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Photoelectron Emission Induced by Low Temperature Hydrogen Plasmas

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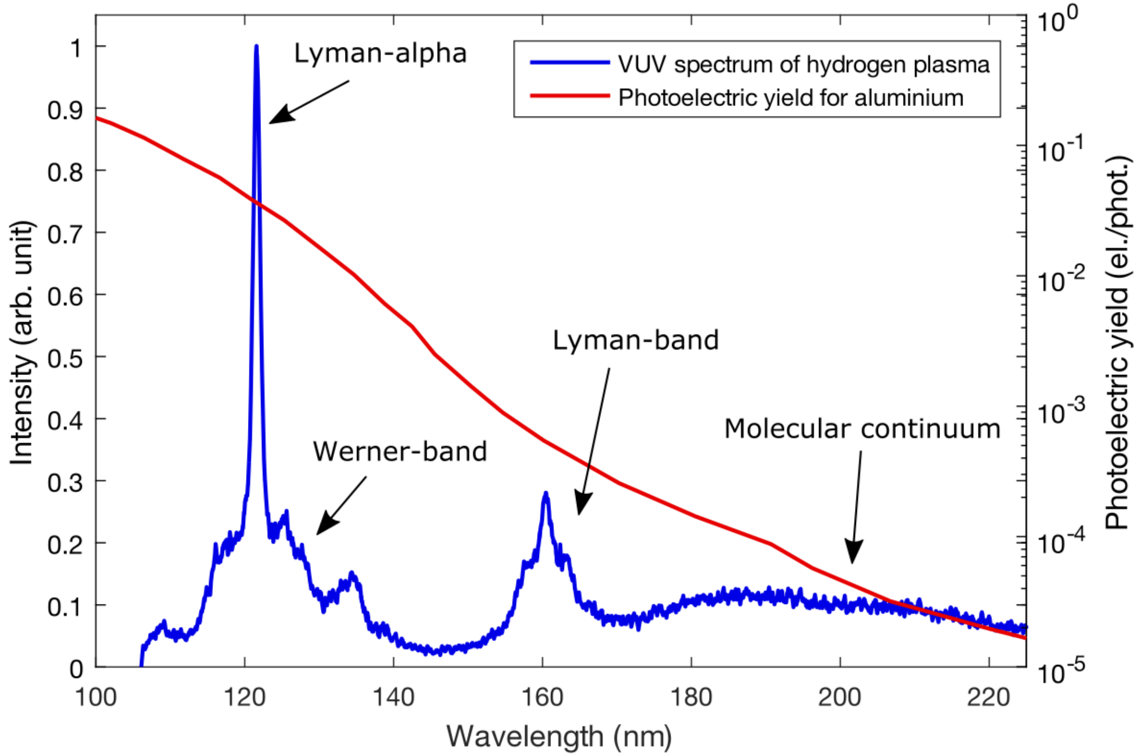
Content

- 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

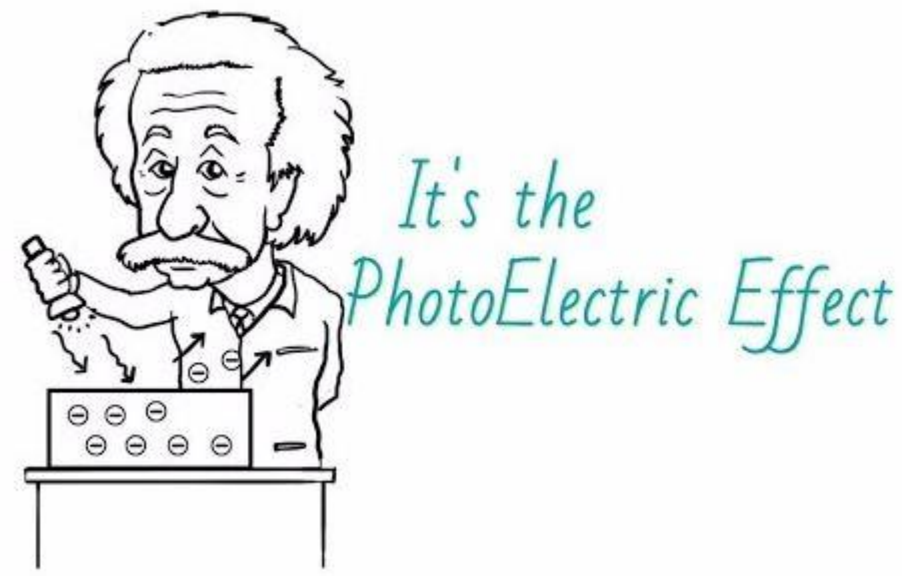
- Hydrogen ion sources are used, for example, in
  - electrostatic accelerators and cyclotrons
  - neutral beam injection
  - large-scale accelerator facilities using charge exchange injection into circular accelerators and storage rings
- Sources of electrons are
  - ionization
  - cathodes
  - walls (secondary electron, photoelectron emission)

