

# Optimized Extraction of $H^-$ by Three-Electrode Faraday Cup System in Magnetized Sheet Plasma Ion Source

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## ABSTRACT

A locally designed rectangular parallelepiped, three-electrode Faraday cup system has been developed. Its design incorporates the capability of simultaneous extraction and deposition of the  $H^-$  ions on substrates. The device functions to attain prescribed selectivity conditions of extracted ions, with controlled energies, for deposition or adsorption. It has been proven to detect the ions at filter bias voltage of 13.61 V with a current density of 5.3 A/m<sup>2</sup> that is relatively higher than reported (Abate & Ramos, 2000).

## INTRODUCTION

Up to now, there is still a question as to how the deposited hydrogen can be responsible for the changes that it causes on some substrates or films. There are still some lapses in the detailed explanation on why estimated range of values of hydrogen densities deposited in the crystal can lead to the modification of the structure from amorphous to polycrystalline (Abelson, 1993), to trivalent rare-earth elements forming hydrides, especially Yttrium and Lanthanum hydrides, and can even cause the element to exhibit metal-semiconductor transitions (Vajda, 1995). The continuous absorption of hydrogen also caused some optical changes in the grown films from shiny mirror to a yellow, transparent window (Huiberts et al., 1996). On other elements, it has been known that the effect of the addition of hydrogen during the processing on the plasma properties and the growing film serve to dramatically improve the electrical and electronic

properties of the deposited film of amorphous and crystalline silicon (Abelson, 1993). Silicon hydrides ( $SiH_x$ ) have been studied carefully as they continue to be prominent materials in microelectronic device manufacturing. They are suited to numerous applications, including photovoltaics and thin film transistors (TFTs) (Srinivasan et al., 1997).

The most common method of preparation of hydrogenated silicon ( $a-Si:H$ ) and polycrystalline silicon films is done by the Plasma Enhanced Chemical Vapor Deposition (PECVD) from discharges composed of  $SiH_4$  or mixtures of  $SiH_4$  diluted in Argon and/or  $H_2$  (Marra et al., 1998).

In this study, ion deposition is employed. Unlike most of the various researches illustrating ion-surface interaction that utilized positive ions, negative hydrogen ions shall instead be used in this study. The  $H^-$  ions (hydrides) will be deposited on the silicon substrate to form the silicon hydrides by ion-surface interaction phenomenon (Williams & Poate, 1984). The objective of this work is to explore the feasibility of a

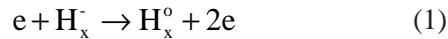
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locally designed device for the extraction of the ions to be deposited. The H<sup>-</sup> ions are extracted, accelerated, and transported from pre-mixed 10% Ar/H<sub>2</sub> sheet plasma and are deposited into a silicon substrate. In this paper, we show some initial data of the extraction, acceleration, and transport towards a detector that will subsequently be replaced with a Si substrate. The transport is done using a developed multi-electrode Faraday cup system.

## THEORY

It is necessary to suppress electrons that are extracted with the anions because collisions are inevitable. The H<sup>-</sup> ion-electron collision can lead to the destruction of H<sup>-</sup> ions, which are commonly called “electronic collisional impact detachment”. The incident electron deionizes a hydride by the emission of the orbital electron. This process is briefly expressed by the reaction



To minimize this, the plasma electrode bias potential is set at a value slightly greater than the floating potential at a point from the sheet plasma. The floating potential at a certain point from the sheet plasma is determined by the Langmuir probe measurements as shown in Fig. 3. It is at that value of the bias potential of the probe tip in which net current is zero. Hence, adjustments must be made to increase the plasma electrode bias potential to a value slightly greater than the floating potential of the probe tip until a low current arises, implying an attraction of anions and electrons. A plasma electrode bias potential is chosen to produce a relatively high detected current. The position of the plasma electrode from the sheet plasma is chosen with the significantly reduced electron density. The reduction of electron density with the increase in the distance between the probe tip and the core sheet plasma is determined and shown in Fig. 4. In the event the ions are extracted through the plasma electrode apertures into the first region bounded by the plasma electrode and the extraction electrode, they appreciably interact with each other by Coulombic repulsion. This repulsion causes the monodirectionally-drifted ions to diverge while moving along the path towards the

detector. Hence, they spread radially. For weak electric field intensity, this radial component of the ionic velocities obviously can strongly reduce the ion flux. To avoid this radial ionic spreading, the electric field between electrodes to the diffusion distance ratio,  $E/l$ , needs to be of such value as to offset the space charge effect. This criterion can be taken impliedly from the Poisson's equation,

$$\nabla^2 V = -4\pi\rho \quad (2)$$

In terms of electric field  $E$ , the above equation can be written as

$$\nabla gE = 4\pi ne \quad (3)$$

where the following replacements

$$\begin{aligned} \rho &= ne; \text{ ion charge density} \\ n &= \text{density of the H}^- \text{ ion} \\ e &= \text{charge of the H}^- \text{ ion} \end{aligned}$$

are used. The criterion can be expressed simply as follows:

$$n = \frac{E_0}{4\pi el} \quad (4)$$

The ion density within the working distance  $l$  can be determined. In fact it has been reported (Sanchez & Ramos, 1994) that an H<sup>-</sup> ion density  $n$  was found in the chamber used here at an optimum condition of approximately  $1.24 \times 10^{10} \text{ cm}^{-3}$ . This low ion density would guarantee a space-charge effect-free transport of extracted ions across the electrodes. Ion transport across the electrodes in the device is therefore possible.

