

Isotope effects in an electron beam excited negative ion source

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Results which focus on comparing operation in hydrogen and deuterium are presented. Measurements of plasma parameters, including electron density, electron temperature, electron energy distribution function and extracted negative ion current, have been made in the source and extractor regions of an electron beam excited negative ion source. For the same operating conditions, negative ion current is found to be higher in deuterium than in hydrogen. © 1996 American Institute of Physics. [S0034-6748(96)04102-3]

I. INTRODUCTION

According to our simulation results,^{1,2} most of H^- ions are produced by a two-step process.³ Namely, H^- ions are generated by dissociative attachment of slow plasma electrons e (with electron temperature $\kappa T_e \sim 1$ eV) to highly vibrationally excited molecules $H_2(v'')$ (effective vibrational level $v'' \geq 5-6$), and these $H_2(v'')$ are mainly produced by collisional excitation of fast electrons e_f with energies in excess of 30 eV. Recently, to test H^- volume production process, we have newly developed a double plasma (DP) type negative ion source,⁴ where plasma parameters, especially the energy and density of e_f are well controlled by changing the injected beam parameters. By using this source, the effect of e_f on H^- production is investigated,⁵ and the results support qualitatively the two-step process of H^- production.

In this paper, with the use of this DP type ion source, we will study D^- production and its isotope effect. The comparison of data relevant to hydrogen H_2 and deuterium D_2 is important for understanding the reasons for different performance of volume D^- sources, compared to H^- sources.

II. EXPERIMENTAL SETUP AND PROCEDURE

Figure 1 shows a schematic diagram of the DP-type negative ion source.^{4,5} The source chamber is made of stainless steel, and is divided by a mesh grid into two regions, i.e., a driver plasma region (the left-hand side) and a target plasma region (the right-hand side). The target plasma region is a conventional multicusp volume source of negative ions equipped with both a magnetic filter and a plasma grid. The plasma conditions are determined by the discharge current I_d and the discharge voltage V_d for the driver plasma, the acceleration voltage V_B (i.e., the potential difference between two chambers) and the gas pressure p . In the present series of measurements, V_d was fixed at 40 V. Electrons in the driver plasma are extracted and injected into the target chamber as an electron beam with beam energy eV_B and the target plasma, i.e., the ion source plasma, is produced by this injected beam. With the change of V_B and the beam current I_B , e_f in the target plasma (the source region of the ion source, i.e., the region of $H_2(v'')$ or $D_2(v'')$ production caused by e_f) are well controlled.^{4,5}

Plasma parameters are measured by Langmuir probes. To obtain an electron energy distribution function (EEDF), the Druyvesteyn method was used. From those data, the density of fast electrons $n_{fe}(E)$ with an energy higher than E was estimated. The right end plate, i.e., the plasma grid, has a single hole (10 mm diam) through which ions were extracted from the source. A magnetic deflection type ion analyzer and Faraday cup were used for relative measurement of the extracted H^- or D^- ions.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Electron beam is injected at $z=0$ cm, i.e., the position of the mesh grid, and plasma is produced. Here, we will call this plasma as an electron beam excited plasma, i.e., EBE plasma. There is a spatial variation in electron density n_e (n_e increases gradually with Z and then saturates near $Z=15-17$ cm) although electron temperature T_e is kept nearly constant value. Both n_e and T_e change remarkably across the magnetic filter in the same manner of the usual volume source, where filter position $Z_f=20$ cm.

Figure 2 shows the plasma parameters in both regions as a function of I_d . They are measured at $z=15$ cm in the source region and at $Z=21$ cm in the extraction region, where the plasma grid is set at $Z=22$ cm. When V_B is kept constant at a certain voltage (i.e., 100 V in this case), I_B increases with increasing I_d and then discharge power, $V_B I_B$, for the target plasma region becomes high. The electron density $n_e(2)$ in the extraction region for D_2 is slightly higher than $n_e(2)$ for H_2 although $n_e(1)$ in the source region for D_2

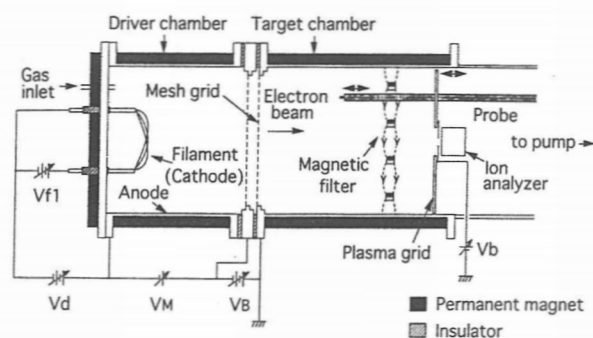


FIG. 1. Schematic diagram of the double plasma type negative ion source.