Hydrogen plasmas are strong sources of VUV radiation

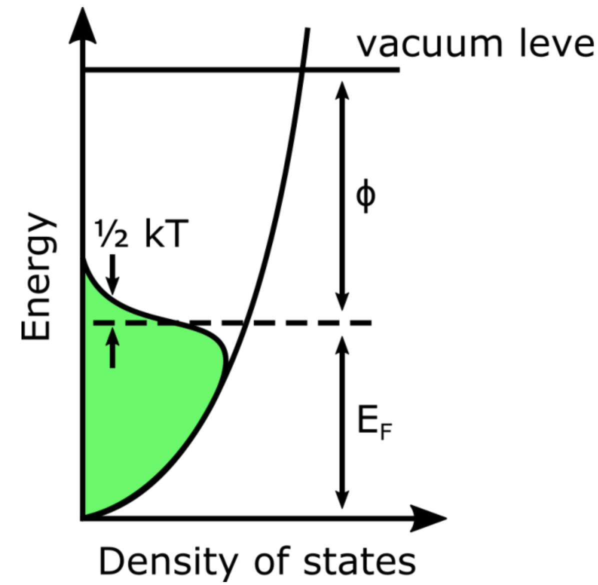


- Up to 30 % of heating power dissipated through VUV emission

Photoelectric effect

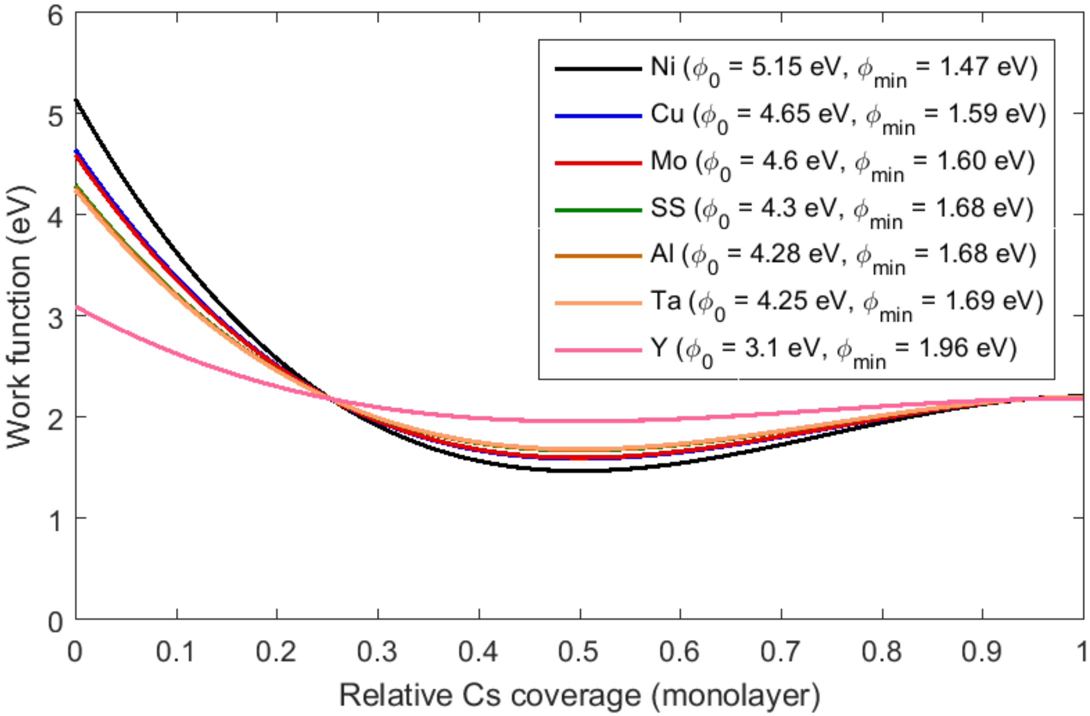


www.youtube.com/watch?v=Obfney9PuLI



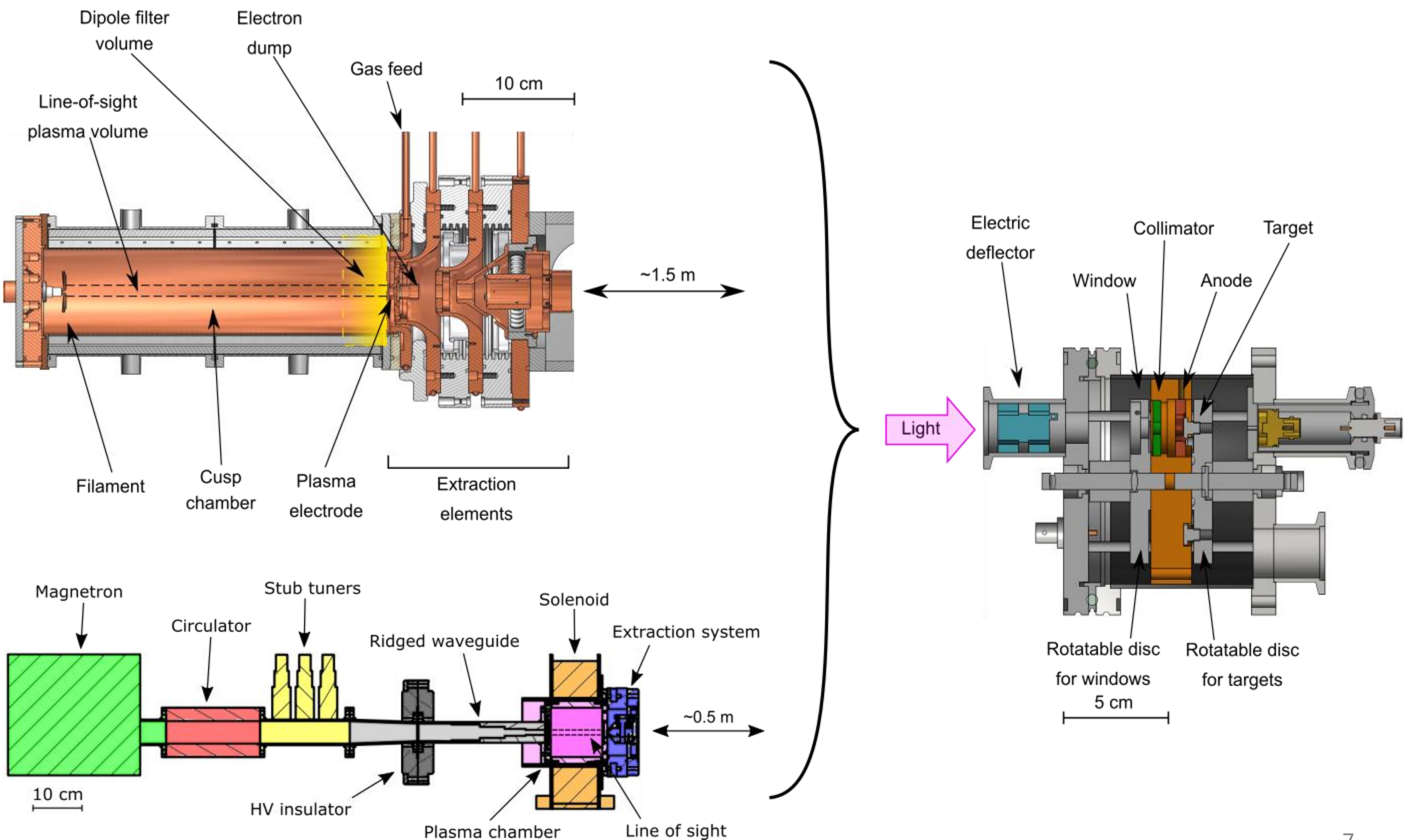
