Cesium Catalysis Effect of H⁻ Ion Production in the Volume Production Type of H⁻ Ion Source

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Abstract

It is suggested that cesium catalysis effect of H^- ion production in a volume production type of H^- ion source is caused by the surface H^- ion production process at a cesium covered plasma electrode. In order to examine this process in detail, we have measured the H^- ion production probability by scattering of thermal hydrogen atoms and low energy positive hydrogen ions from the cesium covered molybdenum surface. The measured H^- ion production probability showed almost good agreement with the quantum mechanical calculation. It was estimated that the dominant process to enhance the H^- ion beam was the surface H^- ion production by scattering hydrogen atoms at a plasma anode.

Introduction

A volume production type of H^- ion source has been developed at KEK. In this source, H^- ion beam of 20mA was extracted by injecting a small amount of cesium vapor in the source chamber. The extracted H^- ion beam current was increased by more than four times compared with the ion beam current before injecting cesium vapor and this effect was related strongly to the decrease of the work function of the plasma electrode surface covered by cesium atoms.[1] The cesium consumption rate was very small compare with the surface type of H^- ion source which is usually used for high energy accelerators. Therefore, the volume production type of H^- ion source is effective to eliminate sparkings in the extraction region during a long period of operation.

It is very conceivable that this cesium catalysis effect is caused by the surface H^- ion production process at the cesium covered plasma electrode. In this process, thermal hydrogen atoms and/or low energy hydrogen ions (H^+,H_2^+ and H_3^+) accelerated by plasma potential may become negative hydrogen ions by taking tunneling electrons from the cesium covered plasma electrode surface.

In order to understand the fundamental process of the cesium catalysis effect in the volume ion source in detail, we have measured the H^- ion production probabilities by scattering of thermal hydrogen atoms (H^0) and low energy (~1eV) positive hydrogen ions (H^+,H_2^+ and H_3^+) at the cesium covered molybdenum target. The results were compared with the quantum mechanical calculation developed by Blandin et al.[2]

Measurement of negative hydrogen ion production by scattering of thermal hydrogen atoms

Figure.1 shows a schematic layout of the experimental setup for the measurement of H^- ion production probability by scattering of thermal hydrogen atoms. Hydrogen atoms were generated by an rf dissociator and injected to the cesium covered molybdenum target through a slit. We measured the scattering H^- ions which were produced at the cesium covered molybdenum target. The H^- ions were detected by a Faraday cup and/or a microchannel plate(MCP) after mass-analyzed by a Wien filter. The workfunction of the cesium covered atoms was monitored by a photoelectric current produced by Ar ion laser beam.[1],[3]

If we assume that the H^- ions are isotropically backscattered from the target at this low energy range, the H^- ion production probability β_0 can be estimated by the following equation.

$$\beta_0 = \frac{N_{H^-}}{\Omega\, N_H} \qquad (1)$$

where N_{H^-} is the number of the H^- ions measured with the Faraday cup, N_H is the number of the hydrogen atoms hit on the molybdenum target and Ω is the acceptance of the H^- ion current measurement system. In this system, Ω was 5.3×10^{-3}.

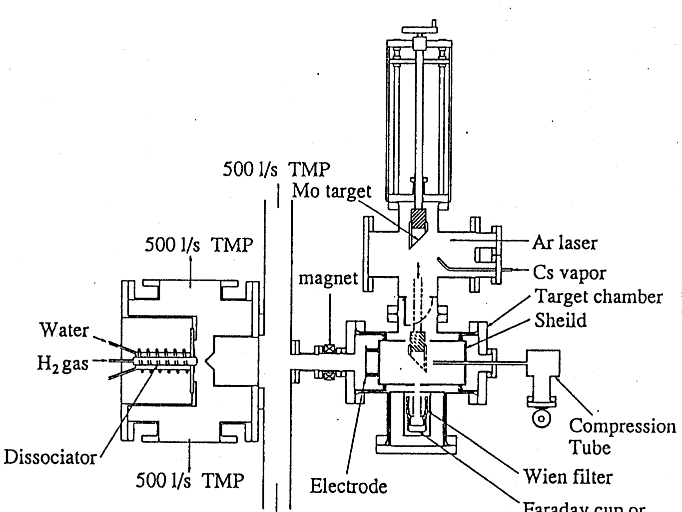

Fig.1 Schematic layout of experimental setup for the measurement of H^- ion production probability by scattering of thermal hydrogen atoms

Before the target was covered by cesium atoms, no H^- ion current was observed. When the work function was decreased by cesium coating on the surface, the H^- ion current which corresponded to $N_{H^-} \sim 1 \times 10^9$ ions/s was measured. The workfunction was estimated to be ~2.1eV. The flux density of the atomic hydrogen beam hit on the molybdenum target was measured with a compression tube method. The flux density of the atomic hydrogen beam was 1.2×10^{14}atoms/cm^2 s and the number of the atomic hydrogen which hit the target was $N_H \sim 7.7 \times 10^{14}$atoms/s. Therefore, the H^- ion production probability by scattering of thermal hydrogen atoms in this measurement was $\beta_0 = 2.5 \times 10^{-4}$.

