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Control of ECR Plasma Potential for Hydrogen Pair-Ion Plasma Generation

水素ペアイオンプラズマ生成に向けたECRプラズマ電位制御

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Generation of hydrogen pair-ion plasma is our target for investigating collective properties of pair plasmas. Hydrogen atomic positive and negative ions (hydrogen pair ions) are produced by a plasma-assisted catalytic ionization method using a porous nickel plate as catalyst and an ECR plasma. Irradiation energy of positive ions to the porous plate can be varied by plasma potential in the ECR plasma. It is clear that the production quantity of pair ions depends on the irradiation energy.

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 the ordinary production method of H^+ and H^- ions. We have proposed a new production mechanism of the ions as a plasma-assisted catalytic ionization method [4,5]. Hydrogen positive ions produced by discharge are irradiated to porous nickel plate and the hydrogen pair ions are produced from the back of the irradiation plane.

2. Experimental Apparatus

Figure 1 shows a schematic diagram of the experimental setup. Microwave (2.45GHz) are introduced into a cylindrical electrode via quartz windows and a horn antenna applied by a magnetic field. Electron cyclotron resonance (ECR) point is in the cylindrical electrode of 12 cm inner-diameter and a hydrogen plasma is generated. A porous nickel plate is set at z = 0 cm, the plasma generated is irradiated. The cylindrical electrode and the porous plate are biased at dc voltages of V_{cy} and V_{pc}, respectively. Plasma parameters are measured using Langmuir probes at z = –6 cm and 5 cm. A grid electrode for electrostatic-wave excitation (z = 10 cm) is biased at dc voltage of V_g, but the grid is used for collector to obtain the ion energy distributions along magnetic field lines here. The hydrogen pressure in the source during operation is about 0.1 Pa. The forward and reflected powers of microwaves are P_f = 500 W and P_r ~ 60W, respectively. The porous nickel plate with a pore size of 0.5 mm, a thickness of 3.2 mm, a specific surface area of 3,750 m^2/m^3, and a porosity of 94.8 % is used as a catalyst.

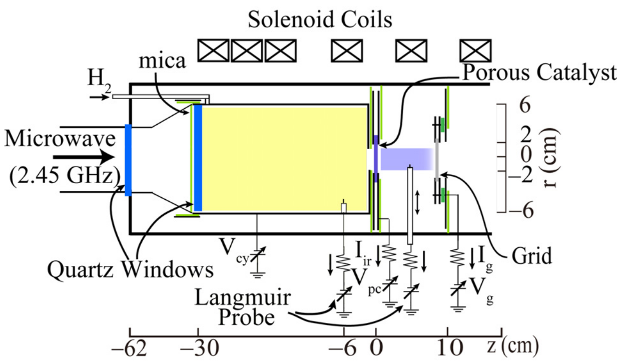

Fig.1. Diagram of experimental setup.

3. Results

The dependences of the irradiation current I_{ir} and the plasma potential ϕ_{us} at z = –6 cm on V_{cy} are shown in Fig. 2(a), where V_{pc} is maintained at 0 V. ϕ_{us} is approximately proportional to V_{cy}. Positive ions are accelerated up to eϕ_{us} (eV) in the sheath formed in front of the porous plate and the irradiation energy can be controlled by adjusting V_{cy}. I_{ir}, which depends on the ECR plasma density, rapidly decreases when V_{cy} decreases to below 20 V because of the superimposed current of electrons. Electrons are electrostatically reflected in the sheath when $V_{pc} < -100$ V, they cannot reach the porous plate, not shown here. Therefore, positive ions are only irradiated when $V_{cy} > 20$ V and $V_{pc} < -100$ V.

