Observation of Molecular and Atomic Ions in Recombination Plasma

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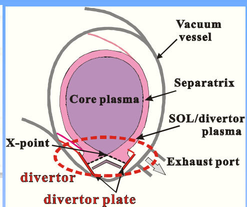
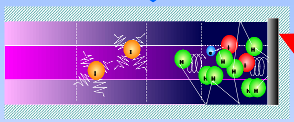
Introduction

In a divertor plasma at low temperature, vibrationally excited molecules persist in dissociation and ionization processes of the plasma volume. However, the role of molecular ions in the divertor plasma is still under discussion and various conclusions have been derived from the analysis of different experiments. It is thus required that experiments which will aid the understanding of the role of dissociative recombination (DR) are carried out. Molecular processes with vibrationally excited molecules have not been reported clearly for high-density plasma.

In this study, we have carried out the experimental observation and modeling of molecular ions in hydrogen /deuterium plasma in a linear plasma device, TPD-SheetIV. Measurements of the densities of molecular and atomic ions were carried out in recombination plasma with a hydrogen /deuterium gas puff. The molecular and atomic ion currents were detected using an "omegatron" mass analyzer.



LHD **Tokamak**



Recombination processes in divertor

Reaction Processes in divertor plasma

Electron-Ion Recombination(EIR)

Radiative recombination: $H^+ + e \Rightarrow H + h\nu$

Three-body recombination: $H^+ + e + e \Rightarrow H + e$

Molecular Assisted Recombination(MAR)

(i) Mutual Neutralization (MN):

$H_2(v) + e \Rightarrow H^- + H, \quad H^- + H^+ \Rightarrow H + H$

(ii) Dissociative Recombination (DR):

$H_2(v) + H^+ \Rightarrow H_2^+ + H$

$H_2^+ + e \Rightarrow H + H, \quad H_2^+ + H_2 \Rightarrow H_3^+ + H$

Molecular Assisted Dissociation (MAD)

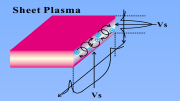
$H_2(v) + H^+ \Rightarrow H_2^+ + H, \quad H_2^+ + e \Rightarrow H + H^+ + e$

Molecular Assisted Ionization (MAI)

$H_2(v) + H^+ \Rightarrow H_2^+ + H, \quad H_2^+ + e \Rightarrow H^+ + H^+ + 2e$

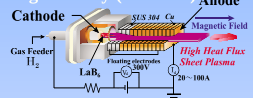
Divertor simulator(TPD-SheetIV)

Scale of plasma thickness $\leq 2\rho_i$
Boundary likely plasma



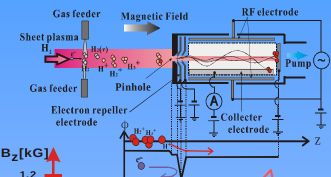
TPD-Sheet plasma source

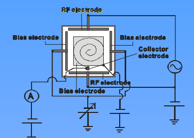
DC discharge
High density (~10^{18}m^{-3})

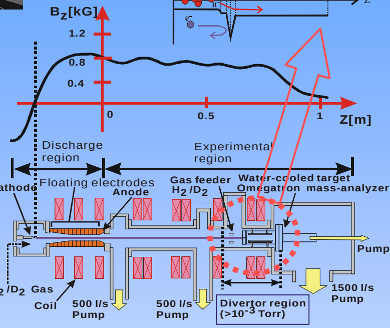


Omegatron mass-analyzer

(H^+, H_2^+, H_3^+, D^+, D_2^+, D_3^+)

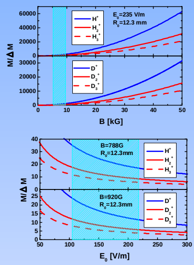






$$f_{ci} = \frac{qB}{2\pi m_{ci}} [Hz]$$

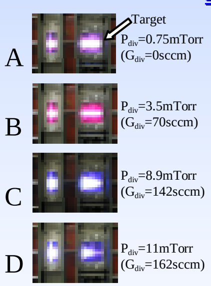
$$\frac{M}{\Delta M} = \frac{ZeR_0 B^2}{2E_0 M}$$

