Lawrence Berkeley National Laboratory

Recent Work

Title

ENHANCEMENT OF H PRODUCTION IN A MULTICUSP SOURCE BY COLD ELECTRON INJECTION

Permalink

<https://escholarship.org/uc/item/62p5242h>

Authors

Leung, K.N.
Ehlers, K.W.
Pyle, R.V.

Publication Date

1985-08-01

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

RECEIVED
LAWRENCE
BERKELEY LABORATORY
NOV 20 1985
LIBRARY AND
DOCUMENTS SECTION

Accelerator & Fusion Research Division

Submitted to Review of Scientific Instruments

ENHANCEMENT OF H^- PRODUCTION IN A MULTICUSP
SOURCE BY COLD ELECTRON INJECTION

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

August 1985

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy
which may be borrowed for two weeks.*

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Enhancement of H^- Production in a Multicusp Source by
Cold Electron Injection*

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

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

August 1985

Abstract

The effect on H^- production by injecting primary electrons with different energies into the three regions of a magnetically filtered multicusp source has been investigated. A substantial increase in H^- yield occurs only when very low energy electrons ($E \approx 1$ eV) are added to the plasma in the filter or extraction chamber region. If the H^- ions are formed by dissociative attachment of vibrationally excited H_2 , then the low-energy electron injection scheme could maintain a low average H^- ion energy which in turn could improve the brightness of the extracted beam.

* This work is supported by the Air Force Office of Scientific Research and by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division of the U.S. Department of Energy under contract No. DE-AC03-76SF00098.

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 ($\sim 40 \text{ mA/cm}^2$) 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 prototype source with a discharge current as high as 350 A. Several methods to improve the efficiency of the filter equipped H^- source have been investigated and reported. By optimizing the extraction chamber length, a factor of 6 improvement in the H^- output has been achieved.³ Experimental results have also indicated that the H^- yield can be enhanced by choosing aluminum or copper as the chamber wall material.⁴

In this paper, the effect on volume H^- production by injecting electrons with different energies into the three regions of the source is studied. We have found that a substantial increase in H^- yield occurs only when very low energy electrons ($E \approx 1 \text{ eV}$) are added into the filter or extraction regions. If dissociative attachment of vibrationally-excited molecules is the primary process responsible for forming the H^- ions, then this low-energy electron injection scheme could maintain a low average H^- ion energy which could in turn improve the brightness of the extracted H^- beam.

I. Experimental Setup

A schematic diagram of the apparatus 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.⁵ These magnet columns are connected at the end flange by four extra rows of magnets. 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.^{2,3,6} 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.

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 $0.1 \times 1.0 \text{ cm}^2$ slot. In order to optimize the H^- output, the first accelerator (or plasma) electrode was biased at a potential equal to, or more positive than the chamber wall.⁶ A steady-state hydrogen plasma was produced by primary electrons emitted from two 0.05-cm-diam tungsten filaments (indicated as set 1 in Fig. 1). The entire chamber wall, together with the filter rods, served as the anode for the discharge.

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,⁷ located just outside the extractor was used for relative measurement of the extracted H^- ions as well as for the analysis of positive ion species. In this experiment, a dc discharge of 80 V, 2 A was employed to generate a source chamber plasma density of approximately $1.5 \times 10^{11} \text{ cm}^{-3}$ at a source pressure of 2×10^{-3} Torr. The plasma density in the extraction region was about $6 \times 10^{10} \text{ cm}^{-3}$.

II. Experimental Results

A second tungsten filament is used to inject additional electrons into the background plasmas. This filament (indicated as set 2 in Fig. 1) can be installed in the source chamber, the filter region or in the extraction chamber. In order to reach the emission temperature, this 0.05-cm-diam filament is typically heated by a dc current of ~ 22 A. The magnetic field generated around the filament by this heater current is strong enough to prevent low energy electrons from leaving the filament.⁸ Thus, emission from the filament is difficult to obtain when the voltage V_d applied between the filament and the anode is low.

The presence of the heater voltage V_h also introduces the possibility of a broad spectrum of energies for the emitted electrons. In principle, the energy acquired by these electrons can vary between eV_d and $(eV_d \pm eV_h)$, depending on whether the discharge power supply is connected to the positive or negative terminal of the filament heater supply. If $V_d \leq V_h$, the spread of the emitted electron energies can be very large and in this case, the result of the H^- ion output measurement would be difficult to interpret.

Both problems can be resolved if data are obtained immediately after the heater current of this second filament is pulsed off as this removes both the magnetic field and V_h . Because of the relatively long thermal time constant of the tungsten filament, Fig. 2(a) shows that with $V_d = 0$ V, a nearly constant emission current of 1 A can be maintained for more than 100 ms. A fast sweep of the spectrometer is taken within a period of 50 ms after the heater voltage is pulsed off. The H^- or the positive ion spectrum can be displayed on a storage oscilloscope as shown in Fig. 2(b) and (d).

