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Experiments on the multiampere negative ion source in National Institute for Fusion Science

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The multiampere negative hydrogen ion source has been developed in National Institute for Fusion Science (NIFS). The ion source is a volume-production type multicusp one with an extraction area of 25×25 cm^2. It is found that high density negative hydrogen ions of more than 1×10^{12} cm^{-3} are produced in the center of the arc chamber with a double magnetic filter configuration. A supply of a small amount of cesium vapor into the arc chamber has greatly enhanced the H^- ion current and reduced the operation pressure. The H^- ion current of 3.3 A has been extracted from a Cs-seeded plasma at the pressure of 0.9 Pa.

I. INTRODUCTION

The development of a high current negative ion source is one of the essential issues for next generation neutral beam injection systems in application to the plasma heating and current drive in fusion plasmas. The negative hydrogen/deuterium ions can be neutralized with high efficiency to high energy neutral beams with a very low divergence. In the LHD project, conducted by National Institute for Fusion Science, the negative-ion-based NBI system (injection power; 20 MW, injection energy; 125 keV for hydrogen and 250 keV for deuterium) has been proposed.[1] It is required to develop the ion source which can deliver 45 A H^- ion current. At the first step of the research and development, we have fabricated a large negative ion source with an extraction area of 25×25 cm^2 and optimized the negative ion production in hydrogen discharges.[2–5]

Recently, it is reported that an enhancement of the H^- ion current is induced by a supply of a small amount of cesium (Cs) vapor into an arc chamber.[6–8] We have also confirmed the increase in the H^- ion current and the reduction of the operation pressure in Cs-seeded discharges.

In the present article, we describe a new magnetic field configuration for the negative hydrogen ion production in pure hydrogen discharges and the extraction characteristics in Cs-seeded discharges.

II. EXPERIMENTAL APPARATUS

A schematic diagram of the negative ion source is shown in Fig. 1. The arc chamber is made of copper and surrounded by Sm–Co magnets to form the magnetic line cusp. The cross section of the arc chamber is 35×35 cm^2 and its depth is 19 cm. Fourteen tungsten filaments are attached to the side walls. Water-cooled rod magnetic filters are installed in front of the plasma grid and the filter field strength can be changed by selecting the total number of the rods. The extraction electrode system consists of four grids as shown in Fig. 1. Each grid is made of copper and has 400 extraction holes of 9 mm in diameter in the area of 25×25 cm^2. In the extraction grid permanent magnets are buried to deflect the extracted electrons.

The extraction voltage V_{ext} is applied between the plasma grid and the extraction grid up to 5 kV, and the acceleration voltage V_{acc} is applied between the extraction grid and the ground grid up to 30 kV. The pulse length is 0.3 s. The extracted H^- ion current is measured by a calorimeter array placed at 1.6 m downstream from the plasma grid.

So as to supply a small amount of Cs vapor into the arc chamber, a cesium oven is attached to the end plate of the chamber via a valve. The oven is heated up to 300 °C. Guiding tubes and the valve are heated at higher temperature than that of the oven to prevent cesium condensation. The amount of Cs vapor is controlled by changing the duration of the valve opening. In the Cs-seeded experiments a molybdenum plasma grid is used without water-cooling. The grid is heated by radiation from arc discharges and its temperature is monitored by a thermocouple during operation. The grid temperature is adjusted by changing duty of the shots.

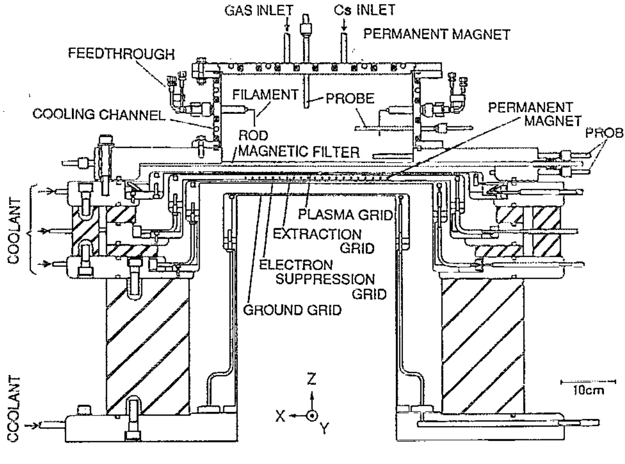

FIG. 1. The schematic diagram of the multicusp negative hydrogen ion source.