- Photon penetration depth in metals about 10 nm
- Escape depth of photoelectron 1-3 nm

Alkali metals

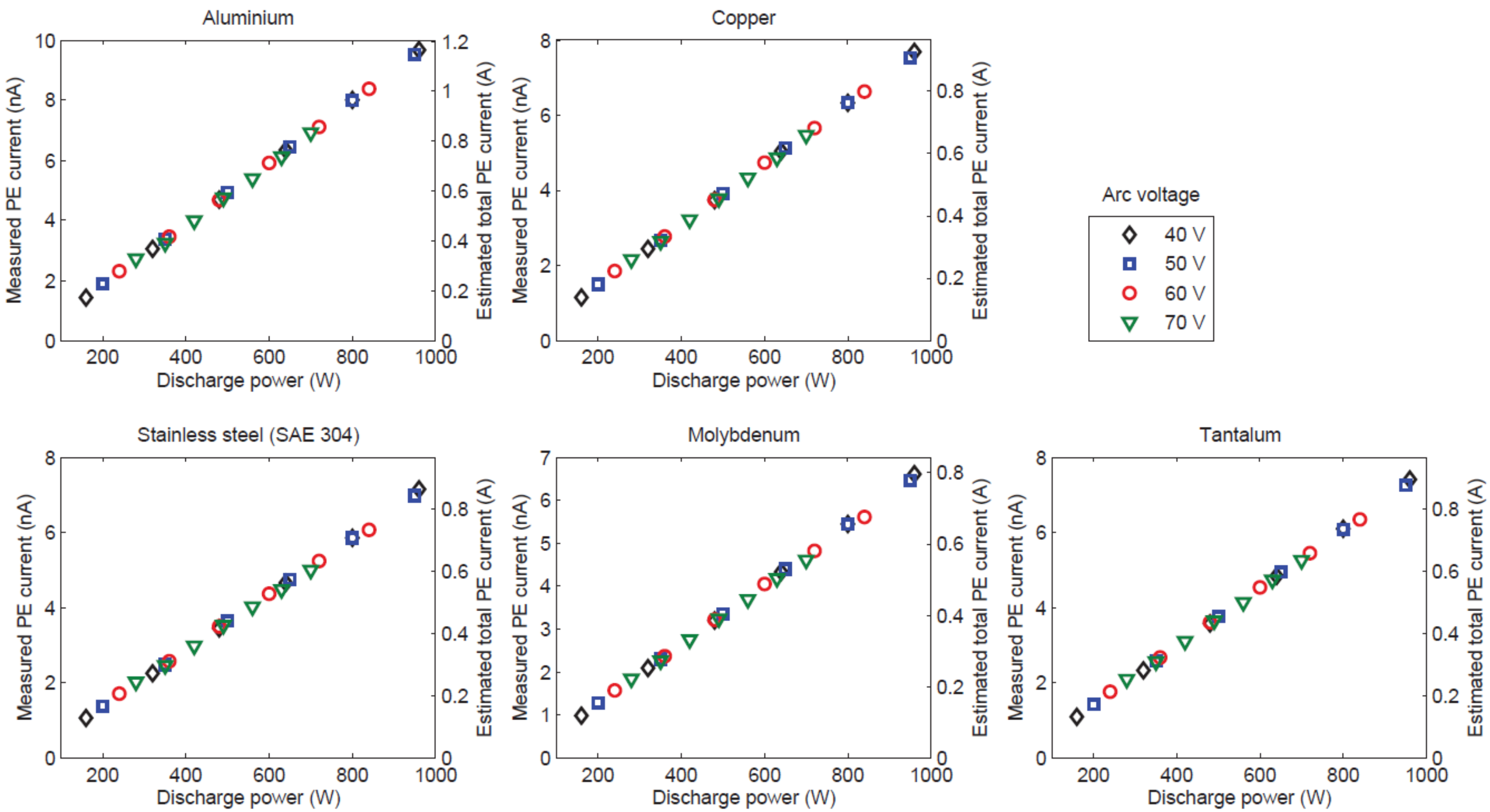


- Alkali metals are used to enhance the surface production of negative ions by lowering the work function
- Photon penetration depth few μm

