Title
TESTING OF A H[SUP]+ [SUB]2 ENRICHED ION SOURCE FOR DEUTERIUM SIMULATION

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Publication Date
1989-06-01

LBL-26824

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Presented at the 1989 International Conference on Ion Sources, Berkeley, CA, July 10–14, 1989, and to be published in Review of Scientific Instruments

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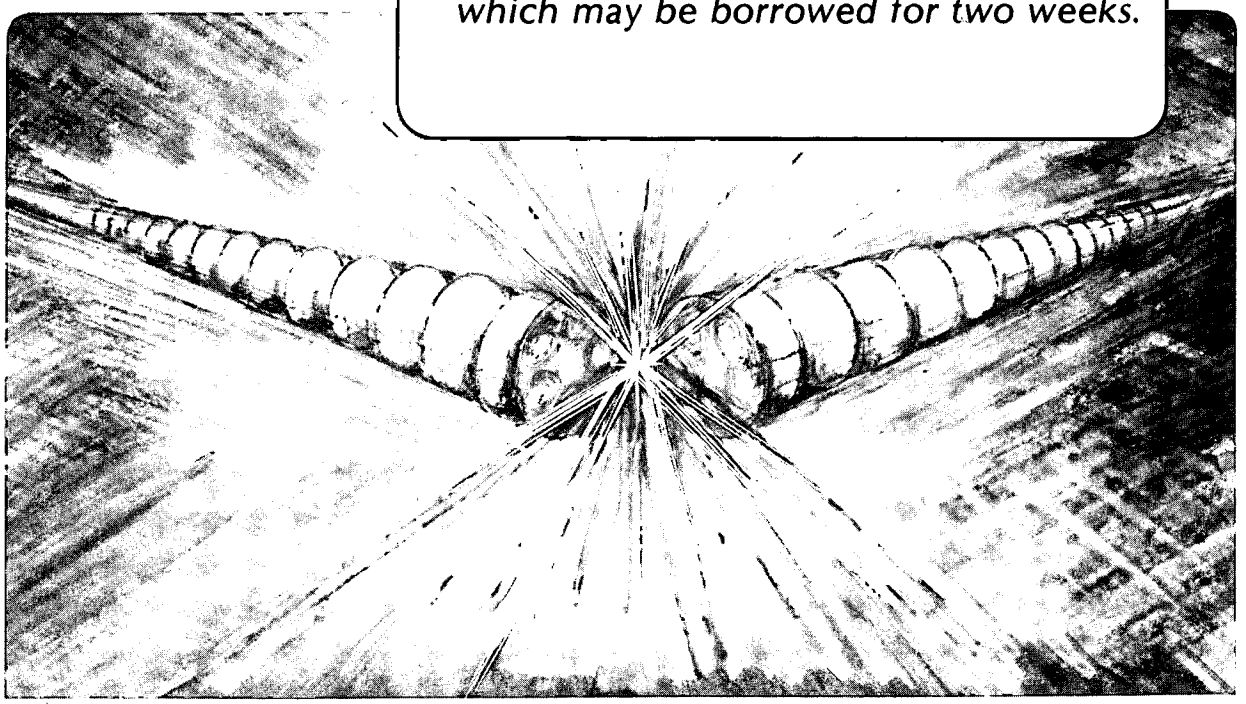

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

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LBL-26824

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Work is supported by McDonnell Douglas Astronautics Co. and the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

June 14, 1989

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ABSTRACT

We have tested a McDonnell Douglas short multi-cusp plasma generator, designed to generate a positive hydrogen ion beam which is enriched with H_2^+ ions. Initial testing shows that the prototype source is capable of producing a positive hydrogen ion beam with H_2^+ percentage greater than 85 %. The total ion current density was 56 mA/cm^2. For a higher current density of 110 mA/cm^2, the percentage of H_2^+ ions is approximately 73 % as measured by a magnetic deflection spectrometer. A comparison between tungsten and lanthanum hexaboride cathodes shows that tungsten filaments can provide better performance. We have also operated the Berkeley 7.5-cm-diam. multicusp source without the magnetic filter. It is found that this source is also capable of generating H_2^+ fractions larger than 75 %.

* Work is supported by McDonnell Douglas Astronautics Co. and the U.S. DOE under contract No. AC03-76SF00098

I. Introduction

There are many applications that require D^+ or D^- ion beams. In order to minimize neutron production during testing of high energy injector components, it is advantageous to employ H_2^+ ions which have the same mass as atomic deuterium ions. A development program is underway to develop a high energy accelerator for space flight. The Cryogenic Accelerator Development Program is being undertaken to demonstrate the high power Q enhancement and increased efficiency of an Radio Frequency Quadrapole (RFQ) accelerator operating at cryogenic, liquid hydrogen (LH_2), temperatures.

