ECR PLASMA JET IONIZER FOR A HIGH INTENSITY POLARIZED H/D-ION SOURCE*

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Abstract

Tests are underway to determine if the hydrogen (or deuterium) plasma jet which has recently been developed at TUNL (Triangle Universities Nuclear Laboratory, Durham, North Carolina, USA) [1] can provide an efficient means for ionizing stored, nuclear-spin-polarized D (or H) atoms. This is being designed to utilize the extremely large, resonant charge-exchange cross section for collisions of H-ions with D-atoms (and D-ions with H-atoms respectively) at energies < 1 eV. It is anticipated that dc, polarized H (or D) ion-beam currents greater than 1 mA may be possible.

1 INTRODUCTION

We are investigating the feasibility of building a more efficient plasma jet ionization system for spin-polarized H or D atomic beams. Such a device would utilize the very large charge-exchange cross section for $H^+ + D^0 \rightarrow H^0 + D^+$ (or $D^+ + H^0 \rightarrow D^0 + H^+$), which rises to $\sim 5 \cdot 10^{-15}$ cm^2 at relative energies as low as ~ 1 eV. Such an ionizer has become feasible at TUNL because of our recent development of a quasi-neutral plasma beam containing ~ 3 mA of positive H ions confined inside a column 5 mm in diameter.

It is also planned to investigate the possibility of the direct production of a negative polarized ion beam via the charge exchange reactions $H^- + D^0 \rightarrow H^0 + D^-$ and $D^- + H^0 \rightarrow D^0 + H^-$ respectively, which exhibit comparable cross sections as the reactions mentioned above.

The plasma-jet currently emerges from an ECR discharge and is guided along the axis of a uniform 1 kG solenoidal magnetic field. It then enters a 23 cm long, 1 cm diameter Teflon tube (storage cell) whose entrance is 7 cm downstream from the plasma chamber exit. Ions emerging from the opposite end of the tube are accelerated and formed into a beam. To examine the efficiency of the charge-exchange process, unpolarized D (H) atoms have been injected at the middle of the tube. Based on experimental results, we will assess the feasibility of injecting instead polarized D (H) atoms to produce polarized ion beams.

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2 TEST SYSTEMS

Looking from left to right (Fig. 1) $\mu-$waves at 2.45 GHz enter through a vacuum tight Aluminum-Oxide (AlO)–window into the ECR plasma–chamber which is completely lined with Boron Nitride (BN). The plasma beam emerges through a 8.5 mm diameter and 35 mm long Macor channel attached at to the BN-chamber. A low carbon steel collar around the water-cooled plasma chamber reduces the axial magnetic field from about 1 kG to below the 875 G needed for the ECR condition inside the plasma chamber.

Using BN as a liner for the plasma chamber has two principal purposes. First it was shown that the usage of BN improves the proton fraction of ion beams produced from a hydrogen plasma [2]. Second the ECR-plasma can be biased to the beam potential while it remains electrically insulated from the grounded vacuum chamber. Via a high voltage feedthrough, the variable bias voltage is connected to an electrical shield which is in contact with the drifting plasma beam exiting the plasma chamber.

Since the plasma touching the shield is an excellent electrical conductor, the same bias voltage defines the plasma potential along the storage cell axis and back into the ECR chamber. Consequently the charge exchange inside the electrically insulated storage cell occurs at a variable beam potential. Acceleration of the emerging beam to ground potential provides for beam energies up to 10 keV.

Guided by the axial field the plasma beam passes through the storage cell. Teflon covers the inner wall of the cell. Neutral atoms of the other kind (i.e. D^0 for an H^+-plasma beam, and vice versa) enter into the cell at the T-junction. These atoms are delivered by the RF-dissociator [4] mounted above the storage cell.

To obtain a small atomic flux comparable to the currently available polarized atomic beams, and to limit the pressure inside the storage cell to about 1×10^{-5} mbar while maintaining the high pressure necessary for the dissociator RF-discharge ($\approx 5 \cdot 10^{-1}$ mbar), the dissociator's inner glass tube is reduced to a $\sim$0.1 mm diameter capillary at its exit. The conductance of the capillary was measured to be 3.8×10^{-3} l/s.

The large electrical potential across the acceleration gap at the right side of the storage cell separates the positive ions leaving the storage cell to the right from the accompanying negative charges (electrons) in the drifting plasma jet.

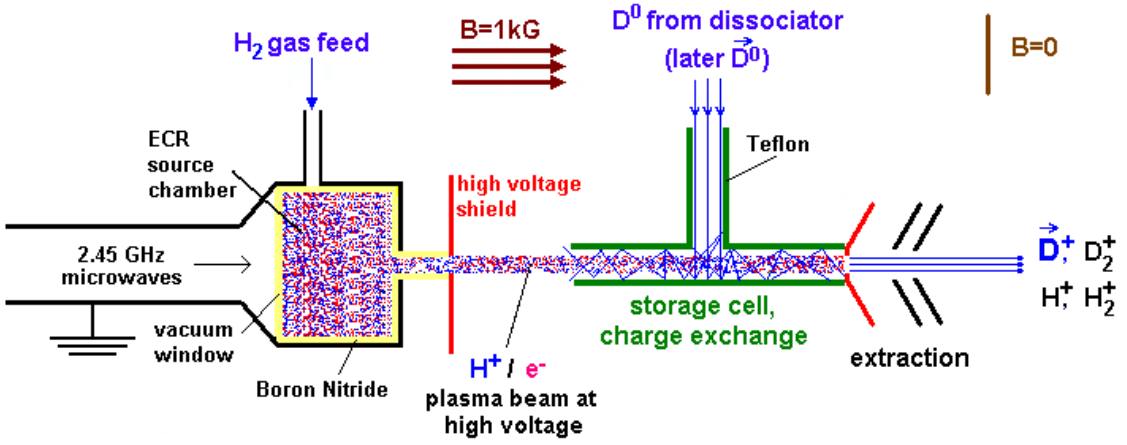

Figure 1: Scheme of the new polarized ion source.