Experimental setup



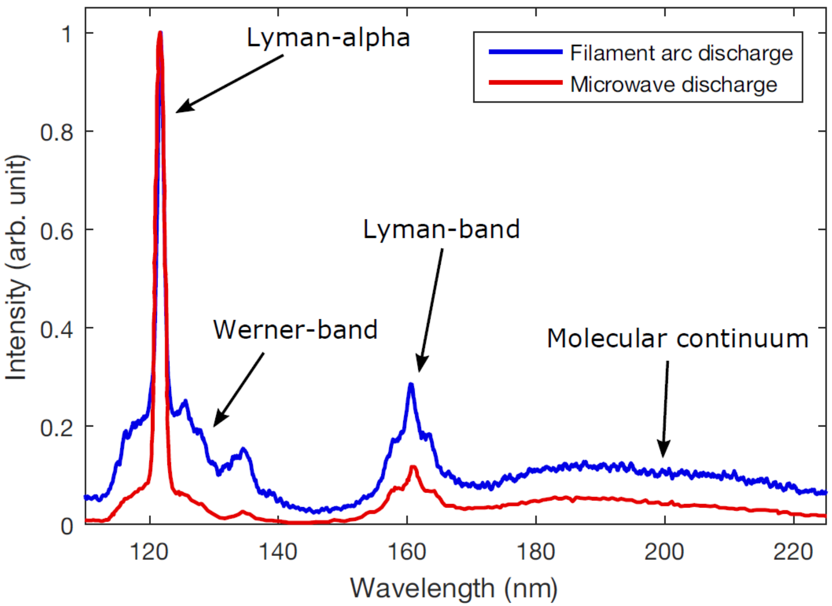
Experimental results



J. Laulainen, T. Kalvas, H. Koivisto, J. Komppula, and O. Tarvainen, AIP Conf. Proc. 1655, 020007 (2015)

Experimental results

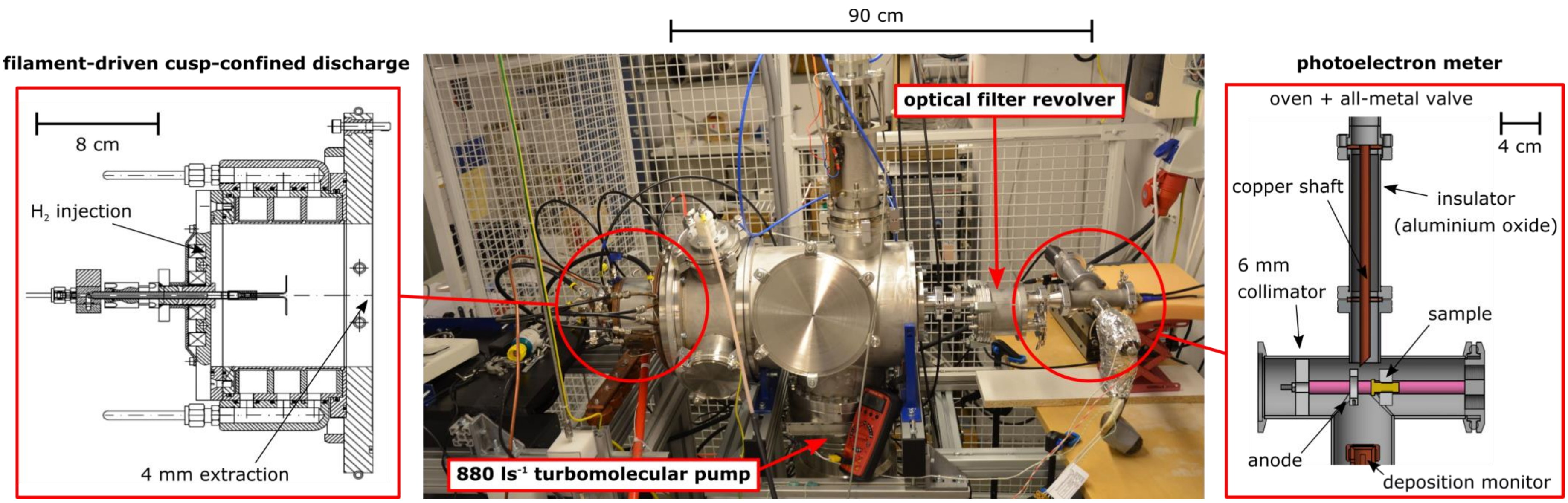
Ion source	Total PE current (AkW^{-1})
2.45 GHz microwave	0.9–1.6
filament-driven multi-cusp	0.8–1.2
Prometheus I, ECR zone	0.5–1.0
Prometheus I, H^- production region	0.08–0.14
14 GHz ECR	0.002–0.007



