Photoelectron Emission Induced by Low Temperature Hydrogen Plasmas

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&

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Content

• Plasma induced photoelectron emission and how to measure it
• Photoelectron emission from metal surfaces
• Photoelectron emission from alkali metal covered surfaces
• What are the possible effects caused by the photoelectrons?
Hydrogen plasma sources

- Hydrogen ion sources are used, for example, in:
  - electrostatic accelerators and cyclotrons
  - neutral beam injection
  - large-scale accelerator facilities using charge exchange injection into circular accelerators and storage rings

- Sources of electrons are:
  - ionization
  - cathodes
  - walls (secondary electron, photoelectron emission)
Hydrogen plasmas are strong sources of VUV radiation

- Up to 30% of heating power dissipated through VUV emission
Photoelectric effect

- Photon penetration depth in metals about 10 nm
- Escape depth of photoelectron 1-3 nm

www.youtube.com/watch?v=Obfney9PuLI
• Alkali metals are used to enhance the surface production of negative ions by lowering the work function

• Photon penetration depth few µm
Experimental setup
Experimental results

Experimental results

<table>
<thead>
<tr>
<th>Ion source</th>
<th>Total PE current (AkW⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.45 GHz microwave</td>
<td>0.9–1.6</td>
</tr>
<tr>
<td>filament-driven multi-cusp</td>
<td>0.8–1.2</td>
</tr>
<tr>
<td>Prometheus I, ECR zone</td>
<td>0.5–1.0</td>
</tr>
<tr>
<td>Prometheus I, H⁻ production region</td>
<td>0.08–0.14</td>
</tr>
<tr>
<td>14 GHz ECR</td>
<td>0.002–0.007</td>
</tr>
</tbody>
</table>


Experimental setup with Cs oven

- filament-driven cusp-confined discharge
- 4 mm extraction
- 880 ls⁻¹ turbomolecular pump
- optical filter revolver
- photoelectron meter
- oven + all-metal valve
- copper shaft
- insulator (aluminium oxide)
- 6 mm collimator
- sample
- anode
- deposition monitor
Cs deposition

- Deposition peak is attributed to work function change and photon penetration depth vs escape depth of the photoelectrons
Cs deposition

Cs desorption

- Desorption peak is caused by diffusion and desorption of Cs
Cs vs Rb

- Cs work function 2.14 eV
- Rb work function 2.16 eV
Possible effects caused by the photoelectrons

• Photoelectrons may affect volumetric rates of various plasma processes depending on the intensity and the energy distribution

\[ e + H_2(X^{1}\Sigma_g^+; v'') \rightarrow H^-_2(2\Sigma_u^+) \rightarrow H(1s) + H^- \quad (E_e \sim 1 \text{ eV}) \]
\[ e + H^- \rightarrow H + 2e \quad (E_e > 2 \text{ eV}) \]
\[ e + H_2(X^{1}\Sigma_g^+) \rightarrow H_2(b^3\Sigma_u^+) \rightarrow H + H + e \quad (E_e > 8 \text{ eV}) \]
\[ e + H_2(X^{1}\Sigma_g^+) \rightarrow H_2(a^3\Sigma_g^+) \quad (E_e > 12 \text{ eV}) \]
\[ e + H_2(X^{1}\Sigma_g^+) \rightarrow H_2(B^1\Sigma_u^+) \quad (E_e > 12 \text{ eV}) \]
\[ e + H_2(X^{1}\Sigma_g^+) \rightarrow H_2(C^1\Pi_u^+) \quad (E_e > 12 \text{ eV}) \]
\[ e + H_2 \rightarrow H_2^+ + 2e \quad (E_e > 16 \text{ eV}) \]
Plasma sheath


$$j_{\text{eff}} = j_{H^-} + \int_0^{hv-\phi} j_{\text{PE}}(E_{\text{PE}}) \sqrt{\frac{m_e}{m_{H^-}}} \sqrt{\frac{E_{H^-}}{E_{\text{PE}}}} dE_{\text{PE}}$$
Photoelectrons effect on plasma sheath

- Effect increases if cathode potential is decreased (e.g. biasing the plasma electrode)
Conclusion

• Photoelectron emission from (clean) metals is in the order of $1 \text{AKW}^{-1}$ of discharge power

• Alkali metal coverage increases emission with thin layer and decreases with thick layer

• Photoelectron emission can change the sheath structure significantly if the emission density is $>1 \text{kAm}^{-2}$ (realization depends on mechanical design of the plasma device, heating method and efficiency)