DEVELOPMENT OF THE KEK VOLUME H⁻ ION SOURCE

Yoshiharu Mori, Toshihisa Okuyama, Akira Takagi

National Laboratory for High Energy Physics(KEK)
Oho 1-1, Tsukuba-shi,Ibaraki-ken 305, JAPAN

abstract

Characteristics and performance of the recently developed volume H⁻ ion source at KEK are described. Observation of the H⁻ beam intensity enhancement by introducing a small amount of cesium vapor is shown. The extracted H⁻ 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. We found that the workfunction of the plasma electrode surface which was decreased by cesium coverage had an important role to enhance the H⁻ beam intensity.

Introduction

A 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, has been used in the 12 GeV proton synchrotron at KEK.[1] This ion source produces about 30mA H⁻ beam with a 90% normalized beam emittance(phase-space area x β x γ) 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 cesium-free or small cesium consuming H⁻ ion source is realized, it becomes a useful H⁻ ion source for accelerators.

One of the potential candidates of such an ion source is a volume-production type of H- ion source, which was originally developed for fusion applications. However, the current denisty of the beam from volume-production type of H⁻ ion source is rather lower compared with that from surface type of H- ion source. K. Leung et al have found that the extracted H⁻ 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⁻ 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.[3] 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. We have made several experiments to examine the cesium effect on the volume H⁻ ion source and found that the surface condition of the beam extracting plasma electrode has a very important role in increasing the H⁻ 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⁻ 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 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⁻ 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_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(λ=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.

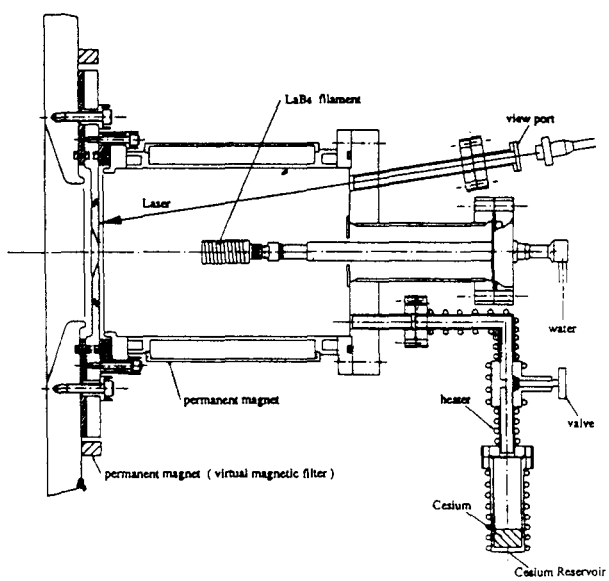

Fig.1 Schematic diagram of the KEK volume H⁻ ion source.

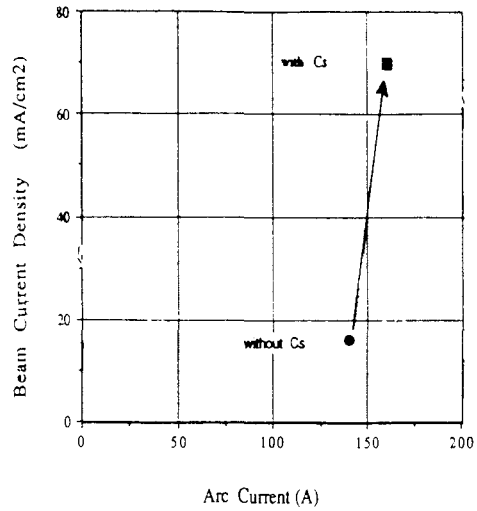

Fig.2 Change of the current density of the H^- ion beam before and after the cesium vapor is introduced into the source.

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. 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^- ion source are summarized.

