Thoughts on negative hydrogen ion extraction

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OUTLINE

1. INTRODUCTION

2. PURPOSE/METHOD

3. PURE HYDROGEN DISCHARGE
(VOLUME PRODUCTION of H^- IONS)

4. CAESIUM SEEDED HYDROGEN DISCHARGE
(SURFACE PRODUCTION of H^- IONS)

5. CONCLUSION

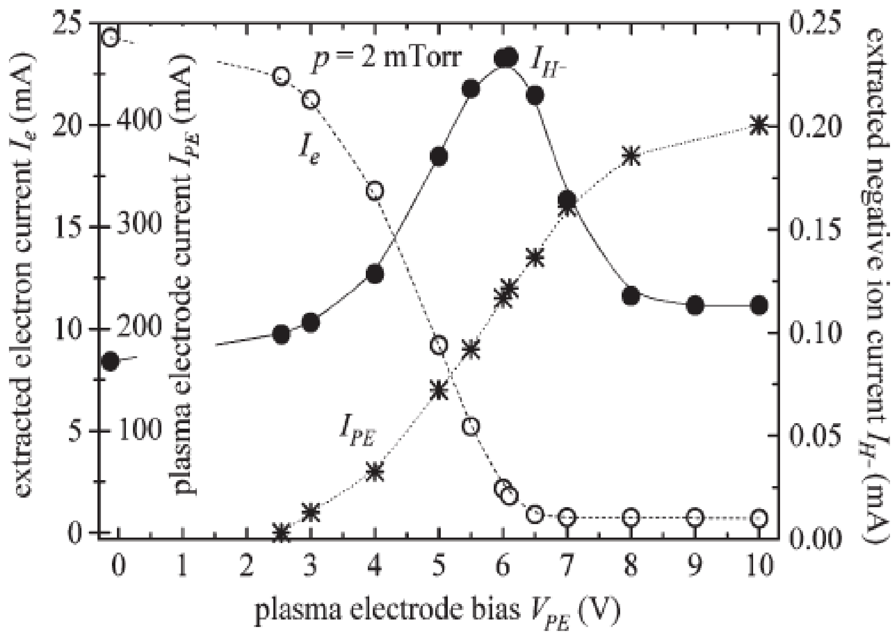
Observed dependencies on Plasma Electrode Bias of Extracted Currents and Negative Ion Density

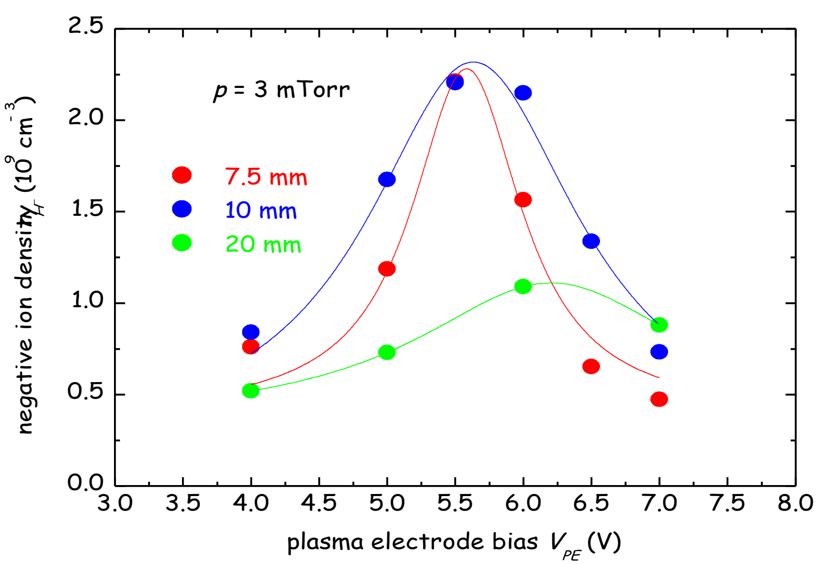
It is generally accepted that a positive plasma electrode (PE) bias (V_b) reduces the extracted electron current.

In some experiments the negative ion current goes through a maximum when the PE bias is varied.

The optimum V_b is close to the plasma potential, which is positive.

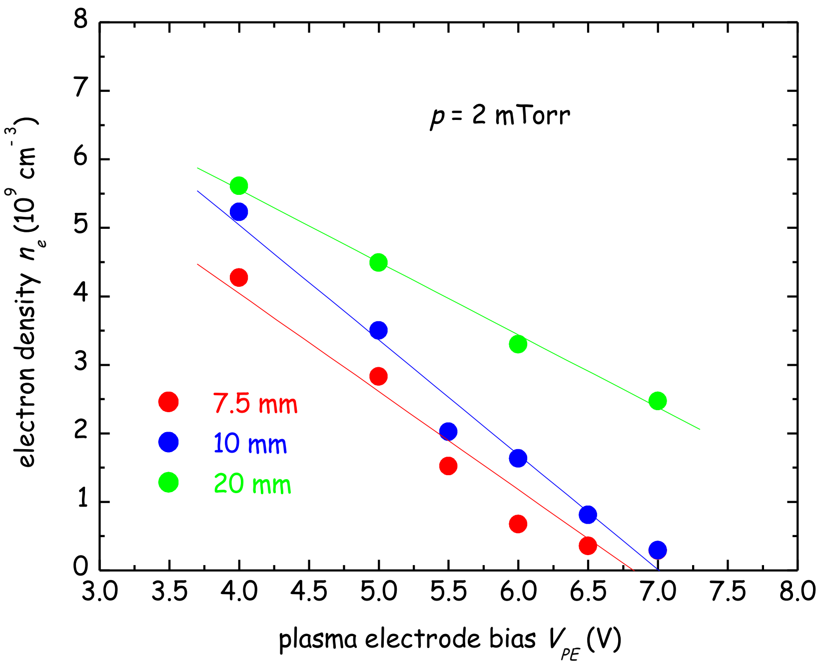
The plasma electrode collects a large electron current in the V_b region of interest.

