Effect of Cesium Seeding on the Production of H^- Ions in a Magnetized Sheet Plasma Source

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ABSTRACT

The effect of the addition of cesium on the production of negative hydrogen ions (H^-) in a magnetized sheet plasma source (SPNIS) is investigated. Plasma parameters and H^- yields were determined from Langmuir probe and **E** x **B** probe measurements, respectively. Significant increase on H^- yield is observed with the addition of a controlled flux of neutral Cs vapor. The maximum enhancement of 88 times compared with the uncesiated case is extracted at 5 cm away from the sheet plasma core at a discharge current of 0.5 A and initial gas filling pressure of 9 mTorr. The value is increased from 5.51 x 10^{-8} A/m^2 for the uncesiated case to 4.86 x 10^{-6} A/m^2 for the cesiated case. The largest negative hydrogen ion current density extracted is 0.0155 A/m^2 at 2.5 A discharge current, 9 mTorr initial gas filling pressure, and 1 cm probe distance from the plasma center. Here, enhancement is only 9.8 times compared with pure hydrogen discharge. The increase in H^- current density is attributed mainly to the cooling effect of Cs as evidenced by the considerable decrease in electron temperature especially at the periphery of the plasma.

INTRODUCTION

The generation of negative hydrogen ions (H^-) is being pursued due to its wide variety of significant applications. H^- ion sources are crucial components of fusion plasma devices and particle accelerators, as well as of other plasma machines. Numerous particle accelerators such as cyclotrons, synchrotrons, tandem accelerators, and proton storage rings require H^- or D^- ions extracted directly from negative ion sources (Leung, 1991; Dudnikov, 2002). H^- ion sources are also used in diagnostics for fusion plasmas and semiconductor-etching-process plasmas, high-energy neutral beam heating, and medical applications (Belchenko & Grogoryev, 2002).

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One of the most important aspects of any ion source is its H^- output. Cesium (Cs) vapor has been injected into various H^- ion sources since the discovery of cesiation of surfaces at INP by Dudnikov in 1971, resulting in dramatic increases of attainable H^- currents (Peters, 1998). Extracted negative ion currents rose by as much as 370 times after cesium was added in certain surface production sources (Dudnikov, 2001).

Various mechanisms to explain the enhancement of H^- production by Cs seeding have been proposed such as the decrease of the work function of the converter or plasma electrode surface due to cesium adsorption (Okuyama & Mori, 1989; Bacal et al., 1998); reduction of electron temperature due to more collisions with the larger Cs cross section; gettering or absorption of atomic hydrogen by cesium, resulting in reduction of H density; and formation of CsH (Fukumasa, 1994), among others.

In general there are three distinct types of H^- ion sources classified by how the ions are produced: surface production sources, volume production sources, and hybrid (surface + volume) production sources (Sanchez & Ramos, 1996). The magnetized sheet plasma negative ion source (Abate & Ramos, 2000; Arciaga et al., 2003) is of the volume type. This is related to the geometry of the ion source. The vibrationally excited hydrogen molecules are produced at the sheet plasma core due to collisions with energetic electrons, then drift to the periphery and combine with cold plasma electrons via dissociative attachment to form H^-. The presence of an anode at one end of the extraction chamber instead of a converter electrode lessens, if not actually hinders, the surface production process. Consequently, positive ions are repelled and thus, obstruct its conversion to negative hydrogen ions by collision with the anode surface. Moreover, the magnetic confinement of the source keeps the positive ions within the center of the sheet plasma. Hence, conversion of positive hydrogen ions to H^- due to collisions with the Cs-covered chamber wall is unlikely to occur. H^- being short-lived means that the production probability via collisions of neutral particles with the chamber wall is small and the probability of destruction as they enter the bulk plasma is great. Specifically, the effect of Cs on H^- production in this source is investigated for the first time. Different system parameters are investigated to determine the efficiency of Cs in enhancing H^- density.

METHODOLOGY

The magnetized sheet plasma ion source has been described previously (Abate & Ramos, 2000; Arciaga et al., 2003). A schematic diagram of apparatus and photo are shown in Fig. 1.

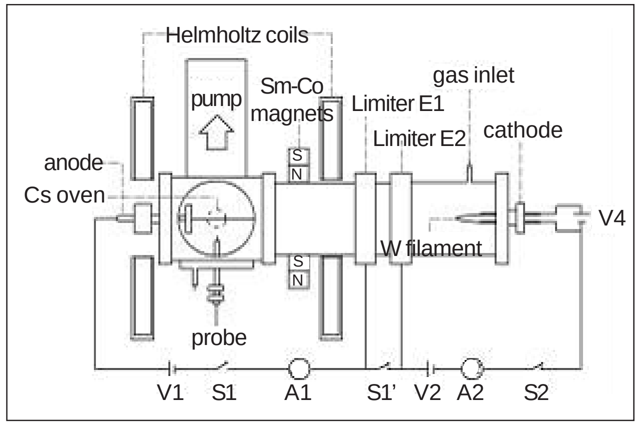

Fig. 1. Schematic diagram of the SPNIS.