A molecular H_2^+ injector was selected to serve as a surrogate for an atomic D^- injector for ground testing of the accelerator. The use of molecular hydrogen in place of atomic deuterium eliminates the radiation problems that would be present at both the injector energy and at the ultimate accelerator energy of multi-MeV. A source capable of producing the necessary H_2^+ enriched plasma was required. A high concentration H_2^+ multicusp source, similar to that previously reported by Ehlers and Leung,[1] was selected. The technology associated with this source is easily extended to that of the D^- source, which is a key contender for negative ion production for the NPB program.

II. Source Description

The short multicusp plasma source (10 cm-long by 17 cm-diam.) was engineered to meet spacecraft flight type lightweight structure and material reliability requirements. The ion source housing was integrally machined from aluminum to minimize the number of vacuum seals required. The ion source was thermally designed for compatibility with a spacecraft flight-type active cooling system. Integral channels were incorporated into the source housing for a liquid freon cooling system. The ion source side-wall contained ten samarium-cobalt magnets arranged in evenly spaced notches around the exterior of the source chamber housing. The rear wall contains four slots for permanent magnets.

Passages were drilled between each of the side wall and rear wall magnets to provide cooling of the magnets near the cusp field interface with the inner arc chamber wall. The cathode assembly and gas feed are mounted on the rear wall.

The chamber flange was used as the structural support which provided a single vacuum sealing surface for both the ion source and the accelerator column subsystems. The plasma and extraction electrodes were supported from the ion source flange. The plasma electrode contained a single aperture (1-mm-diam) and was made from molybdenum. Ten permanent magnets were mounted radially on the plasma electrode and arranged so as to provide continuous line cusps to the rear wall. Integral cooling was provided around each magnet column. In this arrangement, a field-free region of approximately 4 cm diameter exists around the extraction aperture.

The extraction electrode was fabricated from molybdenum and was supported by a lightweight aluminum structure designed for maximum vacuum pumping in the extraction region. The plasma and extractor electrodes were preassembled and aligned to each other, and were then attached to the ion source.

Additional testing was done with the Berkeley 7.5-cm-diam multicusp source described by Leung et al.[2] This source, without the permasnent magnet filter assembly, was adapted to the Mcdonnell-Douglas extractor assembly.

III. Experimental Setup

The plasma source/extractor assembly was mounted on a vacuum chamber equipped with a mass analyzer as illustrated in Fig. 1. The ion source chamber was electrically isolated from the vacuum chamber and was biased positively so as to extract positive ions. Extraction voltage was limited to 4 kV due to the isolation limits of the primary power transformers. The species measurement was accomplished with an 180^{o} magnetic mass spectrometer, similar to that reported by Ehlers et al.[3] There are three Faraday cups, at radii of 2.5, 5 and 7.5 cm (Fig.1) Measurements were typically made with the 5 cm radius because a sufficiently large signal can be obtained with a reasonable magnet current. The

gas pressure in the source chamber was measured with a capacitive manometer attached coaxially with the gas inlet tube.

IV. Experimental Procedure

The source was operated in a pulsed mode with a typical pulse duration of 1 msec and a repetition rate of 5 Hz. The gas feed was continuous and the source pressure was monitored with a capacitive manometer. The discharge was driven by a capacitive discharge power supply gated through a transistor switch.

The mass spectrometer was operated by an automatic sweep circuit. The discharge timing circuit also triggered a timing gate which allowed precise selection of the sampling time. The trailing edge of the timing gate triggered a sampling gate which then triggered the sampling and hold circuit. The sampling and hold output was connected to the Y input of an X-Y recorder. The X co-ordinate was driven by the output of the sweep circuit.

The species measurement was made by comparing the heights of the three ion components (H^+, H_2^+, and H_3^+). The output current was taken as the sum of the currents to the extraction electrode, the spectrometer body and the beam dump. Measurements were made under various discharge conditions, by varying the source pressure, discharge voltage and current, and cathode position. Most measurements were made with the McDonnell-Douglas source. However, additional testing has been made with the Berkeley 7.5-cm-diam multicusp source.[1]

V. Experimental Results

The source was first tested with a 1 cm. diameter coaxial lanthanum hexaboride (LaB_6) cathode placed at the center of the source.[4] The entire chamber including the plasma electrode was used as the anode for the discharge. (The source was also operated with the plasma electrode tied to cathode or electrically floating. In both cases the source efficiency was greatly reduced.)