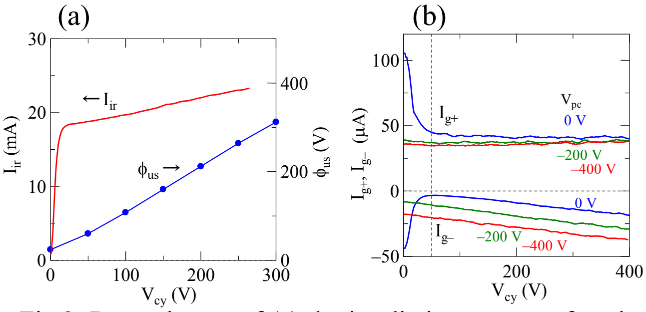

Fig.2. Dependences of (a) the irradiation current of positive ions and the plasma potential at $z = -6$ cm and (b) the grid saturation-currents of positive and negative ions on the dc bias voltage of the cylindrical electrode.

Positive and negative ions are emitted from the surface of porous plate and their fluxes toward downstream are measured using the grid at $z = 10$ cm. The positive- and negative-saturation currents of the grid, I_{g+} and I_{g-}, are obtained at $V_g = -520$ V and +520 V, respectively. The dependences of I_{g+} and I_{g-} on V_{cy} are shown in Fig.2(b). Fast electrons of corresponding to the tail component in the Maxwellian distribution can reach and pass through the porous plate without termination and I_{g-} increases, when $V_{pc} = 0$ V and $V_{cy} < 50$ V; thus, the current dependences are paid attention in $V_{cy} > 50$ V here. I_{g-} increases proportionally with V_{cy} and V_{pc} (the irradiation energy); that is, the negative-ion flux increases. On the other hand, I_{g+} is almost constant and the positive-ion flux appears to be independently of the irradiation energy. We refer to this process involving positive-ion irradiation, dissociative adsorption, surface migration, and desorption ionization as plasma-assisted catalytic ionization. The production mechanism of positive and negative ions is the same excepting desorption ionization.

Current-voltage (I_g-V_g) characteristics of the grid are measured under positive-ion irradiation, as shown in Fig. 3(a), where $V_{pc} = -300$ V without electron irradiation and transmission. The characteristics depending on V_{pc} and V_{cy} have two inflection points. One is at $V_g \sim V_{pc}$ and the other is at $V_g \sim V_{cy}$. Kinetic energy distributions of the ions are calculated from the I_g-V_g characteristics, as shown in Fig. 3(b). The reference potential at $z > 0$ cm is V_{pc} because all ions are emitted from the plate surface.

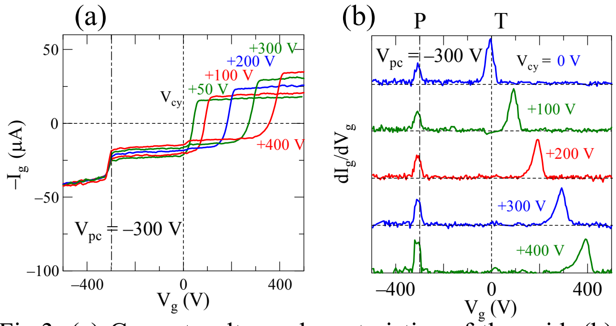

Fig.3. (a) Current-voltage characteristics of the grid. (b) Kinetic-energy distributions of the ions along magnetic field lines. Reference potential is V_{pc} (= –300 V).

There are two components of the ions. One at $V_g \sim V_{pc}$ (= –300 V) is referred as component P and the other at $V_g \sim V_{cy}$ as component T. Kinetic energy of positive and negative ions produced by desorption ionization appears to be less than several eV, and the component P will consist of them, because potential of the component P is close to the reference potential. On other hand, the component T consists of transmitted positive ions irradiated to the porous plate since ϕ_{us} is close to V_{cy}. The quantity of the component P increases proportionally with V_{cy}, that is the irradiation energy, but the quantity of the component T decreases. I_{g+} of $V_g = -520$ V is sum current of the transmitted and produced positive ions, corresponding to I_g of $V_g < -350$ V, and I_{g+} is independently of the irradiation energy. I_g of $V_g > V_{cy}$ corresponding to the negative-ion flux increases proportionally with V_{cy}. Therefore it is concluded that the production quantity of positive and negative ions excepting transmitted positive ions depends on the irradiation energy of positive ions.

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