

## DEVELOPMENT OF THE KEK VOLUME H<sup>-</sup> ION SOURCE

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### [abstract]

Characteristics and performance of the recently developed volume H<sup>-</sup> ion source at KEK are described in the paper. Especially, observation of the H<sup>-</sup> beam intensity enhancement by introducing a very small amount of cesium vapor is shown in detail. The extracted H<sup>-</sup> beam current of 20mA was obtained in the cesium-mode operation. The measured 90% normalized beam emittance was about 1πmm.mrad for 12 mA beam and emittance growth due to the space charge effect was observed when the beam intensity increased. We found that the workfunction of the cesium covered surface of the beam extracting plasma electrode might have an important role to enhance the H<sup>-</sup> beam intensity.

### Introduction

At KEK, the surface-plasma type of H<sup>-</sup> ion source, in which the H<sup>-</sup> ions are generated on the cesiated low workfunction molybdenum surface placed in the hydrogen plasma, is being used in the 12 GeV proton synchrotron.[1] This ion source produces about 30mA H<sup>-</sup> beam with a 90% normalized beam emittance(phase-space area  $\times \beta \times \gamma$ ) 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<sup>-</sup> beam intensity is very sensitive to the cesium coating on the molybdenum surface and if a small cesium consuming or cesium-free H<sup>-</sup> 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<sup>-</sup> ion source, which was originally developed for fusion applications.

Kao Leung et al have recently found that the extracted H<sup>-</sup> beam current could be increased by injecting cesium vapor into the ion source plasma chamber.[2] We have also observed this cesium effect in our volume H<sup>-</sup> ion source. The extracted H<sup>-</sup> ion beam current was increased more than four times of that before injecting cesium vapor and the extracted H<sup>-</sup> ion current reached a maximum of 20 mA.[3] The cesium consumption rate was surprisingly small compared with the surface H<sup>-</sup> ion source and this may hence reduce the difficulties described above in operation of the ion source with cesium vapor. We have made several experiments to examine the cesium effect on the volume H<sup>-</sup> ion source and found that the surface condition of the beam extracting plasma electrode has a very important role in increasing the H<sup>-</sup> beam intensity in the cesium-mode operation. In this paper, the experimental results on the surface effect of the plasma electrode are also described.

### Operation of the ion source

A schematic diagram of the present test apparatus of the KEK volume H<sup>-</sup> 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. The length and the diameter of the plasma chamber are about 160mm and 100mm, respectively. A pair of SmCo permanent magnets, which make a dipole magnetic field, a so called virtual magnetic filter, are placed at the outside of the plasma chamber and close to the plasma electrode. The magnetic field becomes maximum at the anode hole. The plasma electrode is insulated from the plasma chamber by a ceramic plate and small voltage can be applied to the electrode to optimize the H<sup>-</sup> ion beam current. 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<sub>6</sub> 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<sup>-</sup> 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( $\lambda=514.5\text{nm}$ ) 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<sup>-</sup> 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. The beam extraction systems and the beam diagnostics are fabricated in a big vacuum chamber which is evacuated by a 2500 l/s turbo-molecular pump. In table 1, typical operating parameters of the cesium-mode volume H<sup>-</sup> ion source are summarized.

Table 1. Typical operating parameters of the KEK volume H<sup>-</sup> ion source in cesium-mode operation.

ARC CURRENT	100-200A
ARC VOLTAGE	120-150V
FILAMENT CURRENT	70-80A
HYDROGEN FLOW RATE	15-20sccm
BEAM EXTRACTION VOLTAGE	30-40 kV

### Cesium effect

The extracted H<sup>-</sup> beam intensity is dramatically changed by injecting cesium vapor into the plasma chamber. Figures 2-a and

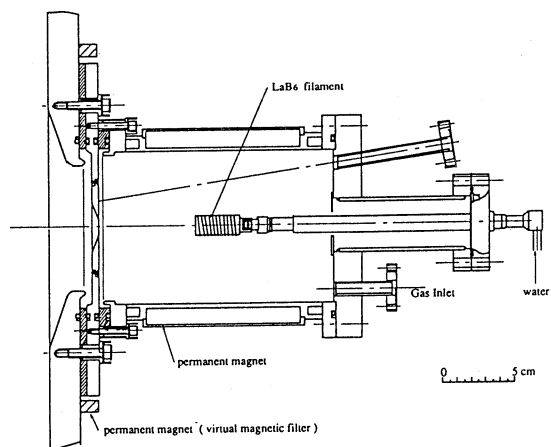


Fig.1 Schematic diagram of the KEK volume H<sup>-</sup> ion source.

