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THE RING MAGNETRON IONIZER*

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ABSTRACT

A ring magnetron D^- charge exchange ionizer has been built and tested. An H^- current of 500 μA was extracted with an estimated H° density in the ionizer of 10^{12} cm^{-3}. This exceeds the performance of ionizers presently in use on polarized H^- sources. The ionizer will soon be tested with a polarized atomic beam.

1. Introduction

At the last polarized ion source workshop, an ionizer based on a magnetron surface-plasma source was proposed [1]. In this ionizer, $\vec{H}^-$ production was via the resonant charge exchange reaction $\vec{H}^\circ + D^- \rightarrow \vec{H}^- + D^\circ$. The use of D^-, originally suggested by Haeberli [2], has the advantages of a large cross section and the availability of high current D^- sources. (D^- is used rather than H^- so that subsequent mass analysis will separate the polarized H^- from the unpolarized ionizing ions.) The difficulty encountered when trying to devise an ionization scheme using D^-, however, was the deleterious effect of the space charge force from the intense D^- beam. The ring magnetron ionizer geometry offered the possibility of providing intense D^- currents (0.5 A), while allowing space charge neutralization of the $\vec{H}^-$ and D^-. A prototype of this ionizer has been built and is presently being tested at Brookhaven.

The source, shown schematically in Fig. 1, has a geometry inverted from typical magnetron surface-plasma sources in that the cathode is the outer and the anode is the inner of two concentric rings. D^- ions are produced on the low work function cathode, accelerated toward the anode by the approximately -200 V cathode voltage, and pass through slits in the anode and into the center of the ring. The polarized H° beam passes axially through the ring and is ionized by charge exchange with the D^-. The center of the ionizer is free of electric fields, so D^+ ions from the magnetron plasma can diffuse into the central region and space charge neutralize the D^- and H^-. The approximately 1 kG axial magnetic field required for source operation is also proper for preserving the beam polarization. H^- ions are then extracted and mass analyzed to eliminate any D^- component. The length of the ionization region is only 2 cm, allowing one to get a higher average density in the ionizer than that obtained in other ionizers, which are considerably longer.

As will be discussed in Section 4, the expected efficiency of this ionizer was more than an order of magnitude above ionizers presently used. The purpose of the initial experiments, to be described

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below, was to see if the space charge could indeed be efficiently compensated, or if other problems would arise, such as gas scattering of the H^- and H° by D_2 outside the magnetron. Results have been encouraging, in that 500 μA of H^- (unpolarized) have been produced by charge exchange of H° with D^-. Tests will begin soon to determine whether there are problems with depolarization during ionization.

