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Control of H^- Ion Density in the Sheet Plasma by an Electron Emitter

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Abstract

The effect of the current I_E and bias voltage V_E of electron emitter on the negative ion density of hydrogen atom n_{H^-} in the circumference of the hydrogen magnetized sheet plasma was studied. The value of n_{H^-} were determined by a probe-assisted laser photodetachment method. Under a secondary hydrogen gas puffing into a hydrogen plasma, n_{H^-} had a maximum value ($n_{H^-} = 2 \times 10^{17}$ m^{-3}) at the gas pressure of 3 mtorr and the peak position of n_{H^-} is localized at the circumference of the sheet plasma. When I_E increases from 0 to 25 A, n_{H^-} increases and becomes eight times larger than of the initial condition. On the other hand, n_{H^-} decreases with applying V_E of the electron emitter against the plasma potential.

Keywords:

negative ion density, hydrogen plasma, magnetized sheet plasma, electron emitter

1. Introduction

The volume production of H^- ions using H_2 discharges is being pursued due to the need for intense H^- ion beams for particle accelerators and for magnetic fusion energy research. Magnetic multipole plasma source have been found to be efficient sources of negative ions of hydrogen atom [1]. The most probable production process of negative ions is the dissociative electron attachment to the vibrationally excited hydrogen molecules. The negative ions of hydrogen atom (H^-) are formed by dissociative attachment of cold electrons to the vibrationally excited molecules which are attributed to electron-impact excitation of molecules by the fast primary electron in the plasma [2,3]. These volume production processes of the negative ions depend on the density of the vibrationally excited molecules and the cold electron in the plasma. However, the control of negative ion density is difficult for the commonly used plasma source, such as, microwave, dc, and rf discharges. Because the collisional processes usually involve plasma with low electron temperature far from thermodynamic equilibrium temperature in its plasma source, it is important to produce and control of plasma with the region of two electron temperature in volume of plasma. In order to produce the hydrogen negative ions, we have proposed a designed system of a magnetized sheet plasma, TPD-SheetIV (Test Plasma produced by Directed current for SHEET plasma), crossed with a vertical gas-flow and an electron-emitter made of tungsten filaments [4-6]. The magnetized sheet plasma is well suited for the production of negative ions because the electron temperature in the central region of the plasma is as high as 10–15 eV, while in the circumferential region of plasma, a low temperature of 1 eV with obtained. After the secondary hydrogen gas is fed to the hydrogen sheet plasma through the gas injector, the density of H^- is controlled by changing the emission current and the applied voltage of the electron-emitter. Also, the geometry of this system is estimated to be nearly one-dimensional (1-D) based on the scale of plasma thickness. Therefore, a quantitative analysis of negative ions of hydrogen atom can be achieved in the magnetized sheet plasma crossed with the vertical gas-flow and equipped with an electron-emitter system.

2. Experimental apparatus and method

The experiment was performed in the linear plasma simulator TPD-SheetIV [4-6]. The plasma in TPD-SheetIV was divided into two regions: the sheet plasma source region and the experimental region. The hydrogen sheet plasma was produced by a modified TP-D type dc discharge. The anode slit was 2 mm thick and 40 mm wide. Ten rectangular magnetic coils formed a uniform magnetic field of 0.7 kG in

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the experimental region. The sheet plasma was terminated by the electrically floating and water-cooled target plate (stainless steel) axially positioned of z = 0.7 m away from the discharge anode electrode. The hydrogen plasma was generated at a hydrogen gas flow of 70 sccm with a discharge current of 50 A. The neutral pressure P_E in the experimental region was controlled by feeding a secondary gas from 0.1 to 20 mtorr. The change of P_E in the experimental region had no effect on the plasma production in the discharge region because the pressure difference between the discharge and the experimental regions extends to 3 orders of magnitude.