## EXPERIMENTAL METHOD

The magnetized sheet plasma negative ion source (SPNIS) is the facility used here. The schematic diagram of this machine is shown in Fig. 1. Langmuir probe measurements are done to determine the corresponding values of the floating potentials at various transverse distances of the probe tip from the sheet plasma. At the same time, the measurement provides information on how electron density varies

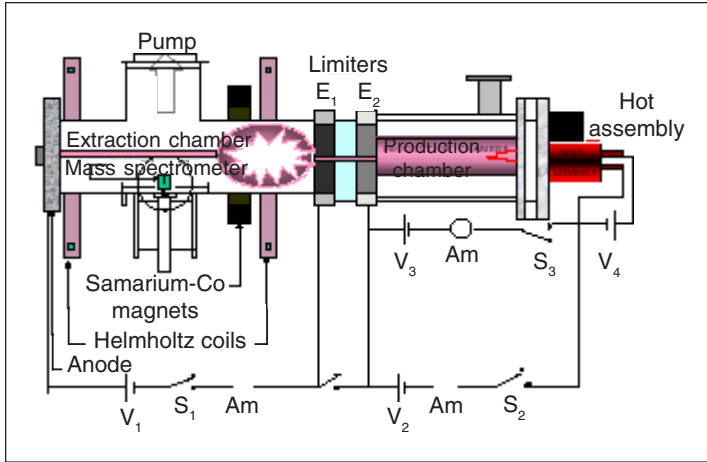


Fig. 1. The schematic diagram for the magnetized sheet plasma negative ion source facility. The device (Fig. 2) installed in the extraction chamber is drawn (encircled).

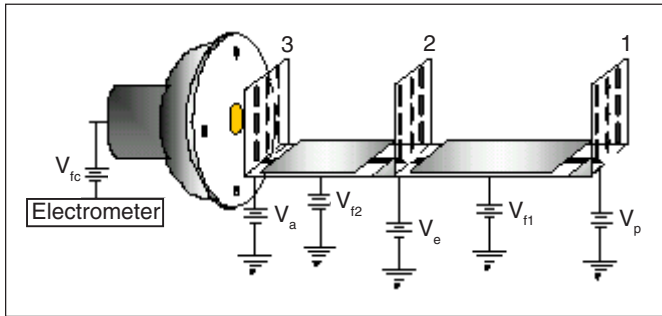


Fig. 2. The three-electrode Faraday cup system. Shown here is the (1) plasma electrode with an array of nine circular apertures, (2) extraction electrode, and (3) acceleration electrode.

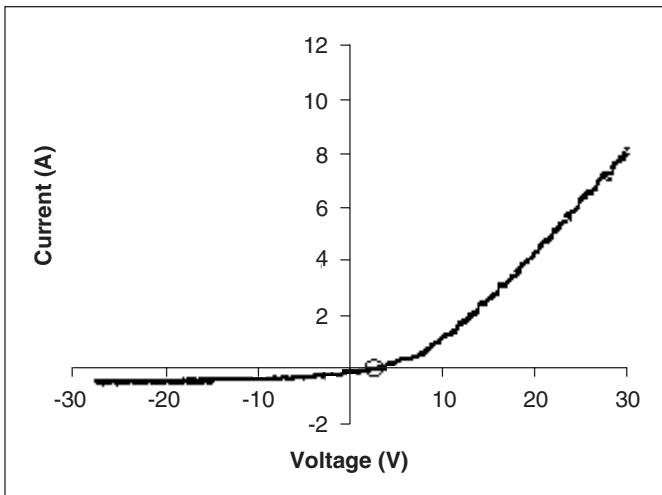


Fig. 3. The characteristic I-V curve of the 10% Ar/H<sub>2</sub> sheet plasma showing the floating potential (encircled). The value is found to be 2.71 V.

with these distances. The results of this measurement serve to set values from which the plasma electrode parameters are based. The device is installed in such a manner that the magnetic fields of the Helmholtz coils of the facility are perpendicular to electric fields between the electrodes of the device while the flat surface of the plasma electrode is parallel to the surface of the sheet plasma. The bias potentials of the electrodes as well as their separation have been adjusted to meet the criterion set by Eq. (4). To offset the magnetic force on an extracted ion by the Helmholtz coils, a pair of parallel conducting plates, one with varying bias potentials while the other fixed on the ground, are installed. The pair of plates spans the separation of the electrodes so as to have the electric field of the plates cause the offset. With the device properly installed, the plasma electrode fixed at the predetermined bias potential and positioned relative to the core's sheet plasma in the extraction chamber, the extraction experiment is conducted at a relatively low gas-filling pressure and discharge current. The H<sup>-</sup> ions are detected using the Faraday cup as the detector that is attached to the computer.

