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Extraction Property of Hydrogen Ions from Plasma Grid with Single Aperture
単孔プラズマグリッドからの水素イオン引出特性

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Negative hydrogen ions are produced by the plasma-assisted catalytic ionization of our suggestion using a plasma grid with a single aperture. A deflection and elimination of electrons are investigated at an extraction grid with perpendicular magnetic fields. Electrons are found to pass through the aperture of extraction grid even though the magnetic flux density is high, when positive ions and electrons coexist in harmony in the aperture.

1. Introduction

Negative hydrogen ions in a negative-ion-based neutral beam injection (NBI) system are produced by surface production with a cesium admixture. However, the use of cesium complicates the ion-source operation and requires the careful stabilization of cesium injection and discharge parameters. Therefore the production of negative ions without a cesium admixture is desirable from the viewpoint of the ion-source operation. We have proposed a plasma-assisted catalytic ionization method for the production of negative ions without a cesium admixture [1,2]. When positive hydrogen ions produced by discharge are irradiated to a grid, negative ions are produced from the back of the irradiation plane. A plasma grid (PG) with many apertures for high extraction current of ions is usually used in hydrogen ion sources. The PG with a single aperture is used instead of the grid here for the purpose of investigation of negative-ion production properties. A magnetic field for electron deflection is applied in the vertical axis of the extraction aperture, where the electrode with the magnetic field is called an extraction grid (EG). The elimination property of electrons deflected is investigated in connection with the direction of the magnetic field and the magnetic flux density.

2. Experimental Apparatus

A hydrogen plasma is generated by a dc arc discharge between filament cathodes and a chamber wall anode in a cuboidal chamber with a cross section of 25 cm×25 cm. The cathodes are four U-shaped tungsten filaments of 0.7 mm diameter and 15 cm length (height of 6 cm and width of 2 cm) biased at a dc discharge voltage of $V_d = -70$ V with respect to the grounded wall anode. The plasma generated in a field-free region is surrounded by azimuthal line-cusp magnetic fields near the chamber wall. The line-cusp magnetic fields are generated by permanent magnets attached to the outside chamber wall. The diffusion of the plasma to the wall is thus reduced by the magnetic mirror effect, resulting in the highly efficient generation of a uniform plasma. The hydrogen pressure in the discharge section during operation is about 0.1 Pa. Plasma parameters in the discharge section are measured using a Langmuir probe. The electron density, the electron temperature, and the plasma potential at the plasma core are typically 5×10^{10} cm^{-3}, 5 eV, and +10 V, respectively. Since there is a tendency that the production amount of negative ions is increased in the case of using the grids made of Al and Ti, the PG is made of Al. A dc voltage V_{PG} is negatively applied to the Al-PG with an extraction aperture of 13 mm diameter and 10 mm length. Positive ions are accelerated up to $e(\phi_s - V_{pc})$ (eV) in the sheath formed in front of the Al-PG, where ϕ_s is the plasma potential. A dc voltage V_{ex} is applied to the EG located at a distance 10 mm from the Al-PG and controls the ion energy in the aperture of the Al-PG. The deflection magnetic field is applied by permanent magnets. The extraction properties are compared in the

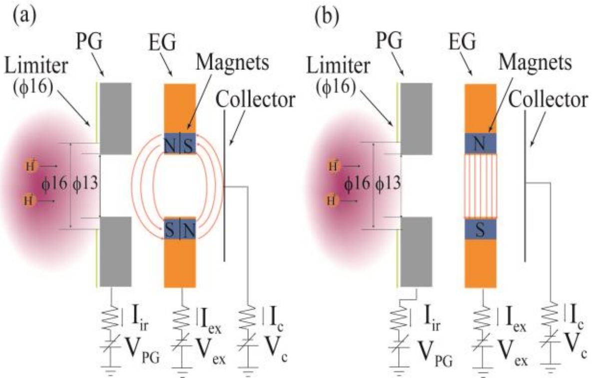

Fig.1. Schematic view of plasma and extraction grids, collector, and direction of applied magnetic fields of B = (a) 39 mT and (b) 340 mT.

different magnetic flux densities, B = 39 mT and 340 mT, and the different magnetic-field direction as shown in Figs. 1(a) and (b), respectively. Charged particles passing through the EG are detected by a collector biased at a dc voltage V_c. Positive and negative saturation currents of the collector, I_{c+} and I_{c-}, are measured at V_c = –350 V and +150 V, respectively.

