S5-3 Production and Measurement of Hydrogen Negative Ions in Low Pressure Hydrogen Discharge Plasmas

水素負イオンの体積生成と計測

Osamu Fukumasa
福政　修

Department of Electrical and Electronic Engineering,, Faculty of Engineering, Yamaguchi University, 2-16-1 Tokiwadai, Ube 755-8611, Japan
山口大学工学部電気電子工学科，〒755-8611 宇部市常盤台 2-16-1

Hydrogen negative H^- ion volume production is studied in a rectangular arc chamber. Axial distributions of H^- ion densities in the source are measured directly using a laser photodetachment method. Relationship between H^- production and plasma parameter control with using a magnetic filter (MF) is discussed. Extracted H^- currents depend directly on negative ion densities in the source.

1. Introduction

Negative ions play important roles in the generation and maintenance of low pressure discharge plasmas and their technological applications, such as ion sources and materials processing.

In pure hydrogen (H_2) discharge plasmas, most of the H^- ions are generated by the dissociative attachment of slow plasma electrons e_s (electron temperature $T_e \sim 1$ eV) to highly vibrationally excited hydrogen molecules $H_2(v'')$ (effective vibrational level $v'' \geq 5$-6). These $H_2(v'')$ are mainly produced by collisional excitation of fast electrons e_f with energies in excess of 15-20 eV. Namely, H^- ions are produced by the following two step process [1, 2]:

$$H_2\,(X^1\Sigma_g,\ v''=0) + e_f \rightarrow H_2^*(B^1\Sigma_u,\ C^1\Pi_u) + e_f' \quad (1a)$$

$$H_2^*(B^1\Sigma_u,\ C^1\Pi_u) \rightarrow H_2\,(X^1\Sigma_g,\ v'') + h\nu, \quad (1b)$$

$$H_2(v'') + e_s \rightarrow H^- + H \quad (2)$$

Production process of D^- ions is believed to be the same as that of H^- ions. This process is also applicable for production of O^- and Cl^-.

Knowledge of spatial and temporal distributions of negative ions is very important. One of the important diagnostic tools for studying negative ion plasmas is based on the laser-photodetachment technique [3], in which one rapidly destroys the negative ions in a certain region in the plasma by an intense laser light, and studies the plasma response by probe measurements[4].

In this paper, plasma parameter control by varying the magnetic field intensity of the magnetic filter(MF) is presented [5,6]. Influence of these plasma parameter distributions on H^- production is discussed with estimated rate coefficients and collision frequencies for production and destruction of H^- ions based on measured plasma parameters. Estimating negative ion densities in the source with using laser photodetachment technique, we discuss the relationship between H^- ions in the source and extracted H^- ion currents.

2. Experimental Set-up

Figure 1 shows a schematic diagram of the ion source. The rectangular arc chamber is 25 cm × 25 cm in cross section and 19 cm in height. The line cusp magnetic field is produced by permanent magnets which surrounded the chamber. The external MF is composed of a pair of permanent magnets in front of the plasma grid (PG). Details are described in elsewhere[5,6].

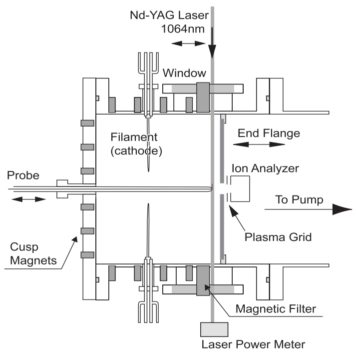

Fig. 1 Schematic diagram of the ion source. The probe, the laser path, and power meter used in photo-detachment experiments are also shown.

H^- densities in the source are measured by the laser photodetachment method[3]. A light pulse from a Nd:YAG laser (wavelength 1064 nm, duration of laser pulse 9 ns, repetition 10 Hz) is introduced from the side wall window of the chamber and passes through the source plasmas.

3. Experimental Results and Discussion

On H^- volume production, desired condition for plasma parameters is as follows: T_e in the extraction region should be reduced below 1 eV with n_e keeping higher. To realize above-mentioned plasma conditions, the MF is used[5,6].

Figures 2 shows axial distributions of plasma parameters (n_e and T_e) in H_2 plasmas. By varying the intensity of the MF, axial distributions of n_e and T_e in H_2 plasmas are changed strongly in the downstream region (from z = 8 to -2 cm).