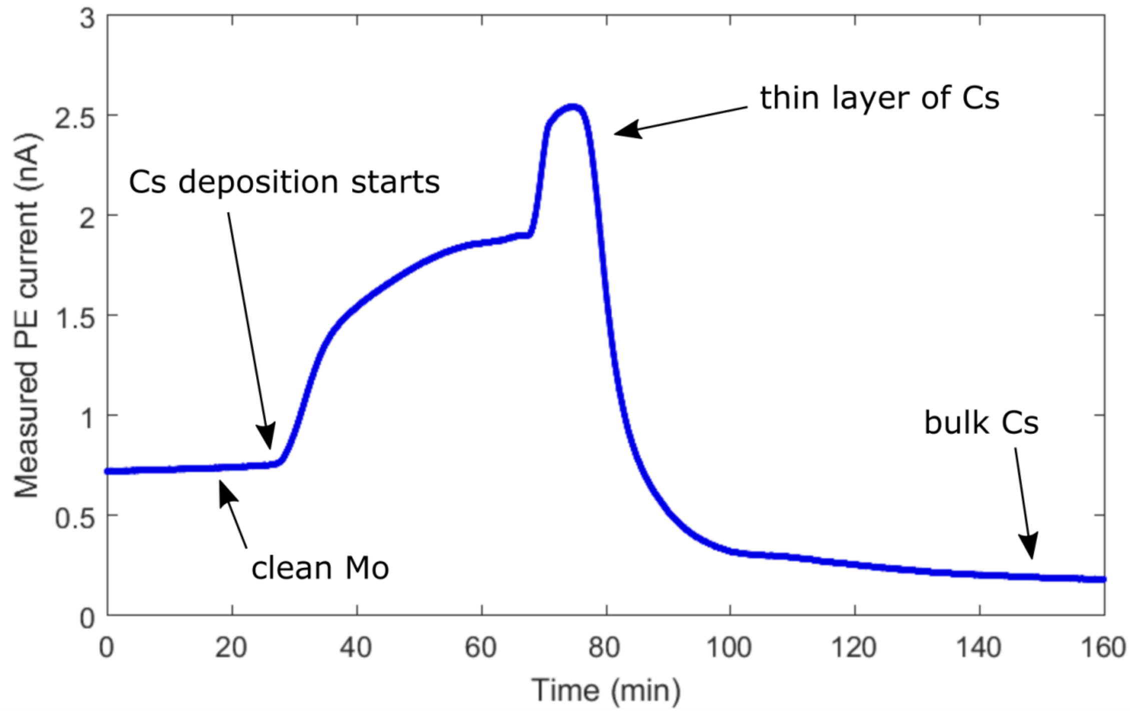
J. Laulainen, T. Kalvas, H. Koivisto, R. Kronholm, O. Tarvainen, S. Aleiferis, and P. Svarnas, AIP Conf. Proc. 1869, 020012 (2017)

