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Effect of Catalyst Materials on Plasma-Assisted Catalytic Ionization
プラズマ支援触媒イオン化機構における触媒材質効果

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Production properties of positive and negative ions by a plasma-assisted catalytic ionization method are investigated using a porous nickel plate. Kinetic energy distributions of positive and negative ions emitted from the plate surface are obtained using the energy difference among the ions. Positive current is higher than negative current. The positive current is found to consist of the positive-ion currents of transmitted through the porous plate and produced on the plate.

1. Introduction

The research and development of negative-ion sources have been extensively performed in connection with neutral beam injection heating for fusion-oriented plasmas and ion guns for proton accelerator. A small admixture of cesium vapor in a hydrogen discharge significantly improves negative-ion production and decreases the current of coextracted electrons [1]. However, the use of cesium complicates the ion source operation and requires the careful stabilization of cesium injection and discharge parameters. There have been many attempts to develop negative-ion sources without a cesium admixture.

We have proposed a plasma-assisted catalytic ionization method for production of H^+ and H^- ions [2,3]. Hydrogen positive ions produced by discharge are irradiated to a porous catalyst, the positive and negative ions are produced from the back of the irradiation plane. In this work, dependences of production quantities of the ions on the irradiation energy and current are investigated attracting attention to energy distributions of the ions.

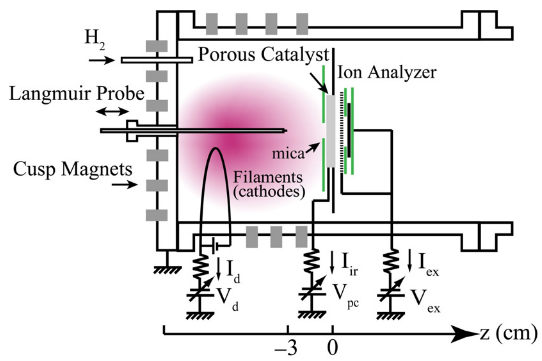

Fig. 1. Schematic diagram of experimental setup.

2. Experimental Setup

A hydrogen plasma is generated by a dc arc discharge between filament cathodes and a wall anode in a cuboidal chamber with a cross section of 25 cm ×25 cm, i.e., a bucket plasma source. The cathodes are four horseshoe tungsten filaments of 0.7 mm diameter and 15 cm length, which are biased at a discharge voltage of $V_d = -70$ V, at which the plasma density is maximized. The plasma generated in a field-free region is surrounded by line-cusp magnetic fields near the grounded chamber wall. Figure 1 shows a schematic diagram of the experimental setup. A commercially available porous nickel plate with a porous body of 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 % is used as a catalyst. The porous plate is negatively biased at a dc voltage of V_{pc}. The positive ions are irradiated and the irradiation current I_{ir} is measured. Since the positive ions are irradiation area is 12.6 cm^2 (diameter of 4 cm) and the other electrode is covered with a mica plate, the irradiation current density J_{ir} can be obtained.

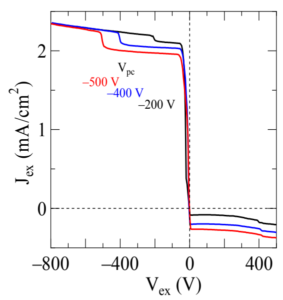

Fig. 2. Current-voltage characteristics of ion analyzer.

The porous plate is located at z = 0 cm, the discharge section corresponds to the region z < 0 cm. Plasma parameters in the region are measured using a Langmuir probe at z = −3 cm. The hydrogen pressure in the source during operation is about 0.1

Pa. Current densities of positive and negative ions from the back of the irradiation plane are measured using an ion analyzer, some type of Faraday cup. The analyzer consists of a grid (SUS316 coated with a film of Cu, 635 mesh, wire diameter of 0.02 mm) and a collector separated 1 mm from the grid at $z = 0.8$ cm.