Initial results were not as expected. The first species measurements indicated the

H^+, H_2^+ and H_3^+ components to be 55, 16 and 29 % respectively. Moving the cathode toward the plasma electrode improved the H_2^+ component as seen in Fig. 2. This result confirms the data previously reported by Ehlers and Leung.[1] It was difficult to attain H_2^+ fractions greater than 40 %. It was suspected and confirmed with inspection that there was a magnetic field shadowing the exit aperture. It was found that two of the vendor supplied plasma electrode magnets were less than 35 % of full strength. This generated a field of ≈ 8 gauss which extended several centimeters into the plasma chamber. While awaiting replacements, the source electrode magnets were rearranged so that the net field near the exit aperture was reduced to less than 5 gauss. H_2^+ fractions of 60 % were attainable in this configuration. It was also observed that with the higher magnetic field, the H^+ fraction was enhanced. This is in agreement with previous reports on enhancing atomic H^+ production by employing a filter magnetic field.[5-7] Installation of the replacement magnets, resulted in a net field of less than 2 gauss. The H_2^+ fraction was immediately improved to > 70%.

Several (LaB_6) cathodes were operated in early tests. It was difficult to strike a discharge below 100 volts and the output was time dependent at higher discharge power. The LaB_6 cathode was replaced with two 0.1-cm-diam tungsten hairpin filaments. The discharge would operate at lower voltages and with little time dependence. The discharge characteristics were repeatable. The tungsten filaments were used for the remaining tests.

Figure 3 shows a plot of the H_2^+ fraction as a function of discharge current, I_d, for a constant discharge voltage, V_d, of 50 volts for several source pressures. It can be seen that the H_2^+ component decreases dramatically with increased pressure.

It can be seen in Fig. 4 that the positive ion output at a constant I_d decreases with increased V_d. This is explained by the fact that the cathode is positioned very close to the plasma electrode which is the main anode for the discharge. As V_d is increased, the

residence time for the primary ionizing electrons is decreased. Therefore the ionizing efficiency will decrease with increasing V_d. This condition was observed at all gas pressures.

Figure 5 illustrates the relationship of the discharge voltage to the H_2^+ fraction. For a constant gas pressure and I_d, increasing V_d, results in the reduction of the H_2^+ fraction. This observation was true at all measured source pressures.

Figure 6 shows the spectrometer output signal for operation at a source pressure of 8 mTorr, V_d of 50 V and I_d of 13 A. An H_2^+ fraction as high as 87 % can be obtained. However, operation above 13 A was not possible at this pressure.

The Berkeley small multicusp source (7.5-cm-dia by 7.5-cm-long) was adapted to the extractor and given some limited tests. This source could be operated with the plasma electrode tied to the cathode rather than the anode, presumably due to a larger anode (or cusp) area than the McDonnell Douglas source. H_2^+ components in excess of 70 % were easily attained with this source.

VI. Conclusion

It has been shown that a short multicusp plasma chamber operated under the proper conditions can provide a stable H_2^+ enriched ion beams. The primary requirements are: (1) the cathode must be sufficiently close to the exit aperture so that molecules once ionized, may be extracted before they dissociate to atomic ions or react with H_2 to form H_3^+ ions; (2) the volume between the cathode and exit aperture must be free of magnetic fields so that the primaries can ionize the molecules as close to the exit aperture as possible; (3) the discharge voltage must be reasonably low so that the primary electrons can perform ionization before reaching the anode walls; and (4) the gas pressure must be kept low so as to reduce the possibility of converting the H_2^+ into H_3^+ ions before extraction.

The tests were very successful in demonstrating that the McDonnell-Douglas source

can provide a plasma with a H_2^+ component greater than 70 % and a total ion density greater than 100 mA/cm^2.

Acknowledgements

We would like to thank C. Hauck, S. Wilde, M. West, D. Moussa and G. Leonard for their Technical assistance. We also thank Jan deVries for his designs of the sample and hold and magnet sweep circuits. This work was supported by McDonnell Douglas Astronautics Co. and the U.S.DOE under contract No. AC03-76SF00098.

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2. K. N. Leung, K. W. Ehlers, C. A. Hauck, W. B. Kunkel and A. F. Lietzke. Rev. Sci. Instrum. 59, 453 (1988).
3. K. W. Ehlers, K. N. Leung and M. D. Williams. Rev. Sci. Instrum. 50, 1031 (1979).
4. K. N. Leung, D. Moussa, and S.B. Wilde.Rev. Sci. Instrum. 57, 1274 (1983).
5. K. W. Ehlers and K. N. Leung. Rev. Sci. Instrum. 52, 1452 (1981).
6. K. W. Ehlers and K. N. Leung. Rev. Sci. Instrum. 53, 1423 (1982)
7. K. W. Ehlers and K. N. Leung. Rev. Sci. Instrum. 54, 1296 (1983).

Figure Captions

1. Diagramatic drawing of the plasma source with diagnostics.
2. The H_2^+ component as a function of the distance of the cathode from the source electrode aperture.
3. The H_2^+ component as a function of discharge current for several source gas pressures.
4. The extracted total ion density as a function discharge current for several discharge voltages.
5. The H_2^+ component as a function of discharge current at various discharge voltages. Source pressure 22 mTorr .
6. Spectsometer output signal showing the distribution of hydrogen ion species. This was the highest H_2^+ fraction attained.

