Relationship between extraction of H^- ions optimized by plasma grid potential and plasma parameters in a bucket source

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Although optimizing the magnetic filter position and the plasma grid potential is one of the most effective factors to enhance H^- yield, details concerning their roles are not now clarified well. In this article, spatially resolved measurements of the electron energy distribution function, plasma fluctuations, and plasma parameters are presented. On the basis of these experimental results, we will discuss the roles of both the magnetic filter and the plasma grid biasing voltage V_b on enhancement of H^- production and extraction of H^- ions.

I. INTRODUCTION

Several different techniques to enhance H^- yield in a multicusp source have been investigated by many authors. Although optimization of magnetic filter,[1,2] optimization of plasma grid bias potential,[3,4] and the addition of cesium or barium to a hydrogen discharge[5,6] can enhance the H^- output current, from our viewpoint, details concerning their roles are not yet well clarified. Among them, in investigating the nature of operation of the magnetic filter and the plasma grid, spatially resolved measurement of the electron energy distribution function (EEDF) and the related plasma parameters are important.

Recently, our experimental results have shown that, with the use of both a movable magnetic filter and a plasma grid, plasma parameters, including the EEDF, are spatially well controlled.[7] Beside these, according to the results of plasma particle simulation,[8] it is also found that, concerning the role of the magnetic filter (i.e., preferential reflection of energetic electrons), plasma fluctuation plays an important role.

In this article, measurements of plasma parameters including the EEDF and plasma fluctuation in the multicusp H_2 discharge are presented. On the basis of these experimental results, we will discuss the roles of the magnetic filter and the plasma grid potential for the enhancement of H^- production and H^- extraction.[9]

II. EXPERIMENTAL APPARATUS AND PROCEDURE

Figure 1 shows a schematic drawing of the apparatus. Details are reported elsewhere.[7,10] The source chamber (16 cm diam, 30 cm long) is made of stainless steel and is surrounded externally by 16 columns of ferrite permanent magnets, which form a longitudinal linecusp configuration for primary electrons and produced plasmas confinements. Plasma parameters were measured by two cylindrical Langmuir probes (0.5 mm diam, 2 mm long). To obtain EEDF using the Druyvesteyn method, the second derivative of the probe characteristic was also measured. From these data, the density of fast electrons $n_{fe}(E)$ with an energy higher than E was estimated.

A samarium-cobalt magnetic filter[1,6] divides the entire chamber into an arc discharge (the right-hand side) and a diffused plasma (the left-hand side). This filter provides a limited region of transverse magnetic field. A plasma grid whose potential is variable, is also equipped in the left chamber.

The left end plate (i.e., the plasma grid) has a single hole (10 mm diameter) through which ions were extracted from the source. A magnetic deflection type ion analyzer, located just outside the plasma grid, was used for relative measurement of the extracted H^- ions as well as for the analysis of the positive ion species.

III. EXPERIMENTAL RESULTS AND DISCUSSION

At any filter position, the EEDF and other plasma parameters (electron density n_e, electron temperature T_e, plasma space potential V_s, floating potential V_f etc.) change steeply across the magnetic filter.[7,9] The entire plasma is divided into two distinct regions (i.e., the source plasma with high-energy electrons and the diffused plasma without high-energy electrons).[7] Figure 2 shows a typical example of spatial variations of the EEDF, where a high-energy part is enlarged and a part of bulk plasma electrons (i.e., below 15 eV) is withdrawn. It shows relative intensities in EEDF and not normalized values. Corresponding to the variation of the EEDF, n_{fe}/n_e (the density ratio of fast to total plasma electrons) decreases remarkably across the filter. Moving the filter toward the plasma grid will allow $H_2(v'')$ and low-energy electrons to diffuse much more easily across the filter, and give much higher $H_2(v'')$ and electron densities in the extraction region. On the other hand, Te in the extraction region is kept nearly

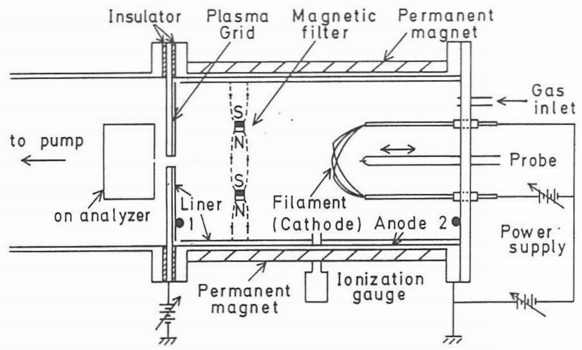

FIG. 1. Schematic diagram of the multicusp H^- ion source equipped with a plasma grid and a movable magnetic filter.

