STUDY OF ARGON ADDITIVE IN A BEAM INJECTION TYPE NEGATIVE ION SOURCE USING VUV EMISSION SPECTROSCOPY

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Abstract. Effects of Ar addition are studied by using a beam injection type negative ion source. With adding Ar, I_{H^-} increases at low base H_2 pressure. At high base H_2 pressure, however, I_{H^-} decreases. VUV emission intensities also decrease at high base pressure. In other words, Ar addition is adverse effect for production of $H_2(v'')$. Therefore, decrease in I_{H^-} is caused by decrease in $H_2(v'')$. In D_2 plasmas, variation patterns of plasma parameters and VUV intensities by Ar addition are nearly the same as ones in H_2 plasmas. Even in low base pressure, however, enhancement of I_{D^-} is not observed.

Keywords : volume negative ion sources, VUV emission, vibrationally excited molecules

1. Introduction

Sources of H^- and D^- negative ions are required for generating efficient neutral beams with energies in excess of 150 keV. In a volume H^- source, most of H^- ions are generated by dissociative attachment of slow plasma electron e_s (electron temperature Te ≦ 1 eV) to highly vibrationally excited hydrogen molecules H_2 (v") (effective vibrational level v" ≧ 5~6). These H_2 (v") are mainly produced by collisional excitation between ground state hydrogen molecules H_2 (v" = 0) and fast electron with energies in excess of 20 eV. Namely, H^- ions are produced by the following two-step process [1].

$$H_2(X^1\Sigma g, v''=0) + e_f(E \geq 20\text{eV}) \rightarrow H_2^*(B^1\Sigma u, C^1\Pi u) + e_f' \qquad (1a)$$

$$H_2^*(B^1\Sigma u, C^1\Pi u) \rightarrow H_2(X^1\Sigma g, v''\neq 0) + h\nu(\text{VUV}) \qquad (1b)$$

$$H_2(v''\geq 5) + e_s(T_e \leq 1\text{eV}) \rightarrow H^- + H \qquad (2)$$

where $H_2^*(B^1\Sigma u, C^1\Pi u)$ is singlet electronically excited hydrogen molecules. Production of D^- ions is believed to be the same as that of H^- ions. To develop efficient D^- ion sources, it is important to clarify production and control of D_2 plasmas and to understand difference in the two-step process of negative ion production between H_2 plasmas and D_2 plasmas.

Concerning enhancement of negative ion production, effects of Ar addition have been studied by several authors [2][3][4]. In DC [2] and ECR [3][4] plasmas, with adding Ar gas to low or high base H_2 pressure, electron density : ne goes up and electron temperature : Te is kept under 1 eV. That is to say, plasma parameters (ne and Te) are suitable for negative ions production. The H^- ion production increases when Ar is added to low base H_2 pressure, On the other hand, it decreases with adding Ar to high base H_2 pressure although plasma parameters are suitable for H^- ions production. In DC and ECR plasmas, with adding Ar to low base pressure, increase in H^- ion production is caused by enhancement of ne. However, with adding

Ar to high base pressure, why H^- ion production is decreased is not clarified well.

So far, we have confirmed that excitation of H_2 (v") depends on fast electrons with energy in excess of 15–20 eV by using VUV spectroscopy [5]. We have also discussed enhancement of negative ion production and isotope effect on H^-/D^- volume production by observing VUV emission intensities [6]. Using VUV spectroscopy is effective in observing the physical process on negative ion production [7].

In this paper, we study effects of Ar addition on H^-/D^- ion production with the use of the beam injection type negative ion source, where energy of primary electrons, i.e. e_f energy, is well controlled and varied. We discuss why the negative ion production decreases with adding Ar by observing VUV emission intensities. We also discuss isotope effect of H^-/D^- production.

2. Experimental Apparatus

Figure 1 shows a schematic diagram of the beam injection type negative ion source. The chamber made of stainless steel is divided by a mesh grid (z = 0 cm) into two regions, i.e. a driver plasma region and a target plasma region. The target plasma region is a conventional multicusp negative ion source equipped with both a magnetic filter (z = 20 cm) and a plasma grid. The magnetic filter field divides the target chamber into the source region (i.e. plasmas with injected high-energy electrons) and the extraction region (i.e. plasmas with low Te).

