

PRODUCTION OF NEGATIVE HYDROGEN AND DEUTERIUM IONS IN MICROWAVE-DRIVEN ION SOURCES*

David Spence, Keith R. Lykke **
Argonne National Laboratory, Argonne, Illinois 60439 USA

Abstract

We report progress we have made in the production of negative hydrogen and deuterium atomic ions in magnetically-confined microwave-driven (2.45 GHz) ion sources. The influence of source surface material, microwave power, source gas pressure and magnetic field configuration on the resulting ion current is discussed. Results strongly suggest that, at least in our source, vibrationally excited molecular hydrogen, the precursor to atomic negative ion production, is produced via a surface mechanism suggested by Hall et al. [1] rather than via a gas phase reaction as is generally believed to be the case in most ion sources.

1 INTRODUCTION

In order to accumulate (store) or accelerate large currents of protons (H^+) in circular machines, it is necessary, from phase-space considerations, that the ions be injected into the circular storage/acceleration ring in the form of negative ions, H^- , with the H being stripped of its electrons to form H^+ at the point of injection. Linac accelerator performance can also be significantly improved through simultaneous acceleration of positive and negative ion beams. Suitable positive ion sources are available now, but negative ion source development has lagged somewhat.

All advanced high current H^- sources currently available, including surface sources and RF driven (2MHz) volume sources require the addition of cesium in order to achieve high H^- current. This is undesirable for several reasons, not the least being the technical problems associated with introduction of cesium into the source in a controllable manner over a long period of time. Moreover, all high current RF H^- and D^- sources developed to date consume tens of kilowatts of power and can only produce beams of a few mA per square centimeter of extraction aperture when operating cw (i.e., 100% duty factor).

Our novel approach to high current cw H^- and D^- formation involves modification of an extremely simple low power consumption (100's of watts vs. 10,000's for other type) microwave-driven source.

*Work supported by US DOE via Laboratory Directed Research and Development Funds.

Previous attempts elsewhere [3] at negative ion extraction from this type of source have been singularly unsuccessful. Our approach involves application of pioneering studies by Hall et al. [1] which demonstrated the effectiveness of freshly evaporated tantalum surfaces in producing copious quantities of vibrationally excited molecular hydrogen (a required precursor to H^- formation). The observations of Hall et al. appear to never have been deliberately, or successfully, applied to the production of high-current cw H^- or D^- beams.

2 APPARATUS AND SOURCE DIAGNOSTICS

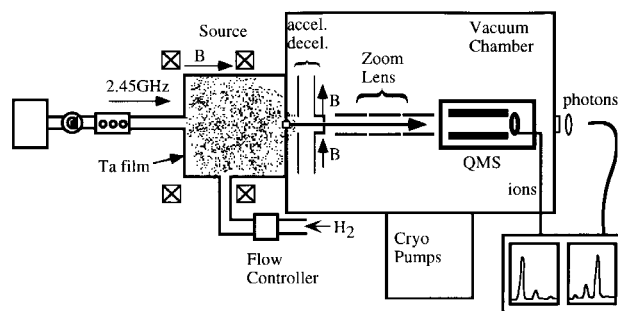


Figure 1: Schematic of apparatus.

The major components of our apparatus shown in Fig. 1 include a magnetically-confined microwave-driven (ECR) source purchased from Atomic Energy of Canada, Ltd. which is powered by a 2.45 GHz microwave generator (2 kW). The microwave generator is coupled to the source via a circulator and a four-stub autotuner. The ion source is attached to a large high-vacuum oil-free diagnostic chamber with a base pressure of 1×10^{-8} Torr.

Ion beams extracted at few hundred volts from the 5 mm source aperture by an accel-decel arrangement are primarily collected on the decel electrode that is in the configuration of a faraday cup. A 0.5 mm aperture in the decel electrode allows a small portion of the beam to be transported to a quadrupole mass spectrometer (QMS) via an electrostatic zoom lens for quantitative beam composition measurement. Light from the ion source is monitored by an optical monochromator by a clear line-of-sight through the QMS (sapphire window). The monochromator continuously monitors the atomic hydrogen Balmer α radiation (656 nm) to give a measure

of the atom concentration in the source under varying conditions.

3 H, D⁻ PRODUCTION MECHANISMS AND RESULTS

The mechanism for production of H is via the dissociative attachment of slow (<2 eV) electrons to vibrationally excited molecular hydrogen [H₂(v)], i.e.,

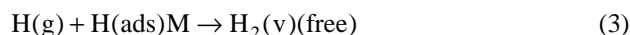


The initial production of H₂(v), the precursor of H⁻, is generally accepted to be by excitation of ground state hydrogen H₂ in the gas phase by fast electrons, i.e.,



It is the initial production of H₂(v) that is the limiting step in the production of H⁻.

Our novel cw H⁻ source takes advantage of observations (in experiments not directly related to ion sources) that copious quantities of H₂(v) are produced by recombinative desorption of two hydrogen atoms on a tantalum surface (M) (the Eley-Rideal reaction mechanism) i.e.,



where H(g) is an atom in the gas phase and H(ads) is an atom adsorbed on a tantalum surface.

In order to produce H₂(v) via equation (3) we have sputtered a thin layer of Ta on the inner surface of our ion source. Our earlier experiments [3] used a bulk Ta liner to the source, which, though effective in producing H⁻ ions led to strong effects. Namely, Ta like other transition metals strongly absorbs hydrogen, which would periodically escape the metal in large pressure bursts. Use of a thin Ta film avoids this unwanted effect. Also, in order to prevent destruction of H⁻ by fast electrons in the source the solenoids are centered over the microwave window rather than over the center of the source. This results in the magnetic field diverging at the extraction aperture and diverting hot electrons. Failure to do this initially resulted in no H⁻ ions being extracted.