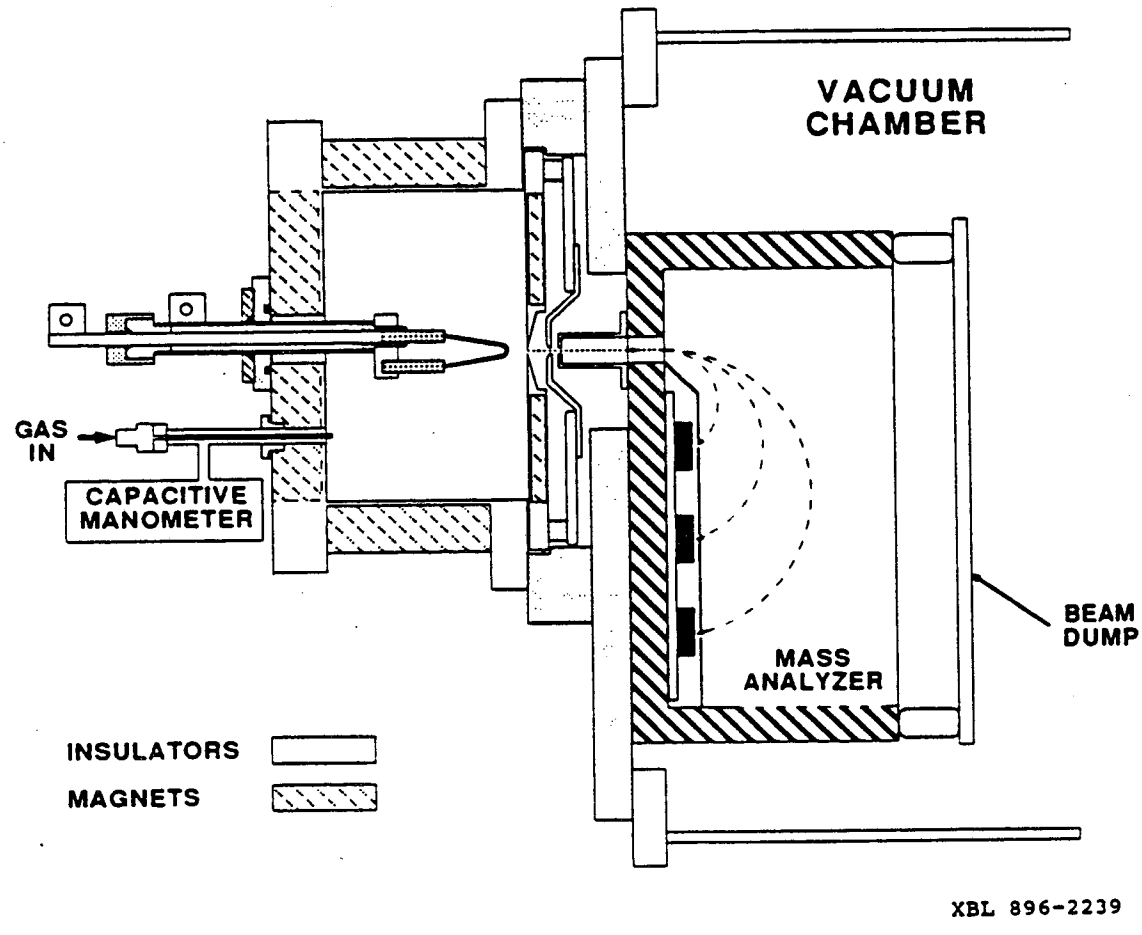
VACUUM
CHAMBER
GAS
IN
CAPACITIVE
MANOMETER
BEAM
DUMP
MASS
ANALYZER
INSULATORS
MAGNETS
XBL 896-2239

