Extracted H⁻ ion current enhancement due to caesium seeding at different plasma grid bias

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Introduction

The surface production on caesiated surfaces due to ions or atoms justifies the extraction of H\(^-\) ions only in the range of bias voltage below the plasma potential: \( V_\text{b} < V_\text{p} \).

Experiments demonstrate that extraction also occurs when \( V_\text{b} > V_\text{p} \).

The purpose of this work is explaining the origin of the H\(^-\) current in the range of bias voltage above plasma potential.
Outline

• Observed extracted H⁻ ion current enhancement due to caesium seeding at different plasma grid bias

• Possible explanations for this enhancement.
I. Experiments showing extracted H\(^-\) ion current enhancement due to caesium seeding in two filamented ion sources

JAERI 10 Amp source


H\(_2\) Pressure: 0.7 Pa
Experiment effected at two values of the extraction voltage, in pure hydrogen and caesium seeded operations. The hydrogen pressure was 0.4 Pa.
Several characteristics of caesiated operation

• In both JAERI 10 Amp and Camembert III sources the H- ion current increases due to caesium by a factor 2.5 at plasma potential.

• In both sources the H- ions are extracted at bias voltage above plasma potential ($V_b > V_p$).

• In Camembert III the extracted current goes down by a factor 2 only, when the bias voltage increases above plasma potential.
II. Possible explanations for the H⁻ ion current enhancement

• In the whole range of bias voltage: the H⁻ ion current is enhanced due to the gettering of atomic hydrogen by caesium.

• At bias voltage **below** plasma potential: direct production of H⁻ ions by positive ions and atoms incident on the caesiumated plasma grid surface.

• At bias voltage **above** plasma potential: the current of volume produced H⁻ ions is enhanced by gettering and flow of negative ions from bulk plasma.
Pure $H_2$

Volume produced ions

Cs seeded source

$H^-$ ions arrived from the bulk plasma

Bias voltage (V)

Direct produced $H^-$ ions due to ions and atoms on Cs surface
*enhanced by gettering reducing $H^-$ destruction
*reduced by gettering via direct production

Volume produced ions eventually enhanced by gettering

Bias voltage (V)
Effect of gettering the atomic hydrogen by caesium

- Gettering reduces the destruction of H- ions by associative and non-associative detachment due to atomic hydrogen. This affects the H- ion current extracted in the whole bias range.

* Gettering reduces the H- ion direct production on caesiated surfaces by atoms and positive ions. This affects the H- ion current extracted with bias voltage below plasma potential.
Evidence for H- ion flow from the background plasma towards the plasma grid

Experiments in NIFS (Japan) using CRDS and probes showed that extracted H- ions at plasma grid bias higher than the plasma potential originated from the plasma volume beyond the extraction region.
Schematic presentation of bias range where volume produced ion extraction is expected.

Bias voltage (V)

- $V_p - 10$
- $V_p - 5$
- $V_p$
- $V_p + 5$
- $V_p + 10$

Volume produced ions

$I_{H^-}$

Pure $H_2$
In actual fact, extracted H- current is maximum near plasma potential. The typical difference $V_{b}^{\text{max}} - V_p < 1$ V.

The associated reduction of the coextracted electron current should be noted. This is the reason for biasing the plasma grid.
Microwave driven Camembert III ion source

In a filamented version of the source, we performed the comparison of *pure hydrogen and * caesiated operations.
Results from JAERI 10 Amp source  

Note that volume H⁻ ions are extracted in a range of 8 V below the plasma potential.

Even in a range of 15 V below the plasma potential in the paper of Okumura et al, AIP CP (1990)
Pure hydrogen and caesiated operation in the filamented version of Camembert III

- In pure hydrogen (with positive extraction voltage) the extracted H-current is maximum when the PG bias voltage $V_b$ is close to plasma potential which is approximately 3.8 V. The H$^-$ current goes down when reducing $V_b$ and is not observed below approximately $V_b=1$V.
- In caesiated operation the plasma potential was lower (0 -2 V ?). An increase of the extracted current was observed for $V_b<2$ V, while the drop of the electron current occurs already at $V_b=0$.
- It is obvious that in Camembert III, as in JAERI 10 Amp source the negative ion current in caesiated operation is enhanced compared to the current found in pure hydrogen operation.
- This enhancement is by a factor 2.5 at plasma potential, in both sources.
- What are the reasons of the negative ion density and current enhancement due to caesium at different values of PG bias?
Experiment in pure Hydrogen and caesiated operation in Camembert III (Ecole Polytechnique)
The typical reduction of the coextracted electron current can be seen here.
Possible explanations of the H⁻ current enhancement due to caesium seeding. I.

