Lawrence Berkeley National Laboratory
Recent Work

Title
CHARACTERISTICS OF A SMALL MULTICUSP H SOURCE

Permalink
https://escholarship.org/uc/item/6ww341hx

Author
Ehlers, K.W.

Publication Date
1986-10-01

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Accelerator & Fusion Research Division

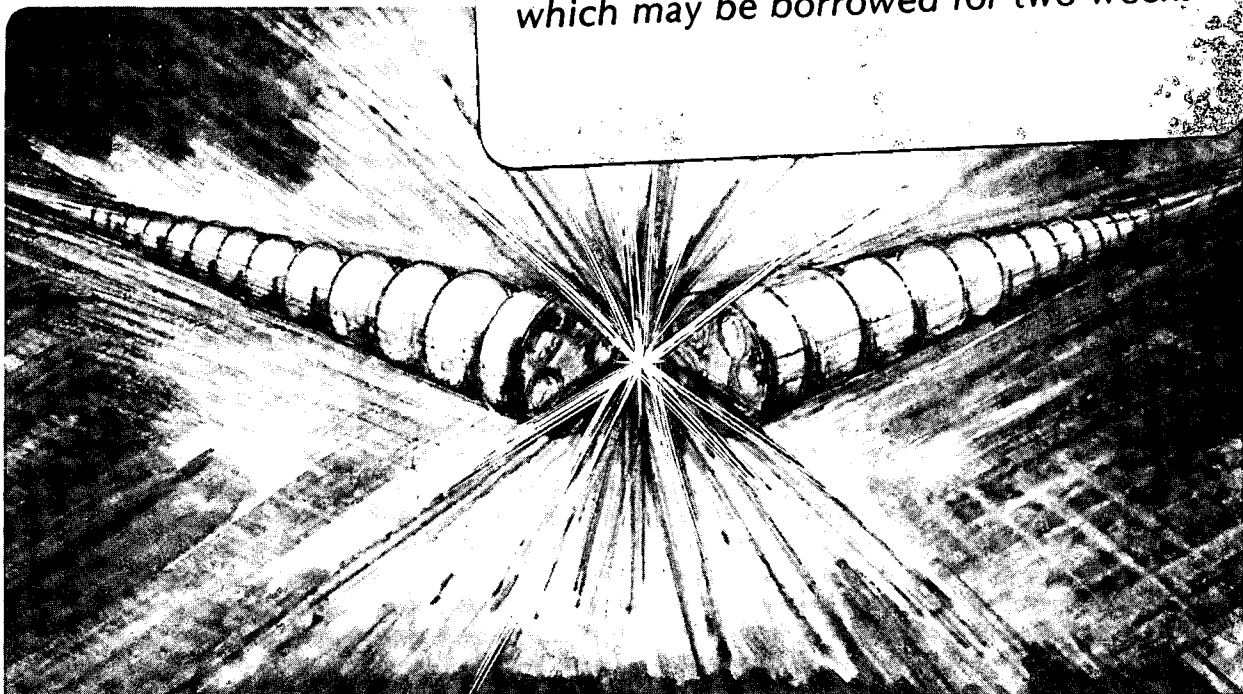**CHARACTERISTICS OF A SMALL MULTICUSP H⁻ SOURCE**

K.W. Ehlers, K.N. Leung, R.V. Pyle, and W.B. Kunkel

October 1986

DISCLAIMER

CHARACTERISTICS OF A SMALL MULTICUSP H⁻ SOURCE*

K. W. Ehlers, K. N. Leung, R. V. Pyle and W. B. Kunkel
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

ABSTRACT

It is shown that the H⁻ current extracted from a magnetically filtered multicusp source can be enhanced by optimizing the extraction chamber length, by employing the proper chamber wall material, by mixing hydrogen with xenon gases in the discharge and by injecting very low energy electrons into the filter and extraction regions. A large improvement in H⁻ yield can be achieved by using a multicusp source with a much reduced plasma volume. In this arrangement, H⁻ current densities as high as 240 mA/cm² have been obtained from a 1-mm-diam extraction aperture.