Figure 1

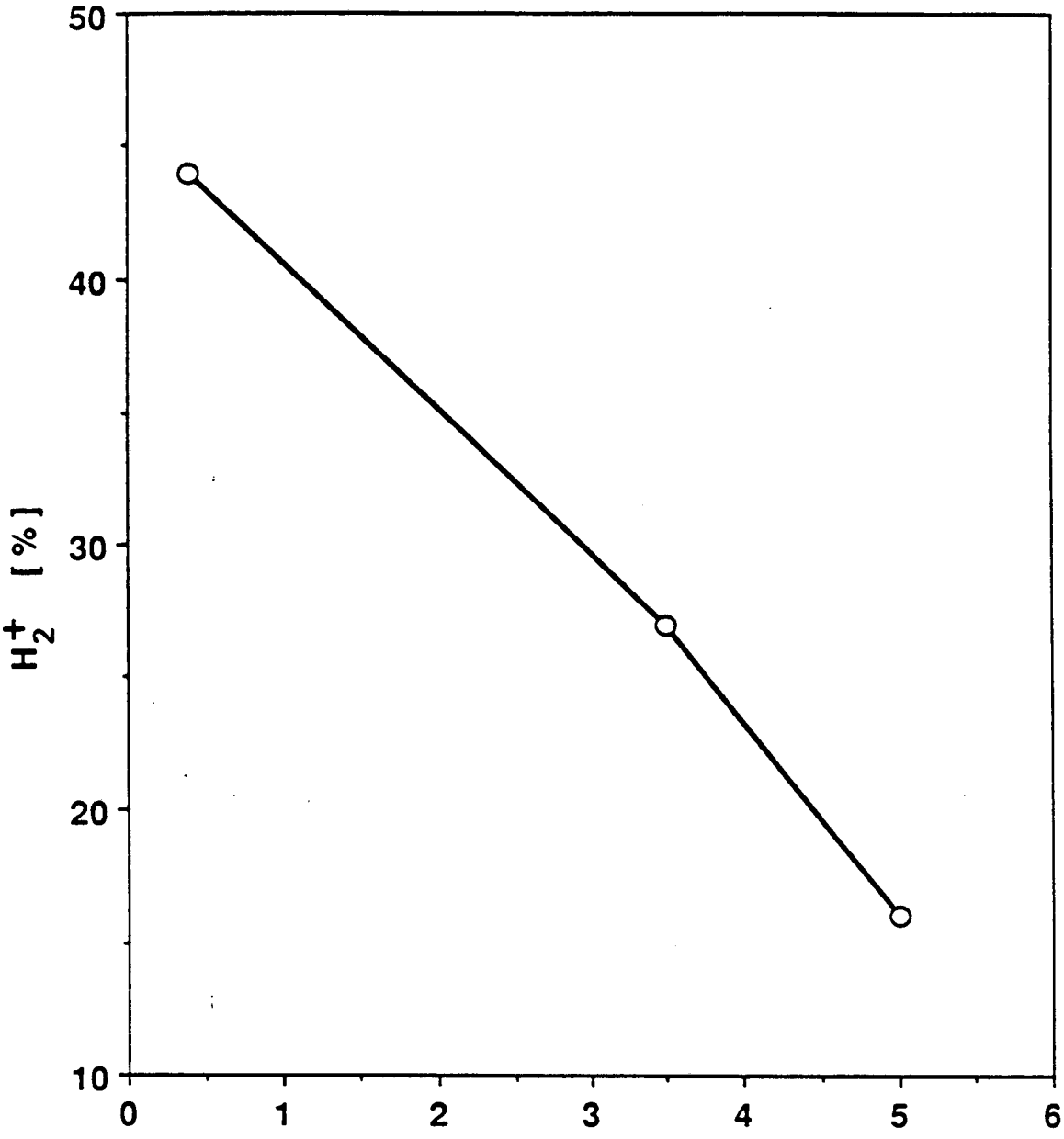
50
40
30
20
10
H_2^+ [%]
0
1
2
3
4
5
6
CATHODE DISTANCE TO PLASMA ELECTRODE [cm]
XBL 896-2268