Table 1 Typical operating parameters of the KEK volume H^- 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

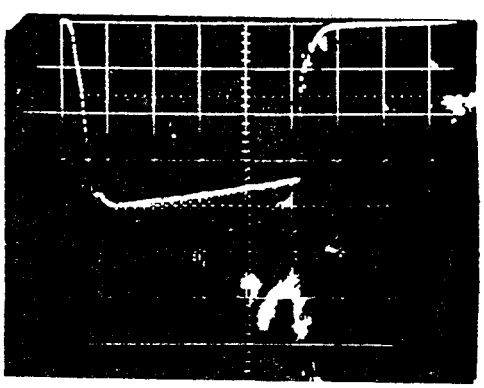

Fig.3 Optimized H^- ion beam current. Vertical axis: 5 mA/div. Horizontal axis: 0.1 msec/div.

Cesium effect

The extracted H^- beam intensity is dramatically changed by injecting cesium vapor into the plasma chamber. Figure 2 shows the change of the current density of the H^- ion beam before and after the cesium vapor is injected, respectively. The current density of H^- ion beam is increased from 16mA/cm² to 70mA/cm². On the other hand, the total drain current which contains mainly electrons from the ion source is dropped from 350mA to less than 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.

We have observed a dramatic beam current increase in the H^- ion source at the cesium-mode operation. One of the explanations on this cesium effect is that H^- ions can be formed directly on the cesiated surface from thermal hydrogen atoms.[4] Although this reaction probability is predicted to be very small, the density of the atomic hydrogen contained in the ion source plasma is very large($n>10^{13}$ atoms/cm²) and this may hence lead an enhancement of H^- ions.

In this process, the workfunction of the inner surface of the ion source, especially the plasma electrode surface, is very important and it has to be reduced by injecting the cesium vapor into the ion source.

In order to examine a cesium catalysis effect, the H^- ion production probability by sacttering thermal hydrogen atoms from a cesium adsorbed molybdenum surface has been measured.[5] Figure 4 shows a schematic layout of the experimental setup used in the measurement. Thermal

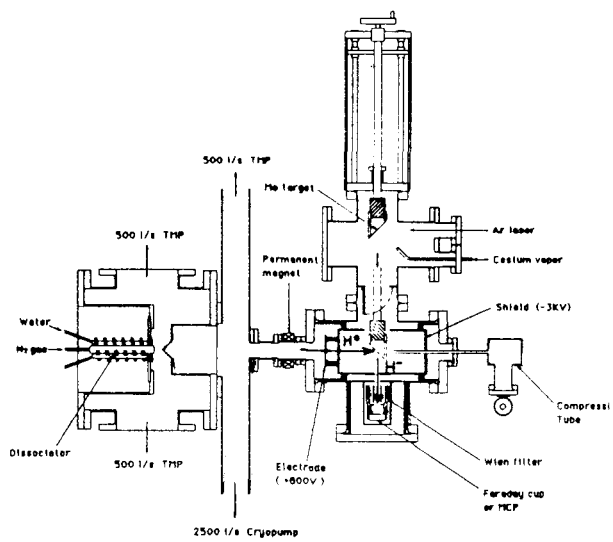

Fig. 4 Schematic setup of the measurement of H^- ion production probability by scattering thermal hydorgen from a cesium adsorbed molybdenum surface.

hydrogen atoms are generated by dissociating hydrogen molecules with an rf dissociator. After passing through a small hole of the skimmer, an atomic hydrogen beam becomes a luminar flow and is scattered from a cesium adsorbed molybdenum surface. After scattering, a small fraction of the hydrogen atoms becomes H^- ions. A part of H^- ions are accelerated by applying a negative potential of 3kV to the molybdenum target and detected by a Faraday cup and/or a microchannel plate(MCP) after mass-analysis with a Wien filter.

The workfunction of the cesium adsorbed surface is determined by measuring the photoemission electron current produced by irradiation of the target surface with an Ar ion laser beam.[6] Figure 5 shows the dependence of the H^- ion production probability on the workfunction of the cesium adsorbed surface. The H^- ion yields detected by the MCP are shown as a function of the photoemission current. The H^- ion yield is normalized by the ion yield measured when the photoemission current is 0.55μA which corresponds to the workfunction of 2.1eV. As clearly seen from this figure, the H^- ion yields increased as the decrease of the workfunction.