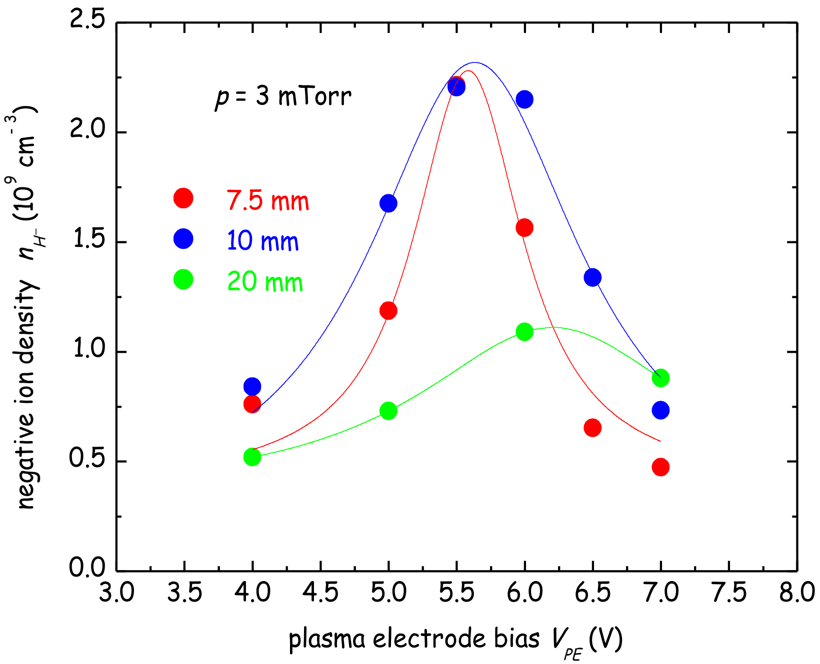




Electron and negative ion densities near the extraction opening.

Why both the negative ion density and the extracted current peak near the plasma electrode bias of 5.5 V ??





PURPOSE

Clarify the effect of the plasma electrode bias in pure hydrogen and caesium seeded hydrogen discharges.

METHOD

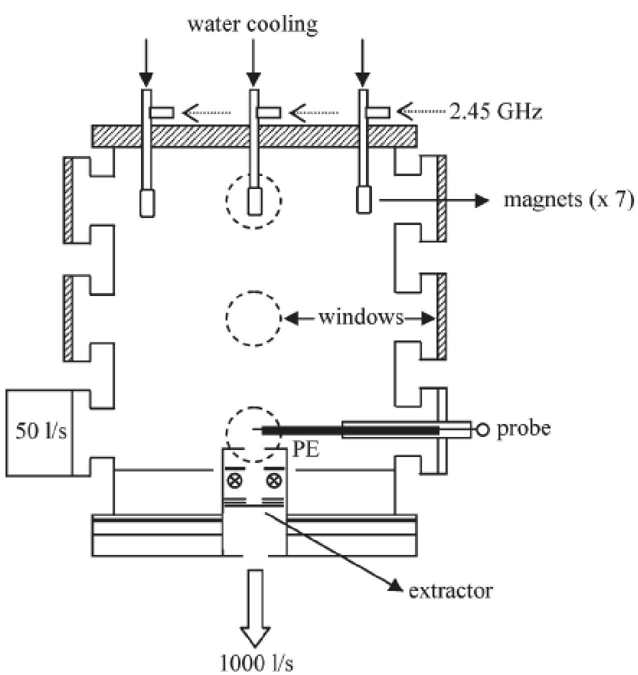
Laser Photodetachment for measuring N-/Ne
Langmuir probe for measuring Ne, Vp

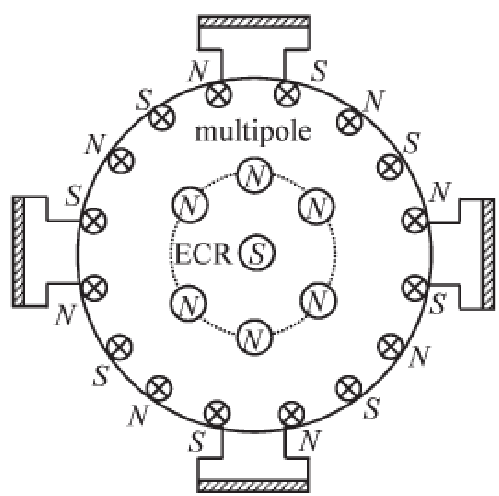
The Experimental Device Camembert III equipped with seven independent ECR Plasma Sources.

