higher than the positive current, contrasting results to in the case of using the porous plate. It is known from the other works that a transmitted current of positive ions through the porous cylinder is relatively low in the case of using the porous cylinder, where the positive current consists of the transmitted current and the produced current of positive ions. The thickness of the porous cylinder is equivalently increased and the transmitted current will decrease under the irradiation in an oblique direction.

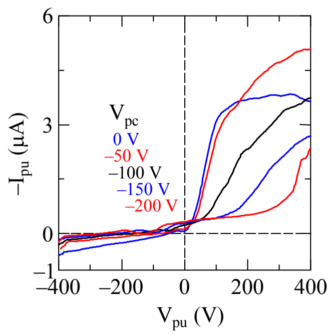

Fig. 4. Probe characteristics in the case of using the cylindrical porous cathode.

References

[1] N. Iwamoto, Phys. Rev. E, **47**, 604 (1993).
[2] M. D. Tinkle, R. G. Greaves, C. M. Surko, Phys. Plasmas **2**, 2880 (1995).
[3] W. Oohara, R. Hatakeyama, Phys. Rev. Lett. **91**, 205005 (2003).
[4] W. Oohara, O. Fukumasa, Rev. Sci. Instrum. **81**, 023507 (2010).
[5] W. Oohara, T. Maeda, T. Higuchi, Rev. Sci. Instrum. **82**, 093503 (2011).