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MARK V MAGNETRON WITH H.C.D. PLASMA INJECTION *

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Abstract

An experiment designed to test the feasibility of negative ion sources based on plasma injection from a hollow-cathode discharge is described. From the plasma column up to 2.3 Amp/cm^2 of positive ion current were drawn onto a cesiated Mo converter. Strong evidence was found for an H^- production at a conversion efficiency of 25%. Based on these encouraging results a 2 Amp/ H^- source has been designed.

I. Introduction

Hollow-cathode discharges (HCD)[1,2,3,4] can produce plasmas which have ideal characteristics for negative ion sources: (1) very high ionization, (2) high plasma densities ($n \approx 10^{13}$ - 10^{14} cc^{-1}), (3) capability to operate dc, (4) HCD plasmas follow the contour of magnetic field lines, (5) background pressure of 10^{-4} - 10^{-5} torr., (6) some cathodes run well in cesium.[4]

The implication of these characteristics is clear: one would hope to construct a negative ion source which would be fed with HCD plasmas, thus producing negative ion beams with a very high gas efficiency. This source would have a very low background pressure and it would run dc. In addition, since the plasma is injected into the source, the bias on the cesium covered grooved converter could be independently adjusted to optimize the conversion efficiency.[5]

II. Feasibility Questions

Theoretically, an HCD fed negative ion source should work very well. One envisions a source in which HCD plasmas are injected along magnetic field lines between two biased plates with a potential difference of 50-100 volts. To test for physical feasibility we must verify that

(1) The bias on the plates won't have an adverse effect on the operation of the HCD.

(2) At least 1 Amp/cm^2 of ion current can be collected on the plate which acts as a converter.

(3) Cesium, which reduces the arc voltage and improves the power efficiency, does not have adverse effects on the system.

(4) Tantalum HCD runs well in H_2.

(5) H^- ions are efficiently produced

(6) A test of a lanthanum hexaboride converter doped with cesium.

Theoretically, the discharge should not be affected by the presence of biased plates. The plasma which streams out of the HCD will be subjected to an $\underline{E} \times B$ drift which is negligible compared to the thermal velocity of the electrons; e.g., in a gap of 0.5 cm at 80 volts and 1 kG, the $\underline{E} \times \underline{B}$ drift is 1.6×10^7 cm/sec, while the thermal velocity corresponding to a temperature of a 9 eV electron is 1.3×10^8 cm/sec.

The current drawn by the converter should easily exceed 1 Amp/cm^2 since the ion saturation current that can be drawn from a hydrogen plasma with a density of 10^{13} cc^{-1} and an electron temperature of only 4 eV is 1.77 Amp/cm^2.

III. The Experiments

A number of experiments were performed at MIT on an HCD device[1] which has been used to train students in basic experimental techniques in plasma physics. The vacuum chamber is basically a cylindrical tube which is 2.5 feet long and about 5 inches in diameter. It is pumped by three diffusion pumps with a pumping speed of close to 2,000 liter/sec. The axial magnetic field is produced by six coils which have 4 inch gaps between them. Thus, the maximum field strength varies from 640 G in the center of a coil to 430 G in the center of the gap (where the experiments were done). On one end of the machine the cathode is mounted on an insulated plate, the rest of the chamber is at ground potential. The cathode itself is a 3 inch long tantalum tube with an i.d. of 3 mm.

Two flat electrodes, a converter and a collector were mounted on opposite windows in the center of the device, i.e. about 12 inches "downstream" from the cathode. Both the converter and collector could scan the discharge radially. The converter consists of a water cooled Mo block with a surface area of 1 cm x 3 cm facing the plasma. Provisions were made to mount small cesium pellets and getters on this block; the getters and pellets were to be heated by the discharge itself. The collector consists of an Al block 2.5 x 5 cm with provisions to attach extension plates on top and bottom. The collector has a hole in it, and it is mounted on a hollow rod such that additional gas could be fed through the collector. Hollow cathode discharges of noble gases in the MIT device[1] and a similar device at RPI[6] produced cylindrical plasmas whose peak density of 2×10^{14} cc^{-1} falls off to 1×10^{13} cc^{-1} in 1.5 cm. The electron temperature in the center is about 9 eV.

(1) Disturbance of the HCD operation. In the first experiment, the converter and collector were brought within .75 cm from each other; the

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collector was at ground potential, the converter at -80 volts, and the magnetic field at 430 G. There was no evidence of disruption nor were there any adverse effects other than a physical obstruction which caused a slight rise in the anode to cathode voltage.