In the driver chamber, plasmas are produced by DC arc discharge between hot filaments and the chamber anode, which is grounded. Electrons in the plasmas are extracted and injected into the target chamber as an electron beam with controlled beam energy eV_B. In the target chamber, H_2/D_2 gases are introduced and plasmas are produced by collision of the injected electron beams with introduced gases. In the source region, the VUV emission measurements related to the H_2 (v") or D_2 (v") production, i.e. the process (1b), are carried out by using the

VUV spectrometer. The spectrometer was normally operated at a resolution of 0.1 nm.

Plasma parameters are measured by using Langmuir probes. A magnetic deflection type ion analyzer is used for measurement of the extracted H^- or D^- ion currents. Plasma grid potential is kept earth potential.

3. Experimental Results and Discussion

3.1 VUV spectrum

Figure 2 shows the typical VUV spectra from both (a) H_2 and (b) D_2 plasmas. Intensity with 121.6 nm in H_2 plasmas is the spectrum of Lyman α. Because H and D are isotope, we believe that the spectrum of Lyman α from D_2 plasmas is nearly equal to that from H_2 plasmas as shown in Fig.2 (b). According to the numerical results [1], H_2 (v" $\geqq$ 5) are more effective for H^- production. In Fig.2 (a), spectra leading to production of H_2 (v" $\geqq$ 5) are ranged from 117.5 to 165 nm [7]. Internal energy of deuterium molecules D_2 (v" $\geqq$ 8) are the same as that of H_2 (v" $\geqq$ 5). Therefore, discussion on VUV spectra in H_2 plasmas should be also applicable for discussion on VUV spectra in D_2 plasmas. Namely, production of highly vibrationally excited deuterium molecules D_2 (v") is related to the emission with the same wavelength range, i.e. 117.5~165 nm. We obtain the total intensity of the VUV spectra by integrating from 110 to 170 nm in both H_2 and D_2 plasmas. In integration of VUV spectra, Lyman α is excluded because it is not concerned with production of negative ions. In the following sections, these integrated intensities are presented for discussing production of H_2 (v") and D_2 (v").

3.2 H^- production in H_2 plasmas

We have measured the dependences of plasma parameters, VUV emission intensities and negative ion currents on H_2 pressure in the range 1 to 4 mTorr, and on Ar additive pressure (10-50 %), for several values of H_2 base pressure (1, 1.5, 2, 2.5, 3, 3.5 and 4 mTorr). These results are shown in Figs. 3-5.

Figure 3 shows plasma parameters [(a) ne and (b) Te] with adding Ar to H_2 plasmas. ne is increased at both low(1 and 2 mTorr) and high(3 and 4 mTorr) base H_2 pressures. Te is not changed, and kept under 1 eV. The value of Te is suitable for H^- ion production at both low and high base pressures. Increase in ne is caused by the higher ionization cross section of Ar gas compared with that of H_2 gas [4].

Figure 4 shows integrated intensities of VUV emission corresponding to the results in Fig. 3. Integrated intensities of the VUV emission are increased a little at low base H_2 pressure, but they are decreased at high base H_2 pressure. About VUV emission with adding Ar, Curran et al proposed the following hypothesis [8] i.e. the sequential energy transfer from the excited argon states through a photon to hydrogen singlet states. This energy transfer process would be the cause of enhanced highly excited vibrational population of hydrogen molecules. However, the phenomenon is not observed in this study. As shown in Fig. 4, intensities of VUV emission is not increasing but decreasing at high base H_2 pressure. Contrary to the above hypothesis, it seems that the vibrational cooling is carried out with Ar addition. According to the results shown in Figs. 3 and 4, at low base pressure, VUV emission and plasma parameters are suitable for H^- ions production.

Figure 5 shows negative ion currents (I_{H^-}) corresponding to the plasma conditions shown in Figs. 3 and 4. I_{H^-} is increased a little at low base pressure. However, I_{H^-} is decreased at high base pressure although ne and Te are suitable for H^- ions production. Decrease in I_{H^-} is caused by decrease in VUV emission intensities, i.e. decrease in H_2 (v") production.

