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Study on a Volume-Production H^- Ion Source

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H^- ions formed by volume-production are extracted from a multicusp ion source. By applying a positive bias 70 V to the plasma electrode, the ratio of H^- ion current to electron current I_-/I_e is improved to 1/25. The effect of the plasma electrode potential on the plasma is studied.

KEY WORDS: Volume-Production/ H^- Ion Source/

INTRODUCTION

A volume-production type H^- ion source is under study for proton linac injection. This source has an advantage over the surface production type; because the latter requires cesium, electric breakdown can be caused. It was reported by Leung et al.[1] that the application of a small bias voltage of up to 2.5 V between the plasma electrode and the anode improved the ratio of I_-/I_e from 1/9000 to 1/120. However, they reported that I_- decreased rapidly as the plasma electrode was biased higher than 2.5 V, and it continued to decrease up to 20 V.

In this paper, the effect of the plasma electrode bias of from 0 V to 70 V on the plasma is studied. When the plasma electrode is biased at between 0 V and 30 V, the behavior of I_-, I_e and I_+ are similar to those reported by Leung et al, and between 10 V and 30 V, I_-, I_e and I_+ remain nearly constant. However I_- and I_+ begin to increase as the electrode is biased higher than 30 V without large increase of I_e, and as a result, the ratio of I_-/I_e is improved to 1/25 at 70 V. It is found that the plasma electron density is not uniform in the extraction region when the plasma electrode is connected to the anode, and the nonuniformity is enhanced by applying a positive bias to the plasma electrode. It seems that the change of I_-/I_e is attributed to the plasma nonuniformity.

1. EXPERIMENTAL SETUP

A schematic diagram of the experimental setup is shown in Fig. 1. The ion source is a water-cooled cubic copper chamber ($12 \times 12 \times 12$ cm^3). Four columns of ceramic magnets are mounted on each external surface of the chamber. The chamber is divided into a discharge region and an extraction region by the transverse magnetic field (called the magnetic filter) formed by ceramic magnets on the chamber. Figure 2 shows the measured transverse field By along the beam axis (z-axis) in the source. The axes of coordinates (x, y, z-axis) are indicated in Fig. 1. A hydrogen plasma is formed by primary electrons emitted from a 0.1-cm-diam tungsten filament which is biased at

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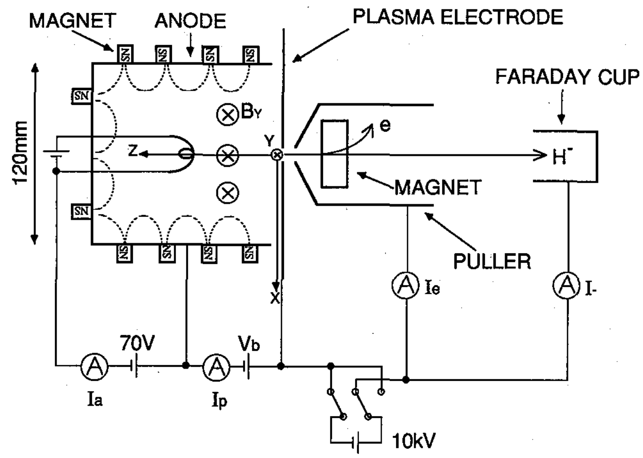

Fig. 1. Schematic diagram of the experimental apparatus. The axes of coordinates (x, y, z-axis) are drawn in the chamber, and its origin is on the extraction aperture. ⊗ indicates the magnetic filter field By.

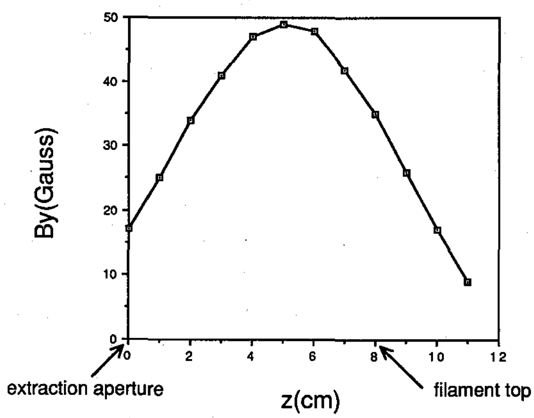

Fig. 2. A plot of the transverse magnetic field By on the beam axis (z-axis).