In 2003 a 2-D network of seven elementary independent ECR plasma sources were installed on the top flange. They are powered by microwaves (2.45 GHz, 0.9 kW).

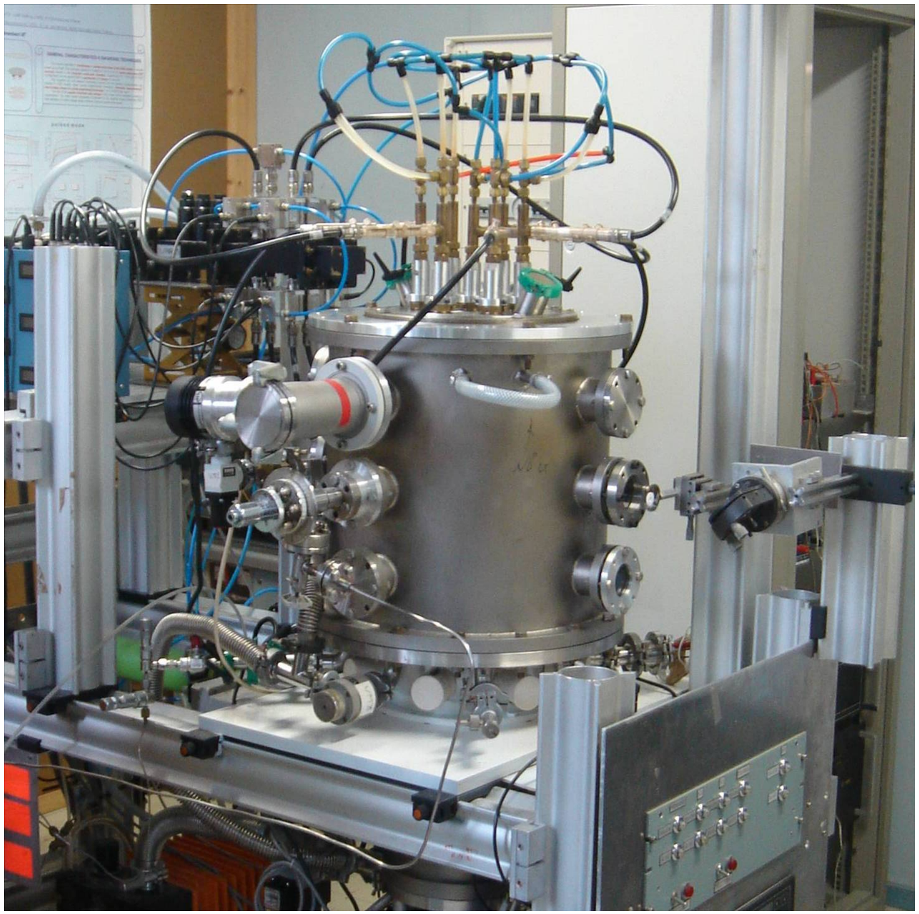
Each source contains a permanent magnet, which provides the magnetic field required for ECR (875 G). This magnetic field also confines the fast electrons. It represents a first magnetic filter, and the region around the magnet – the driver region.

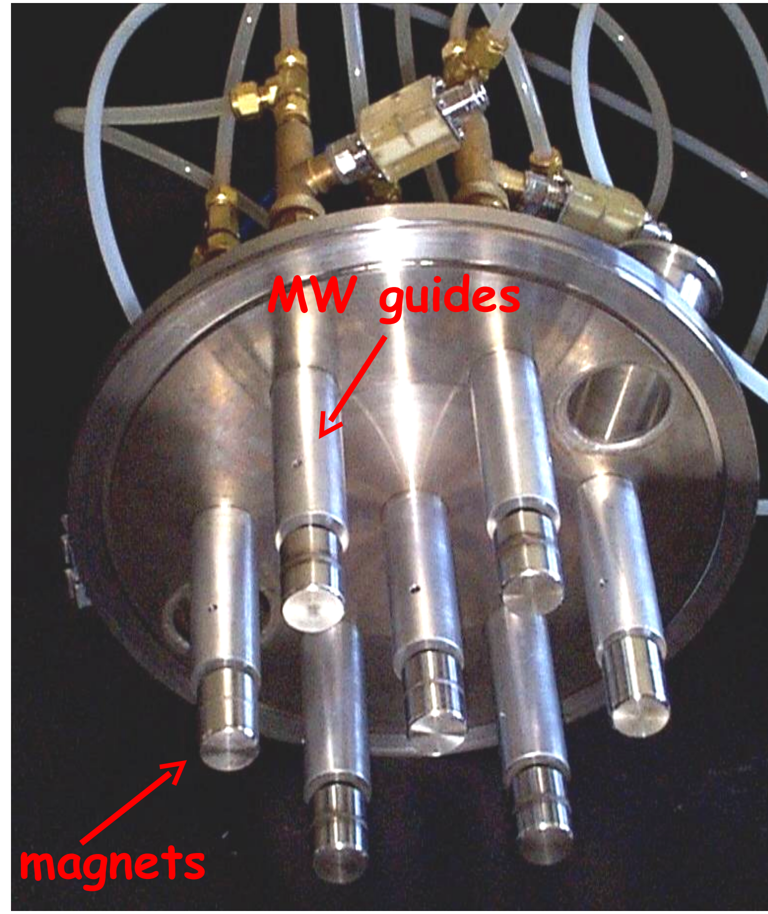
The high electron density produced around the magnets leads to the absorption of the microwaves. Therefore a second magnetic filter installed near the PE works, unlike reported in other ECR sources. This second magnetic filter attains a maximum of 20 Gauss at a distance of 1.35 cm from the PE.