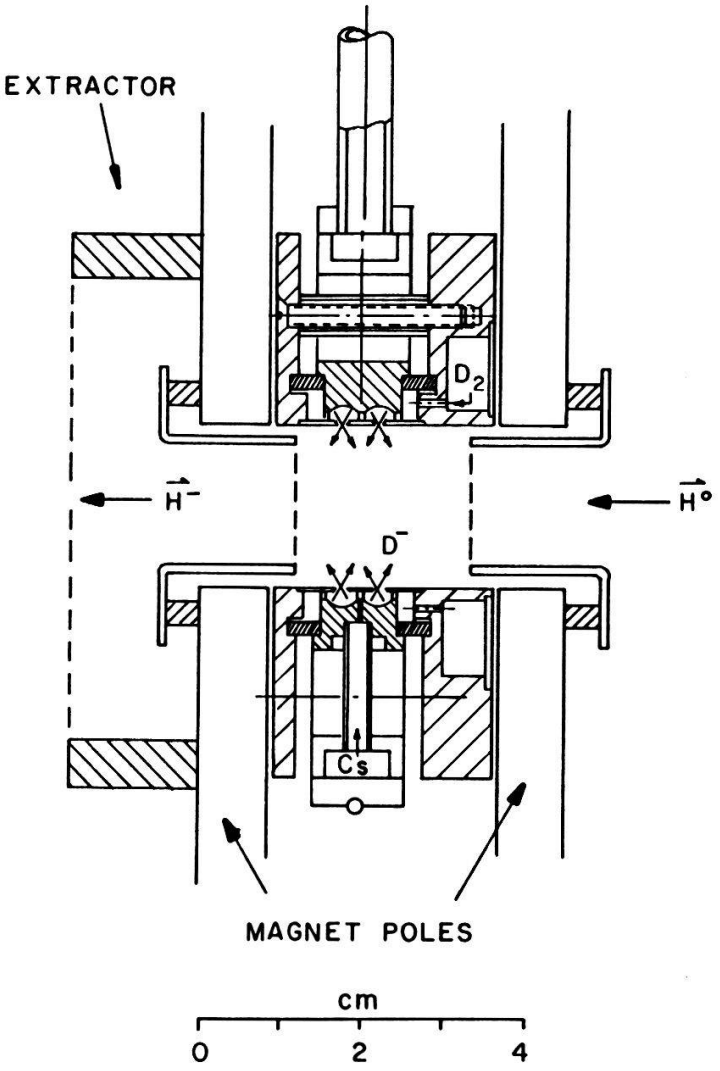

Figure 1 - Schematic of the ring magnetron ionizer.

2. Experimental Setup

The molybdenum cathode of the magnetron is 2.2 cm I.D. and 0.9 cm long, with two grooves in the cathode to geometrically focus the surface-produced D^- into slits in the anode. The stainless steel anode cylinder is 1.9 cm I.D., with a wall thickness of 0.5 mm. Anode slits

are 0.5 mm wide, with a total slit length of 9 cm. Macor rings provide an insulating support between the cathode and the anode. Deuterium gas is fed into the cathode-anode gap uniformly through eight holes in one of the anode end plates. Cesium vapor, required to reduce the work function of the cathode, is fed through four equally spaced holes in the cathode. The source operates with an axial magnetic field of 0.7-1.0 kG.

To first measure the D^- current coming from the magnetron, a 0.5 cm diameter rod was inserted into the center of the ring. A wire spiraled around, but insulated from, the rod could be biased to prevent electrons from reaching the rod. Self-extracted D^- currents of up to 0.7 A were detected in the center of the ring, with a 30-40 A arc current and an arc voltage of 200 V. The pulse width of the source is 5-25 ms, with a 0.4 Hz repetition rate.

In order to test the D^- charge exchange ionization, a setup as shown in Fig. 2 was used, in which the H° beam was not polarized. Hydrogen was fed, either steady state or pulsed, into a pulsed rf dissociator operating at 20 MHz. The Pyrex dissociator bottle had a 3 mm diameter aperture in the nozzle. The hydrogen dissociation could be monitored using a fiber optic cable near the dissociator nozzle to transmit light to a 6563 Å analytical line filter, allowing the measurement of the intensity of the H_α line. (It was found, however, that the maximum H° came at a pressure higher than that giving the maximum optical intensity.) A 5 mm diameter skimmer was located 2.5 cm from the tip of the dissociator and the first stage was pumped by a 2500 ℓ/s oil diffusion pump. The center of the magnetron was approximately 6 cm from the skimmer aperture.