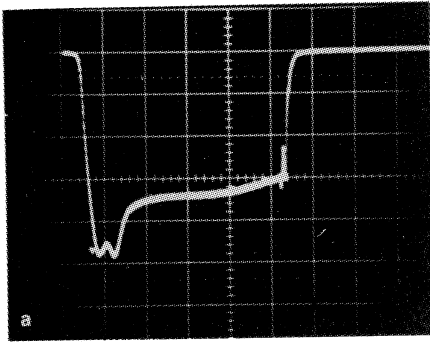


Fig.2-a H<sup>+</sup> beam waveform before injecting cesium vapor. Vertical axis: 1 mA/div. Horizontal axis: 0.1 msec/div.



Fig.3 Optimized H<sup>+</sup> ion beam current. Vertical axis: 5 mA/div. Horizontal axis: 0.1 msec/div.

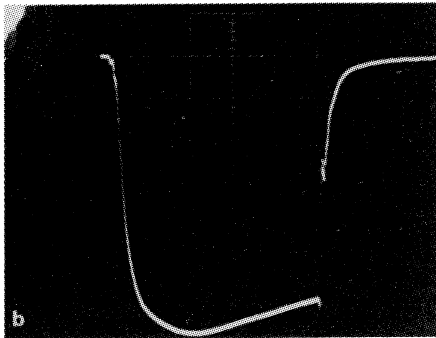


Fig.2-b H<sup>+</sup> beam waveform after injecting cesium vapor. Vertical axis: 2 mA/div. Horizontal axis: 0.1 msec/div.

2-b show the typical H<sup>+</sup> beam waveforms before and after the cesium vapor is injected, respectively. In these figures, the total drain currents(H<sup>+</sup> + electron) from the ion source are also shown. The H<sup>+</sup> 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<sup>+</sup> 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<sup>+</sup> 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 and the result was shown in Fig.4. Some aberration seen in the emittance contour in Fig 4 was probably due to the einzel lens effect because the beam size was relatively large compared with the lens diameter.

We have observed a dramatic beam current increase in the H<sup>+</sup> ion source at the cesium-mode operation. On of the prediction of explaining this effect is that H<sup>+</sup> ions can be formed directly on the cesiated surface from thermal hydrogen atoms.[4] Although this reaction probability is predicted to be very small,[5] the density of the atomic hydrogen contained in the ion source plasma is very large( $n > 10^{13}$  atoms/cm<sup>3</sup>) and this may hence lead an enhancement of H<sup>+</sup> 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. This effect has been recently clarified by the experiments done by our group and the results are presented in this symposium.[6]

In order to examine which surface, the plasma electrode surface or other wall surface, is most effective in generating H<sup>+</sup> ions when the cesium vapor is injected, we cleaned the plasma

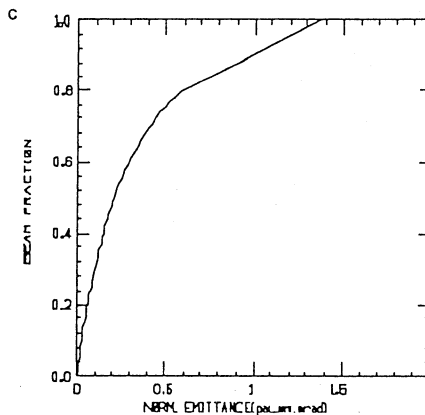
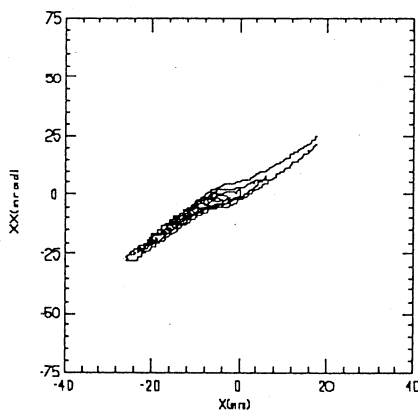


Fig.4 Emittance shape and normalized emittance vs percentage of total H<sup>+</sup> ion beam after injecting cesium vapor. The total H<sup>+</sup> ion

electrode surface only by Ar ion sputtering. Before the Ar ion sputter cleaning, the H<sup>-</sup> 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<sup>-</sup> ion production in the cesium-mode operation. It is interesting that only the plasma electrode surface seemed to be important to enhance the H<sup>-</sup> beam intensity.

### Conclusion

Characteristics and performance of the volume H<sup>-</sup> ion source when the cesium vapor is injected are described. We found that the characteristics of the ion source changed dramatically by injecting the cesium vapor into the ion source. More than four times more H<sup>-</sup> 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.

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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