# CESIUM EFFECT ON VOLUME $H^-$ ION SOURCE

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[abstract]

Observation of the $H^-$ beam intensity enhancement by introducing a very small amount of cesium vapor in the volume $H^-$ ion source developed at KEK is shown in detail. The extracted $H^-$ beam current of 20mA was obtained in the cesium-mode operation and the measured 90% normalized beam emittance was about 1πmm.mrad for 12 mA beam. It was found that the workfunction of the cesium covered surface of the beam extracting plasma electrode was important in increasing the $H^-$ beam intensity.

## Introduction

The volume $H^-$ ion source has been devloped at KEK.[1] The surface-plasma type of $H^-$ ion source, in which the $H^-$ ions are generated on the cesiated low workfunction molybdenum surface placed in the hydrogen plasma, is being used in the 12 GeV proton synchrotron.[2] This ion source produces about 30mA $H^-$ beam with a 90% normalized beam emittance(phase-space area x b x g) of 1.5πmm.mrad in pulse-mode operation. This ion source is rather delicate to keep its maximum intensity during the operation because the $H^-$ beam intensity is very sensitive to the cesium coating on the molybdenum surface. If a small cesium consuming or cesium-free $H^-$ ion source was realized, it would be very useful for the high intensity and high duty accelerators.

One of the potential candidates of such an ion source is a volume-production type of $H^-$ ion source and at KEK, the pulse operated volume $H^-$ ion source has been developed since 1988. It is aiming for a pulsed $H^-$ beam of more than 20mA with a 90% normalized emittance of less than 1 π mm.mrad. One of the difficulties in operation of the volume $H^-$ ion source is its poor efficiency. A relatively large arc current is required to obtain an intense beam current of more than 10mA. Moreover, the total electron drain current from the ion source reaches 100 times of that of the extracted $H^-$ beam.

Kao Leung et al have recently found that the extracted $H^-$ beam current could be increased by injecting cesium vapor into the ion source plasma chamber.[3] We have also observed this cesium effect in our volume $H^-$ ion source. The extracted $H^-$ ion beam current was increased more than four times of that before injecting cesium vapor and the extracted $H^-$ ion current reached a maximum of 20 mA. The cesium consumption rate was surprisingly small compared with the surface $H^-$ ion source and this may hence reduce the difficulties described above in operation of the ion source with cesium vapor.

## Cesium-mode operation

A schematic diagram of the present test apparatus of the KEK volume $H^-$ ion source is shown in Fig. 1. The ion source consists of a cylindrical plasma chamber which is surrounded by SmCo permanent magnets and a single hot filament cathode. A pair of SmCo permanent magnets, which make a dipole magnetic field, a so called virtual magnetic filter, are placed at the the outside of the plasma chamber and close to the plasma electrode. Through the experiment, a single hole of 7.5mm in diameter was used as the anode aperture. The anode material is molybdenum.

A helical coil shaped $LaB_6$ filament is used as a hot cathode and it is attached on the molybdenum supporting rods which are cooled by water. The operating temperature of the filament is about 1400°C and the lifetime is more than several hundred hours.

Cesium vapor is injected into the plasma chamber from the outside reservoir through a heated feedthrough. The high temperature valve, which can be closed to stop the cesium feeding immediately after the $H^-$ ion beam current is increased, is located between the ion source and the reservoir. The reservoir temperature is normally 200-250°C.

At the end plate of the plasma chamber, a small glass window is mounted. By injecting an Ar laser beam(l=514.5nm) through this window, the workfunction changes of the anode electrode can be estimated by measuring the photo-emission electron current from the anode electrode.

The H beam current is measured by a Faraday cup which is placed about 1 meter away from the anode electrode. Beam emittance can be also measured with an electrostatic deflection type of emittance monitor, which is located at the front of the Faraday cup.

## Cesium effect

The extracted $H^-$ beam intensity is dramatically changed by injecting cesium vapor into the plasma chamber. Figures 2-a and 2-b show the typical $H^-$ beam waveforms before and after the cesium vapor is injected, respectively. In these figures, the total drain currents($H^-$ + electron) from the ion source are also shown. The $H^-$ beam current is increased from 3mA to 12mA and on the other hand, the total drain current is decreased from 350mA to 100 mA. By optimizing the various parameters of the ion source after the cesium vapor is injected, the $H^-$ ion beam current was increased to 20mA as shown in Fig. 3.