Figure 2

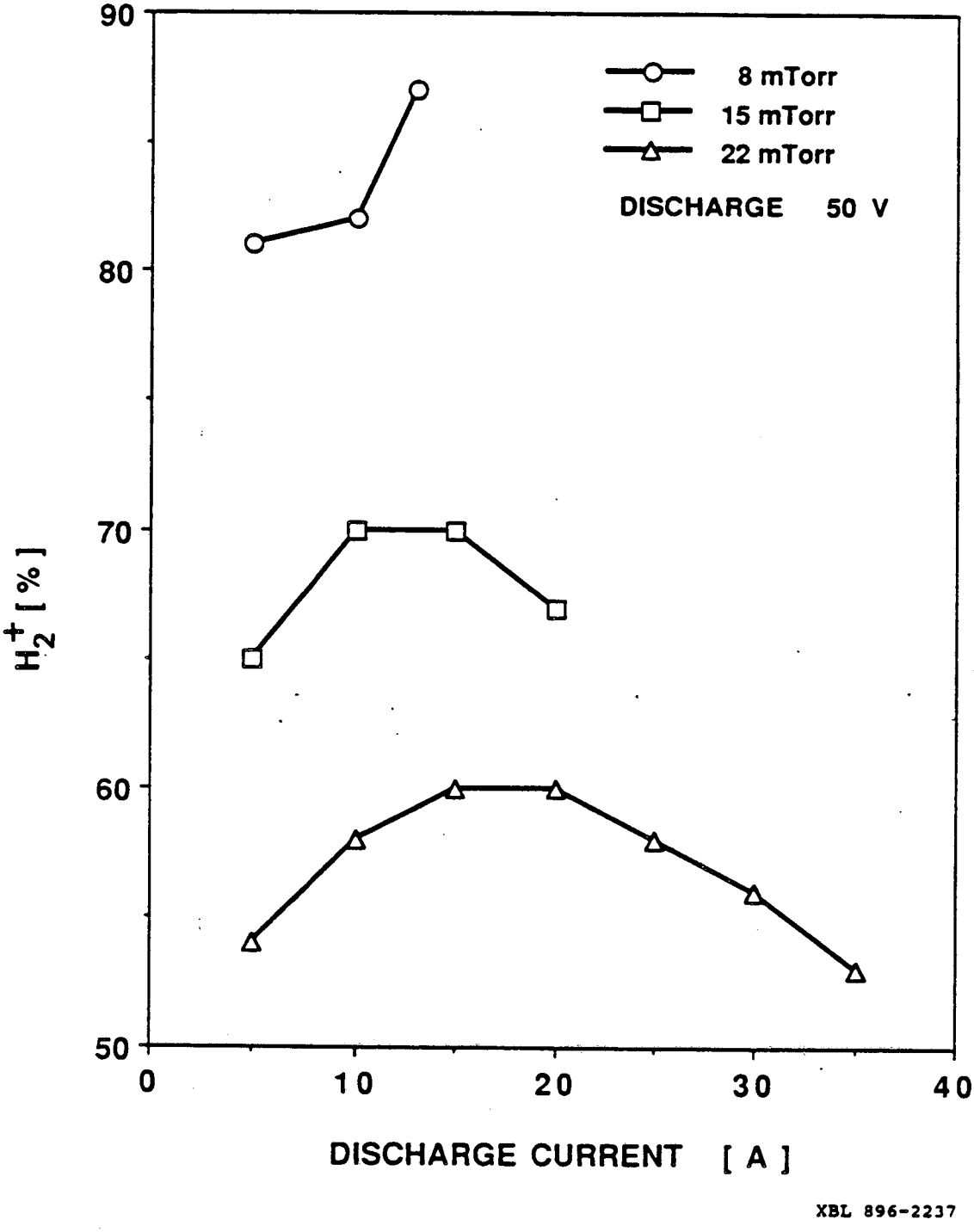
90
80
70
60
50
0
10
20
30
40
8 mTorr
15 mTorr
22 mTorr
DISCHARGE 50 V
H_2^+ [%]
DISCHARGE CURRENT [A]
XBL 896-2237

Figure 3

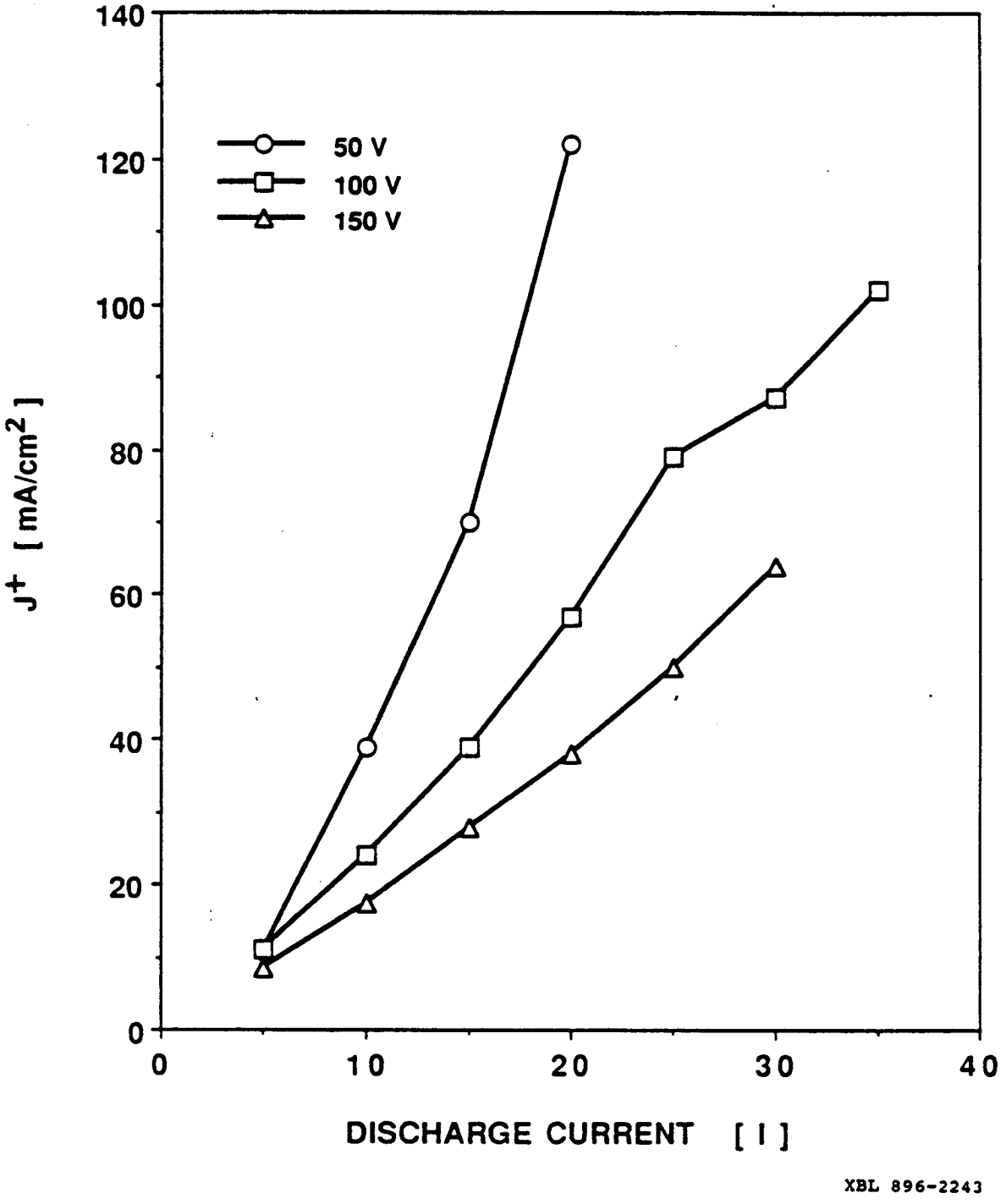
140
120
100
80
60
40
20
0
0
10
20
30
40
50 V
100 V
150 V
J+ [mA/cm2]
DISCHARGE CURRENT [I]
XBL 896-2243