Figure 2 shows H^- ion yields detected by the MCP as a function of the photoemission electron current. The H^- ion yields in the figure are normalized by the ion yield obtained when the photo-emission electron current was 0.55μA which corresponded to the workfunction of 2.1eV. Figure 3 shows H- ion yields measured by MCP as a function of the atomic hydrogen temperature. The atomic hydrogen beam was heated by a tantalum tube which was placed at the exit of the dissociator. The H^- ion yields in the figure are normalized by the ion yield obtained when a tantalum tube is not heated up. As shown in figure, when the tantalum tube temperature increases above 1250K, the H^- ion yield becomes linearly increased. This shows that the atomic hydrogen beam temperature is already about 1250K by plasma heating in the dissociator before the tantalum tube is heated up.

The theoretical H^- ion production probability by scattering of hydrogen atom from the cesium covered metal surface is estimated by quantum mechanical calculation proposed by Blandin et al. In the low energy region, H^- ion production probability is given by the following equation.[2]

$$\beta \approx \frac{2}{\pi} \exp\left(\frac{-\pi\,(\phi - A)}{\alpha\, v}\right) \qquad (2)$$

where ϕ is the work function, A is the electron affinity, v is the scattered atomic hydrogen velocity normal to the surface and α is a constant. When the workfunction is 2.1eV and hydrogen temperature is 1250K, the calculated H^- ion production probability becomes 3.9×10^{-4}. This shows almost good agreement with the experimental value.

We also calculated the H^- ion production probabilities as a function of the workfunction and the atomic hydrogen temperature. These results are shown in the fig.2 and fig.3 by solid lines. Both measurements and calculations show almost good agreement. Therefore, eq.(2) is useful for estimating the H^- ion production probability by scattering of thermal hydrogen atoms from the cesium covered surface in the low energy region. Since the temperature of hydrogen atoms in the volume source is about 0.5eV[4], the H^- ion production probability at the cesium covered surface of the volume ion source, which is estimated from eq.(2), becomes β=0.033. This is not a large number, however, the density of the atomic hydrogen in the volume ion source is normally more than 10^{14}atoms/cm^3. As a result, if we ignore the destruction process of H^- ions in the plasma, an expected H^- ion current density at the plasma electrode surface reaches more than 500mA/cm^2. This large H^- ion current density might be enough for explaining the cesium catalysis effect in the volume production type of H^- ion source.

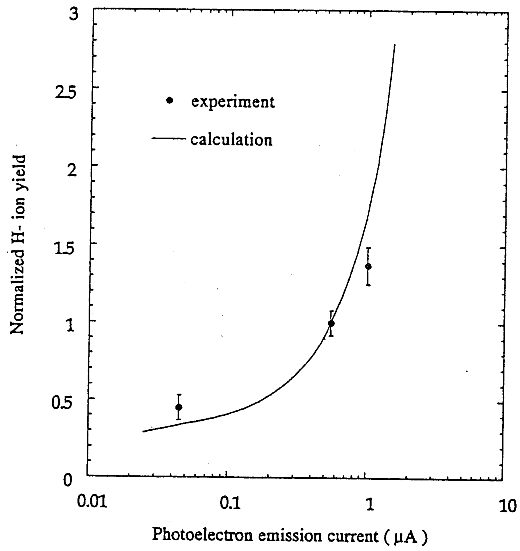

Fig.2 Normalized H^- ion yields as a function of the workfunction

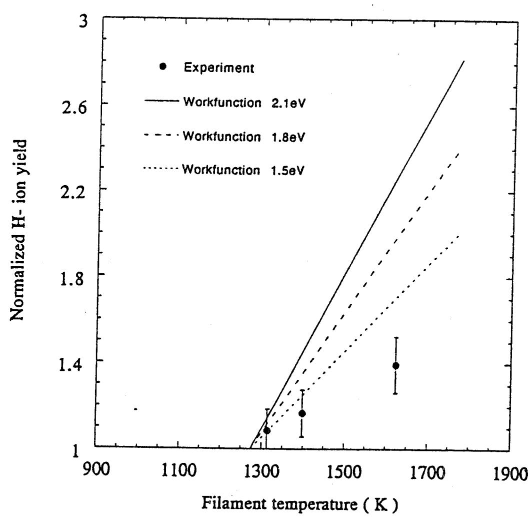

Fig.3 Normalized H^- ion yields as a function of the atomic hydrogen temperature

Measurement of negative hydrogen ion production by scattering of low energy hydrogen ions