J. Laulainen, T. Kalvas, H. Koivisto, J. Komppula, and O. Tarvainen, Rev. Sci. Instrum. 87, 02A506 (2016)

Experimental setup with Cs oven

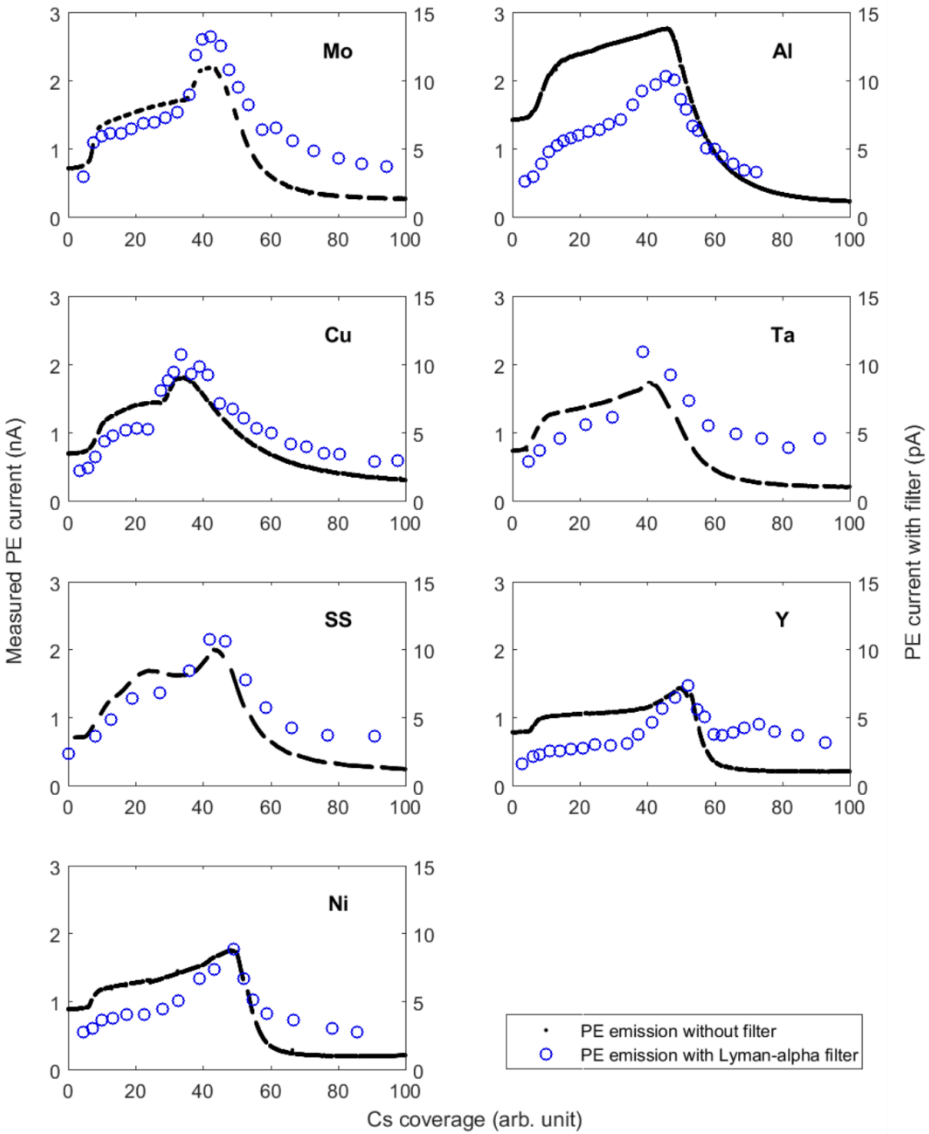


Cs deposition



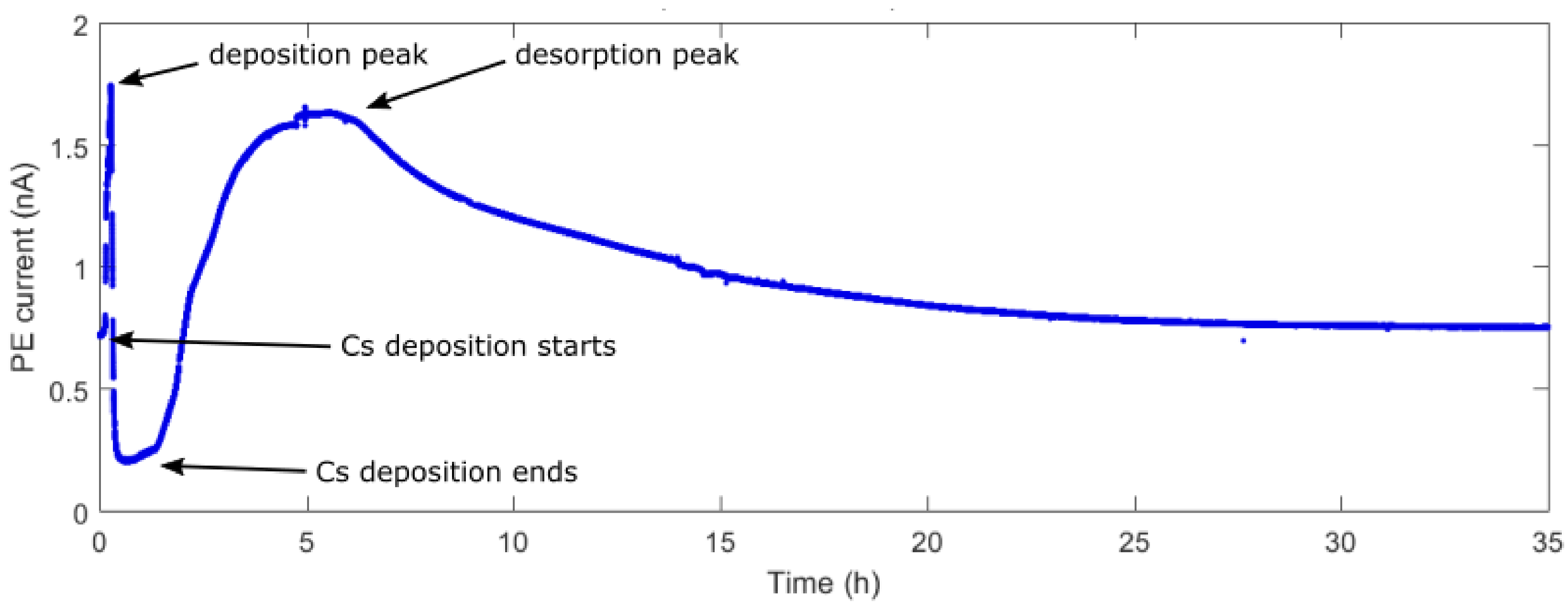
- Deposition peak is attributed to work function change and photon penetration depth vs escape depth of the photoelectrons

Cs deposition



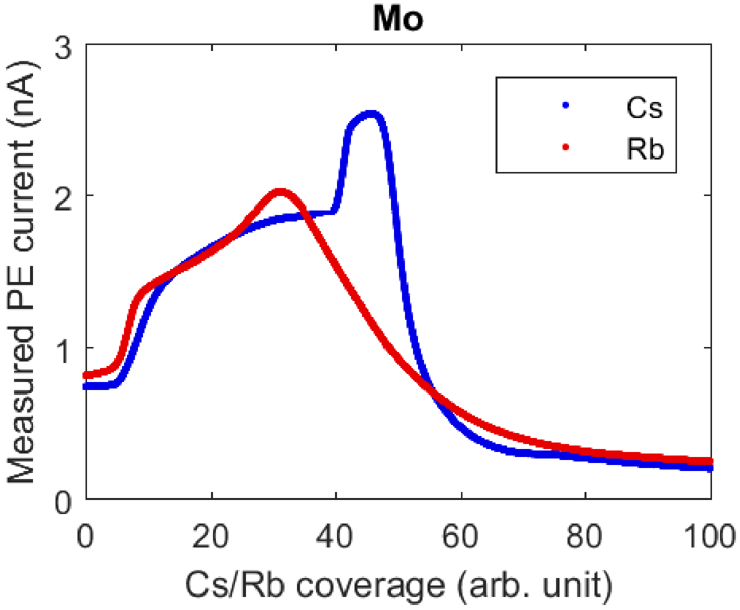
J. Laulainen, S. Aleiferis, T. Kalvas, H. Koivisto, R. Kronholm, and O. Tarvainen, Phys. Plasmas 24, 103502 (2017)