INTRODUCTION

H⁻ and D⁻ ions are used to generate efficient neutral beams with energies in excess of 150 keV.[1] It has been demonstrated that volume-produced H⁻ ions, extracted from a filter-equipped multicusp source can provide high quality H⁻ beams with sufficient current density (40 mA/cm²) to be useful for both neutral beam heating of fusion plasmas and accelerator applications.[2] In order to produce this high H⁻ current density, it was necessary to operate the source with a discharge current as high as 350 A. For long pulse or dc operations, it is desirable to improve this relatively low arc efficiency so as to reduce source cooling requirements and to prolong cathode lifetime.

Several methods to improve the efficiency of the filter-equipped H⁻ source have been investigated. By optimizing the extraction chamber length, a substantial improvement in the H⁻ output has been achieved.[3] Experimental results have demonstrated that the H⁻ yield can be enhanced by choosing aluminum or copper as the chamber wall material[4] or by mixing hydrogen and xenon gases in the source discharge.[5] A substantial increase in H⁻ yield also occurs when very low-energy electrons (E ≈ 1 eV) are added into the filter or extraction regions.[6] Most recently, a small multicusp source has been fabricated and operated successfully to generate volume-produced H⁻ ions.[7] From this new source, H⁻ current densities as high as 240 mA/cm² have been extracted from a

1-mm-diam aperture. The increase in H⁻ output is mainly due to an increase in the source plasma density.

EXPERIMENTAL SETUP

A schematic diagram of the ion source used for generating volume H⁻ ions is shown in Fig. 1. The stainless-steel source chamber (20 cm diam by 24 cm long) is surrounded externally by 10 columns of samarium-cobalt magnets which form a longitudinal line-cusp configuration for primary-electron and plasma confinement. A samarium-cobalt magnet filter divides the entire chamber into an arc discharge and an extraction region. Detailed description of this filtered multicusp source arrangement has been reported previously.[2,8] In brief, the filter provides a limited region of transverse magnetic field which is strong enough to prevent the energetic primary electrons from entering the extraction zone. However, both positive and negative ions, together with cold electrons are able to penetrate the filter and they form a plasma in the extraction region.
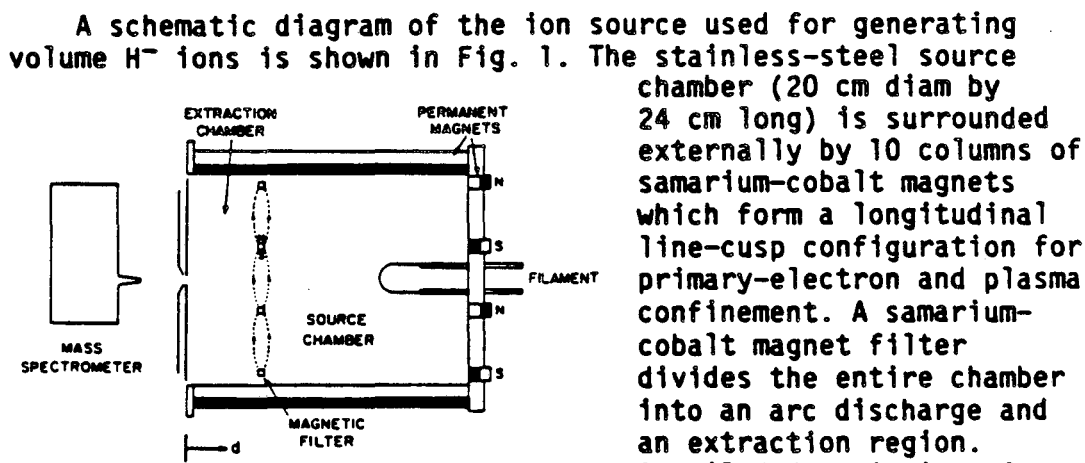
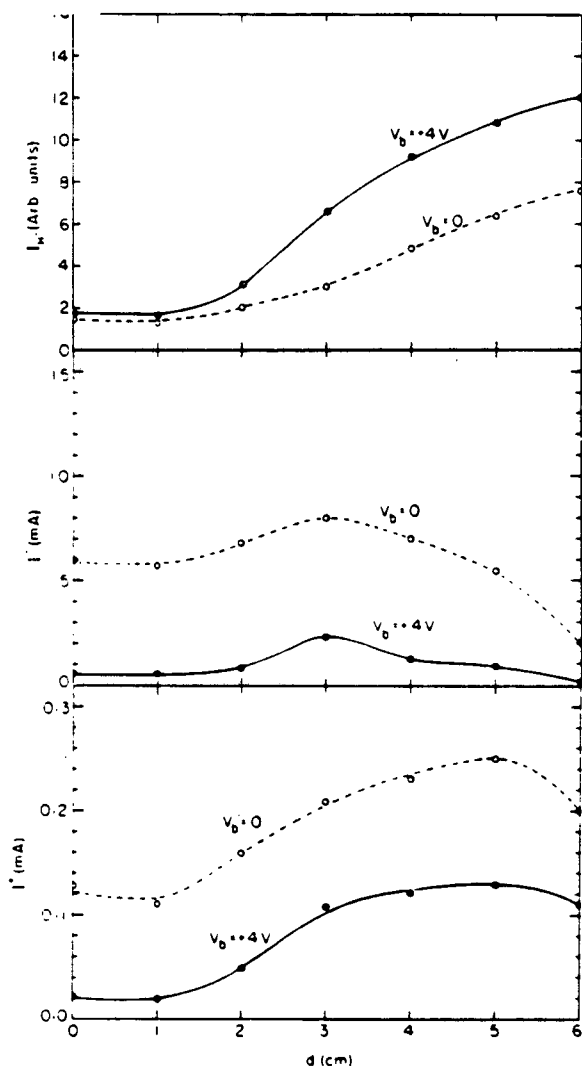Fig. 1 Schematic of the multicusp ion source equipped with a magnetic filter.