The cesium consumption rate was very small in operating the ion source. For example, once the beam intensity was increased after opening the valve for the cesium feed line, it kept almost constant for several ten of hours even when the valve was closed. This is a quite different situation from that of the ordinary surface type of $H^-$ ion source and it helps a lot to eliminate sparkings in the extraction region during long period operation.

The beam emittance was also measured before and after the cesium injection. Figure 4 shows the typical value of the beam emittance after injecting the cesium vapor at beam intensity of 12mA.

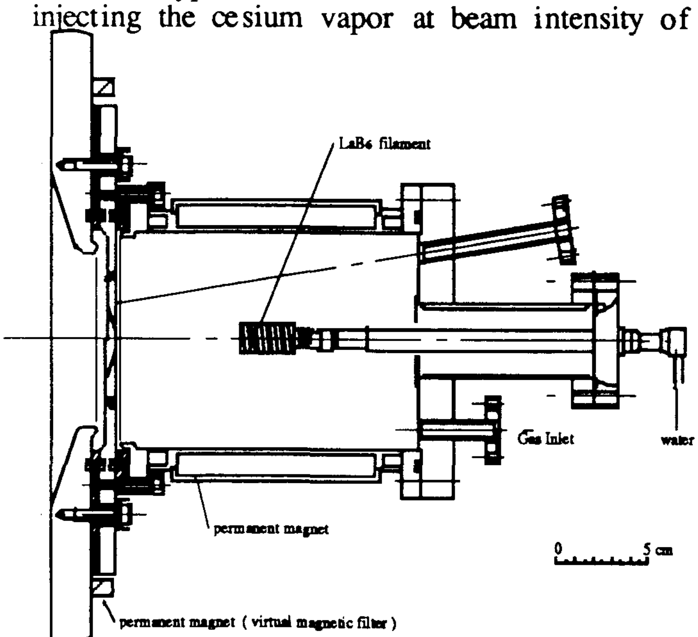


Fig.1 Schematic diagram of the KEK volume H ion source.

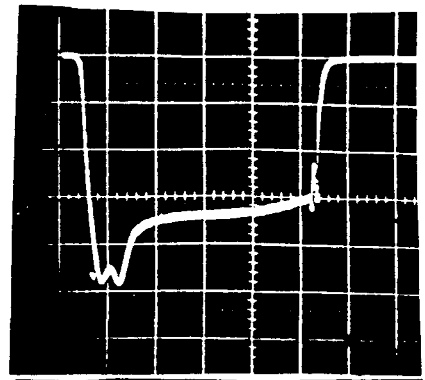

Fig.2-a $H^-$ beam waveform before injecting cesium vapor. Vertical axis: 1 mA/div. Horizontal axis: 0.1 msec/div.

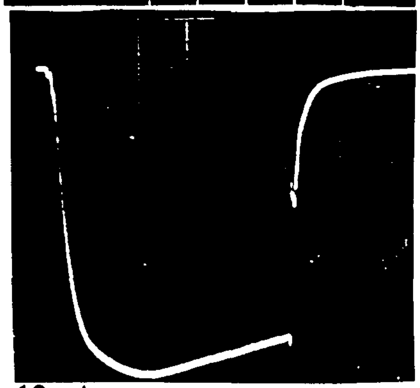

Fig.3-b $H^-$ beam waveform after injecting cesium vapor. Vertical axis: 2 mA/div. Horizontal axis: 0.1 msec/div.

We have observed a dramatic beam current increase in the $H^-$ ion source at the cesium-mode operation. There have been proposed several explanations of this effect. Among them, the following two processes concerning the surface condition of the ion source wall which is covered by cesium atoms are considered as the most likely candidates to account for the effect. One is that numbers of vibrational excited hydrogen molecules, which are considered to play an important role in the volume-production process of H ions, are produced from $H_2^+$ and/or $H_3^+$ ions by picking up electrons from the cesiated low workfunction surface of the ion source inner wall. [4] The other is that $H^-$ ions can be formed directly on the cesiated surface from thermal hydrogen atoms.[5] Although this reaction probability is predicted to be very small,[6] the density of the atomic hydrogen contained in the ion source plasma is very large($n>10^{13}$ atoms/$cm^2$) and this may hence lead an enhancement of H ions. In both processes, the workfunction of the inner surface of the ion source is very important and it has to be reduced by injecting the cesium vapor into the ion source.