(a) Electron injection into the source chamber

The data presented in Fig. 3 were obtained with the background hydrogen plasma produced by a dc discharge of 80 V, 2 A from the filaments of set 1. Figure 3 (a) shows the H^- output as a function of the discharge voltage of the second filament set when it was positioned in the source chamber. The emission current from the filament of set 2 was maintained at approximately 1 A. When electrons with energies of several eV are emitted into the source chamber, the H^- output gradually decreases and reaches a minimum at $V_d \approx -12$ V. As V_d becomes more negative, the H^- yield increases again.

The reduction in the H^- output for $0 > V_d > -23$ V (compared with no electron emission) is due to several effects. Injection of electrons into the source plasma with energies less than the ionization potential energy of the hydrogen gas can increase the plasma electron temperature T_e but slightly reduce the source plasma density.^{9,10} Because of the increase in T_e and the presence of more energetic electrons, the stripping rate of H^- ions by electrons is enhanced. The cross section for this interaction peaks at $E \approx 13$ eV ($\sigma = 5.5 \times 10^{-15} \text{ cm}^2$)¹¹ which is almost equal to the electron injection energy when the H^- output is the minimum. In addition, the rate of H^- formation by dissociative attachment of vibrationally-excited H_2 molecules or by dissociative recombination of H_2^+ ions also decreases as T_e increases and the plasma density decreases.¹²⁻¹⁴ Due to these combined effects, the H^- output is much reduced as V_d is changed from 0 to -20 V.

When V_d is adjusted below -20 V, the injected electrons will have enough energy to ionize or to vibrationally excite the neutral molecules. The background plasma density increases but with no significant change in T_e . As a result, the production rate of the H^- ions in the whole chamber is enhanced and the H^- output is improved. In fact, Fig. 3(a) shows that the H^- yield is even higher than the yield when there is no emission from this second filament.

(b) Electron injection into the extraction chamber

The effect on the H^- yield when electrons were emitted into the extraction chamber from the second filament is illustrated in Fig. 3 (b). When the electron energy is increased by increasing the negative bias on the filament, the H^- output is reduced. However, unlike the data shown in Fig. 3(a), the H^- yield decreases monotonically even when V_d is below -20 V. The continuous drop in H^- yield is caused by the presence of energetic electrons which contribute mainly to the destruction of H^- ions. The extraction chamber now becomes essentially a multicusp source without a filter. Extraction of H^- ions becomes difficult due to the presence of a larger potential gradient. The H^- output decreases which is consistent with the result observed in a previous experiment.⁶

As the bias voltage on the second filament becomes slightly more positive than the anode potential, the H^- output increases and reaches a maximum at a filament bias of about +2.5 V. At this point, there is an increase of about 27% over the yield when there is no emission from the filament. As determined from Langmuir probe traces, the potential of the plasma in the extraction chamber is about +3.5 V with respect to the anode walls. Thus, the maximum H^- yield occurs when the electron injection energy is approximately 1 eV.

When the filament is biased more positive than the plasma potential, electron emission becomes difficult as there is no potential to remove electrons from the filament. In addition, the entire filament becomes a loss element as it can absorb H^- ions and cold electrons from the surrounding plasma. As a result, the H^- ion density and therefore the extracted H^- beam decreases again as illustrated in Fig. 3(b).

(c) Electron injection into the filter region

Figure 3(c) shows the results obtained when the second filament is installed at the center of the magnetic filter. It is difficult to determine accurately the plasma potential in the filter region due to the presence of the magnetic field. Since the maximum of the H^- yield now occurs at $V_d \approx 0$ V, the plasma potential in the central plane of the filter could be 1 V more positive than the anode potential.

The region between two filter rods resembles a Penning discharge geometry.¹⁵ If the plasma potential is slightly more positive than the potential of the filter rods, low energy electrons and H^- ions can be trapped by the potential barrier while both positive ions and energetic electrons can be lost to the filter elements. Low energy negatively charged particles oscillate along the field lines between the rods and their presence can cause a depression in the local plasma potential.¹⁶ Figure 3(c) shows that the presence of a higher concentration of electrons with $E \approx 1$ eV did enhance the H^- yield by more than 52%, while the increase in total discharge power was less than a percent. Langmuir probe traces indicate that the plasma density in the extraction chamber has also increased by approximately 50%. However, there was no appreciable change in the positive hydrogen ion species distribution as illustrated by the mass spectra in Figs. 2(c) and (d).

The above results indicate that only very low energy electrons can enhance the formation of the H^- ions in the filter or extraction chamber region. But 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.¹⁴ Thus, further investigation is required in order to determine the exact process which is responsible for generating the H^- ions.