The open end of the source chamber is enclosed by a two-electrode acceleration system. Positive or negative ions were extracted from the source through a small 0.1 x 1.0 cm² slot. A steady-state hydrogen plasma was produced by primary electrons emitted from two 0.05-cm-diam tungsten filaments. The entire chamber wall, together with the filter rods, served as the anode for the discharge. In order to optimize the H⁻ output, the first accelerator (or plasma) electrode was biased at a potential more positive than the chamber wall.

Plasma parameters were obtained by small planar Langmuir probes located at the center of the source and extraction chambers. A compact magnetic deflection mass spectrometer,[9] located just outside the extractor was used for relative measurement of the extracted H⁻ ions. In addition, a permanent-magnet mass separator was used with a Faraday cup to measure the extracted H⁻ and electron current. With this arrangement, it is possible to measure the ratio of H⁻ to electron current as well as the extracted H⁻ ion current density.

EXPERIMEMTAL RESULTS

(a) Optimization of Extraction Chamber Length

In order to determine the optimum the length of the extraction chamber, spectrometer system was fabricated.[3]

H⁻ yield as a function of a moveable extraction and Figure 2 summarizes the data that were obtained as the extractor was moved from the edge of the extraction chamber (d=0) towards the plane of the filter (d=6 cm). At each extractor position d, it was found that a small positive bias potential (+4 V) relative to the anode would enhance the H⁻ yield accompanied by a reduction in electron current. The data in Fig. 2(a) show that a substantial increase in H⁻ yield (about a factor of 6) occurs when the extractor is moved from the edge of the source to a position near the filter. This result seems to indicate that a sizable portion of the extracted H⁻ ions are formed in the filter region.

The largest part of the extractor power supply drain current 1^- is composed of electrons. Figure 2(b) and 2(c) illustrate that this drain current 1^- and the extracted positive ion current 1^+ behave similarly when d < 3 cm. When d > 3 cm, 1^- decreases but the positive ion current drain does not, indicating that the electrons are drifted away by the E x B motion in the acceleration gap, or more readily collected on the biased plasma electrode.

XBL 847-2896

Fig. 2 H⁻ yield and the extracted electron and positive ion current as a function of the extractor position.

