Volume Production of $D^{-}$ Negative Ions in Low-Pressure $D_2$ Plasmas
- Negative Ion Densities versus Plasma Parameters -

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Background

Two-step process of H\(^-\) volume production

(1) \( \text{H}_2(v''=0) + e_{\text{fast}} (E_{fe} > 20-30\text{eV}) \rightarrow \text{H}_2^*(v') + e'_{\text{fast}} \)

\( \text{H}_2^*(v') \rightarrow \text{H}_2(v'') + h\nu \)

(2) \( \text{H}_2(v'' > 5) + e_{\text{slow}} (\kappa T_e = 1\text{eV}) \rightarrow \text{H}^- + \text{H} \)

Optimization (Enhancement)

Tandem two-chamber system

- optimization of \( f(E), n_e \) and \( T_e \) → magnetic filter/plasma grid

Introduction of cesium

- enhancement of H\(^-\) production (surface effect)

Objectives

Development of high current D\(^-\) ion sources

(1) Production and control of D\(_2\) plasmas
(2) Isotope effect of H\(^-\) and D\(^-\) production

- measurement of VUV emission
- measurement of H\(^-\) and D\(^-\) densities
- extraction of H\(^-\) and D\(^-\) currents
Experimental Set-up

Magnetic Filter Fields

Axial position $z$ (cm)

Magnetic field of M.F. (Gauss)
Experimental Set-up

- Opening Window for Laser Photodetachment
- External Magnetic Filter
- Langmuir Probe
- Cusp Magnets
Axial distributions of plasma parameters in H₂ plasmas

\[ V_d = 70 \text{ V}, \quad I_d = 5 \text{ A}, \]
\[ p(\text{H}_2) = 1.5 \text{ mTorr} \]

Intensity of M.F. :
- 150G
- 120G
- 100G
- 80G
- 60G

Electron temperature, \( T_e \) (eV)
Axial position, \( z \) (cm)

Electron density, \( n_e \) (x 10¹⁰ cm⁻³)
Axial position, \( z \) (cm)
Axial distributions of plasma parameters in D$_2$ plasmas

$V_d = 70$ V, $I_d = 5$ A, $p$(D$_2$) = 1.5 mTorr

Intensity of M.F.: ●150G, ■120G, ×100G, ▲80G, ◇60G

![Graphs showing electron density and electron temperature as a function of axial position.](image-url)
Behaviors of primary electrons in the source

$B_{MF} = 150 \text{ G}$

Filter Magnet

$B_{MF} = 80 \text{ G}$

Filter Magnet
Axial distributions of plasma parameters at $B_{MF} = 80$ G

$B_{MF} = 80$ G, $V_d = 70$ V, $I_d = 5$ A,  
$p$(H$_2$ or D$_2$) = 1.5 mTorr

![Graphs showing electron density and temperature distributions.](image-url)
**Main Process**

- **Dissociative Attachment (DA)**
  \[ D_2(v^\prime) + e \rightarrow D^- + D \]

- **Electron Detachment (ED)**
  \[ D^- + e \rightarrow D + 2e \]
Axial distributions of estimated $<\sigma v>$ and $n_e<\sigma v>$

Experimental conditions are as follows: $V_d = 70$ V, $I_d = 5$ A, $p(H_2) = 1.5$ mTorr
Axial distributions of estimated $<\sigma v>$ and $n_e<\sigma v>$

Experimental conditions are as follows: $V_d = 70 \, \text{V}$, $I_d = 5 \, \text{A}$, $p(D_2) = 1.5 \, \text{mTorr}$
$V_d = 70 \text{ V, } I_d = 5 \text{ A}$

$V_{ex} \sim 1.5 \text{ kV}$

Extraction position: $z = -2.5 \text{ cm}$
D$_2$ plasmas

$V_d = 70$ V, $I_d = 5$ A

$V_{ex} \sim 1.5$ kV

Intensity of M.F.: [●] 150G, [■] 120G, [▲] 80G

Measurement position: $z = -0.5$ cm (1 cm from Plasma Grid)

Extraction position: $z = -1.5$ cm (Plasma Grid position)

**Negative ion densities versus negative ion currents**

- **Graph 1:** Negative ion density $n_-$ ($\times 10^{10}$ cm$^{-3}$) vs. pressure $p$ (mTorr)
  - Solid circles: 150G
  - Solid squares: 120G
  - Solid triangles: 80G

- **Graph 2:** Extracted D$^-$ currents (arb. units) vs. pressure $p$ (mTorr)
  - Solid circles: 150G
  - Solid squares: 120G
  - Solid triangles: 80G
Typical VUV spectra from H$_2$ and D$_2$ plasmas