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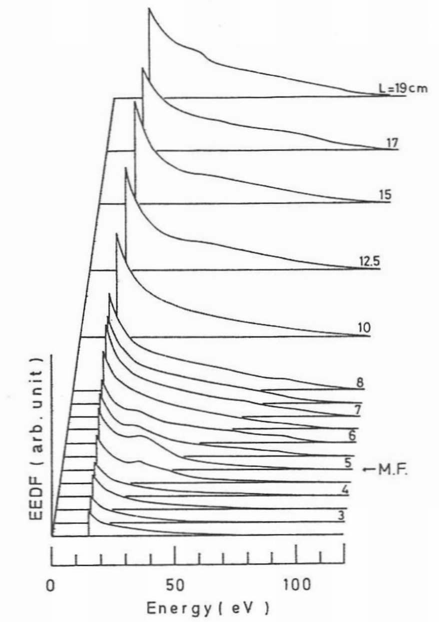

FIG. 2. Axial variations of the EEDF for a certain filter position, i.e., $L_f = 5$ cm. Experimental conditions are as follows: $V_d = 80$ V, $I_d = 2$ A, and $p(H_2$ gas$) = 2.9$ mTorr.

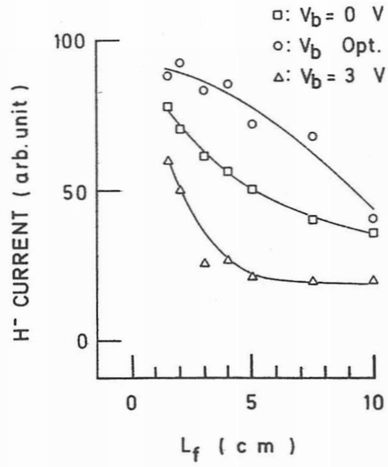

FIG. 3. A plot of the spectrometer signal for the H^- ions as a function of the filter position L_f for three different biasing voltages V_b of the plasma grid. Experimental conditions are as follows: $V_d = 80$ V, $I_d = 2$ A, and $p(H_2$ gas$) = 1.4$ mTorr.

constant below 1 eV. This in turn can improve the conversion of $H_2(v'')$ into H^- ions.[9]

The role of the magnetic filter (i.e., preferential reflection of high energy electrons) is also studied by particle simulation.[8] We simply point out that, in the present low-density plasma (see Fig. 5), most electrons cross the magnetic filter not due to Coulomb collisions[11] but $E\times B$ drift, where E is the fluctuation field and B is the filter field. Because of the finite Larmor radius effect, $E\times B$ drift for electrons decreases with the increase of the electron velocity. Thus, energetic electrons can be reflected preferentially by the filter. Experimentally, plasma fluctuation with a well-defined frequency (i.e., 1–2 MHz, a frequency range of lower hybrid waves) was observed when the probe was biased above the earth potential or nearly equal to plasma potential. It is also found that this fluctuation is localized in the vicinity of the magnetic filter.

Figure 3 shows the extracted H^- currents for three different grid biasing voltages V_b as a function of the filter position L_f. As the filter is moved toward the plasma grid, the H^- currents increase steadily. The dependence of H^- yield on L_f, however, is strongly affected by V_b. These different dependences of H^- yields on L_f are corresponding well to the different variations of plasma parameters (not shown here) for different V_b.

The H^- yield as a function of the plasma grid bias voltage is shown in Fig. 4. At some optimum V_b (i.e., about 1.2 V), the H^- yield becomes maximum.[3,4] Corresponding to this, plasma parameters near the plasma grid ($L = 1$ cm) vary with the change of V_b. With increasing V_b in positive region, n_e decreases monotonically, and both T_e and V_s increase monotonically.[9]

It is principally said that the effect of biasing the plasma grid makes plasma potential gradient in plasmas optimized to extract the volume-produced H^- ions easily. We note, however, that not only V_s but also other plasma parameters (n_e, T_e, etc.) and plasma fluctuation in the extraction region depend strongly on V_b. Typical examples, corresponding to the H^- variation in Fig. 4, are shown in Figs. 5 and 6.

Namely, in Fig. 5, n_e, T_e, and V_s for two different positions, i.e., at the filter position and at the point near the extraction aperture, are plotted as a function of V_b. Changing V_b makes n_e and T_e vary significantly, and then it changes the H^- yield conditions, although V_s (i.e., at the optimized voltage $V_b = 1.2$ V) in the vicinity of the plasma grid is nearly equal to V_s near the filter position. Namely, H^- ions produced near the filter may be also extracted. For reference, axial variations of V_s for three different V_b

