Modeling of hydrogen negative ions in sheet plasma

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Introduction

In a hydrogen recombination plasma at a high density and low temperature, vibrationally excited hydrogen molecules $H_2(v)$ persist in dissociation and ionization processes of the plasma volume. In this study, we have carried out the experimental observation and modeling of molecular ions in hydrogen plasma in a linear plasma device, TPD-SheetIV. Measurements of the densities of molecular and atomic ions were carried out in hydrogen plasma with a hydrogen gas puff. The molecular and atomic ion currents were detected using an omegatron mass analyzer. The ground-state vibrational temperature of hydrogen molecules T_{vib} was deduced by applying the corona equilibrium model with VUV emission spectroscopy. The zero-dimensional, which is developed for solving the system of rate balance equations for ion and gas species, used to predict the measured densities of hydrogen ion species is discussed.

Reaction Processes in recombination plasma

Processes of negative ion

$H_2(5<v''<9) + e \rightarrow H^- + H^*$:(DA) $\quad H^- + e \rightarrow H + 2e$: (ER)

$H^- + H^+ \rightarrow 2H$:(MN)

Electron-Ion Recombination(EIR)

$H^+ + e \Rightarrow H + h\nu$: (RR) $\quad H^+ + e + e \Rightarrow H + e$: (THB)

Molecular Assisted Recombination（MAR）

$H_2(v) + H^+ \rightarrow H_2^+ + H$: (CNV) $\quad H_2^+ + e \rightarrow H^* + H$:(DR2)

$H_2^+ + H_2 \rightarrow H_3^+ + H$: (CNV2) $\quad H_3^+ + e \rightarrow \begin{cases} 3H & \text{: (DR3)} \\ H_2 + H \end{cases}$

Molecular Assisted Dissociation（MAD）

$H_2(v) + H^+ \rightarrow H_2^+ + H$: (CNV) $\quad H_2^+ + e \rightarrow H + H^+ + e$: (eD2)

Molecular Assisted Ionization（MAI）

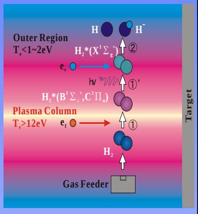
$H_2(v) + H^+ \rightarrow H_2^+ + H$: (CNV) $\quad H_2^+ + e \rightarrow H^+ + H^+ + 2e$: (eDI2)

$H + e \rightarrow H^+ + 2e$: (eI) $\quad H_2(v) + e \rightarrow 2H + e$: (eD)

$H_2 + e \rightarrow H + H^* + e$: (eDn) $\quad H_2 + e \rightarrow H_2^+ + 2e$: (eI2)

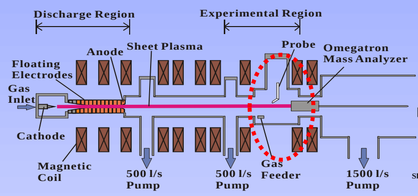
$H_2(v) + e \rightarrow H^+ + H + 2e$: (eDI) $\quad H_3^+ + e \rightarrow H_2^+ + H + e$: (eD3)

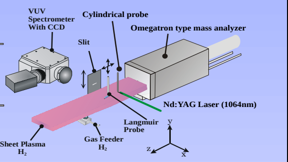
$H_3^+ + H \rightarrow H_2^+ + H_2$: (BCNV2) $\quad H_2^+ + H \rightarrow H_2 + H^+$: (BCNV)



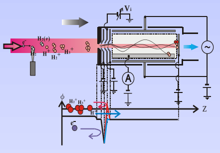
Schematic process negative ion is producted

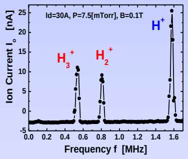
Linear plasma device(TPD-SheetIV)&Measuring system



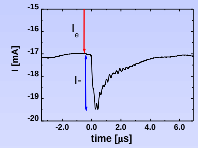


Omegatron mass-analyzer(H^+, H_2^+, H_3^+)





Laser photodetachment H⁻



$$n_i = \frac{4I}{ZeS}\sqrt{\frac{M}{k_B T_e}}$$

n_i [m^{-3}]:Ion density

I[A] : Current

Z : Charge number of ion

S[mm^{-2}] : Are of pinpole(0.75mm^{-2})

M : Mass of ion

T_e[eV] : Electron temperture

$$N_{H^-} = \frac{I_-}{I_e} n_e$$

I_e : electronic current [A]

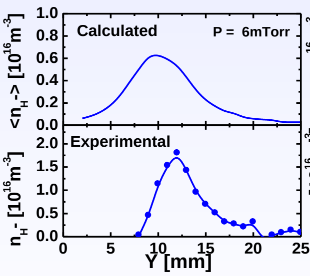
I− : negative ion current [A]

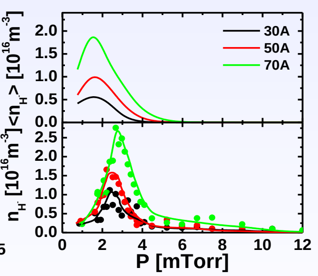
N_e : electronic density [m^{-3}]

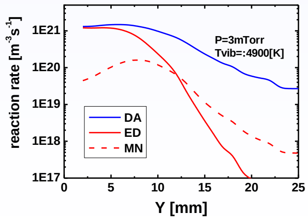
N_{H^-} : negative ion density[m^{-3}]