*gettering by Cs of atomic hydrogen, which would reduce the H⁻ ion destruction by associative and non-associative detachment.*

In all the bias range

The H⁻ current enhancement due to caesium can take place in all the range of bias voltage due to: 
Possible explanations of the H⁻ current enhancement due to caesium seeding. II.

Case of bias voltage below plasma potential.

DIRECT PRODUCTION ON THE CAESIATED PG SURFACE explains the existence of H⁻ ion current in this bias voltage range.
It is usually ascribed to the production of negative ions on the low work function caesiated surface by hydrogen positive ions and atoms.

Gettering of atomic hydrogen by caesium will have 2 opposite effects:
• Enhance the H⁻ current due to reduced destruction of H⁻ ions by atomic hydrogen (associative and non-associative detachment);
* Reduce the H⁻ current, by reducing the direct production by atoms.
Possible explanations of the $\text{H}^-$ current enhancement due to caesium seeding. III.

*Case of bias voltage above plasma potential. I.*

Volume produced $\text{H}^-$ ions are the only component of the extracted current in the absence of caesium.
Volume $\text{H}^-$ ions continue to be produced in the presence of caesium. However the observed current is enhanced compared to its level in pure $\text{H}_2$.

In this bias voltage range direct production (by positive ions and atoms) is not active, presumably because the negative ions cannot leave the surface.
Possible explanations of the $H^-$ current enhancement due to caesium seeding. III.

*Case of bias voltage above plasma potential. II.*

The purpose of this work is explaining the origin of the $H^-$ current enhancement in the range of bias voltage above plasma potential.

We propose the following two explanations for this enhancement:

* gettering of atomic hydrogen by caesium and
* negative ion current enhancement due to negative ion flow from the bulk plasma. This is supported by the experiments in NIFS (2010).
Pure $H_2$

Volume produced ions

 Cs seeded source

Direct produced $H^-$ ions due to ions and atoms on Cs surface
  *enhanced by gettering reducing $H^-$ destruction
  *reduced by gettering via direct production

$I_{H^-}$

H- ions arrived from the bulk plasma

Volume produced ions eventually enhanced by gettering

Bias voltage (V)

$V_p$ -10  $V_p$ -5  $V_p$  $V_p$ +5  $V_p$ +10
Gettering of atomic hydrogen by caesium

- The effect of gettering is to reduce H- destruction by associative and non-associative detachment by atomic hydrogen. Therefore it can enhance the H- density and extracted current, as suggested by Bacal et al. (Rev. Sci. Instrum., 69, 932 (1998)).
- The reduction of the atomic hydrogen density by gettering by caesium was studied recently by Friedl and Fantz (AIP Conf. Proc. 1515, 255 (2013)).
- These authors found that the density of atomic hydrogen is reduced by a factor 2 by caesium seeding in a plasma produced at a hydrogen pressure of 10 Pa. The change in atomic hydrogen density could be much larger when the hydrogen pressure is as low as 0.3 – 0.5 Pa as in the ion source operation, because the same number of absorbed hydrogen atoms represents a higher fraction of their initial density at the lower pressure of 0.3-0.5 Pa than at 10 Pa.
- Gettering also reduces the H- direct production on the caesiated surfaces. However this affects only the H- ion current observed with the PG bias below the plasma potential.
Evidence for negative ion flow from the background plasma towards the plasma grid. I.

- Experiments performed in NIFS using CRDS showed that extraction has no influence on the negative ion density in the extraction region when the plasma grid bias voltage (5.8V) is higher than the plasma potential.
- But extraction leads to a reduction of this density when the bias voltage (1.8 V) is lower than the plasma potential (K. Tsumori, sCCNB, Takayama, 2010).
Evidence for negative ion flow from the background plasma towards the plasma grid. II.

- The experiment at 5.8 V corresponds to suitable conditions for replenishing the depleted extraction region with negative ions originating from the plasma volume, beyond the extraction region.
Conclusion from experiments in NIFS

This measurement proves that the negative ions forming the H- ion current measured at PG bias higher than the plasma potential originate from the plasma beyond the extraction region, but do not originate from the PG surface.
How are formed the negative ions in the bulk plasma?

- The H\(-\) ions are formed in the bulk plasma beyond the extraction region by volume and surface processes mediated by caesium, in addition to the usual volume production.
- The volume processes we refer to here are:
  * gettering of atomic hydrogen by caesium
  * charge exchange between negative ions and atoms.
Conclusion

The enhancement due to caesium seeding of extracted H- ion current in the plasma grid bias range above the plasma potential is explained by:

- gettering of atomic hydrogen by caesium
- negative ion current enhancement due to negative ion flow from the bulk plasma.