The plasma is generated inside the production chamber by thermionic emission of a single 0.5-mm-diameter, 13.0-cm-long hairpin-shaped tungsten wire using a 150 V dc, 150 A power supply (V4 in Fig. 1). The filament potential ranged from 14 to 18V at a corresponding current range of 20–23 A. The tungsten filament is negatively biased with respect to the second intermediate electrode (limiter E2 in Fig. 1). Electrons and negative ions are accelerated into the extraction chamber by the secondary power supply V2 rated at 100 V dc and several amperes. V2 supplies the potential (between 60–70 V) at the production chamber at a current range of 3–4 A. The potential between the extraction chamber (from the limiter E1 to the anode) is supplied by the source V1 between 125 and 150 V, giving rise to a current in the extraction chamber ranging from 0.5 to 1.5 A. A switching sequence from S2 to S1 completes the circuit from the cathode to the anode. The conversion of the cylindrical plasma that is formed in the extraction chamber to a sheet plasma is done by using a pair of strong dipole magnets (~1.5 kG on the surface) with opposing fields and a pair of Helmholtz coils producing a magnetic mirror field. This technique was successfully demonstrated by Abate and Ramos (2000). The sheet plasma form includes fast electrons within the core plasma (of several millimeters) accompanied by cold diffused plasma electrons at the periphery. Negative hydrogen ion current can then be extracted from the sheet plasma configuration using the **E**x**B** probe (Arciaga et al., 2003).

Plasma parameters and H^- yields are determined from Langmuir probe and **E**x**B** probe measurements at pressures of 5, 7, and 9 mTorr and at discharge currents of 0.5–2.5 A at 0.5 A increment for both the uncesiated and cesiated cases.

RESULTS AND DISCUSSION

Emission spectra

The presence of Cs in the hydrogen plasma is detected by an emission spectrometer. A typical spectroscopic

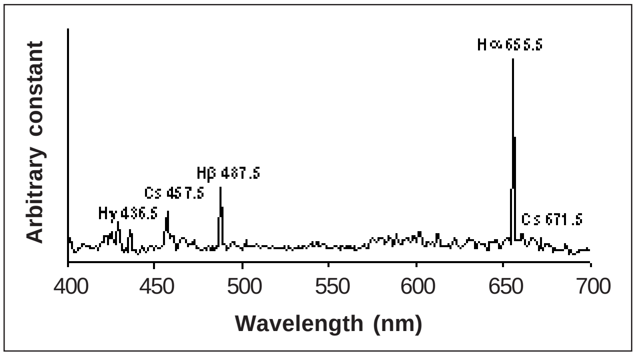

Fig. 2. Spectroscopic scan of Cs-seeded plasma.

scan of the cesiated hydrogen plasma is shown in Fig. 2. The Balmer emission lines and the peaks associated with cesium are seen.

Plasma parameters

A single Langmuir probe of tungsten wire with an exposed tip of 0.5 mm diameter and 5 mm long determines the electron density and electron temperature of the source.

Shown in Fig. 3 is the distribution of electron temperature T_e as a function of probe distance from the sheet plasma center at different initial gas filling pressures for 2.5 A discharge currents. Plots in solid lines show the trend for the pure plasma, while that of the broken lines are for the cesiated H_2 discharge. For the magnetized sheet plasma, T_e generally decreases from the sheet core to the periphery, that is, energetic electrons are present in the center and low-energy electrons are seen at the margins of the sheet plasma. High-energy electrons are responsible for raising the hydrogen molecules to highly rovibrationally excited states. On the other hand, the cold electrons at the periphery are necessary for the formation of negative hydrogen ions by dissociative attachment with the highly rovibrationally excited molecules.