The magnetized sheet plasma crossed with the vertical gas-flow system and electron emitter system is shown in Fig. 1. The secondary hydrogen gas was fed perpendicularly to the hydrogen sheet plasma in the low-pressure experimental region (≤ 10^{-4} Torr). This gas feeder was placed in the gas contact chamber located in front of the anode at a distance of 40 cm and below the sheet plasma at a distance of 2.0 cm. In this condition, neutral-neutral collisional mean free path is ~ 0.5 m in the gas contact chamber. Also, the electron emitter was located above the center of the sheet plasma at a distance of 1.2 cm. The four filaments of the electron emitter were made of tungsten wire (ϕ 0.4 mm) put in parallel. The heating current and bias voltage of the electron emitter were changed from 0 to 25 A and floating potential from 0 to –15V, respectively. The advantages of the magnetized sheet plasma crossed with the vertical gas-flow and equipped with electron emitter system are as follows: (i) the plasma parameters and conditions of the secondary hydrogen gas can be controlled independently because this system is separated into the part consisting of the plasma source and the part consisting of negative ion production; (ii) the plasma density and electron temperature can be widely varied by changing both current and gas flow rate during the discharge, independently; (iii) the secondary hydrogen gas is vertically fed in a narrow zone with both high temperature and low temperature plasma because the sheet plasma is as a two-dimensional boundary-like plasma with a large temperature gradient; (iv) since the geometry of this system is estimated to be nearly 1-D based on the scale of plasma thickness, the experimental results can be compared with the result determined based on the 1-D model; and (v) the density and energy of the electron at the circumference of the sheet plasma are controlled by changing the emission current and bias voltage of the electron emitter. Therefore, this system is capable of treating complex phenomena of the negative ion production as the simple model. The electron temperature and the electron density were measured by a plane Langmuir probe. The plane Langmuir probe was located 3 cm apart from the target plate. A cylindrical probe made of tungsten (Φ 0.4 × 2 cm) was used to measure the spatial profiles of H^- by a probe-assisted laser photodetachment method [7,8]. The maximum laser energy at the fundamental wavelength (1064 nm) was 100 mJ. The pulse length was about 10 ns and the diameter of the beam was 8 mm. The negative ion density was determined from the photodetached electron current. The spatial profile of the negative ions was measured by scanning the cylindrical probe under the laser irradiation.

3. Experimental results and discussion

Figure 2 shows the spatial profiles of n_{H^-}, n_e, and T_e in the y-direction at various P_E without electron emitter. The y-direction is along the thickness of the sheet plasma. A small amount of secondary hydrogen gas puffing into a hydrogen plasma (P_E ~ 0.8 mtorr), both n_e and T_e have hill-shaped profiles with half widths of about ± 2.5 mm and ± 5.0 mm in the sheet plasma, respectively. The produced sheet plasma has a steep electron temperature gradient over the narrow space of several centimeters: the hot plasma (~15 eV) in the central region and the cold plasma (1–2 eV) in the circumferential region. The value of n_{H^-} is localized in the outer region (y = 10–20 mm) where cold electrons (n_e ~ 4 × 10^{17} m^{-3}, T_e = 0.5–1 eV) come from the circumference of the plasma. The peak value of n_{H^-} is 4 × 10^{16} m^{-3} and is less than one order of that