It is confirmed experimentally that decrease in I_{H^-} at high base H_2 pressure is caused by decrease in H_2 (v") production. Concerning plasma parameters and I_{H^-}, our results shown in Figs. 3-5, have the same tendencies as ones in DC and ECR plasmas [2][3][4]. In DC plasmas, Ar addition does not affect VUV emission [2], and the cause of decrease in H^- ion production at high base pressure is written nothing. But we think that decrease in I_{H^-} at high base pressure in DC and ECR plasmas is also caused by decrease in H_2 (v") production.

3.3 D^- production in D_2 plasmas and Isotope effect on H^-/D^- production

Figs. 3 and 4 show plasma parameters [(a) ne and (b) Te] and integrated intensities of VUV emission in D_2 plasmas. Plasma parameters and VUV emission with Ar addition in D_2 plasmas are changed by the same manner as ones in H_2 plasmas. At low base pressure, plasma parameters and VUV emission are suitable for D^- ion production the same as ones in H_2 plasmas. However, values of ne and Te in D_2 plasmas are higher than ones in H_2 plasmas with adding Ar or pure discharge but Te is kept under 1 eV. Values of integrated intensities of VUV emission in D_2 plasmas are lower than ones in H_2 plasmas with adding Ar or pure discharge.

Figure 5 shows negative ion currents (I_{D^-}) corresponding to the plasma conditions shown in Figs. 3 and 4. At low base pressure, I_{D^-} are not increased by Ar addition unlike I_{H^-} in H_2 plasmas although plasma parameters and VUV emission are suitable for D^- ion production. At high base pressure I_{D^-} decreases in its intensitiy as I_{H^-} does.

Difference in the values of ne between H_2 and D_2 plasmas [see Fig. 3 (a)] is caused by difference in mass between hydrogen ions and deuterium ions. Deuterium ions have larger mass than hydrogen ions. That is to say, wall loss time for deuterium ions is longer than one for hydrogen ions. Difference in the values of Te between H_2 and D_2 plasmas [see Fig. 3 (b)] is also explained by difference in mass. In inelastic collisions, electron energy loss with light neutral is larger than that with heavy neutral particles. Then the value of Te may be different between H_2 and D_2 plasmas.

Difference in the value of VUV emission intensities (see Fig. 4) is caused by difference in cross section of vibrational excitation associated with the process (1a) between hydrogen molecules and deuterium molecules. The cross section of H_2 is larger than one of D_2 [9]. So, integrated intensities of VUV emission in D_2 plasmas are smaller than ones in H_2 plasmas.

At low base pressure, I_D- hardly increases compared with I_H- in H_2 plasma (see Fig. 5). But plasma parameters and VUV emission intensities in D_2 plasmas are changed by the same manner as ones in H_2 plasmas (see Figs. 3, 4 and 5). In other words, plasma parameters and VUV emission intensities in D_2 plasmas are suitable for D^- ion production. We think that Ar addition can change collisional process for negative ion destruction and these processes are different between in H_2 plasmas and D_2 plasmas. However, this is an open question. The details are now under study.

4. Summary

The effect of Ar addition in the beam injection type H^-/D^- source is studied. In H_2 plasmas, at low base H_2 pressure, I_H- is increased a little by Ar addition. However at high base H_2 pressure, I_H- is decreased although plasma parameters are suitable for H^- ion production. At the same time, VUV intensities are decreased at high base H_2 pressure. In other words, Ar addition at high base H_2 pressure makes adverse effect on H_2 (v”) production.

In D_2 plasmas, variation patterns of plasma parameters and VUV intensities due to Ar addition are nearly the same as ones in H_2 plasmas. However I_D- are not increased unlike I_H- even if at low base D_2 pressure.

In the further, on enhancement of H^-/D^- production by Ar addition, experiments should be done with changing plasma production conditions (V_B, I_B, and double plasma method).

Acknowledgements

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Figure captions

Fig.1 Schematic diagram of the beam injection type negative ion source.