A comparison of the results in the cesiated and pure hydrogen plasma for all gas pressures and distances clearly indicates a general decrease in T_e for the cesiated case, although overlapping of values can still be seen especially for the 9 mTorr, 2.5 A plasma conditions. As much as 40% decrease in T_e is observed for the conditions of 2.5 A discharge current, 7 mTorr hydrogen pressure, and 4 cm probe distance from the

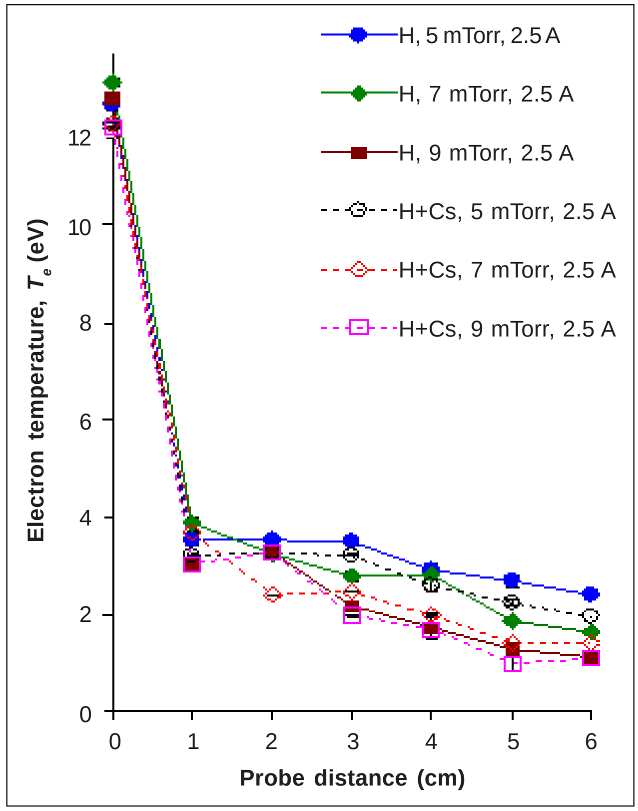

Fig. 3. Spatial distribution of electron temperature at various pressures and discharge current of 2.5 A.

plasma center. This lowering of the electron temperature is important since low-energy electrons play an important role in H^- formation through the dissociative attachment process. Furthermore, higher electron temperatures tend to reduce H^- production because more energetic electrons mean more electron impact processes that neutralize the already produced negative hydrogen ions.

The observed reduction in electron temperature is attributed to the much larger cross sections of excitation and ionization of Cs by electron impact; hence, there are more inelastic excitation and ionization collisions of electrons with the presence of Cs than with hydrogen alone (Bacal et al., 2003).

Figure 3 also shows the behavior of electron temperature as a function of input gas pressure. The increase in pressure causes a corresponding decrease in T_e especially at the periphery. This trend is observed in both the uncesiated and cesiated hydrogen plasmas. The reduction of the effective mean free path between

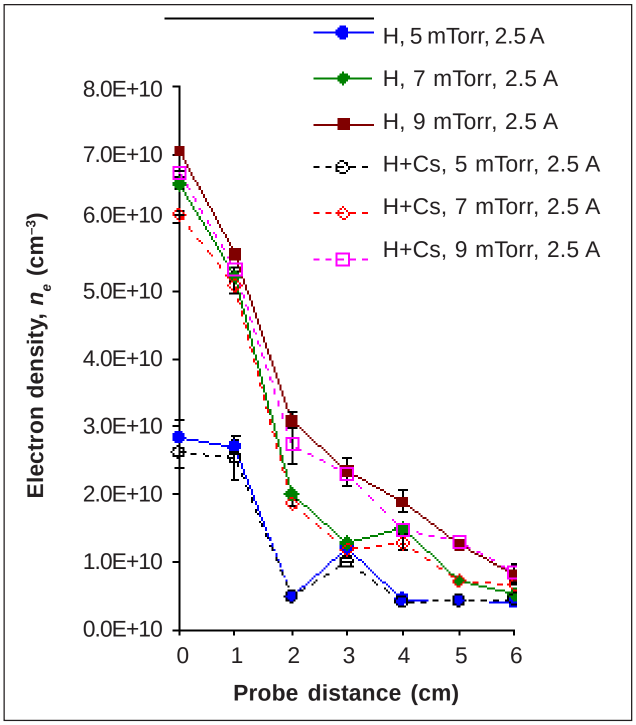

Fig. 4. Spatial distribution of electron density at various pressures and discharge current of 2.5 A.

