Density Measurements of Negative Hydrogen Ions Using Mass Spectrometer

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INTRODUCTION

Measurement of negative ion density in a source plasma is necessary for optimizing the extraction of negative ion current. Bacal and co-workers proposed a method to measure the negative ion density by detaching the electron current due to the photodetachment of negative ions using a pulse laser (Bacal et al., 1979). This paper describes a method to determine the negative ion density in a plasma by a coupled mass analysis and Langmuir probe diagnosis of the plasma. The H^- ion density was estimated from the relation equating the ratio of the negative ion and electron currents to the ratio of the ion and electron densities; $I_- / I_e = n_- / n_e$. The proposed estimates consider the collection factor of n_- / n_e.

EXPERIMENT

The magnetized sheet plasma ion source has been described previously (Sanchez & Ramos, 1996). A schematic diagram of apparatus is shown in Fig. 1. The pump side is connected to the extraction chamber by a steel cylinder, which fits a compact mass analyzer 7.0-cm wide, 5.3-cm deep and 5.18 cm high. The magnetic field of the mass analyzer as function of the input current obeys Ampere's law. Opposite the pump side are ports for a single cylindrical Langmuir probe (to obtain plasma parameters) and ionization gauge. The positions of the probe and mass analyzer are indicated in Fig. 1. Automatic data acquisition routines store the probe and mass spectrometer signals. Subsequent data processing and analysis were done by computer.

Evacuation of the chamber was done with a 500-l/m back up rotary pump coupled to a 10.16 cm oil diffusion pump. Pressures were monitored by ionization and Pirani

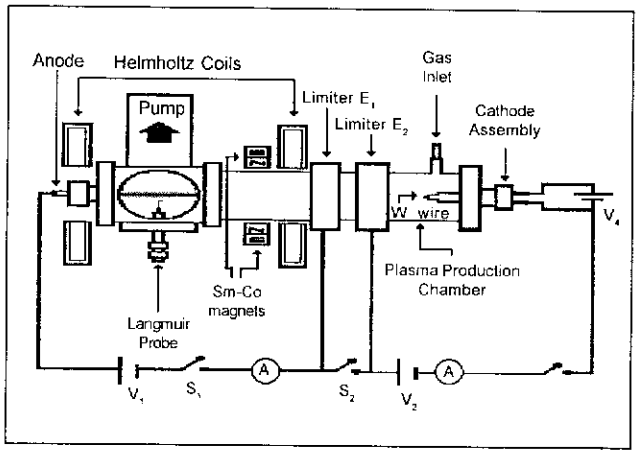

Fig. 1. Schematic diagram of the ion source

gauges. Base pressure was usually of the order of 1.0×10^{-6} Torr. Quoted gas pressures in this work refer to pressures in the extraction chamber. The pressure reading for hydrogen was corrected for the gas sensitivity factor of the vacuum sensors, while argon was not. The sensitivity factor for argon is about 1.3.

RESULTS AND DISCUSSION

A single Langmuir probe of tungsten wire with an exposed tip of 1.0-mm diameter and 2.0-mm long determined the electron density and plasma temperature. The probe is moved in the direction perpendicular to the plane of the sheet plasma. It is aligned along the center of the aperture of the mass analyzer electrode. The increase in gas pressure doubled the electron temperature at the center of the sheet plasma. A similar trend was observed for the electron density. In both cases of different gas filling pressures, the bulk electron temperatures at the center of the sheet were higher by about 6 times compared

to the peripheral region. These higher energy electrons were responsible in raising molecular hydrogen to highly vibrationally excited states. The electron density tailed off immediately at 2 cm from the center of the sheet plasma and hardly changed much thereafter for the case of the 3 mTorr initial gas filling pressure. While for the case of the 4.5 mTorr initial gas filling pressure, the electron density did not vary much from 4 cm onwards relative to the center of the sheet plasma. It is in these peripheral regions where most of the hydrogen negative ions are likely to be formed by dissociative attachment of the vibrationally excited hydrogen molecules with lower energy electrons. The probe trace shown in Fig. 2 and Table 1 gives the values of the electron density and temperature for pure hydrogen gas filling pressure of 4.5 mTorr, extraction plasma current of 1.5A, and filament current of 21A, at a distance of 8.0 cm from the sheet plasma center.