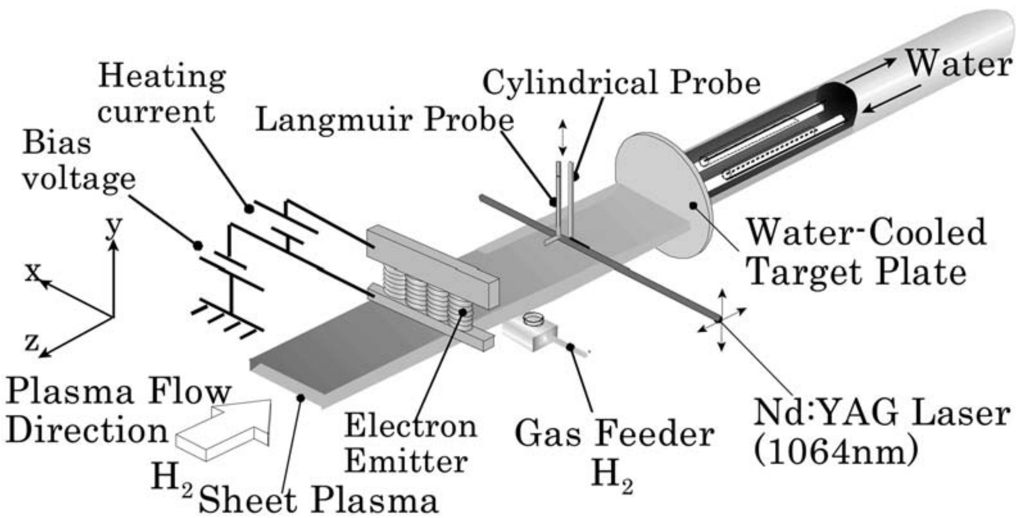

Fig. 1 The magnetized sheet plasma crossed with the vertical gas-flow system and electron emitter system.

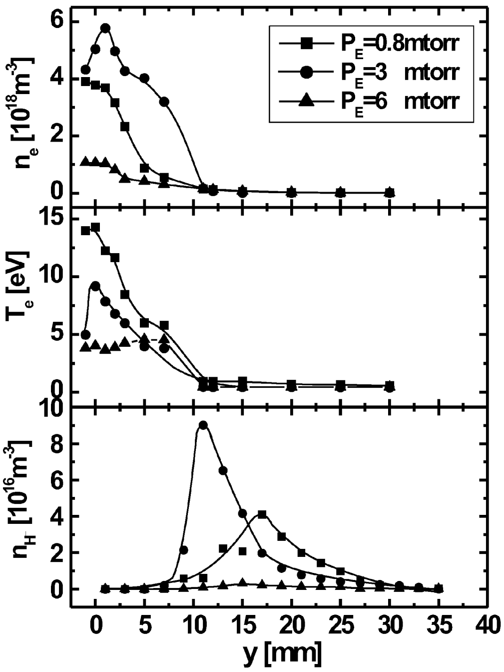

Fig. 2 The spatial profiles of n_{H^-}, n_e, and T_e in the y-direction at various P_E without electron emitter. The y-direction is along the thickness of the sheet plasma.

of the electron density in the circumferential region. At P_E ~ 3.0 mtorr, the peak value of n_{H^-} is 0.9×10^{17} m^{-3} and the ratio of n_{H^-}/n_e in the circumferential region goes up to over 20%. In this condition, the ion-neutral and electron-neutral collision mean free paths are a few centimeters for this gas pressure. Also, the dissociative-attachment cross sections for the metastable molecules at the vibrationally excited state υ = 4, are four orders of magnitude larger than those for the vibrationally ground state υ = 0 [9]. Therefore, the negative ion production by dissociative electron attachment is enhanced when the hydrogen molecule is vibrationally excited in the detached plasma. With further increase of P_E, both T_e in the central region and n_{H^-} in the circumferential region of the sheet plasma gradually decrease.

In Fig. 3, the characteristics of the negative ion density of hydrogen atom n_{H^-} and the temperature of filament of the electron emitter T_F are plotted against the emission current of the electron emitter I_E in the circumferential region of the sheet plasma (y = 10 mm). The bias voltage of electron emitter is floating potential (V_E = 0.6 V) and the gas pressure in the experimental region is ~ 3.0 mtorr. When the value of I_E changes from 0 to 25 A, T_F increases to 1400 K. At the same time, the value of n_{H^-} increases from 1.0×10^{17} m^{-3} to 8.0×10^{17} m^{-3} with increasing in I_E. From the Langmuir probe measurement, the cold electron density in the circumferential region of the sheet plasma increases from 4×10^{17} m^{-3} to 5×10^{17} m^{-3} with the constant electron temperature (T_e ~ 1 eV) when the I_E increases from 0 to 25 A. The negative ion density of hydrogen atom depends on the temperature of the electron emitter T_F, that is, the density of the cold electron.