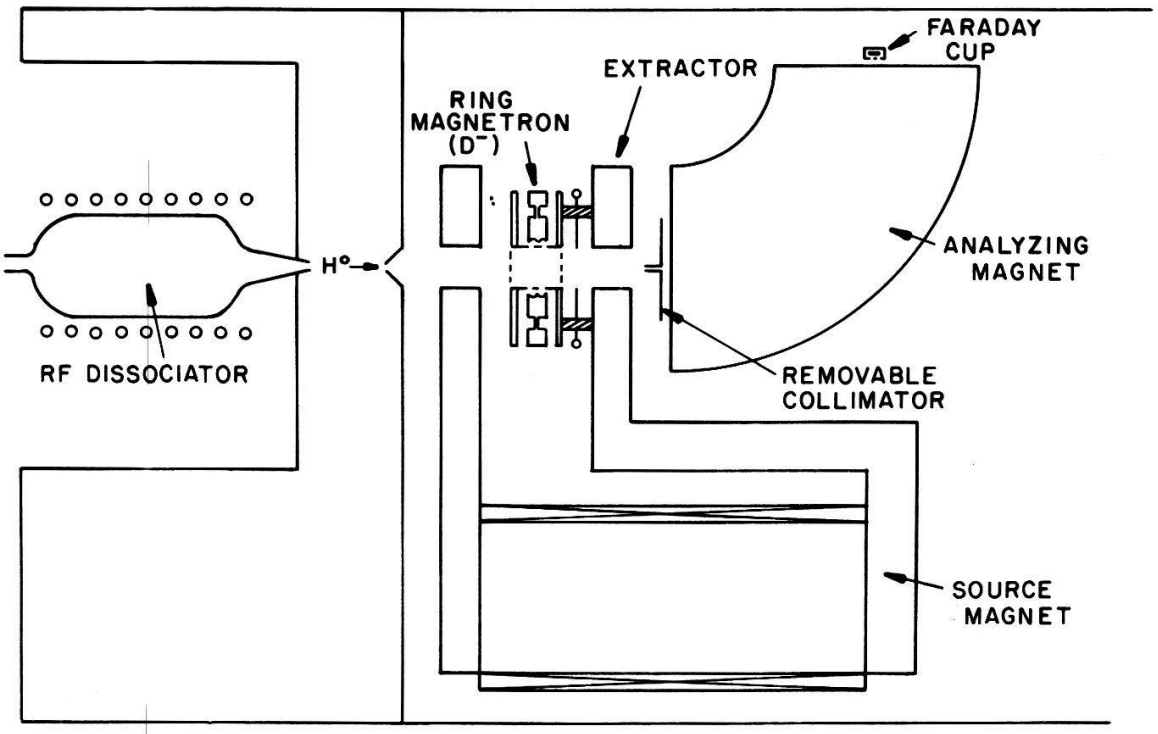

Figure 2 - Experimental setup for measuring the H^- production.

To date, the most successful H^- extraction system has been that shown in Fig. 1, in which grids on both ends of the magnetron can be biased, followed by an extraction grid, which is typically held at 3 kV. All three grids had 85% transparency. (An earlier extraction system is shown in Fig. 2.) Following the magnetron there was a 90° analyzing magnet having a 10 cm bending radius and a 3.3 cm gap. The beam could then be measured on a 1 cm wide Faraday cup after the magnet.

3. Results

H^- coming from resonant charge exchange can clearly be detected. With the magnetron pulsing and the hydrogen gas flowing steady state through the dissociator, but with the dissociator rf turned off, analyzing magnet scans show an extracted D^- peak and a barely detectable H^- peak. When the dissociator is turned on and H° injected into the center of the ring, the H^- peak increases dramatically. Figure 3 is an early result showing the H^-. The upper trace is the Faraday cup current with the analyzing magnet set for H^-. With a 20 ms D^- pulse width, and the dissociator turned off, there is a 3 μA pulse which is D^- being detected due to incomplete mass separation. On the following pulse, the dissociator rf was turned on approximately 10 ms into the magnetron pulse (shown by the signal from the H_α line detector on the lower trace), and an H^- current of 20 μA was measured.

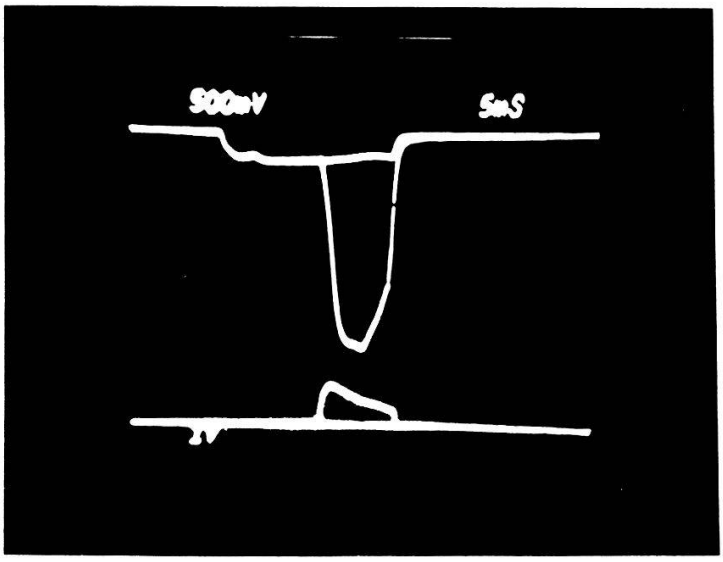

Figure 3 - The upper trace shows H^- produced by resonant charge exchange (10 μA/V). The lower trace shows the H_α signal from the hydrogen dissociator.

