ISOTOPE AND Cs VAPOR EFFECTS IN AN H⁻ VOLUME SOURCE WITH A TOROIDAL CHAMBER*

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Abstract

A volume source of H^- ions, with a full rotational symmetry, has been designed and studied. We have achieved a pulsed H^- current of 50 mA, at a current density of 25 mA/cm^2. Using a reduced aperture of 1 cm^2, the emittance of a 10 - 16 keV beam was measured for different source parameters, and for a beam current of 20 mA it was found to be less than 0.5 π mm mrad (normalized, 4 rms). When operating with deuterium, the D^- output was found to be 50 - 60% of the H^- current obtained under the same discharge conditions. Adding cesium to the discharge increased the H^- output by a factor of two, while reducing the electron current. After the addition of cesium, greater than 30 mA of H^- could be extracted with $I_e/I_{H^-} \approx 1$.

Introduction

Studies of the BNL volume H^- ion source with a toroidal discharge chamber have been in progress since 1988. The source is intended to one day replace an existing magnetron surface-plasma source and to supply 50 mA of H^- ions in 1 ms pulses to the RFQ and linac injectors for the AGS. The source design is distinguished by its toroidal geometry, with the discharge region surrounding the central extraction region, the separation coming from a conical dipole field. Details of the design were reported previously.[1] The conical dipole field, produced by a permanent magnet disc placed in the center of the filament flange, has been shown to be substantially better than a plane dipole field[2] and the former is now being used exclusively. A circular W filament is used in the source. The parametric study of the source consisted of measurements of the H^- or D^- yield and of the accompanying electron component when varying several source parameters (arc current, extraction voltage, plasma electrode bias, gas density, parameters of the filament, strength of the conical field).

In previous studies, an H^- yield of 15 mA was achieved through the 0.5 cm^2 aperture, 35 mA through 1 cm^2 aperture, and 48 mA through the largest aperture of 1.87 cm^2; the ratio I_e/I_{H^-} varied between 20 and 40.[2] Variation of the negative ion yield as a function of the extraction voltage for a constant arc current shows a steep rise first (the Child-Langmuir $V^{3/2}$ law), followed by a semi-plateau. There is also a dependence on the neutral gas density: the yield increases with the density up to a broad maximum; however, the electron component shows a steep fall down to a broad minimum[3] at about the position of the maximum in the H^- yield. The bias on the plasma electrode had a minor effect on the H^- yield, but a more pronounced one on the electron component:[3] as the bias varied from negative values through zero into the positive region, the H^- yield would slowly decrease but the electron component would decrease much faster, resulting in a lower ratio I_e/I_{H^-}. Filament parameters (heating current, position of the filament, size of the W wire) are very important for the source performance. The behavior of the source depends most on the direction of the filament current and on whether the filament is on or interrupted during the arc pulse; the source performance can be optimized by selecting the proper direction of the filament current and by finding the best position of the filament in the axial direction.[2,3] Finally, preliminary results obtained with a small, pulsed coil replacing the center magnetic disc have shown that there is a broad optimum in the H^- yield as the coil current (or conical field) would increase; the electron component was decreasing with the coil current in the whole range of available values.[2] Preliminary results of emittance measurements[4] were obtained for an H^- current of 20 mA. In the range of beam energies between 10 and 16 keV, the normalized 4 rms emittance was lower than 0.5 π mm mrad.

*Work performed under the auspices of the Dept. of Energy.

This paper will first describe results of comparison studies between hydrogen and deuterium, mainly the dependence of negative ion yields and of the electron component on arc current and the strength of the conical field. The source performance was also studied when some cesium was injected; this effect will be described as well.

Isotope Effects

The source geometry used for isotope studies had the conical dipole field, as shown in Ref. 3; however, a smaller filament was selected for an improved performance at lower arc currents.[2] In all isotope effect studies, the extraction aperture was 1 cm^2, the extraction gap was 0.97 cm, and the plasma electrode grounded. A dipole magnet at the exit of the source produced a line integrated field of $\approx 10^{-3}$ T-m, which efficiently deflected the electrons out of the beam. A Faraday cup to measure the H^- current was located 10 cm from the source. The total extractor power supply loading was measured with a current transformer, and the difference between the total loading and the H^- current in the Faraday cup is assumed to be electrons. The source was operated with a 1.5 ms pulse width, at a 0.5 Hz rep-rate. The gas was pulsed, and the extraction voltage was dc.

Figure 1 shows the negative ion yield as a function of the extraction voltage for several values of the arc current in the range between 20 A and 125 A; for each value of the arc current, the gas density was optimized for the best negative ion yield. It is evident that the negative ion yields for deuterium are only 50% to 60% of those for hydrogen, for equal arc currents and extraction voltages. While the shift of the transition region in the curves (for equal negative ion currents) indicates space charge effects in the extraction gap, differences in the yield in the saturation portions of the curves greater than $(M_H/M_D)^{1/2} = 0.7$ (for equal arc currents) indicate a less efficient production mechanism for deuterium.