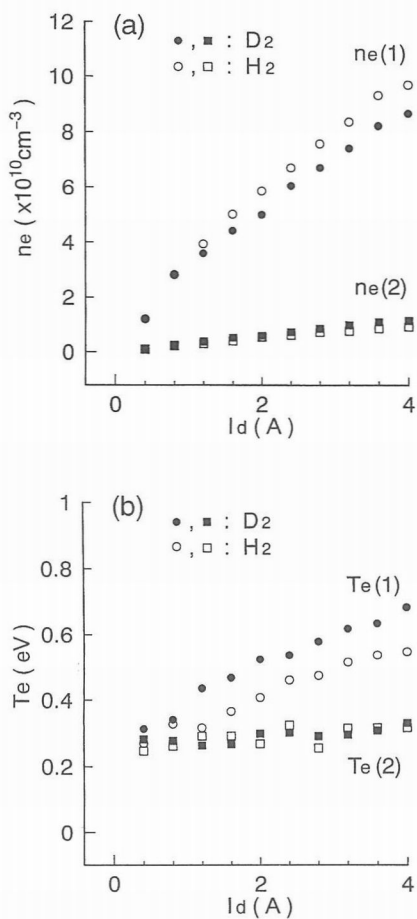


FIG. 2. Plasma parameters in the source and extraction regions versus discharge current I_d in the driver plasma, i.e., (a) $n_e(1)$ and $n_e(2)$, and (b) $T_e(1)$ and $T_e(2)$. They are measured at $Z=15$ cm in the source region and $Z=21$ cm in the extraction region, respectively. The electron beam is injected into the target plasma at $Z=0$, and the magnetic filter and the plasma grid are set at $Z=20$ and 22 cm. Experimental conditions are as follows: Discharge voltage in the driver plasma $V_d=40$ V, gas pressure $p(\text{H}_2$ or D_2 gas)=4 mTorr and the beam acceleration voltage $V_B=100$ V.

is lower than $n_e(1)$ for H_2 . This feature is well reproducible in the present experiment. In the extraction region, because of the magnetic filter effect, electron temperature $T_e(2)$ keeps nearly constant value which is lower than $T_e(1)$ in the source region with increasing I_d , although n_e increases linearly.

Figure 3 shows the dependence of the EEDF on I_d in the source region, corresponding to the results in Fig. 2. They are also measured at $z=15$ cm. With increasing I_d , the EEDF increases in its magnitude, especially in the high energy tail. There is a little difference in the EEDF between D_2 and H_2 , i.e., the bulk plasma. This point is consistent with the difference in $T_e(1)$ shown in Fig. 2(b). Namely, $T_e(1)$ in H_2 is apparently lower than that in D_2 .

Figure 4 shows the dependence of negative ion currents on I_d . Gas pressure $p=4$ mTorr and extraction voltage $V_{\text{ex}}=400$ V. As the plasma grid is set at $z=22$ cm in this case, the distance between the plasma grid and the magnetic filter is 2 cm. The plasma grid potential V_b is kept at earth potential, i.e., the same potential of the chamber. In the present operating conditions, however, the plasma grid is almost optimized to extract the highest H^- or D^- current at

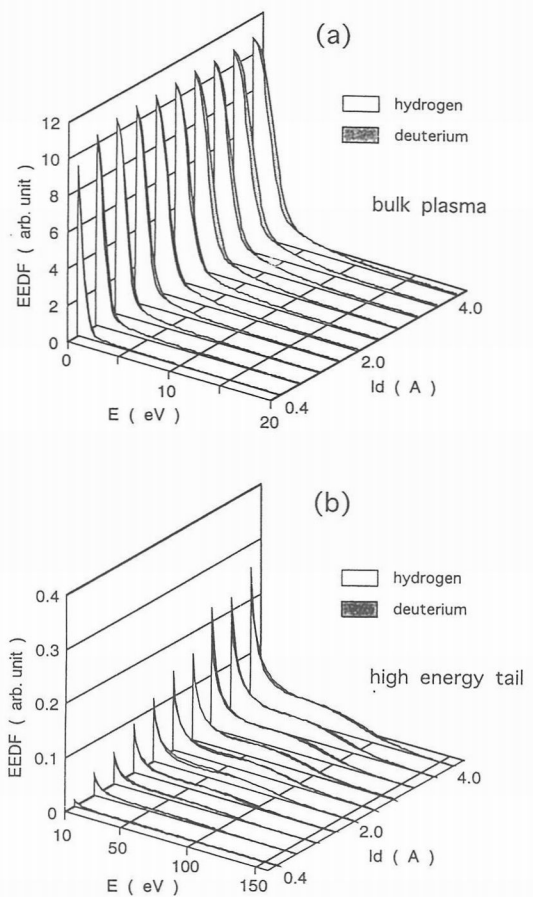


FIG. 3. Electron energy distribution functions (EEDF) for H_2 and D_2 plasmas in the source region vs I_d , i.e., (a) bulk plasma electrons and (b) high energy tail. They are measured at $Z=15$ cm. Experimental conditions are the same as ones in Fig. 2.

every I_d . It is quite interesting that the D^- current is nearly equal to or slightly higher than H^- current.