3. Results

Plasma potential ϕ_s in the discharge section remains approximately constant at +4 V, independently of V_{pc}. Positive ions produced by discharge are irradiated to the porous plate which is negatively biased at V_{pc}. They are accelerated up to $e(\phi_s - V_{pc})$ (eV) in the sheath in front of the porous plate. Positive and negative ions are produced by a plasma-assisted catalytic ionization from the back of the irradiation plane. The irradiation current density of positive ions J_{ir} can be varied by adjusting the discharge power P_d because the plasma density in the discharge section depends on the power. Since the extraction aperture area is 1.3 cm^2 (inner diameter of 1.3cm), the ion current density extracted J_{ex} can be obtained using the ion analyzer. The current density (J_{ex})- voltage (V_{ex}) characteristics of the analyzer are shown in Fig. 2. The positive current is much higher than the negative current. The characteristics depending on V_{pc} have precisely two inflection points. One is at $V_{ex} \sim V_{pc}$ and the other is at $V_{ex} \sim 0$ V. There are two components of the ions in the kinetic energy distributions, taking the potential profiles into consideration. The kinetic energy distributions are calculated by differential from the J_{ex}- V_{ex} characteristics, as shown in Fig.3. The reference potential at $z > 0$ cm is V_{pc} because all ions are emitted from the plate surface. The energy distributions in the cases of the constant irradiation current (P_d = 700 W) and the constant irradiation energy ($V_{pc} = -600$ V) are shown in Figs. 3(a) and (b), respectively. The kinetic energy positive and negative ions produced by desorption ionization appears to be less than several eV, and the former component at $e(V_{ex} - V_{pc}) \sim 0$ eV will consist of them. On the other hand, the latter component at $e(V_{ex} - V_{pc}) \sim -eV_{pc}$ (eV) consists of the transmitted positive ions which are a part of the irradiated positive ions. The transmitted quantity of positive ions is about independent of the irradiation energy (Fig. 3(a)), but the quantity increases proportionally with the irradiation current (Fig. 3(b)).

The produced current densities of positive and negative ions, J_{+pc} and J_{-pc}, and the transmitted current density of positive ions J_{+t} are separately measured. Fig. 4 shows the dependences of J_{+t}, J_{+pc}, and J_{-pc} on (a) the irradiation energy $e(\phi_s - V_{pc})$ (eV) and (b) the irradiation current density J_{ir}. J_{+pc} and J_{-pc} increase both with the irradiation energy under the constant irradiation current and with the irradiation current under the constant irradiation energy. J_{+t} is independent of the irradiation energy. The production quantity of negative ions is greater than that of positive ions. Electronegativity difference between hydrogen atom and nickel atom is considered on desorption ionization in the plasma-assisted catalytic ionization process. The electronegativities of H and Ni are 2.20 and 1.91 in Pauling units, respectively. H tends to attract electron from Ni in desorption of H. Therefore, negative ions will be produced easily. It is found that the higher current of positive ions is caused by the superimposed current of the transmitted positive ions.

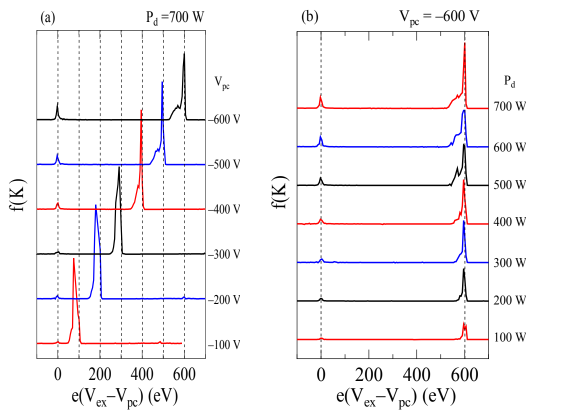

Fig. 3. Dependences of kinetic-energy distributions of the ions on (a) the irradiation energy (V_{pc}) and (b) the irradiation current (P_d).

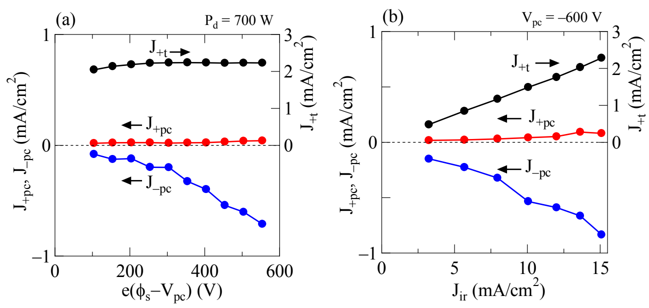

Fig. 4. Dependence of currents of the produced positive and negative ions and the transmitted positive ions on (a) the irradiation energy and (b) the irradiation current density.

References

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