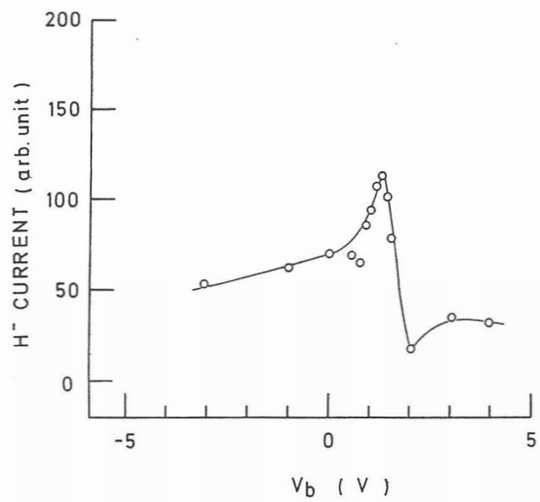

FIG. 4. A plot of the spectrometer signal for the H^- ions as a function of the biasing voltage V_b of the plasma grid. Experimental conditions are as follows: $V_d = 80$ V, $I_d = 2$ A, $p(H_2$ gas$) = 2.4$ mTorr and $L_f = 5$ cm.

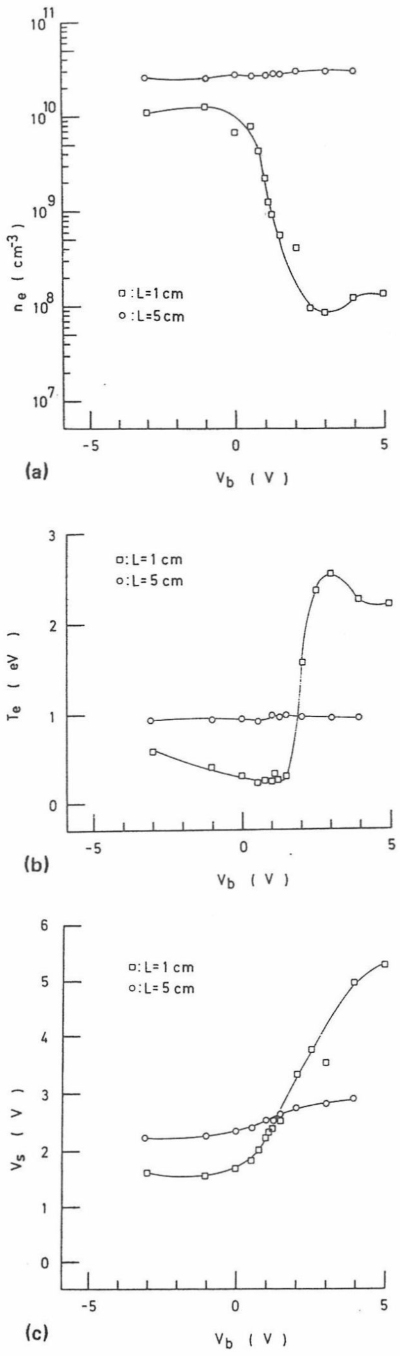

FIG. 5. Some plasma parameters, n_e in (a), T_e in (b) and V_s in (c), as a function of V_b for two different axial points (i.e., extraction and filter regions). They are corresponding to the H^- variation shown in Fig. 4.

are shown in Fig. 6. A significant effect of plasma grid bias upon n_e and T_e is also observed in the extraction region as V_s in Fig. 6.[9]

With biasing the plasma grid positive, in the vicinity of the magnetic filter and the connected extraction region, plasma fluctuation with frequencies not a range of lower-hybrid-waves but a low-frequency-range (i.e., 200–800 kHz) increases its amplitude. When V_b is optimized, however, fluctuation amplitude becomes minimum and then plasma in the extraction region becomes quiescent. Plasma fluctuation plays an important role for transport and dynamics of negative ions through the motion of electrons although the relationship between the H^- extraction and plasma fluctuation is not yet well clarified

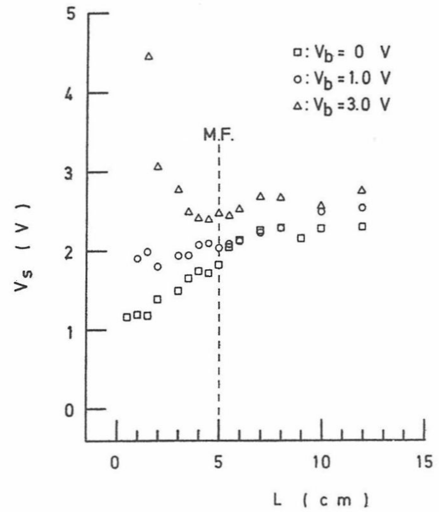

FIG. 6. Plasma space potential V_s as a function of the distance L from the plasma grid for three different plasma grid biasing voltages V_b. Experimental conditions are the same as ones in Fig. 4.

In summary, spatially resolved measurements of the EEDF, plasma fluctuations, and plasma parameters (n_e, T_e, V_s, etc.) are obtained. On the basis of these experimental results, we have studied the effects of magnetic filter position and plasma grid biasing voltage V_b on enhancement of H^- yield and extraction of H^- ions.

ACKNOWLEDGMENT

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