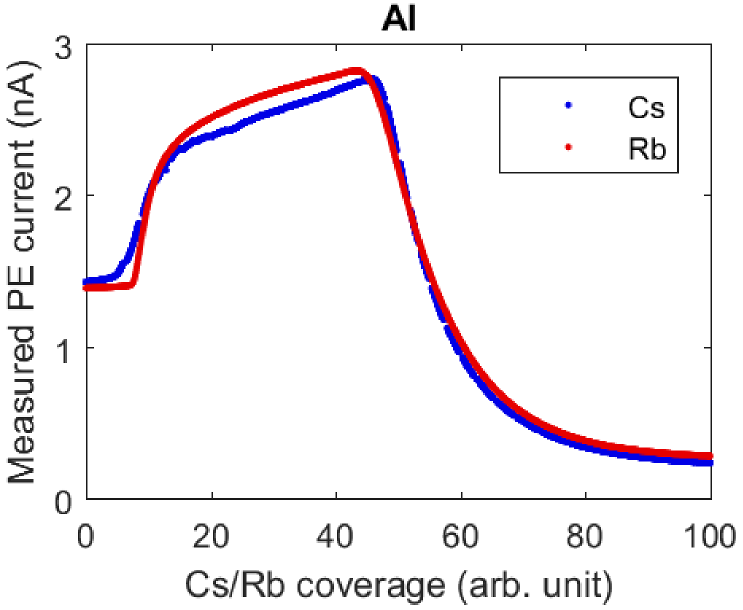
Cs desorption



- Desorption peak is caused by diffusion and desorption of Cs

Cs vs Rb





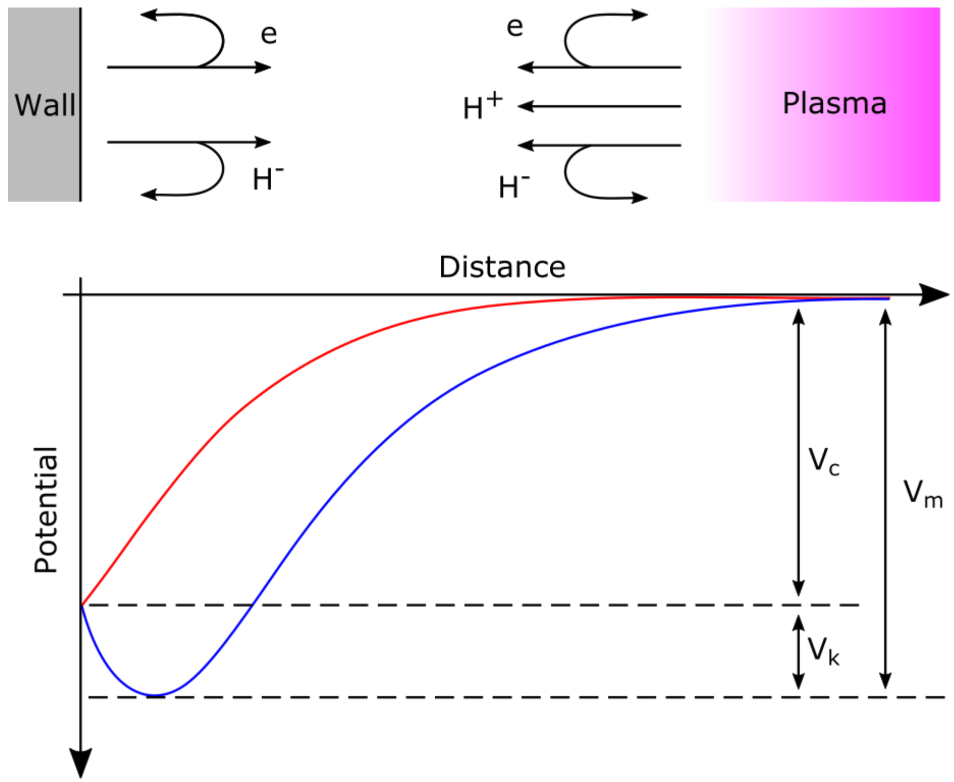
- Cs work function 2.14 eV
- Rb work function 2.16 eV