- 3 -

With the extractor located at d=0, the extractable H⁻ current density for 1 A of discharge current in this test source geometry is 0.12 mA/cm^2 and the ratio of I_e/I_{H^-} is 200. When the extractor is moved very close to the filter (d=6 cm), the H⁻ current density for the same discharge current increases to 0.7 mA/cm^2 and the ratio of I_e/I_{H^-} is less than 2.
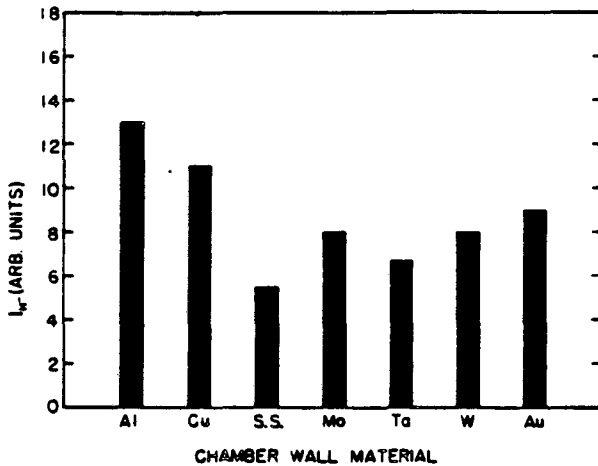

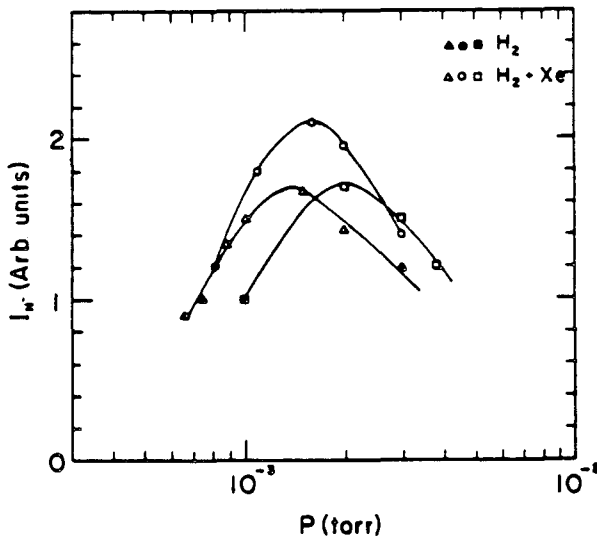Fig. 3 Relative yield of H⁻ ions when the source is operated with different liners.

Fig. 4 The H⁻ yields as a funstion of total hydrogen and xenon pressure for three different hydrogen base pressures (indicated by ▲ ● ■). The discharge is maintained at 80 V, 3 A.

(b) Optimization of Chamber Wall Material for H⁻ Production

To study the effect of wall materials on the H⁻ yield, thin (0.13 mm thick) cylindrical metal liners were installed on the chamber wall.[4] These liners were cleaned in an ultrasonic alcohol bath before installation. To ensure good thermal and electrical contact with the source chamber, two stainless-steel rings were used to force the liner to lie flush against the vessel wall. Figure 3 shows the magnitude of the H⁻ output signal when seven different metal liners are compared under the same plasma conditions. The results show that aluminum and copper generate the highest H⁻ yield while stainless-steel produces the lowest. The H⁻ output of other metal liners such as Mo, Ta, W, and Au falls between those of Al and stainless-steel.