−70 V with respect to the chamber wall (the anode). The open end of the chamber is enclosed by the plasma electrode which can be biased at a positive potential (from 0 to 80 V) with respect to the anode.

The electron density n_e, the electron temperature kT_e and the plasma potential V_p are obtained by Langmuir probes[2)] placed at several positions in the source. To extract H^- ions, a negative potential of 10 kV is applied to the source chamber with respect to ground. The extracted electrons are separated from the H^- beam by the permanent magnet mass separator located in the puller. To extract positive ions, a positive potential is applied to the chamber. The total current of extracted ions is measured by a Faraday cup located behind the separator.

2. EXPERIMENTAL RESULTS

A. Plasma parameters and its nonuniformity

Figure 3(a), 3(b) and 3(c) shows n_e, kT_e and the plasma potential V_p (the plasma potential with respect to the anode) measured at five positions on the plane of $z=5$ mm as a function of the plasma electrode bias V_b (from 0 to 1.6 V). Probe currents suddenly become very noisy when the plasma electrode is biased higher than 1.6 V, and it is impossible to determine the plasma parameters (the plasma parameters are determined by Langmuir probe trace on the oscilloscope screen). Probe positions are indicated by coordinates (x, y, z) in Fig. 3 (x, y, z (mm) are distances in the coordinate systems of Fig. 1). Fig. 3(a) illustrates that the application of bias to the plasma electrode

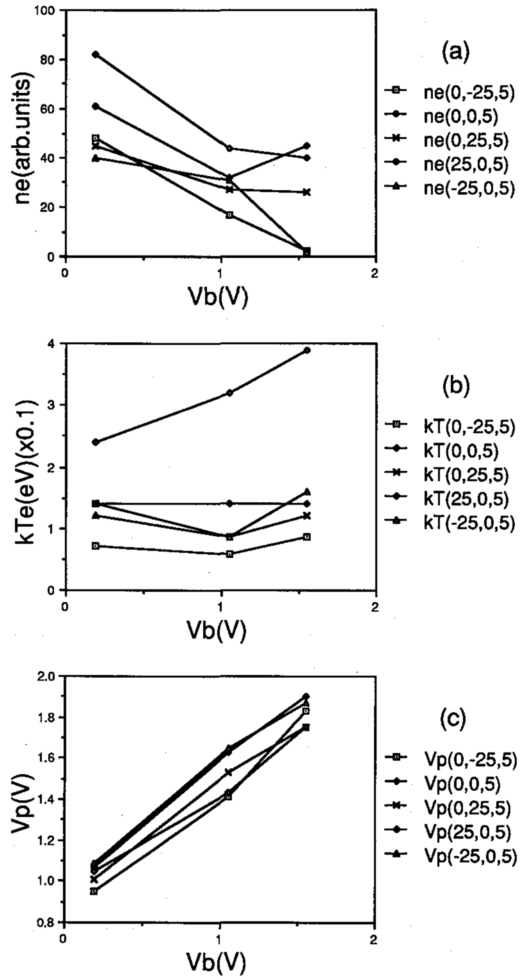

Fig. 3. (a) The plasma electron density, (b) the plasma electron temperature and (c) the plasma potential as a function of the plasma electrode bias voltage at five positions in the extraction region. The probe position is indicated by coordinates (x, y, z) like n_e (x, y, z).

