22P162

Development of Beam Passing Hydrogen Negative-Ion Source by Plasma-Assisted Catalytic Ionization Method
プラズマ支援触媒イオン化法を用いたビーム通過型水素負イオン源の開発

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Production properties of positive and negative ions by a plasma-assisted catalytic ionization method are investigated using a porous nickel cylinder. The production quantity of negative ions increases with irradiation energy and current of positive ions in a discharge plasma, which has two peaks at least and the irradiation energy of the peak shifts to high energy due to increasing the irradiation current.

1. Introduction

The research and development of negative-ion sources have been extensively performed in connection with neutral beam injection (NBI) heating for fusion-oriented plasmas. 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, the porous catalyst is cylindrical, not tabular. Backstreaming positive ions, accelerated in the opposite direction, enter the negative-ion sources for NBI. If the tabular porous plate is used for negative-ion production, the backstreaming strike and cause damage to the porous plate. Therefore, the porous catalyst should be cylindrical so that the backstreaming can pass through it. At this stage, the production properties are paid attention in the case using a capped porous cylinder for eliminating the passing electrons and positive ions through inside the porous cylinder.

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. The plasma is surrounded by line-cusp magnetic fields near the grounded chamber wall. Figure 1 shows a schematic diagram of the experimental setup.

A porous cylinder of 4 cm length is made of a porous nickel plate rolled 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 %. The porous cylinder is negatively biased at a dc voltage of V_{pc}. The positive ions are irradiated and the irradiation current I_{ir} is measured. An extraction aperture, an exit of the porous cylinder, is located at $z = 0$ cm. Plasma parameters in the discharge section are measured using a Langmuir probe at $z = -12$ cm. The hydrogen pressure in the source during operation is about 0.1 Pa. Current densities of positive and negative ions from the porous cylinder 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 $z = 1$ cm.

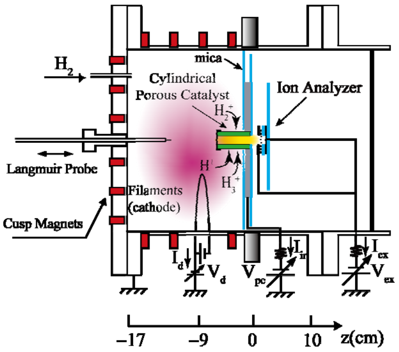

Fig. 1. Schematic diagram of experimental setup.

3. Results

Positive ions produced by discharge are irradiated to the porous cylinder which is negatively biased at V_{pc}. Positive and negative ions are produced by a plasma-assisted catalytic ionization inside the porous cylinder. The ion current extracted I_{ex} is measured using the ion analyzer. Since the extraction aperture area is 1.3 cm^2 (inner diameter of 1.3 cm), the ion current density extracted J_{ex} can be obtained. The current density (J_{ex}) - voltage (V_{ex}) characteristics of the analyzer are shown in Fig. 2. The negative current is mach higher than the positive current, contrasting results to in the case of using a porous plate. The characteristics depending on V_{pc} have 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 of positive and negative ions produced by desorption ionization appears to be less than several eV, and the former component at $V_{ex} \sim V_{pc}$ will consist of them. On the other hand, the latter component at $V_{ex} \sim 0$ V consists of the transmitted positive ions irradiated to the porous cylinder, since the plasma potential in the discharge section is close to 0 V.

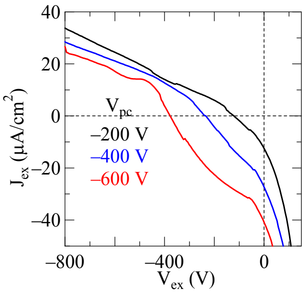

Fig. 2. Current density-voltage characteristics of ion analyzer

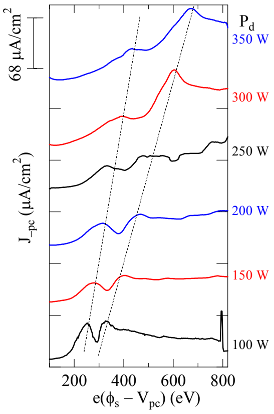

Fig. 3. Current density of negative ions produced depending on the irradiation energy of positive ions and the discharge power.

Since J_{ex} of $V_{ex} > 0$ V is only the current density of negative ions, the current density J_{-pc} is measured at $V_{ex} = +100$ V, where the subscript of J_{-pc} indicates the negative ions produced on the porous catalyst. J_{ex} of $V_{ex} < V_{pc}$ is a sum current density of the transmitted and produced positive ions. The current density of transmitted positive ions J_{+t} is obtained from current difference at $V_{ex} = 0$ V and –25 V. The current density of produced positive ions J_{+pc} is obtained from current difference between J_{ex} of $V_{ex} = V_{pc} - 100$ V and J_{+t}, taking the symmetry to the current density of negative ions into consideration. The dependences of J_{-pc}, J_{+t}, and J_{+pc} on the irradiation energy e($\phi_s - V_{pc}$) (eV) and P_d corresponding to the irradiation current of positive ions are shown in Figs. 3, 4 (a), and 4 (b), respectively, where the plasma potential ϕ_s in the discharge section remains approximately constant at +20 V. J_{-pc}, the production quantity of negative ions, tends to increase with the irradiation energy and the irradiation current (P_d) in Fig. 3. There are at least two peaks at a given irradiation current. The peak energies are found to increase with the irradiation current. The peaks are a distinctive production property of negative ions. Both J_{+t} and J_{+pc} increase with the irradiation energy and current in Figs. 4(a) and (b). The transmitted quantity of positive ions, J_{+t}, is found to be less than the production quantity, J_{+pc}, in contrast to in the case using the porous plate. Since the irradiation flux of positive ions in a direction perpendicular to the porous surface decreases and the flux in an oblique direction increases, the thickness of the porous cylinder is equivalently increased and the transmitted quantity will decrease.

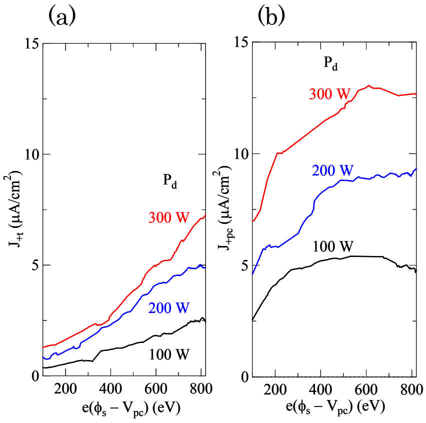

Fig. 4. Current densities of (a) transmitted positive ions and (b) produced positive ions depending on the irradiation energy and the discharge power.

References

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