§20. Measurement of the Negative Ion and Control of Recombination Plasma in the LHD Divertor

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In hydrogen recombination plasma at a high density and low temperature, it is observed that the mutual neutralization in MAR via H^- ion formation occurs in the periphery of the plasma where cold electrons (~1eV) are found in detached plasma. Therefore, negative ions play an important role in MAR processes of recombination plasma, providing a new method of controlling detached plasmas.

In this study, we have carried out the modeling of negative, molecular, and atomic ions in hydrogen plasma in a linear plasma device, TPD-SheetIV[1,2]. The electron density and temperature were measured using a Langmuir probe. Also, the ground-state vibrational temperature of hydrogen molecules T_{vib} was deduced by applying the corona equilibrium with VUV emission spectroscopy. The zero-dimensional model used to predict the measured densities of hydrogen ion species is discussed.

To model the ion density in this experiment, a simple zero-dimensional model is developed for solving the system of rate balance equations for ion and gas species. The processes included in the model are

$H + e \rightarrow H^+ + 2e,$ (el)

$H_2(v'') + e \rightarrow 2H + e,$ (eD)

$H_2 + e \rightarrow H + H^* + e,$ (eDn)

$H_2(v'') + H^+ \rightarrow H_2^+ + H,$ (CNV)

$H_2 + e \rightarrow H_2^+ + e,$ (eI2)

$H_2(v'') + e \rightarrow H^+ + H + 2e,$ (eDI)

$H_2^+ + e \rightarrow H^* + H,$ (DR2)

$H_2^+ + e \rightarrow H^+ + H + e,$ (eD2)

$H_2^+ + e \rightarrow 2H^+ + 2e,$ (eDI2)

$H_2^+ + H_2 \rightarrow H_3^+ + H,$ (CNV2)

$H_3^+ + e \rightarrow H_2^+ + H + e,$ (eD3)

$$H_3^+ + e \rightarrow \begin{cases} 3H \\ H_2 + H, \end{cases} \quad \text{(DR3)}$$

$H_3^+ + H \rightarrow H_2^+ + H_2.$ (BCNV2)

$H_2(v''<9) + e \rightarrow H^- + H^*,$ (DA)

$H^- + e \rightarrow H + 2e,$ (ER)

$H^- + H^+ \rightarrow 2H,$ (MN).

Here, we have ignored radiative and three-body recombination. H* refers to electronically excited atomic hydrogen. For the purposes of calculating the average velocities, the neutral velocities are assumed to be negligible compared with the ion and electron velocities. The neutral densities of hydrogen molecules are obtained from the measured neutral gas pressure P.

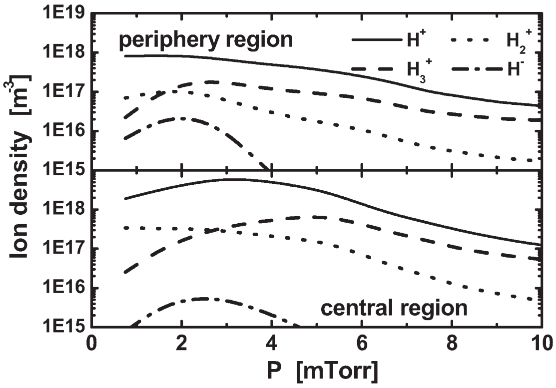

Fig.1 Characteristics of the calculated ion densities (H^+, H_2^+, H_3^+ and H^-) in the periphery region and central region are plotted against gas pressure P.

The corona model used to calculate the population distribution of the vibrational levels resulting from a Boltzmann population distribution in the ground state characterized by a temperature of hydrogen molecule. Assuming a thermal (Boltzmann) population of ground state vibrational levels, and given the Franck-Condon matrix for electron-impact excitation from the ground state to the upper state, a ground-state vibrational temperature of hydrogen molecule T_{vib} can be found which results in a best fit to the observed relative intensities of VUV spectrum.

Figure 1 shows the calculated ion densities (H^+, H_2^+, H_3^+ and H^-) in the periphery region and central region are plotted against gas pressure P at the discharge current I_d of 50 A in the hydrogen plasma. In the reactions involving H_2, H_2^+, and H^-, T_{vib} is 1000 ~ 4500 K. With increasing P_{div}, the ion density of H^- has a maximum value at P_{div} ~ 2.0 mTorr and gradually decreases. In the periphery region, the formation of the H^- of the dissociative electron attachment (DA) is small comparison with that of the molecular ions for these conditions. From a zero-dimensional model, the calculated atomic, molecular and negative ion densities were found to predict the observed dominant ion densities in recombination plasma.

1)A.Tonegawa,T.Nishijima,M.Ono,K.Kawamura, J.Plasma Fusion Res.SERIES **2** (2007) 1079-1083.
2)A.Tonegawa, K.Kumita, M.Ono, T.Shiguya, K.Kawamura, Jpn. J. Appl.Phys. **45** (2006)8212-8216.