(2) Operation in the hydrogen mode. Up until this set of experiments the MIT machine was operated in Argon, with only small traces of hydrogen. In our experiment this tantalum HCD ran very well in hydrogen. The "hot spot" on the cathode stayed at the tip (unlike in Argon where the hot spot is in the middle). This fact indicated that the projected lifetime of a Ta cathode operating in this mode should be far greater than the 20-25 hours of operation in Argon. The arc current in the hydrogen mode was 22-29 Amp and the arc voltage was 60-90 volts. Electric probe measurements indicate that n and T_e are the same as in noble gas discharges.[1,5] Hydrogen HCD discharges seem to be more quiescent than Argon discharges.

(3) Cesium injection through the cathode. Traces of Cs were injected through the cathode. The results were spectacular: the arc voltage dropped to about 50 volts and the arc current could be varied from 3 to 100 Amp with the arc voltage being almost constant.

(4) Positive ion current collected by the converter as a function of the converter bias and radial position, arc current and gas feed. Figure 1 shows the converter current density versus bias and radial position. The maximum current density collected by the converter was 1.3 Amp/cm^2.

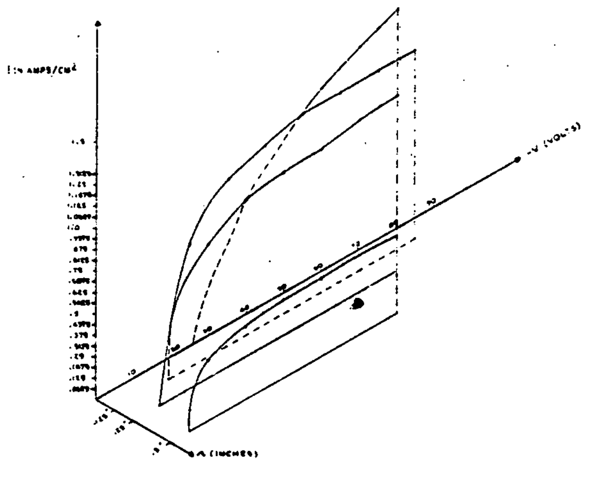

Fig. 1: Current density collected by the converter as a function of its radial position and bias. The arc voltage and current were 66 volts and 27 Amp respectively, and the magnetic field was 430 gauss. About 25% of the gas was fed through the collector.

In this case, part of the gas was fed through the collector. When the gas was fed through the cathode only, slightly less than 1 Amp/cm^2 were collected. Next, a MACOR shield was placed around the the converter to insure that contributions to the current collected from the side are negligible, as one would expect from the steep density gradient. Indeed, the current collected by the converter with the MACOR shield in place was over 80% of the current collected without it. Finally, traces of Cs were injected through the cathode, and the converter current was measured as a function of arc current at a fixed radial position. As expected (Fig. 2), the converter current increased linearly with the arc current.

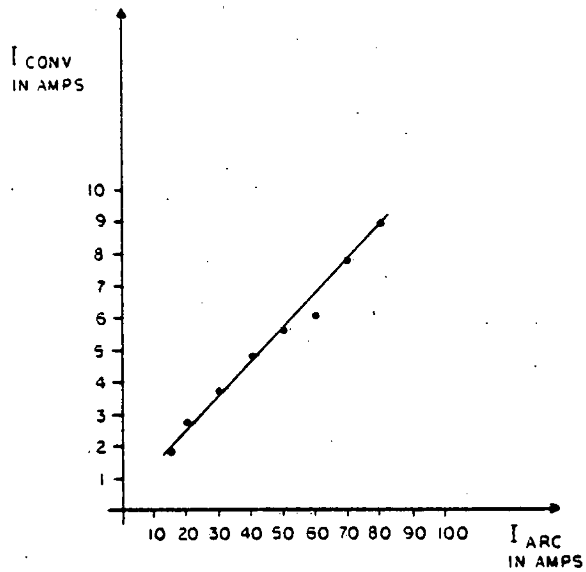

Fig. 2: Total current collected by the converter at a fixed radial position versus the arc current. Hydrogen and traces of cesium were fed through the cathode only. The converter bias was fixed at -74 volts.