Figure 4 shows the spatial profiles of n_{H^-} in the y-

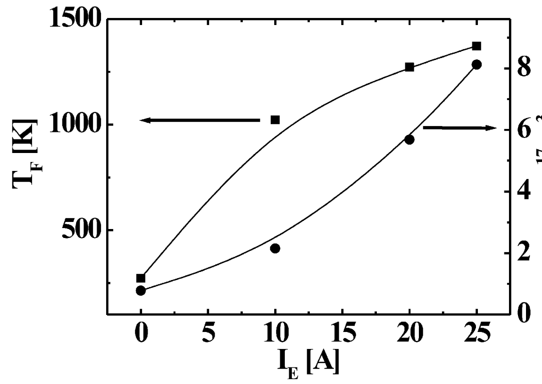

Fig. 3 The characteristic of the negative ion density of hydrogen atom n_{H^-} and the temperature of filament of the electron emitter T_F are plotted against the emission current of the electron emitter I_E in the circumferential region of the sheet plasma (y = 10 mm).

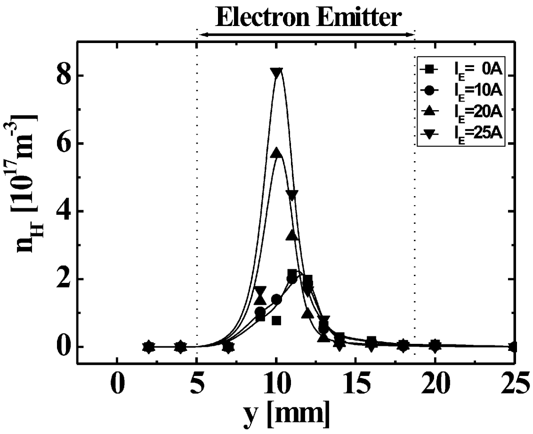

Fig. 4 The spatial profiles of n_{H^-} in the y-direction at various emission current of electron emitter I_E. The I_E changes (■)0, (●)10, (▲)20, (▼)25 A.

direction at various emission current of electron emitter I_E, i.e., (■)0, (●)10, (▲)20, (▼)25 A. The bias voltage of electron emitter is floating potential (V_E = 0.6 V) and the gas pressure in the experimental region is ~ 3.0 mtorr. The value of n_{H^-} has hill-shaped profiles and is localized in the circumference region (y = 8–13 mm) with the cold electrons (T_e ~ 1eV). With increasing in I_E, the value of n_{H^-} increases and its peak position slightly sifted to the center to the sheet plasma. On the other hand, n_{H^-} decreases with applying negative bias voltage V_E against the plasma potential. The energy of emission electron is changed by applying negative bias voltage. The negative ion is produced by attachment of its emission electrons to vibrationally excited hydrogen molecules. The cross section for dissociative attachment of electrons to vibrationally excited hydrogen molecules decreases with increasing the energy of electron. Therefore this characteristic of n_{H^-} against the applying V_E is related to the cross section for dissociative attachment of electrons to vibrationally excited hydrogen molecules [10]. The negative ion density of hydrogen atom in the circumference of the hydrogen magnetized sheet plasma is controllable by changing the current I_E and by the bias voltage V_E against the plasma potential of the electron emitter.

4. Conclusion

We demonstrated the control of negative ion of hydrogen atom in the magnetized sheet plasma crossed with a vertical gas-flow and equipped with electron emitter system. The effect of current I_E and bias voltage V_E of electron emitter on the negative ion density of hydrogenatom n_{H^-} in the circumference of the hydrogen magnetized sheet plasma is elucidated. Under these conditions, n_{H^-} increases when I_E increases from 0 to 25 A. On the other hand, n_{H^-} decreases with applying V_E of the electron emitter against the plasma potential. The energy of emission electron is changed by applying negative bias voltage. The negative ion is produced by attachment of its emission electrons to vibrationally excited hydrogen molecules. The cross section for dissociative attachment of electrons to vibrationally excited hydrogen molecules decreases with increasing the energy of electron. Therefore this characteristic of n_{H^-} is related to the cross section for dissociative attachment of electrons to vibrationally excited hydrogen molecules.

Acknowledgments

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