$B_{MF} = 80$ G, $V_d = 70$ V, $I_d = 5$ A, $p$(H$_2$ or D$_2$) = 3 mTorr
Integrated VUV spectra from H₂ plasmas

Intensity of M.F.: ● 150G, ■ 120G, ▲ 80G

$V_d = 70 \, V, \quad I_d = 5 \, A, \quad p(H_2) = 1 - 7 \, mTorr$ \quad $p(H_2) = 2 \, mTorr, \quad V_d = 70 \, V, \quad I_d = 1 - 7 \, A$
Integrated VUV spectra from H$_2$ and D$_2$ plasmas

- **D$_2$ plasma**
- **H$_2$ plasma**

![Graphs showing integrated intensity vs. power and pressure](image)

- $B_{MF} = 80$ G, $V_d = 70$ V, $I_d = 5$ A
- $B_{MF} = 80$ G, $p$(H$_2$ or D$_2$) = 2 mTorr
Summary

(1) Production and control of D$_2$ plasmas
   • Controlling spatial distributions of $n_e$ and $T_e$ with the MF
   • Good Combination between the MF and the filament position

(2) Volume production of D$^-$ ions (Isotope effect)
   • Optimum condition for D$^-$ production is different
     from that for H$^-$ production. (for example, pressure)
   • Extracted H$^-$ and D$^-$ currents have clear relations
     with ion densities in the source.
   • VUV emission from D$_2$ plasmas is slightly
     lower than that from H$_2$ plasmas. (0.9 ~ 0.95)

For further studying D$^-$ production, simultaneous measurements of
VUV emission and negative ion density in the source is necessary.
END
Axial distributions of H\(^-\) ion densities

Filter Magnet

\[ n_-(x 10^{10} \text{ cm}^{-3}) \]

Axial position \( z \) (cm)

\[ V_d = 70 \text{ V}, \quad I_d = 5 \text{ A}, \quad p(\text{H}_2) = 1.5 \text{ mTorr}, \]
\[ E_{\text{laser}} = 30 \text{ mJ}, \quad D_{\text{laser}} = 6 \text{ mm}, \quad V_p = 10 \text{ V}. \]
Axial distributions of $H^-$ and $D^-$ ion densities

$V_d = 70$ V, $I_d = 5$ A,
$p(D_2) = 3$ mTorr, $p(H_2) = 1.5$ mTorr,
$E_{\text{laser}} = 30$ mJ, $D_{\text{laser}} = 6$ mm, $V_p = 10$ V.
Axial distributions of H\(^-\) and D\(^-\) ion densities

\[ V_d = 70 \text{ V}, \quad I_d = 5 \text{ A}, \]
\[ p(D_2) = p(H_2) = 1.5 \text{ mTorr}, \]
\[ E_{\text{laser}} = 30 \text{ mJ}, \quad D_{\text{laser}} = 6 \text{ mm}, \quad V_p = 10 \text{ V}. \]
Production Processes of Negative Ions

Volume Production

Surface Production Process in Cs-seeded Volume Negative Ion Source

\[ H_2 + e_f \rightarrow H^*_2 + e_f' \]

\[ H^*_2 + e_s \rightarrow H^- + H \]

\[ H^0 \text{ Atom} \]

\[ H^- \text{ Ion} \]

\[ H^+, H_2^+, H_3^+ \text{ Positive Ion} \]

Cesium Coverage

Plasma Grid

Extraction Grid
Negative ion density measurement by laser photodetachment

Photodetachment process

\[ \text{H}^- + h\nu \rightarrow \text{H} + e^- \]

Laser beam

Nd-YAG Laser: 1064nm

Photodetached signals

\[ \frac{n_-}{n_e} = \frac{\Delta I^-}{I_{es}} \]

Probe Current

Time (\mu s)

0 0.4 0.8 1.2 1.6

0 mA

\( I_{es} \)

\( \Delta I^- \)

Negative ion density \( n_- \)
Axial distributions of plasma parameters in D$_2$ plasmas

$V_d = 70$ V, $I_d = 5$ A, $p(D_2) = 3$ mTorr

Intensity of M.F.:  
- ● 150G, ■ 120G, × 100G, ▲ 80G, ◆ 60G

![Graph showing electron density and electron temperature distributions](image)

Electron density $n_e (\times 10^{10} \text{ cm}^{-3})$

Electron temperature $T_e (\text{eV})$

Axial position $z$ (cm)
Experimental conditions are as follows: $V_d = 70 \text{ V}$, $I_d = 5 \text{ A}$, $p(D_2) = 3.0 \text{ mTorr}$
Power dependence of VUV spectra from H$_2$ plasmas

$B_{MF} = 80$ G

$p(H_2) = 2$ mTorr, $V_d = 70$ V, $I_d = 1 - 7$ A