Fig.2 Typical VUV spectra from (a)H_2 and (b)D_2 plasmas. Experimental conditions are as follows: gas pressures $p(H_2) = p(D_2) = 3$mTorr, beam acceleration voltage $V_B = 100$ V and beam current $I_B = 1.5$ A

Fig.3 Pressure dependence of plasma parameters at the negative ion production region($z = 21.5$ cm) in H_2/D_2 plasmas, (a)electron density ne and (b) electron temperature Te. Experimental conditions are as follow: $V_B = 100$ V and $I_B = 1.5$ A.

Fig. 4 Integrated intensity of VUV emission spectra from H_2/D_2 plasmas, corresponding to the results in Fig. 3.

Fig. 5 Negative ion currents in H_2/D_2 plasmas, corresponding to the results in Figs.3 and 4. Extracted voltage $V_{ex} = 600$ V

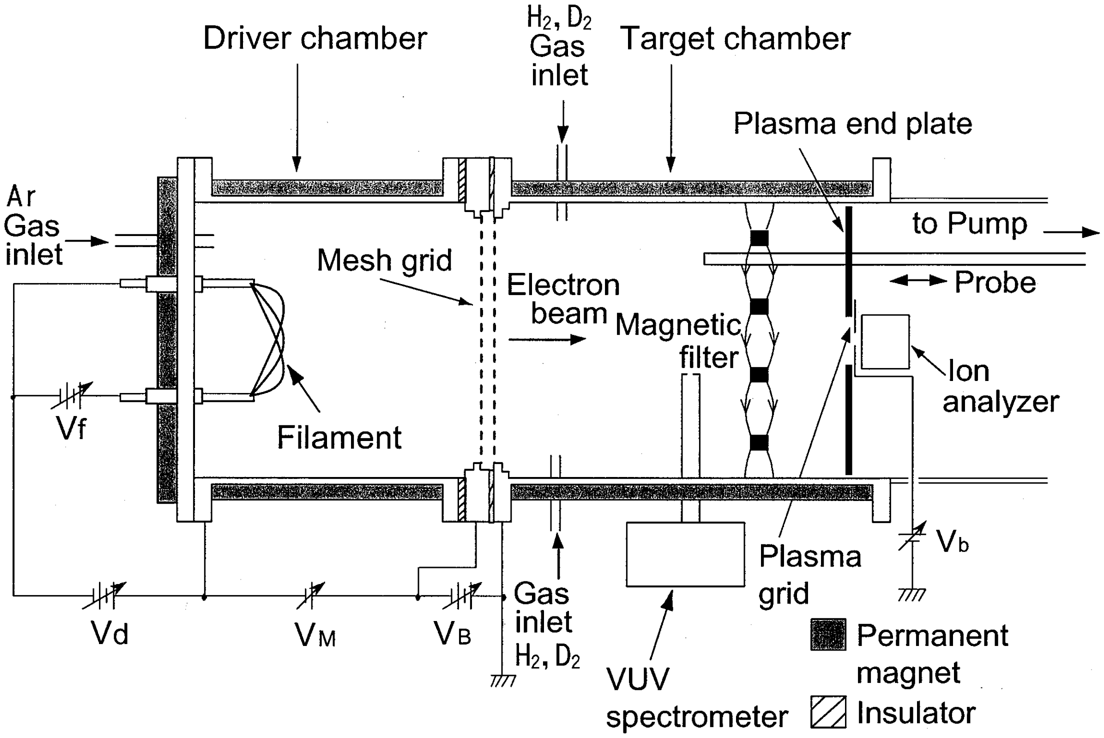
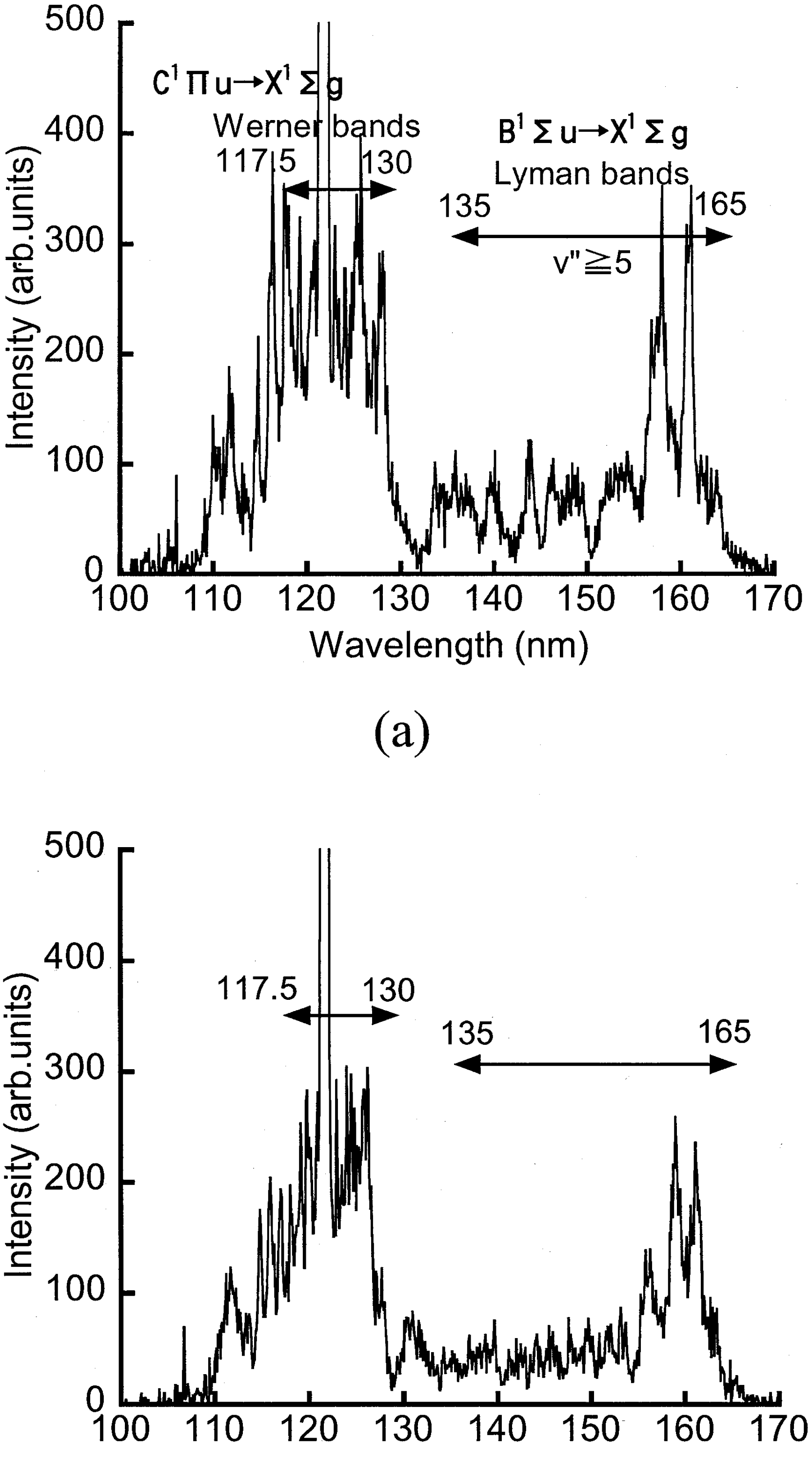