H^- negative ion multi-cusp volume source "Camembert III" now installed in LPSC - Grenoble





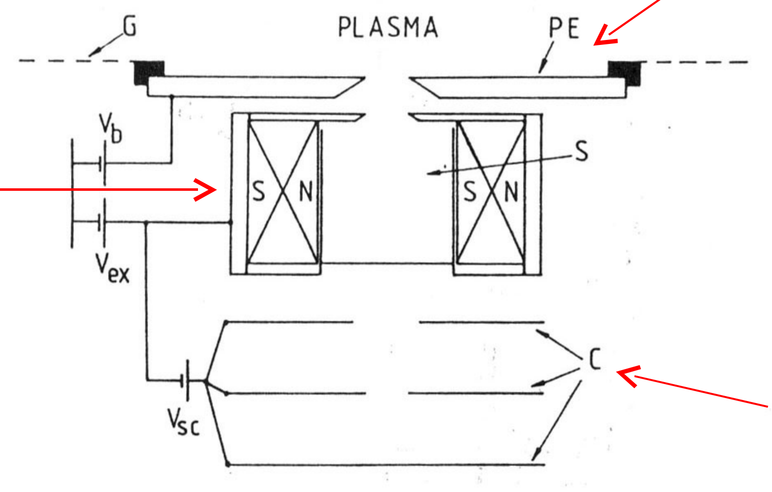
the extraction system of the source

Magnetic filter 20 Gauss

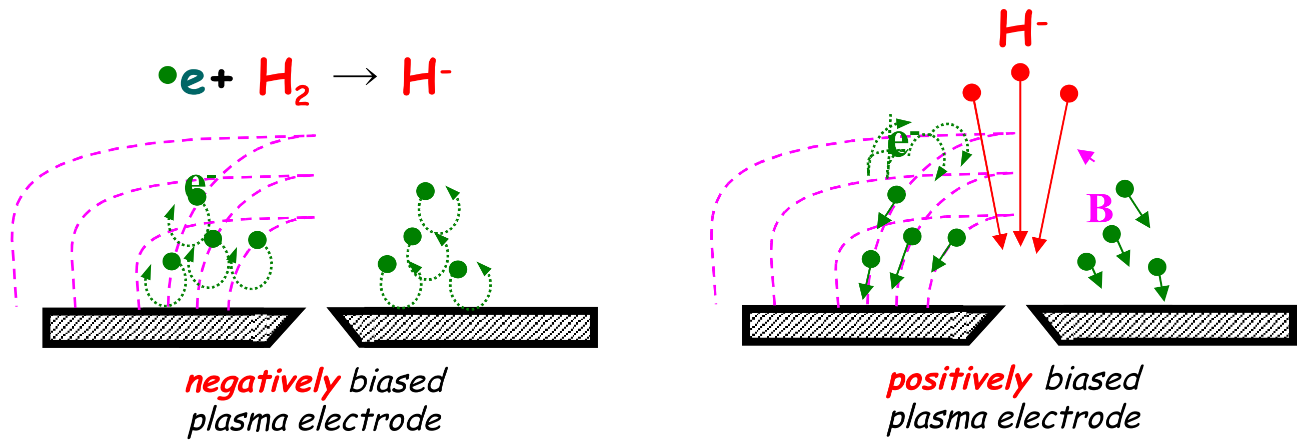
plasma electrode – biased: -10 to 10 V

H^- - e^- separator

H^- collector



Magnetic filter 20 Gauss



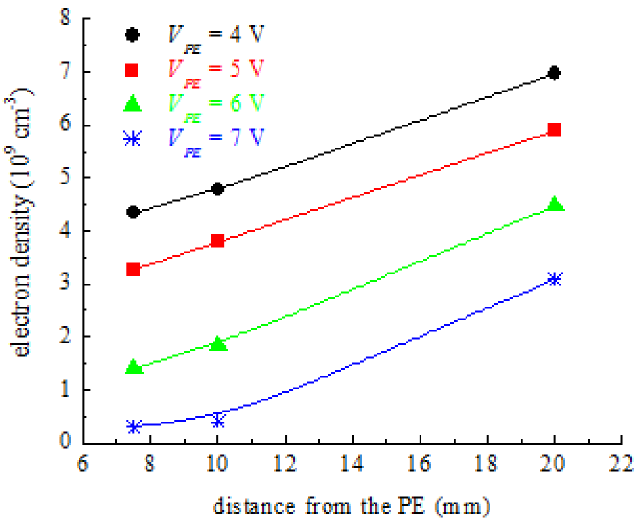
Spatial Variation of the Electron Density

We present here data obtained at a pressure of 3 mTorr. Note:

The electron density goes down linearly when approaching the PE.