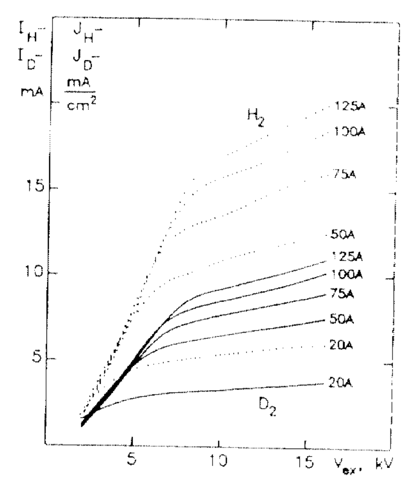

Fig. 1: Negative ion field vs the extraction voltage V_{ex}, with arc current as parameter, for hydrogen (dotted) and deuterium (solid lines).

Figure 2 shows the ratio I_e/I^- as a function of I^-, for a constant extraction voltage of 16 kV and a grounded plasma electrode. In this respect as well, the performance of the source with deuterium is much worse because both the arc power efficiency and the extraction efficiency are much lower than when hydrogen was used.

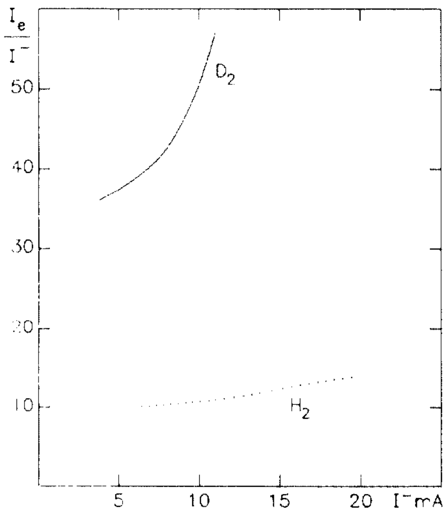

Fig. 2: Ratio I_e/I^- vs I^- for a constant extraction voltage of 16 kV, for hydrogen (dotted) and deuterium (solid line).

An interesting experiment was then performed with the pulsed coil replacing the center permanent magnet. In this way, it was possible to vary the conical field strength from low values up to and beyond the corresponding value for the permanent magnet. The arrangement for timing pulses was such that the current in the coil was initiated first and only after reaching a flattop, the arc was triggered. A coil current of 400 A corresponded approximately to the 3 kG field of the permanent magnet. Figure 3 shows the ratio I_e/I^- as a function of I^-, for several values of the pulsed coil current (in the range 200-600 A). Values of the arc current are indicated on the curves.

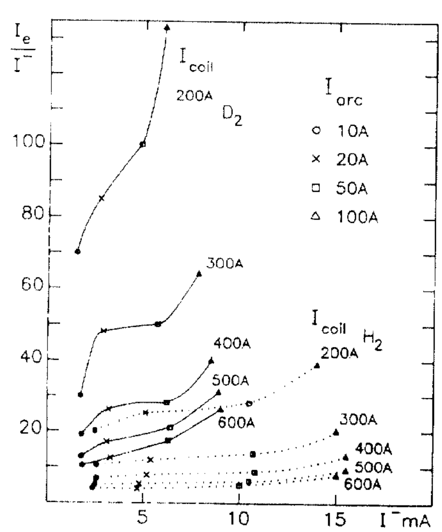

Fig. 3: Ratio I_e/I^- vs I^- for several values of the current in the coil producing the conical dipole field, for hydrogen (dotted) and deuterium (solid lines).

It is true again that the yield and the ratio I_e/I^- are less favorable when the source is running with deuterium; when the performances are compared for the same coil current, the D^- yield is always about 50 - 60% of the H^- yield and the ratio I_e/I^- higher by at least a factor of 3. However, by adjusting the values of the coil current it is possible to match the values $I_e/I^- = f(I^-)$ for the two gases, although the arc efficiencies would still differ. It is, therefore, possible that one could reduce the isotope effect (as manifested in I_e/I^-) by substantially increasing the strength of the conical dipole field when the source is running with deuterium.

Cesium Vapor Effect

The beauty of the volume source, when compared to surface-production H^- sources, is the fact that it operates cesium-free. At several laboratories, however, cesium has been tried in volume sources, and it is of interest to see what the effect of cesium is in this source, since the geometry is quite different from other volume sources.

The experimental setup was the same as that used for the isotope effect studies, except that both 1 cm^2 and 1.87 cm^2 extraction apertures were tried, and a larger diameter filament was used. In our standard configuration, there is a ≈ 5 cm diameter cover over the SmCo disc magnet in the filament flange. This magnet produces the conical filter field, and the cover, which is floating electrically, shields the magnet from the plasma. A small Cs oven was incorporated into this cover. Pellets made from a mixture of cesium dichromate and titanium were placed in the cover, a heater and thermocouple were added to it. When the pellets are heated to 400 - 500 °C, cesium vapor is released. The source had no hot inner liner to the discharge chamber, as was used in Refs. 5 and 6, so cesium presumably condensed fairly quickly on the water cooled chamber walls.