Driver chamber
H_2, D_2 Gas inlet
Target chamber
Plasma end plate
Ar Gas inlet
to Pump
Mesh grid
Electron beam
Magnetic filter
Probe
Ion analyzer
Vf
Filament
Plasma grid
Vb
Vd
VM
VB
Gas inlet H_2, D_2
VUV spectrometer
Permanent magnet
Insulator

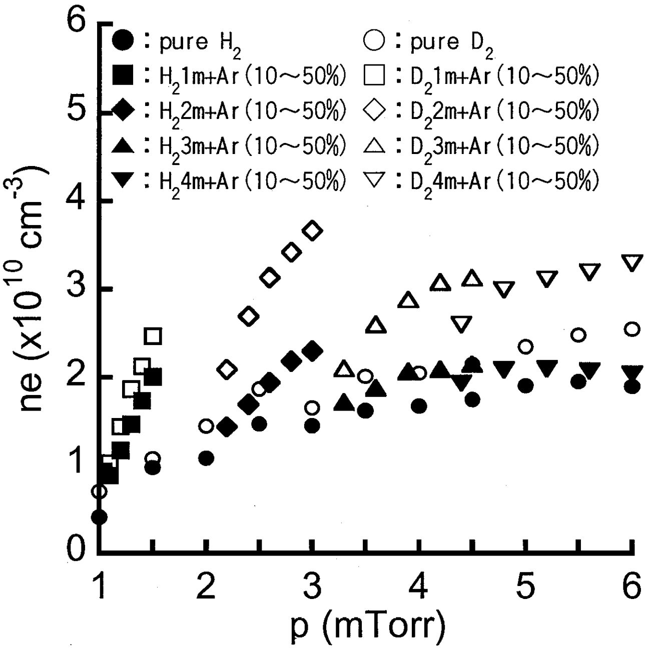
Fig.1


500
400
300
200
100
0
Intensity (arb.units)
100 110 120 130 140 150 160 170
Wavelength (nm)
C¹Πu→X¹Σg
Werner bands
117.5
130
B¹Σu→X¹Σg
Lyman bands
135
165
v"≧5
117.5
130
135
165

(a)

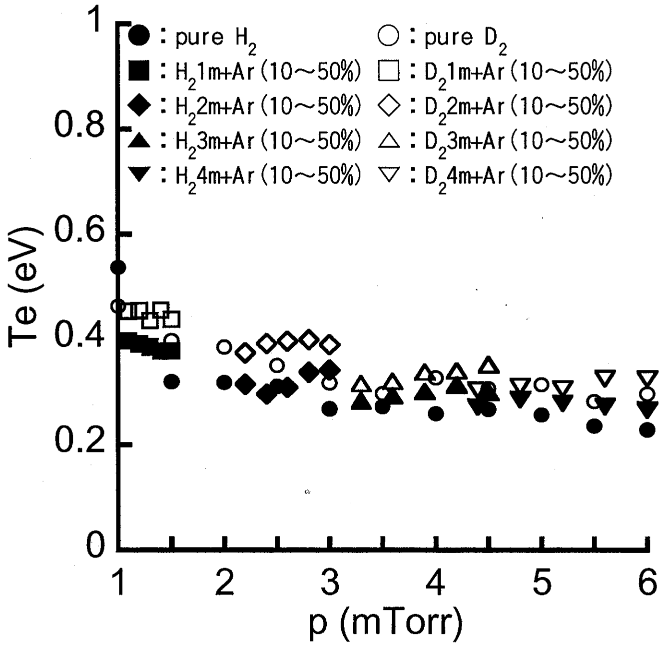
(b)

Fig.2



● : pure H_2
○ : pure D_2
■ : $H_2$1m+Ar (10∼50%)
□ : $D_2$1m+Ar (10∼50%)
◆ : $H_2$2m+Ar (10∼50%)
◇ : $D_2$2m+Ar (10∼50%)
▲ : $H_2$3m+Ar (10∼50%)
△ : $D_2$3m+Ar (10∼50%)
▼ : $H_2$4m+Ar (10∼50%)
▽ : $D_2$4m+Ar (10∼50%)
ne ($\times 10^{10}$ cm^{-3})
0
1
2
3
4
5
6
p (mTorr)
1
2
3
4
5
6

(a)



● : pure H_2
○ : pure D_2
■ : $H_2$1m+Ar (10∼50%)
□ : $D_2$1m+Ar (10∼50%)
◆ : $H_2$2m+Ar (10∼50%)
◇ : $D_2$2m+Ar (10∼50%)
▲ : $H_2$3m+Ar (10∼50%)
△ : $D_2$3m+Ar (10∼50%)
▼ : $H_2$4m+Ar (10∼50%)
▽ : $D_2$4m+Ar (10∼50%)
Te (eV)
0
0.2
0.4
0.6
0.8
1
p (mTorr)
1
2
3
4
5
6

(b)