Possible effects caused by the photoelectrons

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

$$
\begin{aligned}
&\mathrm{e} + \mathrm{H_2}(\mathrm{X}^1\Sigma_g^+; v'') \to \mathrm{H_2^-}(^2\Sigma_u^+) \to \mathrm{H(1s)} + \mathrm{H^-} && (E_\mathrm{e} \sim 1\,\mathrm{eV}) \\
&\mathrm{e} + \mathrm{H^-} \to \mathrm{H} + 2\mathrm{e} && (E_\mathrm{e} > 2\,\mathrm{eV}) \\
&\mathrm{e} + \mathrm{H_2}(\mathrm{X}^1\Sigma_g^+) \to \mathrm{H_2}(b^3\Sigma_u^+) \to \mathrm{H} + \mathrm{H} + \mathrm{e} && (E_\mathrm{e} > 8\,\mathrm{eV}) \\
&\mathrm{e} + \mathrm{H_2}(\mathrm{X}^1\Sigma_g^+) \to \mathrm{H_2}(a^3\Sigma_g^+) && (E_\mathrm{e} > 12\,\mathrm{eV}) \\
&\mathrm{e} + \mathrm{H_2}(\mathrm{X}^1\Sigma_g^+) \to \mathrm{H_2}(\mathrm{B}^1\Sigma_u^+) && (E_\mathrm{e} > 12\,\mathrm{eV}) \\
&\mathrm{e} + \mathrm{H_2}(\mathrm{X}^1\Sigma_g^+) \to \mathrm{H_2}(\mathrm{C}^1\Pi_u^+) && (E_\mathrm{e} > 12\,\mathrm{eV}) \\
&\mathrm{e} + \mathrm{H_2} \to \mathrm{H_2^+} + 2\mathrm{e} && (E_\mathrm{e} > 16\,\mathrm{eV})
\end{aligned}
$$

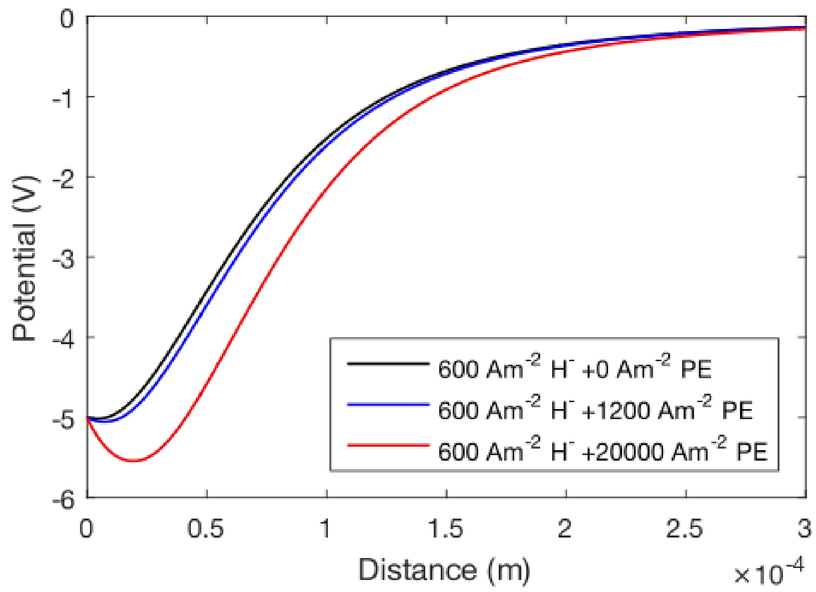
Plasma sheath

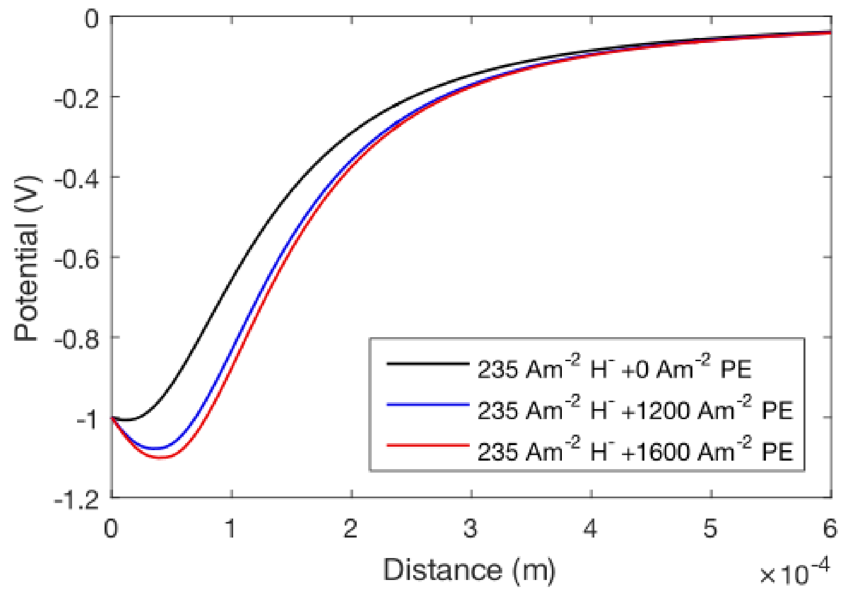


R. McAdams, D. B. King, A. J. T. Holmes, and E. Surrey, Rev. Sci. Instrum. 83, 02B109 (2012)

$$j_{\mathrm{eff}} = j_{\mathrm{H^-}} + \int_0^{h\nu-\phi} j_{\mathrm{PE}}(E_{\mathrm{PE}}) \sqrt{\frac{m_{\mathrm{e}}}{m_{\mathrm{H^-}}}} \sqrt{\frac{E_{\mathrm{H^-}}}{E_{\mathrm{PE}}}} \, \mathrm{d}E_{\mathrm{PE}}$$

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 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 kAm^{-2} (realization depends on mechanical design of the plasma device, heating method and efficiency)