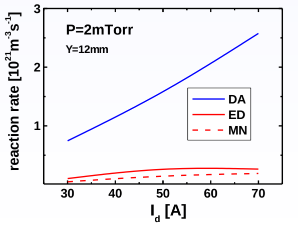
・Vibrationally excited hydrogen molecules $H_2(v)$	… VUV spectroscopy
・Atomic and molecular ion temperature (T_i(Total))	… Omegatron mass-analyzer
・Electron density and temperature (n_e,T_e)	… Langmuir probe

Experimental Results and Modeling of H⁻









Modeling of molecular and atomic ions

Rate balance equation of H^+, H_2^+, H_3^+ and H^-

$$\frac{\partial n_{H^+}}{\partial t} = 0 = n_H n_e S_{eI} + n_{H_2^+} n_H S_{BCNV} + n_{H_2} n_e S_{eDI} + n_{H_2^+} n_e S_{eD2} + 2n_{H_2^+} n_e S_{eDI2} + C_{H^+}$$
$$- n_{H_2} n_{H^+} S_{CNV} - n_{H^+} n_e S_{Tbr} - n_{H^+} n_e S_{Rr} - n_{H^-} n_{H^+} S_{MN} - \frac{n_{H^+}}{\tau_i}$$

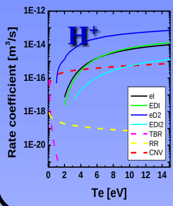
$$\frac{\partial n_{H_2^+}}{\partial t} = 0 = n_{H2} n_1 S_{CNV} - n_2 n_H S_{BCNV} + n_{H2} n_e S_{eI2} - n_2 n_e S_{DR2} - n_2 n_e S_{eD2}$$
$$- n_2 n_e S_{eDI2} - n_2 n_{H2} S_{CNV2} + n_3 n_e S_{eD3} + n_3 n_H S_{BCNV2} - n_2/\tau_i,$$

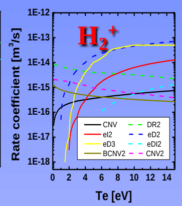
$$\frac{\partial n_{H_3^+}}{\partial t} = 0 = n_{H2} n_2 S_{CNV2} - n_3 n_e S_{eD3} - n_3 n_e S_{DR3} - n_3 n_H S_{BCNV2} - n_3/\tau_i,$$

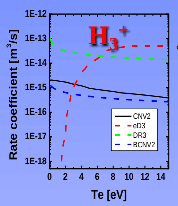
$$\frac{\partial n_{H^-}}{\partial t} = 0 = n_{H_2} n_e S_{DA} - n_{H^-} n_e S_{ED} - n_{H^-} n_{H^+} S_{MN} - N_{H^-}/\tau_i$$

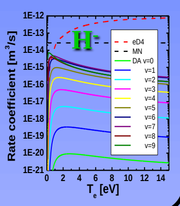
※*S*:Rate coefficient, τ_i:ion lifetime, C_1:chamber influx rate of H⁺

Rate coefficients for H^+, H_2^+, H_3^+ and H^-



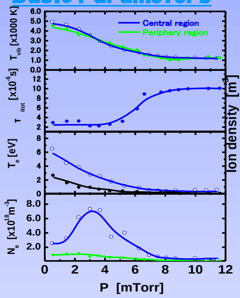




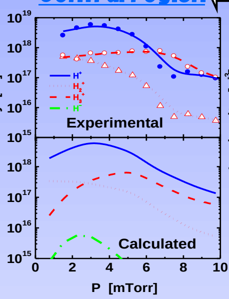


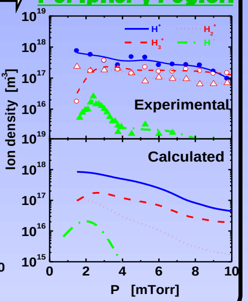
Experimental Results and Modeling

Basic Parameters

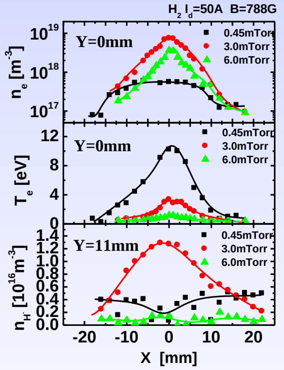


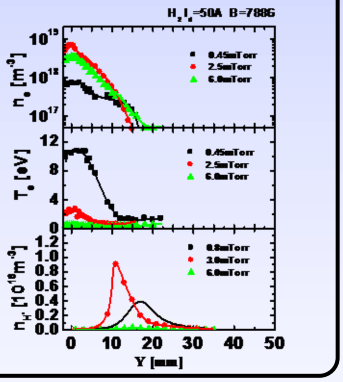
Central region ⇔ Periphery region





Experimental Results of H⁻in sheet plasma





Conclusions

The modeling and experimental results of H⁻ with vibrationally excited hydrogen molecules $H_2(v'')$ has been demonstrated in a high density plasma (10^{18}-10^{19} m^{-3}). A zero-dimensional model based on available rate coefficients was found to predict the observed dominant ion densities.

(1)H⁻ ions (*DA*) are localized in the periphery region where there are low energy electrons from the edge of the plasma.

(2)It is shown that the creation of H_2^+ (*CNV*) and the conversion of H_2^+ into H_3^+ (*CNV2*) are important processes for high gas pressure.

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