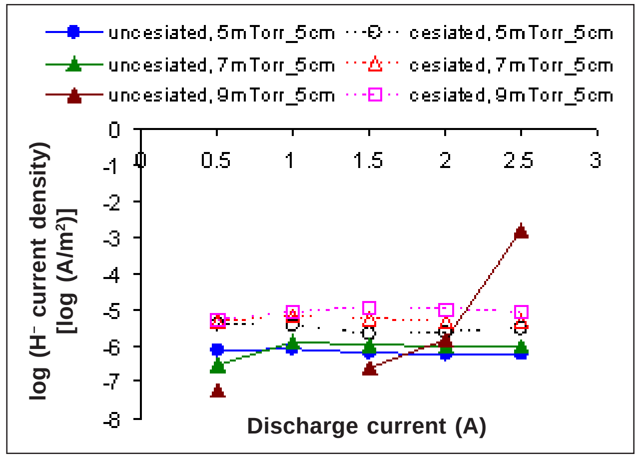

Fig. 5. Dependence of H$^-$ production with discharge current for varying gas pressures at 5 cm away from the core plasma.

particles within the bulk of the plasma is likely to be the cause of the decreasing trend of T_e for higher pressures. The mean free path is smaller on account of higher densities, and the frequent collisions contribute to the continuous loss of initial energies of the electrons. The spatial variation of electron density n_e at various gas pressures is illustrated in Fig. 4. The graphs in solid lines are for uncesiated hydrogen discharge, while those of the dotted lines are for the cesiated hydrogen plasma.

The same spatial distribution as the electron temperature is seen in this plot. Electron density generally decreases with probe distance from the sheet of the plasma. This condition arises from the source's geometry, limiting the high-density energetic electrons at the center in order to minimize the interaction of "hot" electrons with the formed H$^-$. Few low-energy electrons drift towards the periphery.

The addition of Cs has not much effect on the electron density. There is no detected decrease in n_e contrary to what others have observed.

H$^-$ enhancement with the addition of Cs vapor to pure H_2 plasma

The effect of the addition of Cs on the production of H$^-$ is shown in Fig. 5. Upon addition of Cs on the H_2 discharge, a significant increase on H$^-$ yield is observed. The maximum enhancement of 88 times occurred at 5 cm away from the central plasma with discharge current of 0.5 A and initial gas filling pressure of 9 mTorr. The value is increased from 5.51 x 10^{-8} to 4.86 x 10^{-6} A/m^2. However, the largest H$^-$ yield is achieved at 1 cm relative to the plasma core, with 2.5 A discharge current and 9 mTorr initial gas filling pressure. Here, enhancement is only 9.8 times compared with pure hydrogen discharge. The value obtained is 0.0155 A/m^2 from 0.00156 A/m^2. This increase in the negative ion current density with the addition of Cs is closely related to the drop of electron temperature at the periphery of the sheet plasma as presented in the section on Plasma parameters.

CONCLUSIONS

The effect of the addition of Cs vapor on the H$^-$ production in a volume production source was investigated. The H$^-$ current density was compared for the pure and cesiated hydrogen plasmas. A maximum increase of 88 times corresponding to H$^-$ current density of 4.86×10^{-6} A/m^2 is achieved at 5 cm away from the central plasma with discharge current of 0.5 A and initial gas filling pressure of 9 mTorr. The increase in H^- current density is attributed mainly to the cooling effect of Cs as evidenced by the considerable decrease in electron temperature especially at the periphery of the plasma. However, the highest H^- yield of 0.0155 A/m^2 is obtained at 1 cm relative to the sheet plasma core, with 2.5 A discharge current and 9 mTorr initial gas filling pressure. Here, enhancement is only 9.8 times compared with pure hydrogen discharge.

REFERENCES

Abate, Y. & H.J. Ramos, 2000. *Rev. Sci. Instrum*. **71**: 3689.

Arciaga, M.E., A.G. Mendenilla, & H.J. Ramos, 2003. *Rev. Sci. Instrum*. **74**: 951.

Bacal, M., F. El Balghitin-Sube, L. I. Elizarov, & A. Y. Tontegode, 1998. *Rev. Sci. Instrum*. **69**: 932.

Bacal, M., et al., 2003. *Rev. Sci. Instrum*. **74**: 951.

Belchenko, Yu. I. & E. V. Grogoryev, 2002. *Rev. Sci. Instrum*. **73**: 939.

Dudnikov, V., 2001. 30 years of high intensity negative ion sources for accelerators. *Proceedings of the 2001 Particle Accelerator Conference*. 2087.

Dudnikov, V., 2002. *Rev. Sci. Instrum*. **73**: 992.

Fukumasa, O., T. Tanebe, & H. Nation, 1994. *Rev. Sci. Instrum*. **65**: 1213.

Leung, K.N., 1991. *PAC*. 2076.

Okuyama, T. & Y. Mori, 1989. Research report IPPJ-914. Nagoya, Japan.

Peters, J., 1998. Review of negative hydrogen ion sources: High brightness/high current. *Proceedings of LINAC '98*. 1031.

Sanchez, J.K.C.D. & H.J. Ramos, 1996. *Plasma Sources Sci. Technol*. **5**: 416.