Efficiency of Cs-free Materials for H⁻/D⁻ Production

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1. Introduction

**Negative Hydrogen Ion Sources**

- **Volume production**
  - $H_2$ plasma: $H, H_2, H_x^+, e^-$

- **Surface production**
  - $H_2$ plasma: $H, H_2, H_x^+, e^-$

**Converter surface**

- **High performance**
  - high current dens.
  - reliable & reproducible
  - stable (long pulses)
  - homogeneous (large beams)

**Caesiation $\rightarrow$ low WF**
- Cs chemical reactive
- Complex redistribution dynamics

**Issues**
- Careful conditioning
- Cs consumption
- Diagnostics

$\rightarrow$ **Alternatives to Cs?**
1. Introduction

Surface Assisted $\text{H}^{-}$ Formation

Surface reformation
\[ \text{H} + \text{H}_{\text{ads}} \rightarrow \text{H}_2(\nu) \]

Volume production (DA)
\[ \text{H}_2(\nu) + e^- \rightarrow \text{H} + \text{H}^- \]

Direct e\(^{-}\) capture
\[ \text{H}, \text{H}_x^+, \text{H}_{\text{ads}} + e^- \text{ (surface)} \rightarrow \text{H}^- \]

Sputtering of ads. H

 Comparative studies under identical and controlled conditions close to ion source parameters

Effect | Materials
---|---
Supporting volume formation | Refractory metals (W, Ta)
Direct conversion | Caesiated surfaces
Inherent low WF (LaB\(_6\), MoLa) | Carbon materials (Diamond, BDD)

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Laboratory Experiment HOMER (ECR)

Microwave
f = 2.45 GHz
P_{max} = 1 kW

Sample surface (floating or biased, heatable)
Sample holder (height adjustable)
Meshed grid

Nd:YAG
\( \lambda = 1064 \text{ nm} \)

Coil

Driver

Downstream
\( p \geq 0.3 \text{ Pa } H_2/D_2 \)
\( T_e \approx 1 - 2 \text{ eV} \)
\( n_e \approx 10^{16} - 10^{17} \text{ m}^{-3} \)
\( n_H \approx 10^{18} - 10^{19} \text{ m}^{-3} \)
# Investigated Materials

<table>
<thead>
<tr>
<th>Effect</th>
<th>Material group</th>
<th>Materials</th>
<th>Work function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supporting volume formation</td>
<td>Refractory metals</td>
<td>Bulk Tantalum (Ta), Bulk Tungsten (W)</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>Caesiated surfaces</td>
<td>Stainless steel + Cs (in-situ)</td>
<td>2.1 eV (bulk)</td>
</tr>
<tr>
<td>Direct conversion</td>
<td>Inherent low WF</td>
<td>Lanthanum-doped molybdenum (0.7 % La, MoLa), Lanthanum hexaboride (LaB₆)</td>
<td>&lt; 3 eV &lt; 3 eV</td>
</tr>
<tr>
<td></td>
<td>Carbon materials</td>
<td>Non-doped diamond, Boron-doped diamond (BDD)</td>
<td>–</td>
</tr>
</tbody>
</table>

Investigations of H⁻ density depending on:

- Pressure: 0.3 – 3.0 Pa
- Distance: 1.5 – 4.5 cm
- Sample bias: -30 – +30 V
- Temperature: 100 – 550 °C
Rating of Cs-free Materials

W, Ta, diamond, BDD, LaB$_6$, MoLa

Cs-free material

Laser photo detachment

Influence on H$^-$ density

Permanent offset

Influence on H$^-$ volume production

Efficiency of H$^-$ formation

vs.

Stainless steel (V2A) reference

In-situ caesiumation

0-dimensional modeling

Diagnostics

YACORA H$^-$

Langmuir probe $\rightarrow$ $n_{ion}$, EEDF, $\phi_{pl}$, $\phi_{fl}$

OES $\rightarrow$ $n_H$, $T_{gas}$, $T_{vib}$

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Target for Cs-free materials - Cs

\[ \chi_{Cs} \approx 2.1 \text{ eV} \] (confirmed at lab exp. ACCesS \(\rightarrow\) Poster MonP18)

- H\(^-\) density increased by a factor of 2.5 \(\rightarrow\) **Goal for Cs-free materials**
3. Results - Cs-free

**Cs-free Materials - LaB$_6$ & BDD**

- Bias between sample and vessel walls
  - Influence on energy of charged particles impinging/leaving the surface
  - Influence on plasma parameters
- Plasma potential always higher
  - Particle energy varies between 20 eV and 1 eV
3. Results - Cs-free

**Cs-free Materials - LaB$_6$ & BDD**

- **V2A**: $\text{H}^-$ volume formation: absolutely determined by $\text{H}_2(\nu)$ and $\text{H}/\text{H}_2$
  relative variation due to EEDF ($T_{\text{eff}}$)

- **BDD**: enhanced volume formation expected → but **no enhancement measured**
  and severe plasma-induced erosion detected

- **LaB$_6$**: similar volume formation expected → but **enhancement measured** ($\chi < 3$ eV)

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3. Results - Cs-free

Cs-free Materials - MoLa in H₂/D₂

- MoLa (χ < 3 eV): ≈ 60% enhancement comp. to V2A
- D₂: enhanced volume formation expected (nₑ) enhanced volume destruction expected (D/D₂) compensating → Similar H⁻/D⁻ density

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Cs-free Materials - Overview

- No enhancement by: bulk Ta & W, diamond & BDD
- Only low work function materials enhance beyond volume formation
- No material comparable to Cs → lowest work function
Conclusion

- **Cs-free materials** investigated under
  - identical and
  - ion source parameters
- **Compared to**
  - pure volume formation and
  - caesiation
- **No material comparable to Cs**
  \( \chi_{\text{bulk}} \approx 2.1 \text{ eV}, \text{ increase by } 150\% \)
- Carbon materials show **severe erosion** (none of the other materials)
- Most promising: materials with **inherent low work function** (LaB\(_6\), MoLa)
  \( \chi < 3 \text{ eV}, \text{ increase by } \approx 50\% \)
- Comparable negative ion densities for **H\(_2\)/D\(_2\) operation**