Figure 4

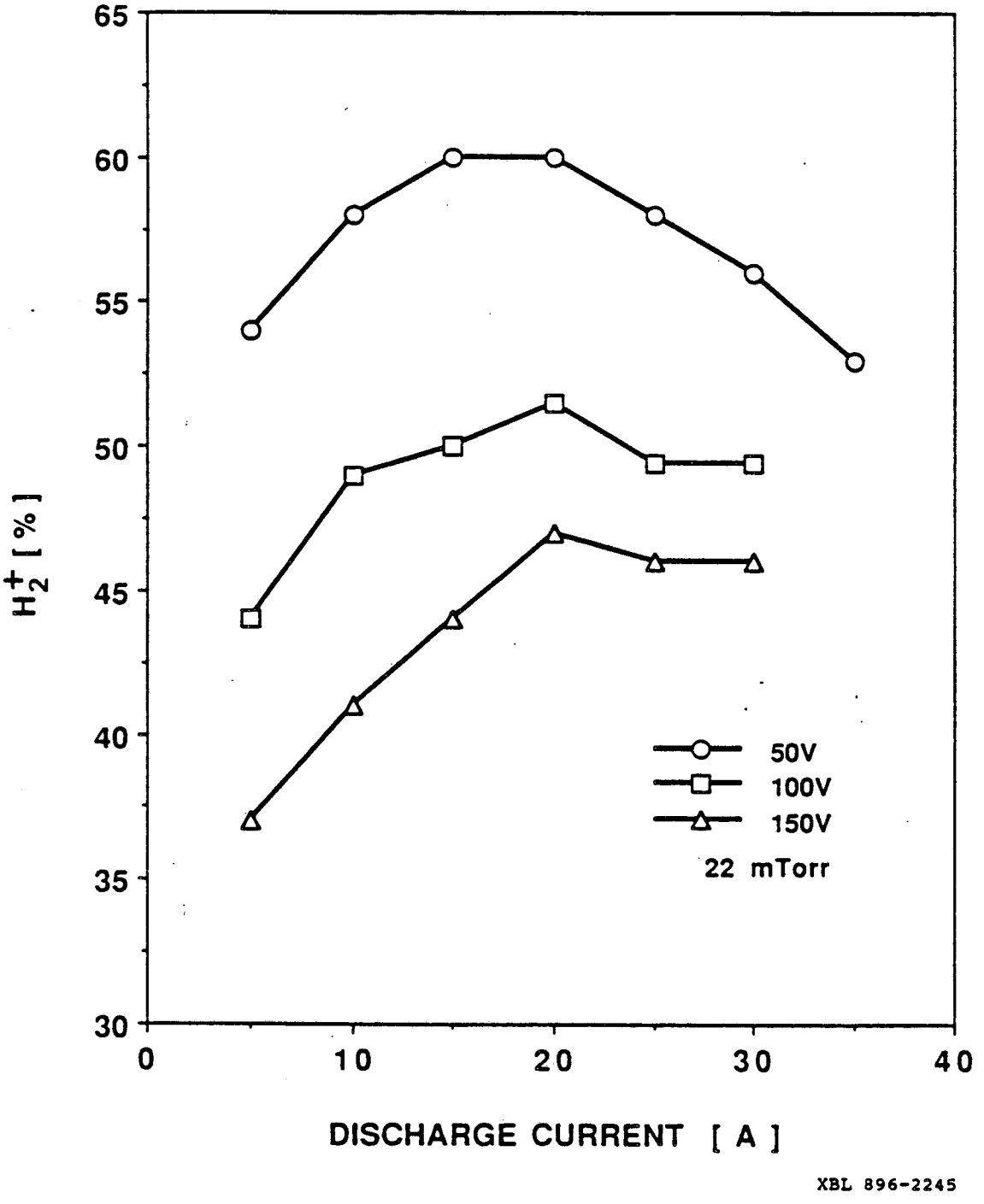
65
60
55
50
45
40
35
30
0
10
20
30
40
H_2^+ [%]
DISCHARGE CURRENT [A]
50V
100V
150V
22 mTorr
XBL 896-2245