As mentioned earlier, the extraction voltage was approximately 3 kV, which was too low to focus the full H^- beam onto the 1 cm Faraday cup. Magnet scans showed the beam to be greater than 2 cm FWHM. Therefore, when peak H^- currents of 200 μA were detected, the

total H^- current, integrated by sweeping the magnet, was 500 μA. The output current was quite sensitive to the bias on the end grids. The H^- current could sometimes be doubled with a less than 10 V bias on the grid on the extraction end, suggesting that the grids were important for adjusting the plasma potential in the center of the ring for optimum H^- extraction. The optimum biases for both end grids would vary depending on source conditions. The output was also very sensitive to "noise" in the magnetron discharge. The discharge can become more or less noisy depending on source pressure, magnetic field, and Cs supply rate. Peak output currents always occurred under quiet discharge conditions. Noise could be causing rapid fluctuations in the ion densities in the center of the ionizer, reducing the space charge compensation.

4. Discussion

In order to compare the present result of 500 μA H^- with other ionizers, one must know the H° density in the ionization region. Attempts to measure this reliably with a quadrupole mass spectrometer were unsuccessful. From the typical performance of other room temperature dissociators, the estimated density in the ionization region is 1×10^{12} cm^{-3} for the present geometry. This density is approximately three times the estimated density in the ionization region of the AGS polarized H^- source [3]. The extracted H^- current is about a factor of 12 higher, suggesting that the magnetron is a factor of four more efficient than our Cs° beam ionizer. While this improvement is less than expected, the results are encouraging considering the relatively early stage of development. In addition, one must consider the advantage of the large H° acceptance angle of the ionizer (due to its short length) when finally using this ionizer on a polarized source.

In initial calculations of the expected performance of the ionizer [1], one pictured the H° beam passing through the ring magnetron "target" of D^-, D°, and D^+, and a fraction of the atoms emerging as H^- formed by charge exchange. Destruction of H^- ions before exiting the ionizer was also considered However, after considering the short mean free path for scattering of H^- by D^+ before leaving the ionizer, more recent calculations have used what seems to be a more realistic model. Here, one estimates the D^-, D°, and D^+ densities in the ionizer, and for a given H° density then calculates the H^- production and destruction rates, the loss rate of H^- ions across the magnetic field to the walls, and the rate of extraction of H^- ions from the plasma in the ionizer. The H^- density (and extracted current) builds up quickly in time until an equilibrium condition is reached. The results of these calculations are not too different from those given in [1], although now they emphasize a high H° density in the ionizer, while the original calculations favored a high H° flux through the ionizer (i.e., the ionization efficiency was approximately independent of H° velocity).

For an H° density of 1×10^{12} cm^{-3}, the calculated H^- current is approximately 2 mA, a factor of four higher than what was measured. There are, however, still large uncertainties in the calculated value. The electron density and temperature in the ionizing region would have

to be measured in order to include their contribution to H^- destruction properly. The loss of H^- ions to the walls by diffusion across the magnetic field is difficult to estimate, especially if a noisy discharge condition causes plasma instability. Therefore, until more complete measurements of source parameters can be made, the calculations merely serve to suggest possible ways of improving the ionization.

The atomic beam stage of a polarized H^+ source (from the ZGS) has been prepared, and the ring magnetron is now being installed in place of the electron bombardment ionizer. The extraction and focusing has been designed for operation at 20 keV, and is followed by an ExB mass filter/spin precessor. The polarization of the H^- beam will be measured at 20 keV using a polarimeter developed by Yale University [4]. All components for this test have been built and are presently being assembled. Following these tests, the ionizer will be combined with the cold atomic beam source [5].

5. Acknowledgments

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6. References

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Rapporteur's report, Session (L), S. Jaccard:

G. Clausnitzer : What do you expect as uniformity of the D^- field, as the ions are bent in the magnetic field?

Answer A slightly depopulated center is expected but this is not a major drawback because of the large solid angle of acceptance and production.

T.B. Clegg : What can you say about a d.c. operation?

Answer This is not obvious. Something would have to be undertaken to avoid the melting of the cathode. It would also be necessary to run with less gas to operate the discharge at proper pressure ($\sim$.1 Torr).

J. Arvieux : Would it be possible to run the ionizer with H^- ions?

Answer That could be tried.

R. York : What can you say about beam emittance?

Answer We have calculated it from extraction area and magnetic field. It should not be very much different from the PONY 1 cesium ionizer we are using now.