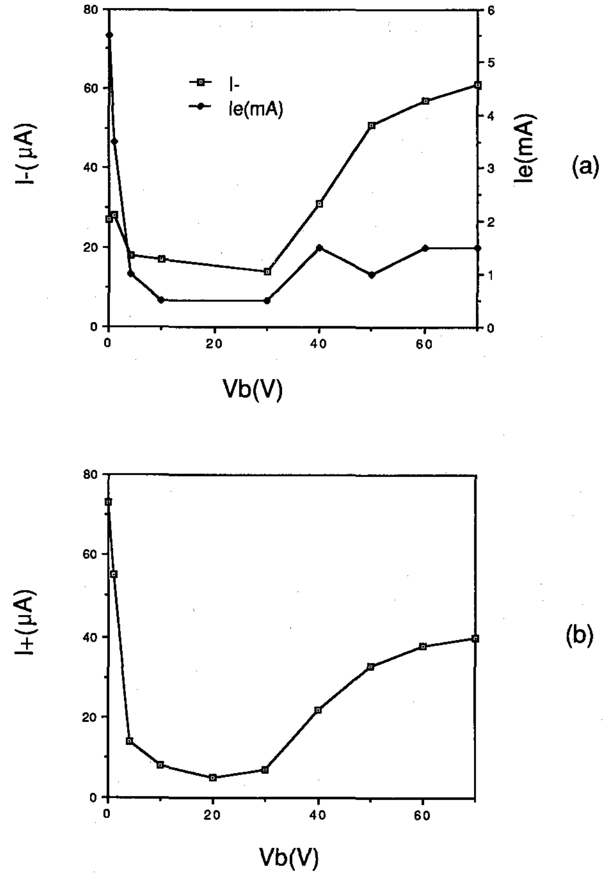

Fig. 4. (a) The extracted H^- ion current and electron current and (b) the extracted positive ion current as a function of the plasma electrode bias voltage.

enhances the plasma nonuniformity. When the plasma electrode bias is changed from 0.2 V to 1.6 V, n_e (0, −25, 5) and n_e (−25, 0, 5) are reduced by a factor of 20. Figure 3(c) illustrates that V_p at each position changes in a similar way, and there is little change of difference between each V_p.

B. Extracted current I_-, I_e and I_+

Figure 4(a) shows the extracted H^- ion current I_- and electron current I_e (for negative ion extraction), and Fig. 4(b) shows the extracted positive ion current I_+ (for positive ion extraction) as a function of the plasma electrode bias V_b with a discharge current of 10 A, a gas pressure of 8 m Torr, the extraction aperture of 13 mm^2 and an extraction voltage of 10 kV. When the plasma electrode is connected to the anode, I_-, I_e and I_+ are 27 μA, 5.5 mA and 73 μA, respectively, and the ratio of I_-/I_e is 1/200. I_e is expressed by $I_e = en_eS\ (kTe/2\pi m_e)^{1/2}$, where S is the area of the extraction aperture, and n_e and kT_e are the plasma electron density and temperature near the extraction aperture. So the change of I_e is attributed to the change of n_e or kT_e. There is no significant change in I_- when the plasma electrode is biased at 1 V, but I_e and I_+ decrease to

3.5 mA and 55 μA. The behavior of I_e from 0 V to 1 V is consistent with that of n_e (0, 0, 5) and kT_e (0, 0, 5) in Fig. 3(a) and (b). However, like I_e and I_+, I_- decreases as the plasma electrode is biased higher than 1 V. I_-, I_e and I_+ decrease to 14 μA, 0.5 mA and 7 μA, respectively, when the plasma electrode is biased at 30 V. When the plasma electrode is biased higher than 30 V, I_-, I_e and I_+ begin to increase rapidly with the bias voltage V_b. They increase to 61 μA, 1.5 mA and 40 μA respectively at V_b=70 V. As a result, the ratio of I_-/I_e is improved to 1/25 by biasing the plasma electrode at 70 V. 430 μA of the H^- ion and 11.5 mA of the electron current are extracted with the extraction aperture of 110 mm^2, a discharge current of 10 A, a gas pressure of 8 m Torr and the plasma electrode bias voltage of 70 V. The H^- ion current density is 0.4 mA/cm^2 and the noise amplitude (peak to peak) is about 30% of I_-. The application of a positive bias to the plasma electrode improves the ratio of I_-/I_e, but on the other hand, it increases the noise amplitude of the extracted H^- ion current. It seems that the noise is due to the potential gap between the anode and the plasma electrode. I am planning to insert some electrodes into the chamber so that the noise can be reduced by modifying the potential gradient in the chamber.

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