(c) Effect of Mixing H₂ with Xe on H⁻ Production

The effect on the H⁻ yield by adding xenon gas into the hydrogen discharge[5] is illustrated in Fig. 4. The
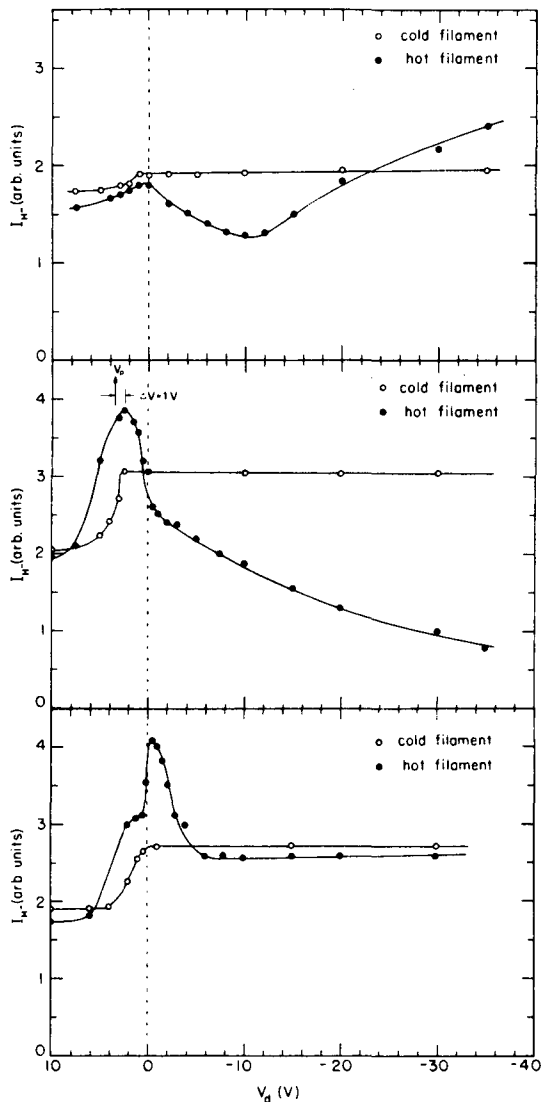
Fig. 5 H^- yield as a function of the discharge voltage of the second filament when it is installed inside (a) the source chamber, (b) the extraction chamber, and (c) the filter region. The data shows the H^- yield when the filament is operated with the without electron emission.
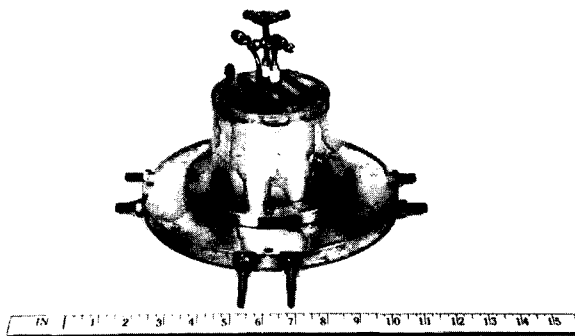
XBL 853-1480A

source was initially operated with only pure hydrogen. As xenon gas was introduced into the discharge, and with the bias potential V_b on the plasma electrode optimized, the H^- output first increased, reached a maximum, and then decreased as the pressure was increased. The data in Fig. 4 also show that the highest H^- output occurs at a total pressure of 1.5 x 10^{-3} Torr when xenon is added to the optimum hydrogen base pressure of 8 x 10^{-4} Torr. At this point, the increase in H^- yield is more than 75% for a constant discharge power of 80 V, 3 A. If the ionization gauge readings on the source pressure are corrected for hydrogen and xenon, then the real increase in pressure due to the addition of xenon gas is just 13%.

(d) Enhancement of H^- Production by Cold Electron Injection

The effect on H^- yield by adding electrons with different energies into the ion source[6] is illustrated in Fig. 5. A background hydrogen plasma was initially produced by a dc discharge of 80 V, 2 A from one set of filaments located in the source chamber. Additional primary electrons are then injected into the source chamber, the extraction chamber or the filter region from a second set of filaments. The emission current from the filament of set 2 was maintained at approximately 1 A. The H^- output as

a function of the discharge voltage of the second filament set when it was positioned in the three regions is presented in Fig. 5. The data in Fig. 5(a) show that there is a reduction in H⁻ yield when electrons with energies lower than the ionization energy of H_2 are introduced into the source chamber. However, an increase in H⁻ output was obtained when electrons with energies ≈ 1 eV are added into the filter or extraction region (Fig. 5(b) and 5(c)). This result indicates that only very low-energy electrons can enhance the formation of the H⁻ ions in the filter or extraction chamber region. Since both dissociative attachment of vibrationally excited H_2 molecules and dissociative recombination of H_2^+ ions have the highest reaction rate for forming H⁻ at these low electron energies, further investigation is required in order to determine the exact process which is responsible for generating the H⁻ ions.