When Cs was added to the discharge, the H^- current increased, one could operate at lower gas pressure, and the electron current decreased. Also, the discharge and H^- current pulses became flatter. Figure 4 shows the H^- current as a function of arc current with and without cesium, for the 1.87 cm^2 aperture. For both the 1 cm^2 and 1.87 cm^2 aperture, the H^- current approximately doubled with the addition of Cs. With the plasma electrode floating, the ratio of electron to H^- current, I_e/I_{H^-} stayed in the range of 10 - 20 for 50 - 150 A arc, and did not change with the addition of Cs. With the plasma electrode grounded, however, the ratio was 5 - 10 at 50 - 150 A without Cs, and dropped to ≤ 1 when Cs was added.

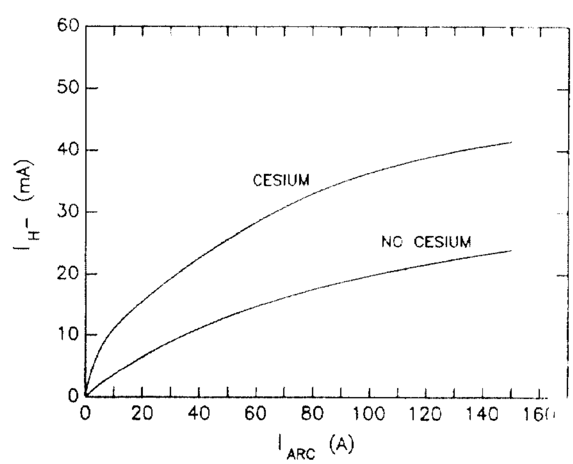

Fig. 4: H^- current vs discharge current, with and without cesium in the source. Extraction voltage = 16 kV.

In Figure 5, the H⁻ current and the I_e/I_{H^-} ratio are shown as a function of bias on the plasma electrode, with and without cesium added. Note that when cesium has been added, one can adjust the plasma electrode bias to get a very low I_e/I_{H^-} ratio without much loss in H⁻ current.

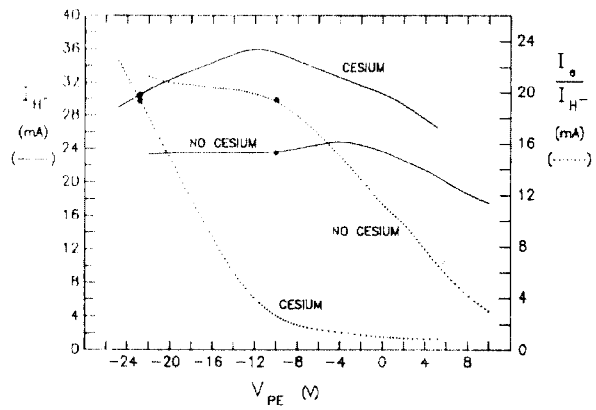

Fig. 5: H⁻ current and electron-to-H⁻ ratio, as a function of the plasma electrode bias, with and without cesium. I_{arc} = 150 A, V_{arc} = 250 V, V_{ext} = 16 kV. The dots indicate the floating potential.

Figure 6 shows an H⁻ current pulse and the power supply loading ($I_e + I_{H^-}$) after adding cesium. We are not aware of any other "volume" H⁻ source which has obtained > 30 mA of H⁻ with < 30 mA of extracted electrons. We have not yet been able to quantify the reduction in operating pressure when Cs was added, but it appears to be at least a factor of two.

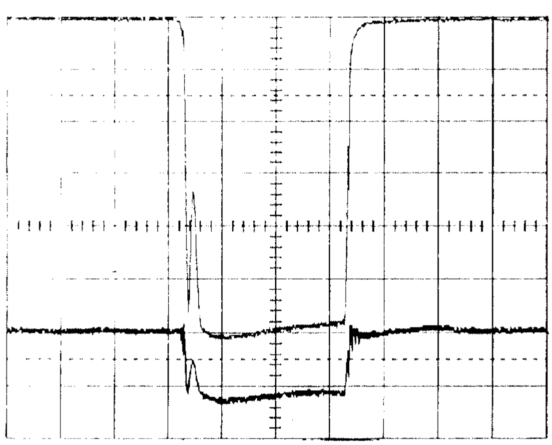

Fig. 6: H⁻ current (upper trace, 5 mA/div.) and total extractor supply load (lower trace, 50 mA/div.). Time Scale = 0.5 ms/div. Taken with cesium in the source.

When the Cs heater was turned off, effects of the Cs remained, except for a partial drop in the H⁻ current. Even when the source was opened to air, but not cleaned, some effects remained. While the H⁻ current dropped back to near the levels before Cs was introduced, the operating pressure remained low, and the I_e/I_{H^-} ratio remained at ≈1. Only a thorough cleaning brought the source back to its original "cesium-free" levels.

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