(d) Improving the brightness of the H^- beam

In the past, it has been observed that as the discharge power is increased, the electron temperature in both the source and extraction chambers increase accordingly. Electron temperatures as high as 2 eV or more have been measured near the extractor when a discharge power of 30 kW was supplied to this filtered multicusp source geometry.¹⁷ We have also observed experimentally that as the discharge power is increased, the emittance of the H^- beam grows, indicating that the H^- ion temperature may have increased.²

The quality of the extracted H^- beam is commonly defined by the "brightness" which varies inversely proportional to the H^- temperature.¹⁸ If one assumes that dissociative attachment of vibrationally excited H_2 molecules is the main formation process, then the average energy of the H^- ions formed will depend on the electron temperature in the region where the H^- ions are produced. The dependence of the average H^- ion energy on T_e has been calculated by Wadehra.¹⁹ It is found that the average H^- energy rises rapidly (about a factor of 4) when T_e is increased from 0.5 to 2 eV. Thus, the need for cold electrons in the filter and extraction regions may be important for improving the H^- beam brightness as well as for increasing the H^- production.

Attempts have been made to reduce the electron temperature of the plasma in the extraction chamber by the cold electron injection technique described in the previous sections. The experiment was performed with a low source pressure of 4×10^{-4} Torr. With the source operated at a discharge of 80 V, 3 A from the filaments of set 1, a higher electron temperature of 1 eV was obtained for the extraction chamber plasma as illustrated by the probe trace in Fig. 4(a). The H^- output is small as indicated by the spectrometer output signal (Fig. 4(a)). When electrons with energies ≈ 0.5 eV were injected into

the extraction chamber from the second filament, the electron temperature was reduced to 0.5 eV as shown in Fig. 4(b). The probe trace also indicates that the density of the extraction chamber plasma has increased by a factor of 3. However, the H^- yield has improved by more than a factor of 4. The additional increase in the H^- yield is due to the reduction in T_e which has already been discussed in the previous sections.

Although we have not as yet shown experimentally that the decrease in T_e has resulted in a decrease in the H^- energy as we suspect, we are planning to measure the H^- energy before and after the injection of the cold electrons. The results of this investigation will be reported in the near future.

Acknowledgment

We would like to thank D. Moussa and D. Kippenhan for technical assistance. This work was supported by the Air Force Office of Scientific Research and by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division of the U.S. Department of Energy under contract No. DE-AC03-76SF00098.

Figure Captions

Fig. 1 Schematic diagram of the multicusp ion source equipped with a magnetic filter.

Fig. 2 Oscilloscope traces showing (a) the emission current from the second filament and the magnet current as a function of time, (b) the H^- ion signal, and (c) and (d) the positive hydrogen ion species distribution without and with low energy electron emission from the second filament.

Fig. 3 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 and without electron emission.

Fig. 4 Oscilloscope traces showing the Langmuir probe characteristics and the H^- ion signal when the source is operated (a) without, and (b) with very low energy electrons emitted into the extraction chamber.

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, T. K. Samec, and A. Lamm, Phys. Lett. A51, 490 (1975).
6. K. N. Leung, K. W. Ehlers, and M. Bacal, Rev. Sci. Instrum., 54, 56 (1983).
7. K. W. Ehlers, K. N. Leung, and M. D. Williams, Rev. Sci. Instrum., 50, 1031 (1979).
8. K. W. Ehlers and K. N. Leung, Rev. Sci. Instrum., 50, 356 (1979).
9. Noah Hershkowitz and K. N. Leung, Appl. Phys. Lett., 26, 607 (1975).
10. K. N. Leung, R. D. Collier, G. R. Taylor, and R. E. Kribel, Appl. Phys. Lett., 31, 154 (1977).
11. Udit Narain and N. K. Jain, J. Phys. B 9, 917 (1976).
12. J. R. Hiskes, A. M. Karo, M. Bacal, A. M. Breneteau, and W. G. Graham, J. Appl. Phys. 53, 3469 (1982).
13. B. Peart and K. T. Dolder, J. Phys. B 8, 1570 (1975).
14. J. R. Trow, (Ph.D. Thesis) Lawrence Berkeley Lab. Report LBL-19136 (March 1985).
15. F. M. Penning and J. H. A. Moubis, Physica, 4, 1190 (1937).
16. P. Rohwer, H. Baumann, W. Schutze, and K. Bethge, Nucl. Instr. and Meth. 211, 543 (1983).
17. P. A. Pincosy, K. W. Ehlers, and A. F. Lietzke, Lawrence Berkeley Lab. Report LBL-17732.

18. Paul Allison, Joseph D. Sherman, and H. Vernon Smith, Jr., Los Alamos National Lab. Report LA-8808-MS (June, 1981).
19. J. M. Wadehra, Phys. Rev. A 29, 106 (1984).

Fig. 1

(b)

(d)

(d)

XBB 853-1899

Fig. 2

XBL 853-1480A

Fig. 3

XBB 854-3417

Fig. 4

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

*LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720*