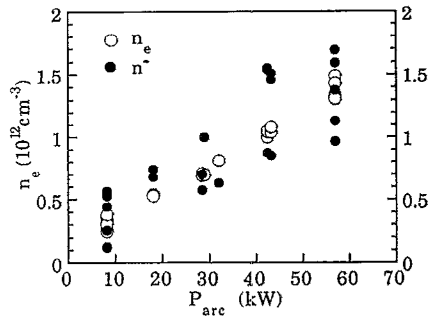

FIG. 2. H^- ion densities (closed circles) and electron densities (open circles) in the center region of the arc chamber as a function of the arc power. The gas pressure is 2.1 Pa.

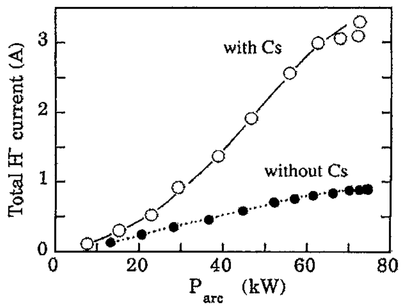

FIG. 3. Total H^- currents as a function of the arc power with Cs (open circles) and without Cs (closed circles). With Cs operation; $V_{acc} = 17.5$ kV, $V_{ext} = 5.0$ kV, and $p = 0.92$ Pa. Without Cs operation; $V_{acc} = 21.0$ kV, $V_{ext} = 4.0$ kV, and $p = 1.9$ Pa.

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. Pure hydrogen experiments

In a pure hydrogen volume source, magnetic filters are usually set in front of the plasma grid. The magnetic field separates the H^- ion production/extraction region from the driver region where the vibrationally excited hydrogen molecules H_2^* are produced.[9,10]

We have utilized the cusp fields for separating these regions and the magnetic filter field for reducing the extracted electron current. To distinguish these filter configurations, we call the former a single magnetic filter (SMF) configuration and the latter a double magnetic filter (DMF) configuration. In order to make the DMF configulation, the filaments are placed near chamber walls, where the cusp fields still exist. The energetic electrons emitted from the filaments are trapped by the mirror of the cusp fields and H_2^* are expected to be produced in this region. On the other hand, there only exist thermal electrons in the center of the chamber, which produce H^- ions through the dissociative attachment process with H_2^*.

To confirm the H^- ion production in the center region, H^- ion densities are measured directly by the photodetachment technique with a Nd-YAG laser. Figure 2 shows the electron density and H^- ion density measured in the center region as a function of the arc power. The H^- ion density is nearly the same as the electron density and attains to more than $1 \times 10^{12}\ \mathrm{cm}^{-3}$.[5]

The extraction currents, which almost correspond to the extracted electron currents, and the H^- ion currents increase with the increase in the arc power. In the DMF configuration, it is observed that the extracted electron currents can be controlled by the magnetic filter field without affecting the H^- ion currents.

So far, the H^- ion current of 1.4 A is obtained from a pure hydrogen discharge with the DMF configuration, in the condition of $V_{ext} = 3.5$ kV, $V_{acc} = 30$ kV, and $p = 1.6$ Pa.[4]

B. Cs-seeded experiments

Figure 3 shows the H^- ion current as a function of the arc power before and after Cs supply of about 100 mg. This amount of Cs corresponds to 9×10^{16} particles/cm², assuming that all chamber walls are uniformly covered with these Cs atoms. After the Cs supply the H^- ion current is enhanced three times larger than that in no Cs-seeded operation. In the Cs-seeded experiments, the filaments are set at the field free region and the source is operated with the SMF configuration.

The enhancement is greatly influenced by the plasma grid temperature. When the temperature changes from 100 to 200 °C, the H^- ion current increases from 1.5 to 3.1 A as shown in Fig. 4. When the water-cooled copper plasma grid is used in the Cs-seeded plasma, H^- ion current increases only a several percent compared with that in the no Cs-seeded operation.