The higher the positive bias V_b., the lower the electron density. This shows that the electrons are efficiently eliminated from the PE neighborhood due to the applied positive PE bias.

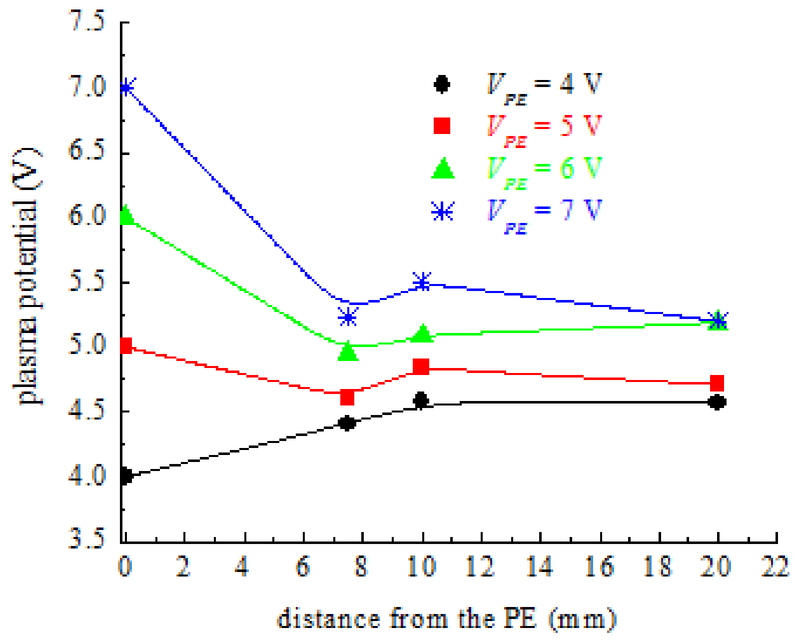
* Compared to the electron density at the center of the source ($3x10^{10}$ cm^{-3} at 3 mTorr), the electron density at 1 cm from the plasma electrode. is reduced by a factor 10, when the PE bias V_b = + 6 V is applied.



Spatial Variation of the Plasma Potential

* An indication of a small plasma potential maximum versus distance from the PE exists for V_b > 4 V at a distance of 1 cm.
* The plasma potential varies abruptly near the PE for extreme bias values, when ion or electron sheats are formed, but stays approximately constant for the medium value V_b = 5.5 V, which is close to the plasma potential far from the PE. Let us denote this value V_b*.

This value of the PE bias - Vb* - is important, since the maximum negative ion density occurs at this bias value . The electron temperature values increase abruptly when V_b > V_b*.



Why is a potential peak formed ??

Due to the weak magnetic field the electrons are magnetized, while negative ions are not. This is basically due to their mass difference.

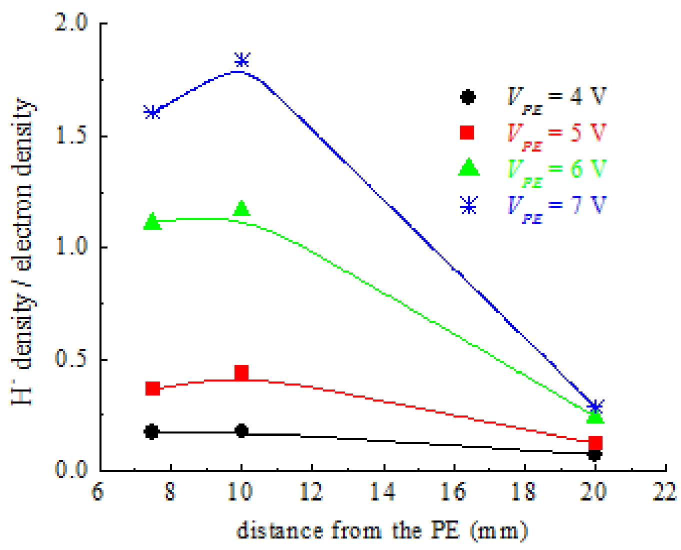
The magnetized electrons are easily lost along the field lines.

As a result the potential peak arises.

Spatial Variation of the Negative Ion/Electron Density Ratio (Electronegativity)

The ratio n^-/n_e is the primary result of the photodetachment measurement.

Note that this relative density goes up with the PE bias and attains the value of 1.9 for the highest V_b. Thus, the negative ions constitute the major negative species.