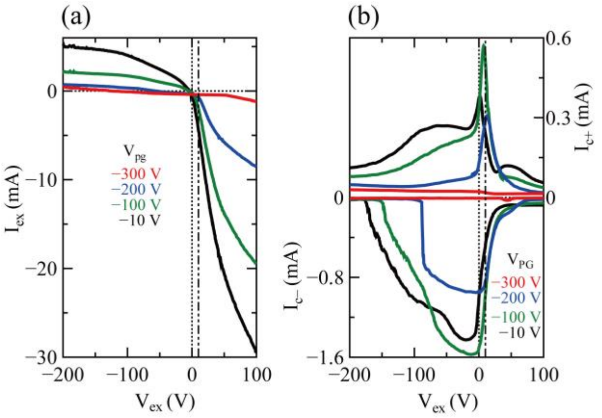

Fig.2. (a) Extraction current of EG and (b) positive and negative currents of collector as function of V_{ex}, depending on V_{PG} in the case of Fig. 1(a).

3. Results

The current I_{ex} flowing to the EG along the deflection magnetic field lines as a function of V_{ex} is measured, where the irradiation current density is constant at J_{ir} = 15 mA/cm^2. The I_{ex} – V_{ex} characteristics depending on V_{PG} are shown in Fig. 2(a). In the case of Fig. 1(a) at the deflection magnetic field of 39 mT, the I_{c+} and I_{c-} of collector current as a function of V_{ex} are shown in Fig. 2(b). Since the negative current of I_{ex} is much greater than the positive current in Fig. 2(a) at V_{PG} > –200 V, electrons pass through the aperture of the Al-PG. At the aperture center of the Al-PG, the potential is higher than V_{PG} and the depth of the sheath is shallow because of shielding on the Al-PG surface. Fast electrons, which are not reflected electrostatically, penetrate into the aperture and pass through the Al-PG. I_{c-} is higher than I_{c+} at –200 V < V_{ex} < +10 V from Fig. 2(b), where the plasma potential ϕ_s is about +10 V. If some of positive ions are negatively ionized, I_{c+} seems to become almost equal or higher than I_{c-}. I_{c-} mainly consists of electrons because of I_{c+} < I_{c-}. Electrons seem to pass through the deflection magnetic field and reach the collector. 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 negative current of I_{ex} is small at V_{PG} = –300 V, electrons are electrostatically reflected at the aperture of the Al-PG and do not reach the collector at V_{ex} < ϕ_s. The magnetic flux density of 39 mT for deflection elimination of electrons appears to be low as described above, the elimination property of electrons is investigated under the strong magnetic fields applied locally.

In the case of Fig. 1(b) at the deflection magnetic field of 340 mT, the I_{ex} – V_{ex} characteristics and the I_{c+} and I_{c-} as a function of V_{ex} depending on V_{PG} are shown in Fig. 3(a) and (b), respectively. Electrons pass through the aperture of the Al-PG at V_{PG} > –200 V from Fig. 3(a), the same as Fig. 2(a). I_{c-} is higher than I_{c+} at –20 V < V_{ex} < +10 V from Fig. 3(b), electrons reach the collector even though the range of V_{ex}, which electrons can pass through the EG, is narrow as compared with the case of Fig. 2(b). As the deflection magnetic field is strong, electrons are hard to pass through the EG, but they cannot be completely eliminated by the magnetic field. Electrostatic reflection of electrons at the Al-PG is valid for suppression of electron passing. It is necessary to increase the thickness of the Al-PG so that the potential at the aperture center of the Al-PG is sufficiently negative. The positive currents decrease as the deflection magnetic field is strong. Thus, the magnetic fields for elimination of secondary electrons by ion impact only need to be applied.

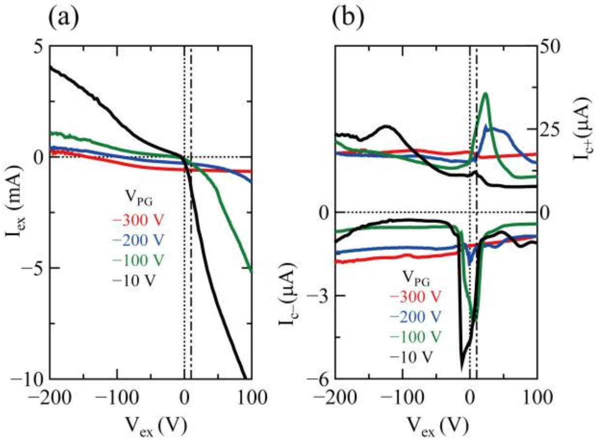

Fig.3. (a) Extraction current of EG and (b) positive and negative currents of collector as function of V_{ex}, depending on V_{PG} in the case of Fig. 1(b).

References

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