In order to measure the H^- ion production probabilities by scattering of positive hydrogen ions, a hydrogen ion source was attached instead of the dissociator shown in fig.1 and a Wien filter was installed after the extraction anode of the ion source to analyze hydrogen ions of H^+,H_2^+ and H_3^+ separately. Hydrogen ions (H^+,H_2^+ and H_3^+) were extracted from the ion source at the energy of 100eV and hit the molybdenum target at the glancing angle of 6 ° after analyzed by the Wien filter. With this angle, the normal velocity component of the H^+ ion is almost 1.4 x 10^4m/s and this corresponds to the energy of 1eV. The

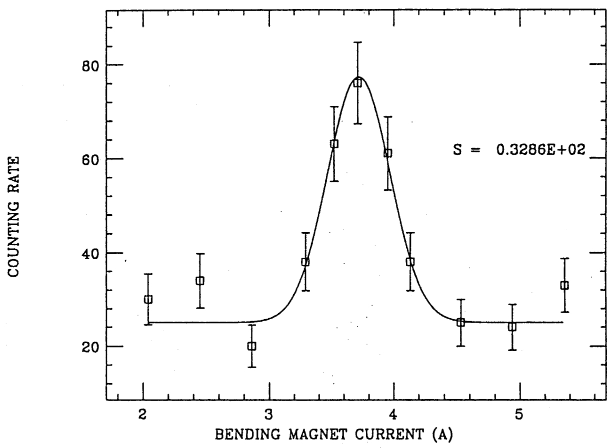

Fig.4 H^- ion yields by scatteing of H^+ ions

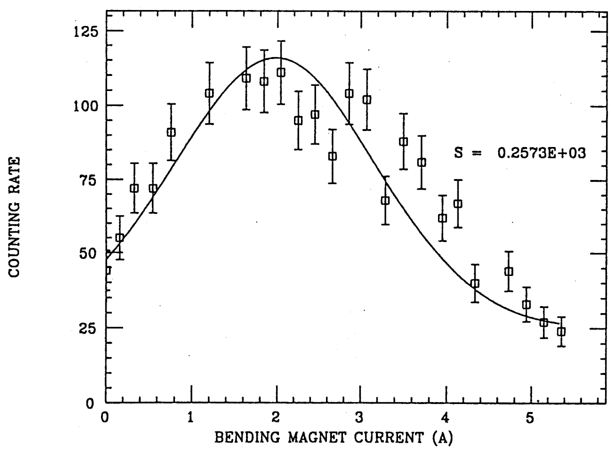

Fig.5 H^- ion yields by scattering of $H3^+$ ions

backscattering H^- ions produced at the cesium covered molybdenum target were analyzed by a dipole magnet and detected by a MCP.

Figure 4 and figure 5 are the measured H^- ion yields by scattering of $H^+$and $H3^+$ ions as a function of the current of the analyzing magnet, respectively. The solid lines in the figure show curves fit by least squares method. For H_2^+ ions, the apparent H^- ion current peak was not observed. From these measurement, the H^- ion production probabilities by scattering of H^+ ions and $H3^+$ ions are estimated by the following equations.

$$\beta_1 = \frac{n_{H^-}(1 - \gamma)}{n_{H^+}} \qquad \text{for } H^+ \qquad (3)$$

$$\beta_3 = \left(\frac{n_{H3^-}}{I_{H_3^+}}\right)^2 \left(\frac{I_{H^+}}{n_{H^-}}\right)^2 \beta_1 \qquad \text{for } H_3^+ \qquad (4)$$

where n $_{H^-}$ and n $_{H3^-}$ are H^- ion yields by scattering of H^+ ions and $H3^+$ ions detected with MCP ,respectively, and n_{H^+} is H^+ ion yield detected also with MCP before cesium atom is covered the target. Here, γ is a Auger neutralized coefficient when H^+ ions were injected to a pure molybdenum target and this can be estimated theoretically. In this energy range, γ is 0.97.[5] Also, I_{H^+} and I_{H3^+} show the beam current measured at the molybdenum target for H^+ and $H3^+$ ions, respectively. The measured H^- ion production probabilities for H^+ and $H3^+$ ions were β_1= 0.014 and β_3= 0.03, respectively. The H^- ion production probabilities by scattering of H^+ ions can be also estimated theoretically by eq.(2). The theoretical value is ~0.02 at T = 1eV and ϕ = 2.1 eV. This shows good agreement with the experimental value. However, these effects might contribute small for the enhancement of H^- ion beam current in the volume H^- ion source, because the density of hydrogen ions (H^+ and $H3^+$ ions) are relatively small compared with the density of atomic hydrogens in the plasma.

Conclusion

We have measured the H^- ion production probabilities at the cesium covered molybdenum target by scattering of thermal hydrogen atoms and low energy hydrogen ions. The measured H^- ion production probability by scattering of thermal hydrogen atoms (T= 1250K) was $2.5\text{x}10^{-4}$ and those by scattering of the low energy H+ ions and H3+ ion (T=1eV) were 0.014 and 0.03, respectively. These results showed good agreement with the quantum mechanical calculation. From these results, it was estimated that the cesium catalysis effect in the volume production type of H^- ion source can be explained by the surface H^- ion production process by scattering of hydrogen atoms.

References

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