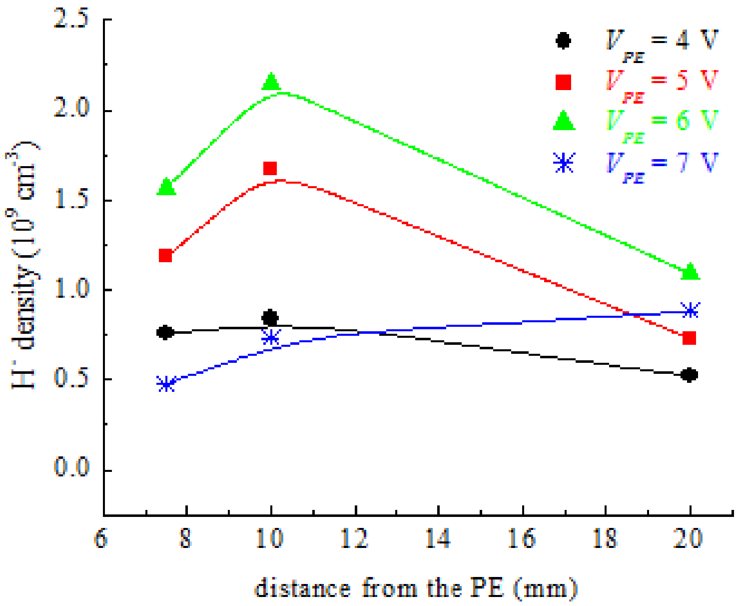


Spatial Variation of the Negative Ion Density

The highest negative ion densities are found in the neighborhood of the plasma electrode, at distances where the electron density is reduced.

The optimum PE bias is V_b *= 5.5 V, i.e. the PE bias close to the plasma potential far from the PE.

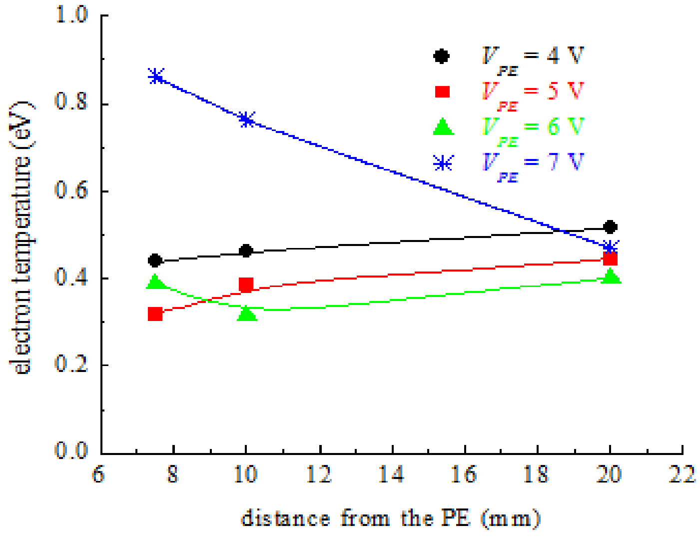
Even at a distance of 20 mm the effect of the magnetic field and the PE bias starts to go down.



Spatial Variation of the Electron Temperature

For Vb < 6 V the electron temperature is low (0.3 - 0.5 V) but goes up abruptly near the PE when Vb > 6 V.

It is likely that the measured value of the electron temperature includes a contribution from the directed velocity of the electrons accelerated towards the PE.



Why do we find the maximum N- density at 1 cm from the plasma electrode??

The negative ions are attracted in the positive potential peak region in order to restore the charge neutrality.

The highest negative ion densities are found at distances where the electron density is reduced and where the plasma potential attains a maximum.

The negative-ion densities are highest at 1 cm from the plasma electrode for V_b = 5 to 6 V, but they go down when approaching more the PE .

We conclude that the high negative ion densities measured at 1 cm are due to their confinement in the potential well observed there.

Under these conditions the loss of negative ions to the PE is low.

They diffuse to the PE, but are not accelerated to it.

Why the extracted H- current maximum occurs at the same PE bias range as the H- density maximum??

The extraction is effected due to the electric field produced by the voltage applied between the PE and the extraction electrode.

The reservoir of negative ions is the same for extraction and for collection by the PE.

If the PE collects many negative ions, not much are available for extraction. Pn the contrary, when no negative ions are collected by the PE, there are copious quantities available for extraction.

Thus the PE and the extraction orifice compete for negative ions.
The extracted current is maximum when the PE does not collect much H- ions, i.e. in the Vb range when the H- ions are confined in the potential well and are not accelerated towards the PE.

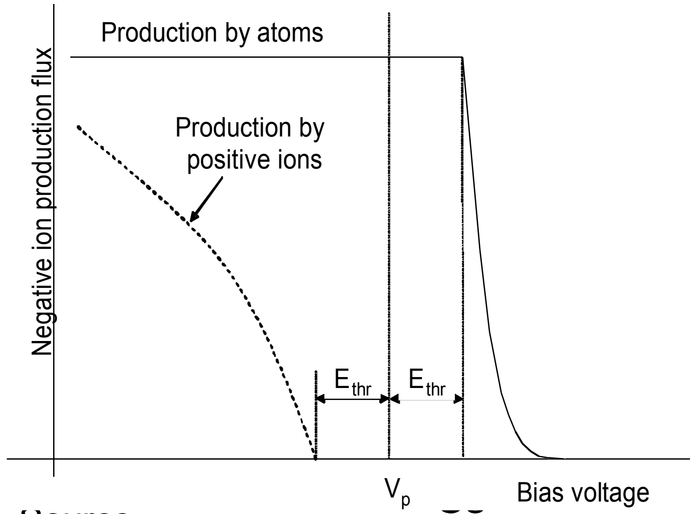
What do we expect when the negative ions are supposed to be produced on the caesiated Plasma Electrode surface ?