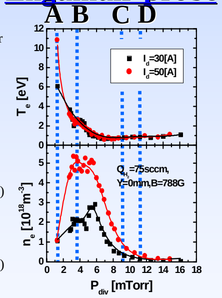


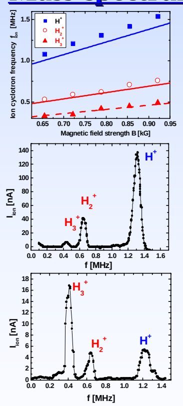
- Molecular and atomic ion densities (n_{H^+}, $n_{H_2^+}$, $n_{H_3^+}$, n_{D^+}, $n_{D_2^+}$, $n_{D_3^+}$) ··· Omegatron mass-analyzer
- Electron density and temperature (n_e, T_e) ··· Langmuir probe

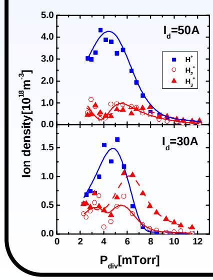
Hydrogen plasma

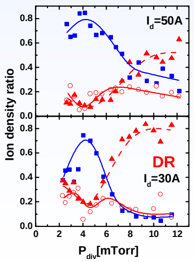
Lngumuir-probe / Mass-spectrum

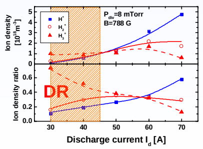






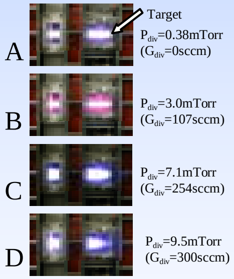


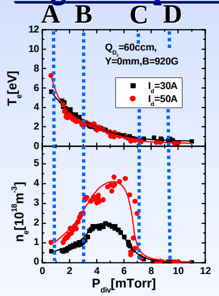


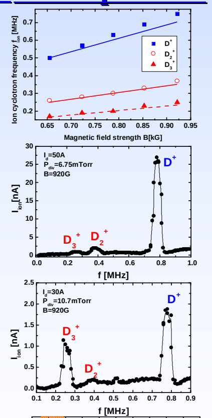


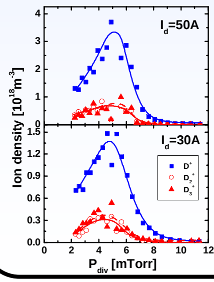
Deuterium plasma

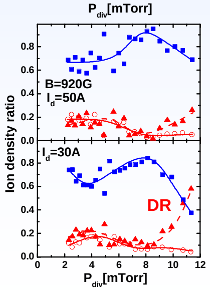
Lngumuir-probe / Mass-spectrum

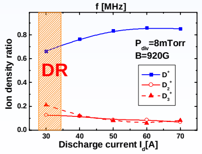












Low density =>**Dissociative Recombination(DR)**

$H_2(v) + H^+ \Rightarrow H_2^+ + H$

$H_2^+ + e \Rightarrow H + H, \quad H_2^+ + H_2 \Rightarrow H_3^+ + H$

High density

=>**Molecular Assisted Dissociation(MAD)**

$H_2(v) + H^+ \Rightarrow H_2^+ + H, \quad H_2^+ + e \Rightarrow H + H^+ + e$

=>**Molecular Assisted Ionization(MAI)**

$H_2(v) + H^+ \Rightarrow H_2^+ + H, \quad H_2^+ + e \Rightarrow H^+ + H^+ + 2e$

Conclusion

Measurements of the ion densities of atomic and molecular ions were carried out in recombination plasma with a hydrogen/deuterium gas puff using an "omegatron" mass analyzer.

(1) At a low gas pressure, the electron impact ionization (MAI) and the electron impact dissociation (MAD) become the dominant processes for high discharge current and the plasma will consist of H^+ and H_2^+.

(2) For low electron temperature (Te < 1.0 eV) using a small amount of secondary hydrogen gas puffing into a hydrogen plasma, the conversion of H_2^+ into H_3^+ tends to increase and the plasma will contain H_3^+. It is shown from these results that the creation and destruction of H_2^+ are important processes in hydrogen plasma.

(3) The effect of MAR in the deuterium plasma is smaller than that in the hydrogen plasma.

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