## RESULTS AND DISCUSSION

The ignition produces the plasma at a discharge current of 0.5 A, with a gas-filling pressure of 0.005 Torr. The Langmuir probe measurements are conducted primarily to determine corresponding values, the floating potential at various positions of the probe, and more importantly, to determine the electron density at every chosen position. With the probe positioned at 3 cm from the sheet plasma, an I-V characteristic curve with a floating potential value of 2.71 V is produced. This floating potential value then serves as the basis for the plasma electrode bias potential. The choice of the position relative to the sheet plasma and the bias potential of the plasma electrode are decided from the graph, as shown in Figs. 3 and 4.

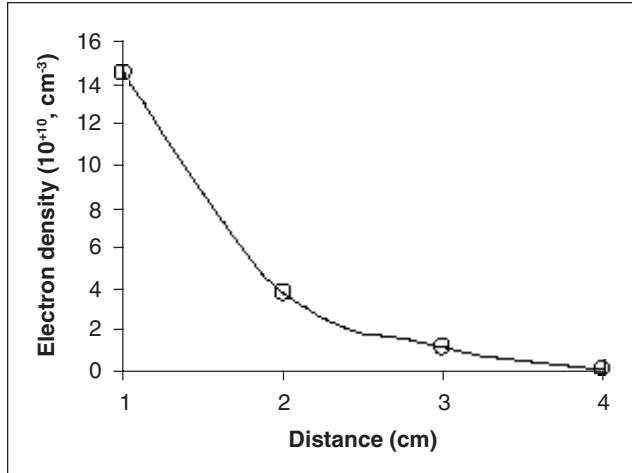


Fig. 4. Using the characteristic curve (Fig.1), the variation between the electron density and the position of the probe relative to the sheet plasma can be derived. The result of the derivation is illustrated.

The plasma electrode is fixed at a bias potential value of ~3.1 V, where a high detected current is produced while the extraction electrode, which is the next electrode (Fig. 2), is biased at 57 V. Similar to the plasma electrode, the extraction electrode has a rectangular array of 3 x 3 apertures, each with a diameter of 1.5 mm. Just 1 mm behind the aperture on the center of the electrode is the 9-mm disk Faraday cup, the detector, which is also biased using a 68-V battery. The bias potential of one of the plates that are 1.49 cm apart, is scanned from -30 to 30 V. With the device attached to the computer, automatic data acquisition routines store the ionic signals. A peak is detected at deflecting plate voltage of 13.61 V. This would mean that the magnetic force causing the ions to deflect away from the detector is offsetted by the electric force  $Ee$ , corresponding to this voltage, of the fields between the plates,

$$Ee = evB \quad (5)$$

The potential difference (57 V – 3.1 V) across the plasma and the extraction electrodes provides the energy for the ion transport, and is calculated at 53.9 V while the separation of the electrodes is set at 3.0 cm:

$$\frac{1}{2}mv^2 = e(53.9 \text{ volts}) \quad (6)$$

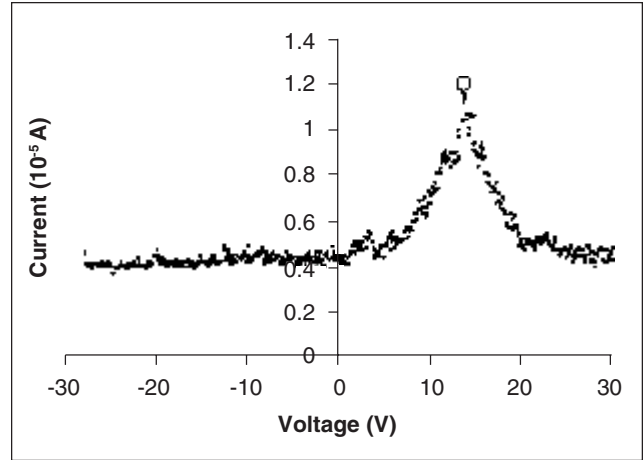


Fig. 5. The value of the deflecting plates' voltage offsets the effect of the Helmholtz magnetic field on the extracted H<sup>-</sup> ions. The coordinates of the peak are (13.61 volts, 11.97 μA).

Using the values of the potential difference across the plasma and extraction electrodes, and the distance between them, Eq. (4) is clearly satisfied with the right-hand side of the inequality estimated at ~1020 cm<sup>-3</sup>.

Hence, we have the peak shown in Fig. 5, indicating an unobstructed extracted ion transport. Equating Eq. (5) and Eq. (6), an expression for the mass of the ion can be derived. With the measured  $B = 57.6$  gauss of the Helmholtz coils,

$$m = 1.16 \times 10^{-27} \text{ kg.}$$

The error is attributed to instrumental error of the Langmuir probe measurements known to be about 30%. The current density is easily calculated as follows,

$$J = \frac{I}{A} = \frac{11.97 \mu\text{A}}{(1.5 \text{ mm})^2} = 5.3 \text{ A/m}^2 \quad (7)$$

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