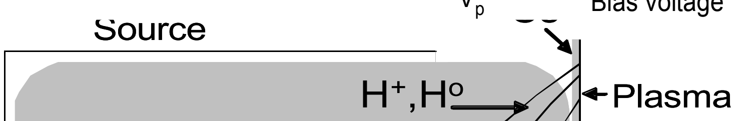
In this case a Negative (with respect to the plasma potential) Plasma Electrode Bias is necessary.

Two reasons for this::

* Positive ions produce in part the negative ions; to accelerate them a negative PE bias is necessary;

* the negative ions formed on the PE surface can leave it only if the Plasma Potential is positive with respect to the Plasma Electrode.





Caesiated rf source from IPP Garching

Photodetachment measurements at 2.2 cm from the PE are described in

Christ-Koch et al, PSS&T, **18**, 025003 (2009)

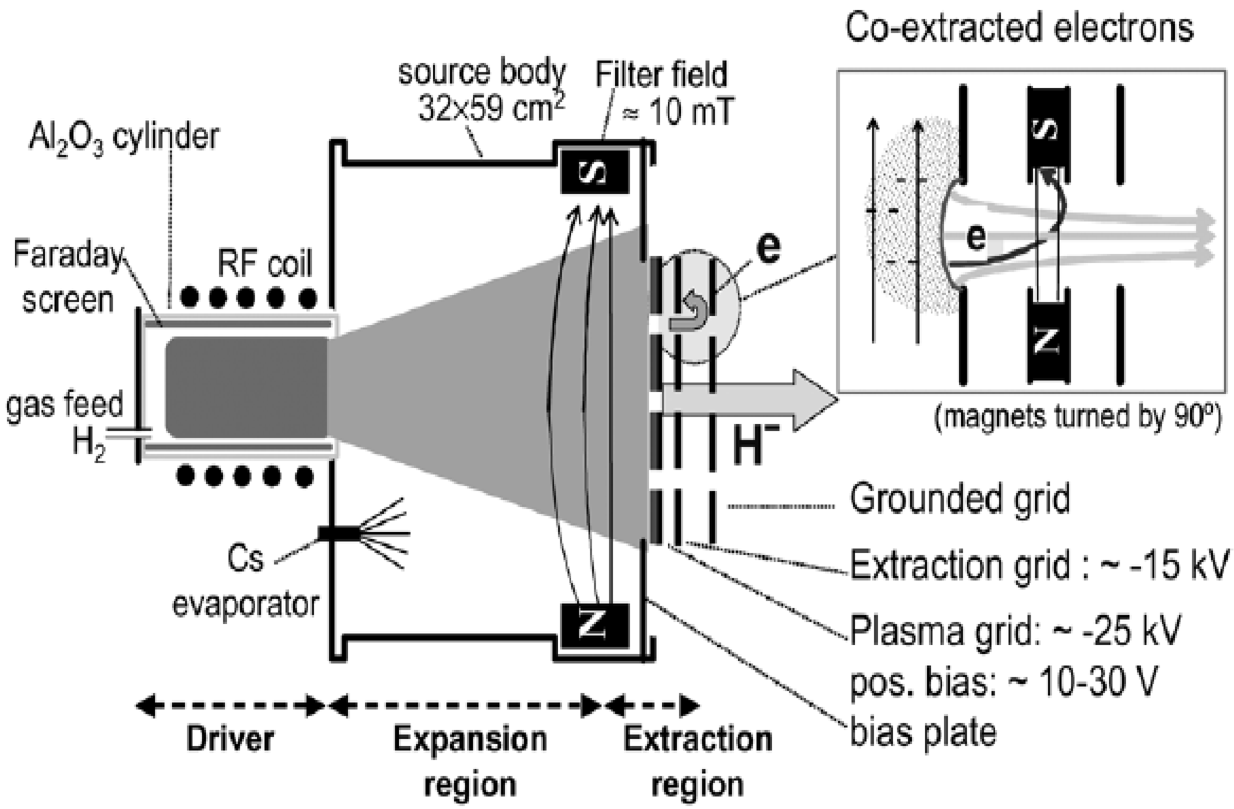


Figure 1. Schematic drawing of the rf-driven ion source at IPP.