Fig.3

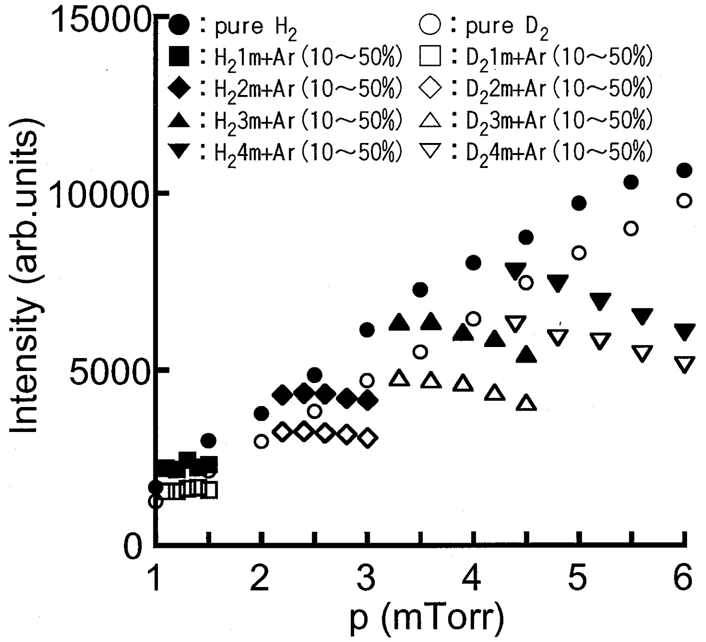

● : pure H_2
○ : pure D_2
■ : $H_2$1m+Ar (10〜50%)
□ : $D_2$1m+Ar (10〜50%)
◆ : $H_2$2m+Ar (10〜50%)
◇ : $D_2$2m+Ar (10〜50%)
▲ : $H_2$3m+Ar (10〜50%)
△ : $D_2$3m+Ar (10〜50%)
▼ : $H_2$4m+Ar (10〜50%)
▽ : $D_2$4m+Ar (10〜50%)
Intensity (arb.units)
15000
10000
5000
0
1
2
3
4
5
6
p (mTorr)

Fig.4

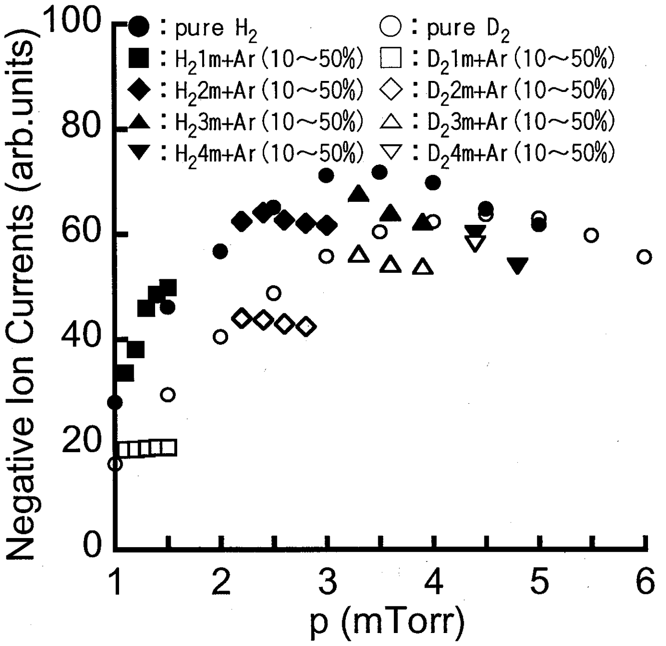

● : pure H_2
○ : pure D_2
■ : $H_2$1m+Ar (10〜50%)
□ : $D_2$1m+Ar (10〜50%)
◆ : $H_2$2m+Ar (10〜50%)
◇ : $D_2$2m+Ar (10〜50%)
▲ : $H_2$3m+Ar (10〜50%)
△ : $D_2$3m+Ar (10〜50%)
▼ : $H_2$4m+Ar (10〜50%)
▽ : $D_2$4m+Ar (10〜50%)
Negative Ion Currents (arb.units)
100
80
60
40
20
0
1
2
3
4
5
6
p (mTorr)

Fig. 5