The H^- ion production probability by scattering hydrogen atoms from a cesium adsorbed surface is expected to depend on the velocity to the surface of the scattered hydrogen atoms. Figure 6 shows the velocity dependence of the H^- ion production probability as a function of the atomic hydrogen temperature. The atomic hydrogen beam was heated by placing a resistively heated tantalum tube at the exit of the dissociator. As can be seen from this figure, when the temperature of the tantalum tube increases above 1250K, the H^- ion yield begins to linearly increase with temperature as expected.

The measured H^- ion production probability by scattering thermal hydrogen atoms(T=1250K) was estimated to be almost 2.5 x 10^{-4}. This results is in good agreement with the theoretically estimated value.[5] Since the temperature of hydrogen atoms in the volume source is about 0.5 eV,[8] the H^- ion production probability at the cesium covered surface of the volume ion source is estimated to be

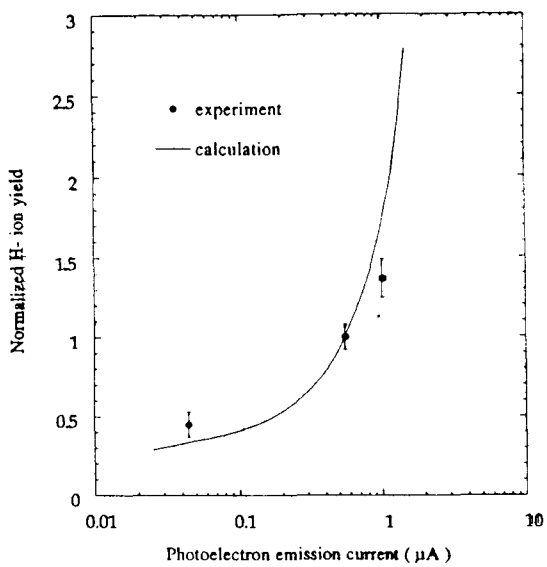

Fig. 5 The dependence of the H^- ion production probability on the workfunction of the cesium asdorbed surface.

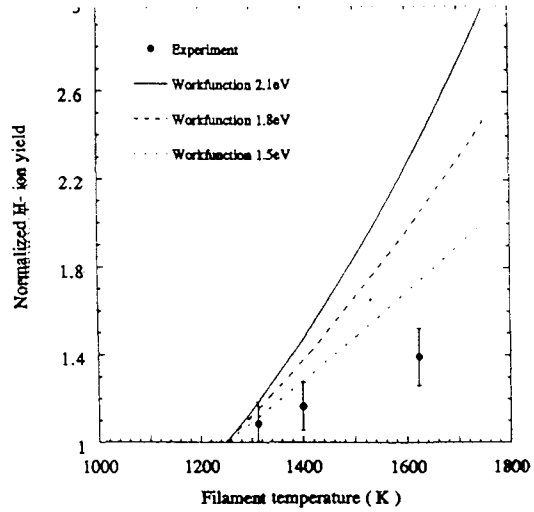

Fig. 6 The velocity dependence of the H^- ion production probability as a function of the atomic hydrogen temperature.

about 0.013. Although this is not a large number, the density of the atomic hydrogen in the voulme ion source is normally more than 10^{14} atoms/cm^3 and the expected H^- ion current density at the plasma electrode can reach values in excess of 200 mA/ cm^2 assuming no beam loss.

Conclusion

Characteristics and performance of the volume H^- 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^- 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 H^- ion production probability by scattering thermal hydrogen atoms from the cesium adsorbed molybdenum target was measured. It is very likely that the enhancement of the H^- ion beam current in the voulem H^- ion source by injecting cesium vapor is due to the surface H^- ion production by scattering low energy hydrogen atoms from the cesium covered plasma electrode.

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