In order to check this, we have measured workfunction changes of the plasma electrode before and after the cesium injection. The workfunction change was measured by detecting the photo-emission electron current which is generated by a single mode Ar ion laser beam(l= 514.5nm).[7] While we made the measurements

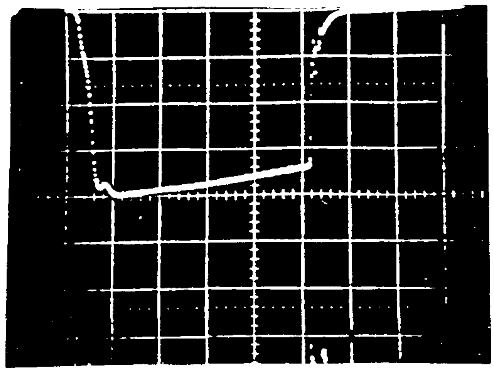

Fig.3 Optimized $H^-$ ion beam current. Vertical axis: 5 mA/div. Horizontal axis: 0.1 msec/div.

several times, the results were always very reproducible. In Fig.5, photo-emission electron current changes are plotted as a function of time elasped after the valve of the cesium feedline was opened. Also we found that the workfunction kept decreasing for long time during the operation of the ion source even after the valve of the cesium feedline was closed. This may relate to the fact that the cesium consumption rate is very small.

In order to examine which surface, the plasma electrode surface or other wall surface, is most effective in generating $H^-$ ions when the cesium vapor is injected, we cleaned the plasma electrode surface only by Ar ion sputtering. Before the Ar ion sputter cleaning, the $H^-$ ion current was 12 mA, however, it decreased to about 3mA just as before the cesium injection and the photo-emission electron current was also disappeared after one hour cleaning. Thus the plasma electrode surface seems to affect very much on the enhancement of the $H^-$ ion production in the cesium-mode operation. It is interesting that only the plasma electrode surface seemed to be important to enhance the $H^-$ beam intensity.

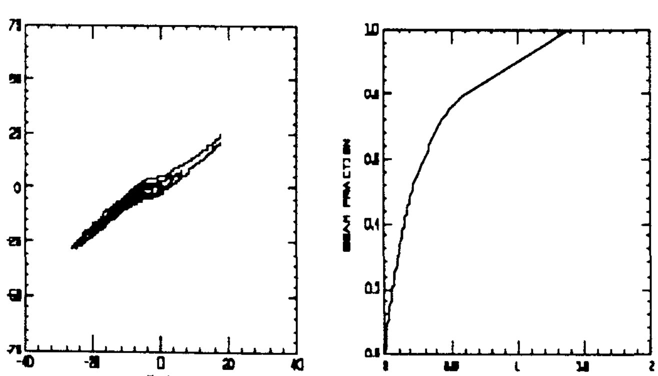

Fig.4 Emittance shape and normalized emittance vs percentage of total $H^-$ ion beam after injecting cesium vapor. The total $H^-$ ion beam current was 12 mA.

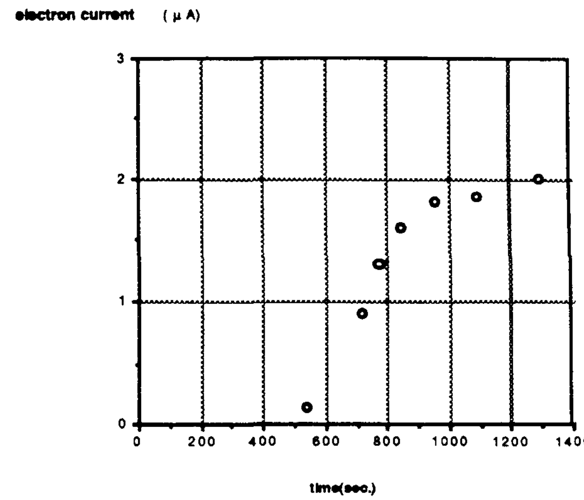


Fig.5 Photo-emission electron current changes as a function of time elapsed after the valve of the cesium feedline was opened.

## Conclusion

The characteristics of the volume $H^-$ ion source changed dramatically by injecting the cesium vapor into the ion source. More than four times more $H^-$ ion beam current was extracted after the cesium injection and, nevertheless, the cesium consumption rate was very small. It was also observed that the surface condition of the plasma electrode played an important role in the cesium-mode operation by the workfunction measurement with a photo-emission electron technique, .

The authors appreciate Profs. H. Sugawara, Y. Kimura, S. Fukumoto and M. Kihara for their continuous encouragement. They are also indebted to Mr. K. Ikegami for his technical support.

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