Another remarkable cesium effect is the reduction of the operating pressure. Figures 5(a) and 5(b) show the H^- ion current and the extraction current as a function of the operating gas pressure without and with Cs supply, respectively. In the no Cs-seeded operation, the optimum gas pressure for the maximum H^- ion current is more than 2.0 Pa, and the extraction current increases as the pressure increases as shown in Fig. 5(a). While, in the Cs-seeded operation, the optimum gas pressure decreases below 1.0 Pa with the enhancement of the H^- ion current as shown in Fig. 5(b). The extraction current reduces slightly by the Cs supply and is kept nearly constant as the pressure increases. As shown in Fig. 6, it is observed that the optimum pressure decreases with an increase in the arc

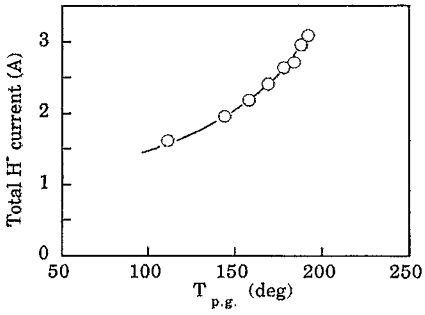

FIG. 4. Total H^- ion currents as a function of a plasma grid temperature. $V_{acc} = 17.5$ kV, $V_{ext} = 5.0$ kV, $p = 0.92$ Pa, and $P_{arc} = 65$ kW.

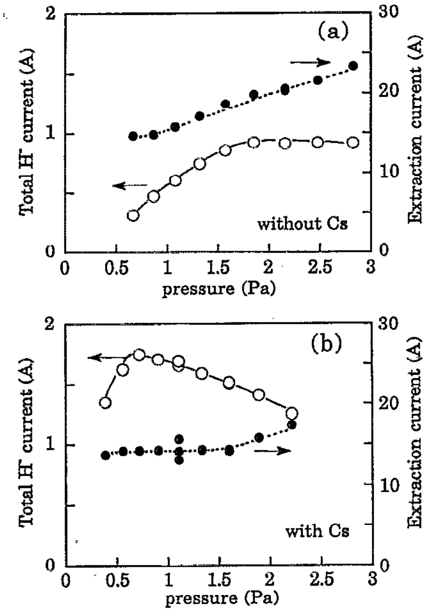

FIG. 5. Total H^- ion currents (open circles) and extraction currents (closed circles) as a function of the filling gas pressure. (a) No Cs-seeded operation; $V_{acc} = 21.0$ kV, $V_{ext} = 4.0$ kV, $P_{arc} = 75$ kW. (b) Cs-seeded operation; $V_{acc} = 21$ kV, $V_{ext} = 4.0$ kV, $P_{arc} = 65$ kW.

power, where the grid temperature is kept constant at 200 °C. The reduction of the operating gas pressure brings many advantages to the high power source operation, such as the decrease of the stripping loss in the accelerator and the reduction of gas loads to cryo-panels. So far, we have obtained the H^- ion current of 3.3 A at the pressure of 0.9 Pa.

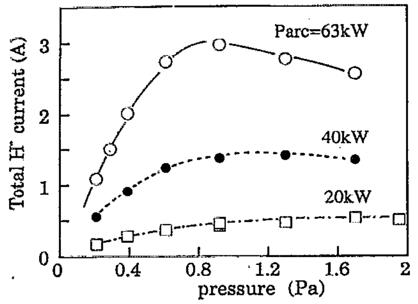

FIG. 6. Total H^- ion currents as a function of the filling gas pressure for three different arc powers; $P_{arc} = 65$ kW (open circles), 40 kW (closed circles), and 20 kW (open squares). $V_{acc} = 17.5$ kV, $V_{ext} = 5.0$ kV.

Since the work function becomes low due to the adsorption of Cs atoms on the metal surface, it is expected that the population of H^- ions is enhanced by the electron capture to hydrogen atoms and that the population of vibrational excitation molecules is enhanced by the collision of the positive ions (H_2^+ and H_3^+) to the cesiated surfaces.[8] These processes may contribute to the enhancement of the H^- ion current. The dependence of the H^- ion current on the grid temperature may be related to the cesium coverage depth on the surface.

IV. CONCLUSIONS

We have utilized the cusp fields for separating the regions and the magnetic filter field for reducing the electron currents in the DMF configuration. The high H^- ion density of more than 1×10^{12} cm^{-3} is observed in the center of the arc chamber.

A small amount of Cs supply enhances the H^- ion current and reduces the operation pressure. These Cs effects are influenced by the plasma grid temperature. The optimum gas pressure decreases with an increase in the arc power. So far, we have obtained 1.4 A H^- ion current in the pure hydrogen discharges and 3.3 A H^- ion current in the Cs-seeded discharges.

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