The extracted H^- current is optimum when the plasma electrode lies between 7-8 cm from the center of the sheet plasma, that is, in the peripheral region (Abate & Ramos, 2000). This relates to the probe measurements of electron density and temperature. The high temperature electrons at the center of the sheet plasma excite the hydrogen molecules to vibrational states. The presence of cold electrons from 2 cm onwards relative to the center of the sheet plasma means that ions are likely to form in these regions by dissociative attachment with vibrationally excited hydrogen molecules. The positive plasma potential at the periphery obtained from the probe measurements makes confinement of electrons and ions within the plasma. This would lead to high ion currents extracted on the mass analyzer at the periphery (Abate & Ramos, 2000). The maximum value of extracted H^- current corresponds to the case when the bias potential of the extraction electrode was slightly less than the value of the plasma floating potential. This is inherent in the focusing character of the mass analyzer to optimize the extracted H^- output as described previously (Sanchez & Ramos, 1996). The difference in the potential between the bias to the plasma electrode and the plasma potential in the peripheral region contributes to the probability of extracting more H^- in the peripheral region.

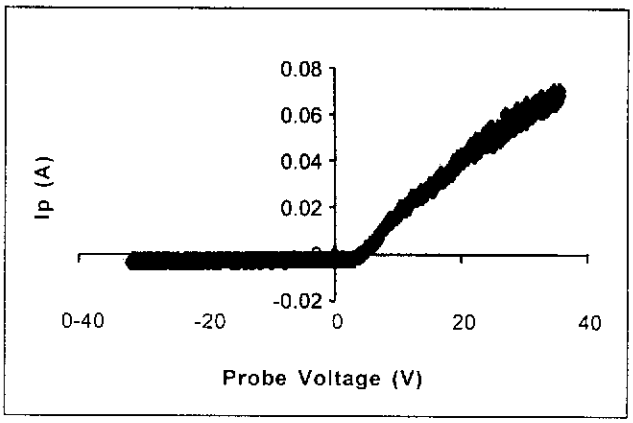

Fig. 2. Langmuir probe trace (8 cm from the center of the sheet plasma)

Table 1. Plasma parameters deduced from Fig. 2

Te (eV)	Ies (A)	Vs(V)	ne (cmE-3)
1.05	0.008	5.94	1.64E+11
1.67	0.012	6.95	1.96E+11
0.98	0.006	5.49	1.28E+11

By taking the ratio of the currents of the extracted H-ions and the extracted electrons as measured by the spectrometer and equating the ratio of the ion density to electron density using the Langmuir probe, value obtained equidistant to the plasma electrode enables one to determine the H-ion density near the aperture opening of the extraction electrode in the extraction region. The collected data are the peaks shown in Fig. 3. The ratio of the ion current to the electron current was found by integrating the area under the curves shown in Fig. 3 for equal DB intervals. This gives a value equal to 0.288, that is, $I_-/I_e = 0.288$. If the collection

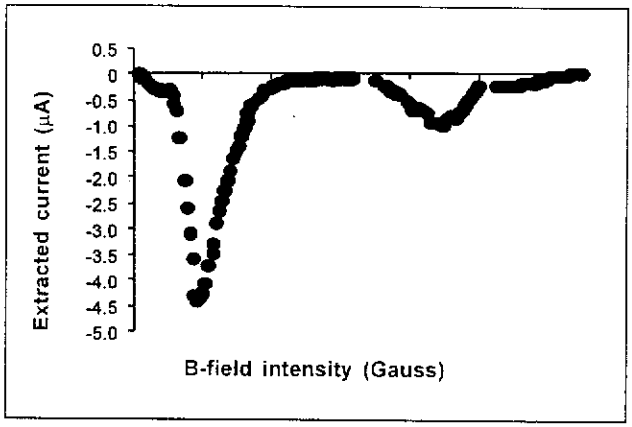

Fig. 3. The mass analyzer signal of the extracted electron and H- ion currents as a function of the mass analyzer magnetic field

factor of n_-/n_e is not considered, the ratio of the ion current to the electron current gives, $I_-/I_e = 0.22$. Which introduces about 23.6 % error on the result. The H^- density was estimated from the relation equating the ratio of the negative ion and electron currents to the ratio of the ion and electron densities: $I_-/I_e = n_-/n_e$ (Abate & Ramos, 2000). The result of the calculation of the negative ion density gives a value equal to $n_- = 0.47 \times 10^{11}$ cm^{-3}. The results considered were not optimized.

CONCLUSION

The density of the ions was estimated using the ratio of the ion to electron currents detected in the mass spectrometer and multiplying it by the electron value in the plasma periphery using the result obtained by the Langmuir probe method. The obtained negative ion density is comparable to the electron density near the extraction electrode with a relatively high $n_-/n_e = 0.288$. It is necessary to take the collection factor into account for a better estimation using this method. The method is used as an alternative to more expensive laser systems in determining the density of negative ions.

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