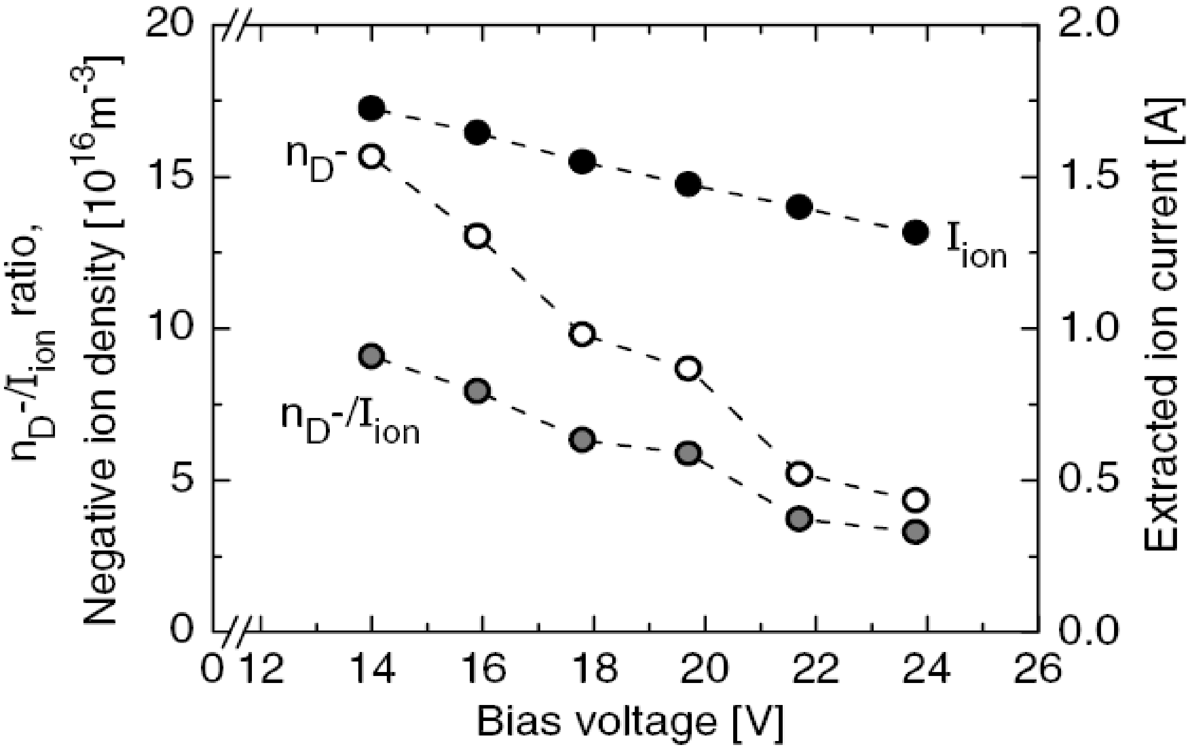


Figure 11. Negative ion density and extracted ion current for different bias voltages applied to the plasma grid in deuterium discharges at 53 kW and 0.45 Pa. Shown is also the density to current ratio (grey filled symbols, left axis).

- The negative ion density is measured at 2.2 cm from the plasma electrode.

- The variation of the negative density at this location is reported along with the extracted negative ion current.

- It is striking that the negative ion density is decreasing (by a factor 3) when the bias is varied from 14 to 24 V, while the extracted current decreases only very slightly.

- The plasma potential is 21 V in this case

- One can note that the extracted current does not decrease at plasma potential.

It can be questioned whether the negative ions extracted at PE bias above the plasma potential are surface-produced negative ions.

This question has been discussed by McAdams and Surrey at NIBS2008 in Aix.

Several possible H^- density enhancement mechanisms related to the introduction of cesium have been suggested by Steen and Graham (AIP Conf. Proc. 380 (1996), pg. 16).

Note that $H_2(v'')$ is the precursor of H^- in volume production: $H_2(v'') + e \Rightarrow H^- + H$

Volume Effects

*Enhancement of $H_2(v')$ production bu charge transfer of H_3^+ with Cs:

$$H_3^+ + Cs \Rightarrow H_2(v'') + H + Cs^+$$

The article by Mann et al, Chem. Phys. Lett. **473**, 14 (2009) is very encouraging

- Collisional cooling of electrons, lower Te help volume production and reduce detachment by electrons.

- We can suggest recombinative dissociation of H_3^+:

$$H_3^+ + e \Rightarrow H_3^*$$

H_3^* can decay into $H_2^+ (v'') + H$ and $3 H$

Surface Effects

1) Enhancement of $H_2(v'')$ production by:

a) H_3^+ neutralization at the caesiated walls

$$H_3^+ + \text{caesiated wall} \Rightarrow H_2(v'') + H$$

b) recombinative desorption of H atoms

$$H + H + \text{caesiated wall} \Rightarrow H_2(v'')$$

2) Direct surface production of H^- by atom and ion collisions with caesiated walls: this is the well known negative surface ionization.

Conclusion

* The investigation of the spatial distribution of negative ions in the extraction region allowed a better understanding of the observed dependence of negative ion current on plasma electrode bias, for pure hydrogen operation.

* A similar study in caesiated discharges could lead to important progress in understanding this type of operation.

* The investigation of the new mechanisms of H^- ion volume production, enhanced by the presence of cesium, is highly desirable.
The reality of such processes was shown in a work effected ten years ago in my group at Ecole Polytechnique.