Figure 5

Spectrometer Output Signal

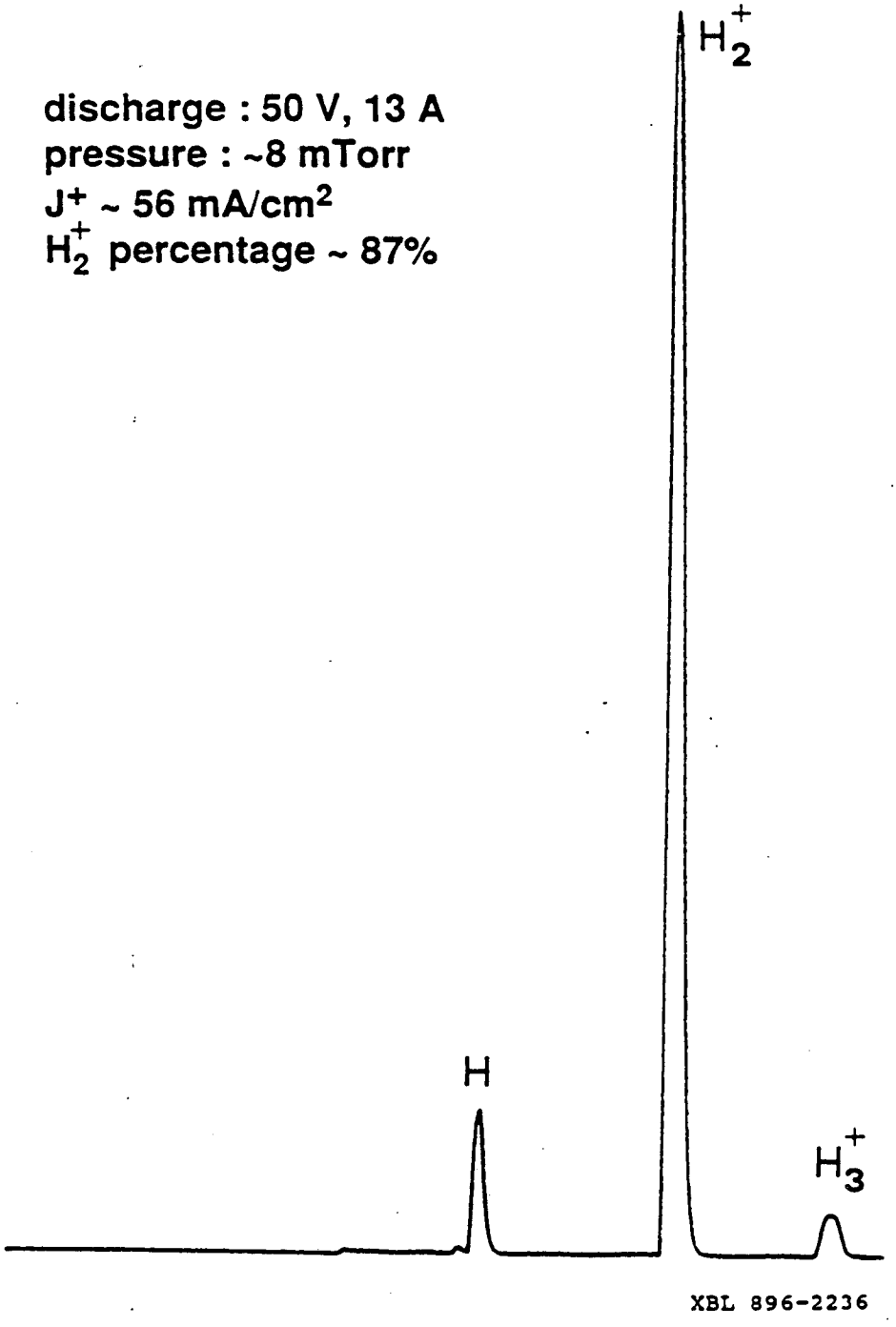

Figure 6

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