CBB 865-3985

Fig. 6   A small multicusp H⁻ source.

(e) <u>H⁻ Generation from a Small Filtered Multi-cusp Source</u>

In order to generate intense H⁻ beams, a high density source plasma is required. For this reason, a small multicusp source (7.5 cm diam by 8 cm long) has been constructed to generate volume H⁻ ions.[7] This source (Fig. 6) is equipped with a strong neodymium magnet filter and the mag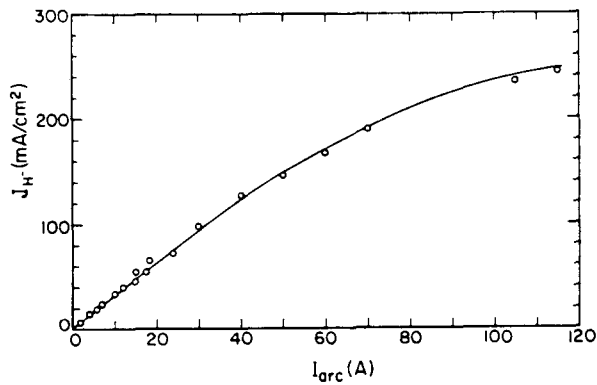netic-field-free discharge volume is small (2.5-cm-diam by 4 cm long). To enhance the H⁻ yield, the chamber wall of the source is fabricated from copper. The first electrode of the accelerator is placed very close to the filter plane so as to reduce the extraction chamber length.

At low discharge power, the plasma density in the source region is about 5 times higher than that of the larger multicusp source described in the previous sections. The spectrometer output signal shows that the H⁻ yield also increase by about the same amount. This small source can be operated with either tungsten or directly-heated LaB_6 cathodes. Since the entire source chamber wall together with the surrounding dipole magnets are cooled by a water jacket, the source is capable of long pulse or steady state operation at high discharge power.

This source has been operated at short pulse lengths (~ 7 ms) to generate a small H⁻ beam (extraction aperture diameter = 1 mm) for arc current as high as 120 A. Figure 7 is a plot of the extracted H⁻ current density J_{H^-} versus the

Fig. 7 Extracted H⁻ current density versus arc current.

discharge current for a constant arc voltage of 150 V. The result demonstrates that H^- current densities as high as 240 mA/cm^2 can be obtained from the source with an arc current of about 120 A. The ratio of extracted electron current of H^- current is about 4. Experiments are now planned to enlarge the aperture size so that higher H^- current can be extracted.

REFERENCES

1. K. H. Berkner, R. V. Pyle, and J. W. Stearns, Nucl. Fusion 15, 249 (1975).
2. R. L. York, Ralph R. Stevens, Jr., K. N. Leung, and K. W. Ehlers, Rev. Sci. Instrum. 55, 681 (1984).
3. K. N. Leung, K. W. Ehlers, and R. V. Pyle, Rev. Sci. Instrum. 56, 364 (1985).
4. K. N. Leung, K. W. Ehlers, and R. V. Pyle, Appl. Phys. Lett. 47, 227 (1985).
5. K. N. Leung, K. W. Ehlers, and R. V. Pyle, Rev. Sci. Instrum. 56, 2097 (1985).
6. K. N. Leung, K. W. Ehlers, and R. V. Pyle, Rev. Sci. Instrum. 57, 324 (1986).
7. K. N. Leung, K. W. Ehlers, R. V. Pyle, and W. B. Kunkel, (to be published).
8. K. N. Leung, K. W. Ehlers, and M. Bacal, Rev. Sci. Instrum. 54, 56 (1983).
9. K. W. Ehlers, K. N. Leung, and M. D. Williams, Rev. Sci. Instrum. 50, 1031 (1979).