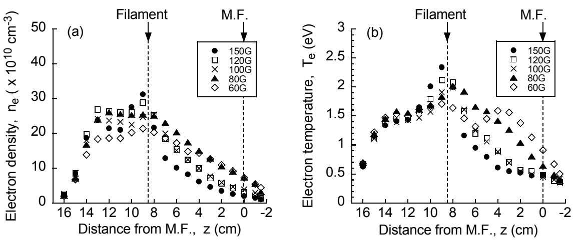

Fig. 2 Axial distributions of plasma parameters (a) n_e and (b) T_e in H_2 plasmas. Experimental conditions are as follows: V_d = 70 V, I_d = 5 A, $p(H_2)$ = 1.5 mTorr. Parameter is the magnetic field intensity of the MF.

For the MF with 150 G (B_{MF} = 150 G), not only T_e but also n_e are decreased far from the MF, i.e. z = 8 cm, in the source region. On the other hand, decreasing points of n_e and T_e are shifted to downstream region for the case of 80 G and 60 G. In this source, due to the external MF, width of the half-maximum of magnetic field intensity is wider (about 16cm in this case) than the case of rod filter. Thus, the external MF has the merit of control of plasma parameters gradually. T_e control can be done precisely with keeping n_e high in the extraction region. The grid method is also applicable to control T_e[7].

H^- density distributions across the MF are measured and its dependence on plasma parameters are studied. Figure 3 shows axial distributions of H^- ion densities, where B_{MF} = 150 G and 80 G, respectively. Plasma parameters corresponding to these H^- ion densities are shown in Fig. 2. Spatial distributions of H^- densities are varied by changing plasma parameters. When B_{MF} = 150 G, H^- density distribution decreases toward to the extraction hole (i.e. z = -2 cm). On the other hand, when B_{MF} =80 G, H^- density distribution remains nearly constant value although n_e decreases toward to the extraction hole. In front of the extraction hole (i.e. plots at z = -1.5 cm), H^- density with 80 G is higher than that with 150 G by a factor about 2. Extracted H^- currents are also the same ratio. Extracted H^- currents depend on H^- densities in the source.

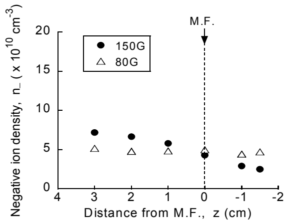

Fig. 3 Axial distributions of H^- ion densities. Experimental conditions are as follows: V_d = 70 V, I_d = 5 A, $p(H_2)$ = 1.5 mTorr. Parameter is the magnetic field intensity of the MF. Corresponding plasma parameters are shown in Fig. 2 (with B_{MF} = 150 G and 80G).

A two-dimensional PIC particle simulation, which can correctly treat the cylindrical geometry of the laser beam region, has been conducted to discuss the physics related with the photodetached electron dynamics and to estimate quantitatively various values related with it in the timescale of 20 - 60 ns after the photodetachment [8,9].

4. Summary

Production and control of plasma parameters in H_2 plasmas are performed by varying the intensity of the MF. Extracted H^- currents are mainly determined by H^- densities in the source. According to the discussions based on estimated rate coefficient and collision frequencies of dissociative attachment and electron detachment processes[6], for enhancement of H^- production, it is reconfirmed that T_e in the extraction region should be reduced below 1 eV with n_e keeping higher. For further studying enhancement of H^- production, simultaneous measurements of VUV emission and negative ion density in the source is necessary.

Acknowledgments

The author would like to thank Prof. H. Naitou, S. Mori and Y. Sakurai for their useful discussions.

Reference

[1] J. R. Hiskes and A. M. Karo: J. Appl. Phys. **56** (1984) 1927.
[2] O. Fukumasa: J. Phys. **D22** (1989) 1668.
[3] M. Bacal and G. W. Hamilton: Phys. Rev. Lett. **42** (1979) 1538.
[4] L. Friedland et al.: Phys. Rev. **E49** (1994) 4353.
[5] O. Fukumasa et al.: Contrib. Plasma Phys. **44** (2004) 516.
[6] O. Fukumasa and S. Mori: PNNIB-10 (2004).
[7] K. Kato et al.: Appl. Phys. Lett. **65** (1994)816.
[8] H. Naitou et al.: Plasma Phys. Control. Fusion **46** (2004) 1217.
[9] Y. Sakurai: private communication (2004).