There is another example of measuring the currents of the negative ions. Figure 5 shows the dependence of negative ion currents on p . The results are reported for $I_d=3$ A, $V_d=40$ V, and $V_{\text{ex}}=400$ V. At first, negative ion currents increase with p up to 4 mTorr, and then saturate at about 4–5 mTorr. When p is increased above 3 mTorr, difference between D^- and H^- currents becomes distinguishable. Again, at the same operating conditions, the D^- current is higher than the H^- current.

So far, the isotope effects have been reported by several authors.^{6–9} In general, the experimental results show that the negative ion current or density in D_2 plasmas is lower than that in H_2 plasmas. In the present experiment, however, we have found that at the same operating conditions, the D^- current is higher than the H^- current although discharge current is rather low. This point is quite different from other experimental results^{6–9} and, at the same time, is most interesting.

As is discussed elsewhere,^{4,5} when H^- ions are produced by the so-called two-step process where $\text{H}_2(v'')$ are produced in the source region and H^- ions are formed in the extraction

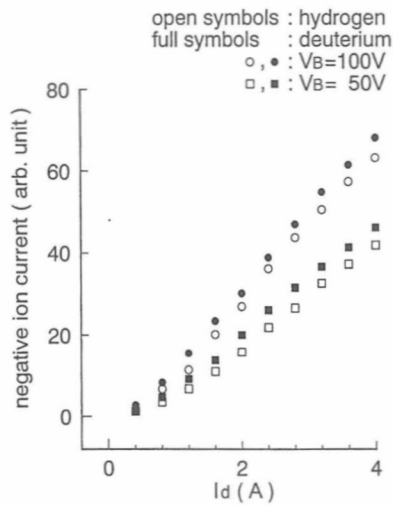


FIG. 4. Extracted H^- and D^- currents vs I_d , where plasma grid potential V_b is set at equal potential to the anode. Experimental conditions are as follows: $V_d=40$ V, $p(H_2$ or D_2 gas) $=4$ mTorr and extraction voltage $V_{ex}=400$ V.

region, H^- density is written briefly as follows:

$$H^- \text{ density} = n_{fe}(1)n_e(2)N_{H_2}\langle\sigma v\rangle_{v''}\langle\sigma v\rangle_{DA}\tau_{v''}\tau_-,$$

where $n_{fe}(1)$ is e_f density in the source region, $n_e(2)$ is n_e in the extraction region, N_{H_2} is density of hydrogen molecules, $\langle\sigma v\rangle_{v''}$ is reaction rate of vibrational excitation by e_f in the source region, $\langle\sigma v\rangle_{DA}$ is reaction rate of dissociative attachment in the extraction region, $\tau_{v''}$ is the life time of $H_2(v'')$, and τ_- is the life time of H^- ions. Roughly speaking, H^- density is proportional to the product of $n_{fe}(1)$ and $n_e(2)$,^{4,5} if T_e keeps a certain constant value during the change of electron densities. Because reaction rates and life times depend on T_e . The production process of D^- ions is believed to be the same as that of H^- ions.

According to the measured plasma parameters, there is no distinguishable isotope effects in both $n_e(2)$ and $T_e(2)$. They are the key parameters to the dissociative attachment process, i.e., the H^- or D^- formation process. Therefore, the difference observed in H^- and D^- currents should be derived from the production of $H_2(v'')$ or $D_2(v'')$. Concerning this point, the EBE plasma could have the advantage compared with the usual tandem sources (i.e., filament cathode), although so far we have no clear experimental results. In the future, we will measure the plasma parameters in D_2 plasmas for high discharge current ($I_d > 10$ A), and compare the results in the EBE plasma with that of the usual tandem sources.

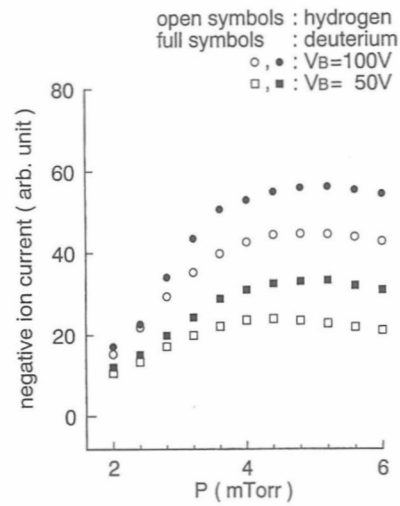


FIG. 5. Extracted H^- and D^- currents versus gas pressure. Experimental conditions are as follows: $V_d=40$ V, $I_d=3$ A, and $V_{ex}=400$ V.

IV. CONCLUSIONS

We have studied D^- production and its isotope effects. Measurements of the basic plasma parameters have been made in the source and extraction regions of the EBE plasma source operating in both H_2 and D_2 . It is found that D^- current is higher than H^- current at the same operating conditions although discharge current is rather low.

ACKNOWLEDGMENT

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