Electrons necessarily extracted along with the negative ions were removed from the beam prior to mass analysis by a weak (~30 Gauss) transverse magnetic field in the region of the accel-decel electrodes. About 100 mA of extracted electrons were collected on these electrodes.

Simple arguments show that if production of H₂(v) occurs via equation (2) (as previously generally believed), then production of H (D⁻) is proportional to [e]², where [e] is the electron density in the plasma, whereas if it is via equation (3) then H (D⁻) production is proportional to [e]³. If one assumes that [e] is proportional to microwave

power (as we can demonstrate for H⁻ production), then the H⁻ current will be proportional to (power)³. This is indeed what we observed, shown in Fig. 2 below, thus confirming a novel mechanism for production of H⁻ and D⁻.

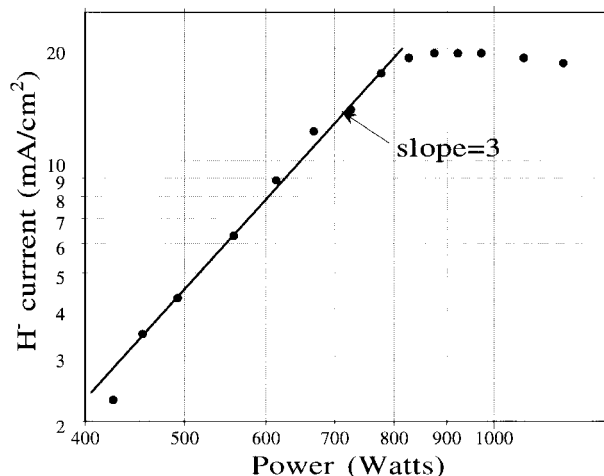


Figure 2: Log-log plot of H⁻ (D⁻) current extracted from microwave driven (ECR) source vs. microwave power to source. Plot indicates current is proportional to cube of power and strongly supports the surface production of H₂(v) hypothesis.

Based on the ratio of total H⁻ extracted to H⁻ sampled by the mass spectrometer in other experiments, we estimate that a total H⁻ current of 4-5 mA being extracted from the 5 mm diameter source aperture.

A comparison of the performance of our H⁻, D⁻ ECR source compared with the arc-driven CWDD source at ANL, the previous D⁻ cw current record holder, is shown in the table below.

	Current	Beam Aperture	Current Density	Power Consumption
Present cw source H, D ⁻	4-5 mA	5 mm	20 mA/cm ²	700 W
CWDD source D ⁻	22 mA	23 mm	4 mA/cm ²	50,000 W

Because of H₂/D₂ isotope effects, the production rate for D⁻ is generally much lower than H⁻, often by a factor greater than ten. This results from H₂(v) production via equation (2) leading to low vibrationally excited levels from which the isotope effect is pronounced, whereas H₂(v) via equation (3) is expected to lead to populations of high vibrationally excited levels from which the isotope effect can disappear. This is what we observe in our experiments. Figure (2) shows H and D⁻ mass spectra obtained under identical experimental conditions where the cw ion currents are represented by the areas of the peaks and are essentially the same for H⁻ and D⁻ and indicating little or no isotope effect.

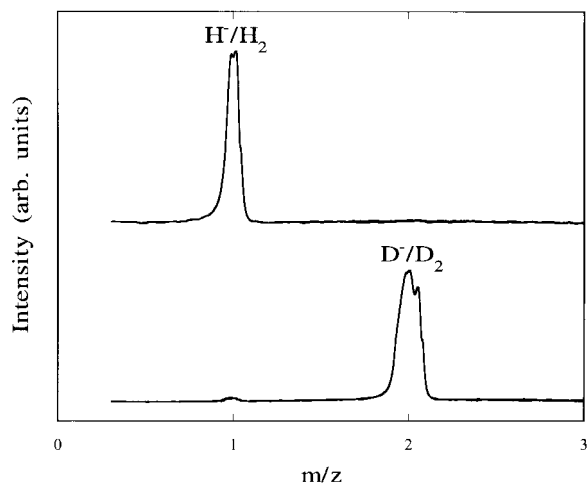


Figure 3: Mass spectra of H/H_2 and D/D_2 extracted from modified microwave driven (ECR) ion source. Spectra obtained under identical source conditions (power, density, etc.) shows no isotope effect for H/D production. A first for any type of source.

4 ACKNOWLEDGEMENTS

We thank C. Batson for continued technical expertise in this project.

**Present Address: National Institute of Standards and Technology, Washington, D.C.

5 REFERENCES

- [1] R. I. Hall, I. Cadez, M. Landau, F. Pichou, and C. Schermann, "Vibrational Excitation of Hydrogen via Recombinative Desorption of Atomic Hydrogen Gas on a Metal Surface," *Phys. Rev. Lett.* **60**, 337 (1988).
- [2] J. S. C. Wills, Chalk River Laboratory, private communication.
- [3] D. Spence, K. R. Lykke, and G. E. McMichael, "Plasma Modified Production of High-Current, High-purity cw H^+ , D^+ and H^- Beams from Microwave-driven Sources." *Proc. 1996 Int. LINAC Conf.* Geneva, Switzerland, 26-30, Aug. 1996.