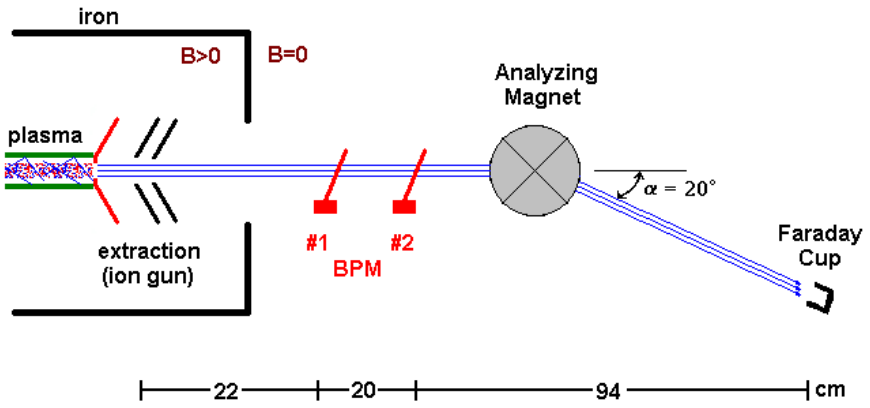

Figure 2: Accelerated beam diagnostic systems.

Two beam profile monitors (BPM) for the accelerated ion beam consist of straight 0.8 mm diameter wires which are moved across the beam. These are located 22 cm and 42 cm, respectively, downstream of the acceleration gap (see Fig. 1). The electrical current produced on the scanner wires by the impinging ions and secondary electrons is measured. This current is proportional to the beam intensity integrated along the wire.

Beyond these profile monitors, species present in the ion beam can be selected by an analyzing magnet and collected in a downstream Faraday cup (see Fig. 1).

3 RESULTS

Three different types of measurements were made.

3.1 *ECR-Plasma Jet*

First, the plasma flux emerging from the ECR discharge down the B-field axis was measured. During these measurements the microwave power dissipated in the ECR discharge was varied between 200 W and 1000 W, but was typically 400 W. A mass flow of and 0.2-1 sccm of H_2 gas was fed into the ECR discharge.

After gyrating along the axial magnetic field the plasma beam was intercepted by an intensity monitor placed 10 cm downstream (not shown in Fig. 1). The entrance hole of this monitor was 1.5 mm.

The hydrogen ions entering the monitor recombine to molecular hydrogen inside as they hit the stainless steel walls. Thereby, the H_2 partial pressure inside the monitor is increased. A calibrated vacuum gauge connected to the monitor measures the pressure rise.

Assuming the incident ions in the plasma jet were all H^+, the total integrated beam flux measured with this method was about 3 mA with a diameter of 5 mm FWHM.

3.2 *Extracted Ion Beam*

Second, ions were extracted and accelerated from the plasma jet after it passed through the storage cell. Using a 5 mm diameter aperture at the exit of the storage cell (Fig. 1) up to I_p=2 mA ion beam current was extracted with an accelerating volatage of $\sim$10 kV. High values of $> 95\%$ have been measured for the fraction of H^+ (or D^+) in this beam.

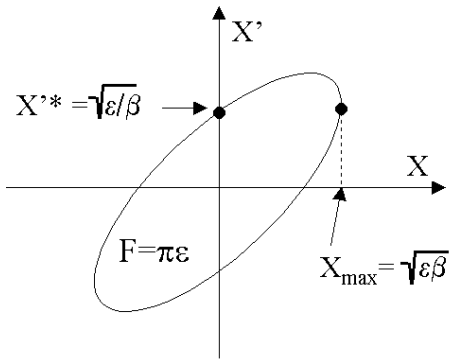

Figure 3: Measured emittance parameters of the beam.

Using the beam profile monitors and the downstream Faraday cup it was possible to measure both the beam width x_{max} and the divergence x'^* when the beam profile monitor was at the center of the beam. From Fig. 3 it is obvious that the product x_{max} x'^* yields the beam emittance ϵ. The normalized emittance measured was typically $\epsilon_n = 0.06$ $\pi-$mm mrad.

3.3 Charge Exchange

Finally, charge exchange measurements have just begun with D_0 from the dissociator fed into the storage cell from above (see Fig. 1) and with the H^+ plasma jet travelling through the cell. By measuring the H^+ (from plasma jet) and D^+ (from $H^+ + D^0 \rightarrow H^0 + D^+$) mass fractions in the extracted and accelerated ion beam, the total ionization efficiency η=I(D^+)/I_p(H^+) has been found to be $\eta \approx 0.06$.

This value already suggests a comparable efficiency to that currently available in the existing polarized ion source at TUNL, where ionization occurs by the process $H^0 + e \rightarrow H^+ + 2e$ [3]. This early result however indicates an efficiency which is much smaller than the expected value. This discrepancy is most likely caused by a smaller than expected D_0 partial pressure inside the storage cell because of incomplete dissociation of D_2 in the RF-dissociator. Measurement of the degree of dissociation will be performend in the near future.

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