(5) Cesium coated converter. In an attempt to detect H^- ions, cesium getters and pellets (composition 75% Ti, 25% Cr_2 Cs_2 O_7) were placed on the converter, which was then immersed in the plasma. The pellets heated up and the released cesium was seen flowing from the pellets and getters on the converter surface. A marked increase in the converter current was observed. With some gas feed through the collector, the converter current density was recorded to be 2.3 Amp/cm^2. Next, the converter was pushed in until its surface reached the center of the plasma and the collector block was inserted far enough such that the plate extended beyond the converter. Figure 3 is a schematic representation of the experimental setup. The converter was biased to -82

volts with respect to ground, and measurements were made of the collector current with the plate above and below the converter.

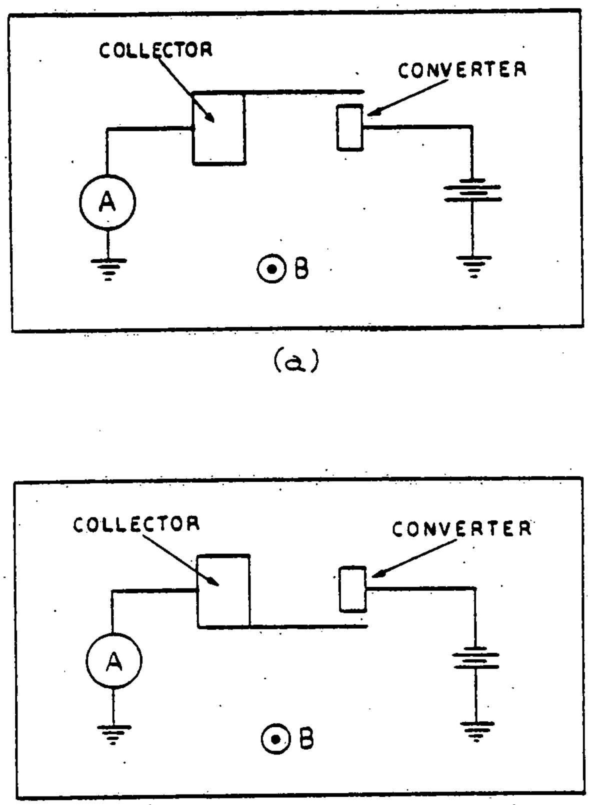

Fig. 3: Schematic of the experimental setup. Discharge conditions: arc current 26 Amp, arc voltage 67 volts, partial gas feed through the cathode, cesium covered converter biased to -82 volts, and background pressure 3 x 10^{-4} torr. With the converter at the center of the discharge, the collector current was (a) 0.8 Amp, (b) 2.9 Amp.

The negative potential of an HCD plasma and the direction and strength of the magnetic field are such that with the plate above the converter, the collector, when connected to ground draws only electrons. In this configuration (Fig. 3a), 0.8 Amp were recorded. With the plate at the bottom negative ions can be collected as well. Indeed, by flipping the plate to the bottom (Fig. 3b), 2.9 Amp were collected. Next, with the plate in the "bottom" position, the converter was retracted. Figure 4 displays the collector current versus the converter current for various radial positions. The collector current is strongly dependent on the converter current. Since the HCD plasma is symmetric, the top and bottom electron densities can be assumed to be the same, and therefore, the electron contribution to the current collected by the collector with the plate in the bottom position can be assumed to be 0.8 Amp.

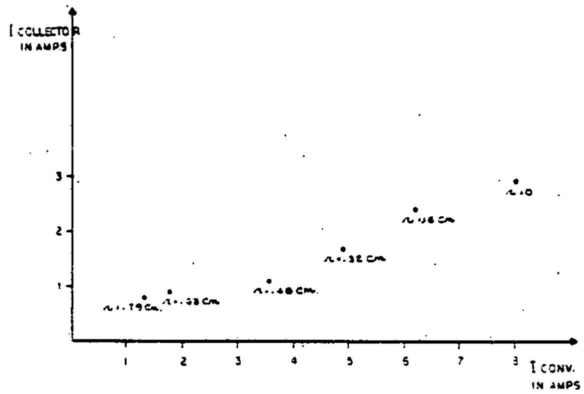

Fig. 4: Collector current versus converter current and radial position.

Thus, with the plate in the bottom position, the negative ion current $I_- = I_{collector} - 0.8$. Figure 5, which is a plot of $I_-/I_{conv.}$ vs the radial position of the converter, is indicative of strong attenuation of the negative ion current.

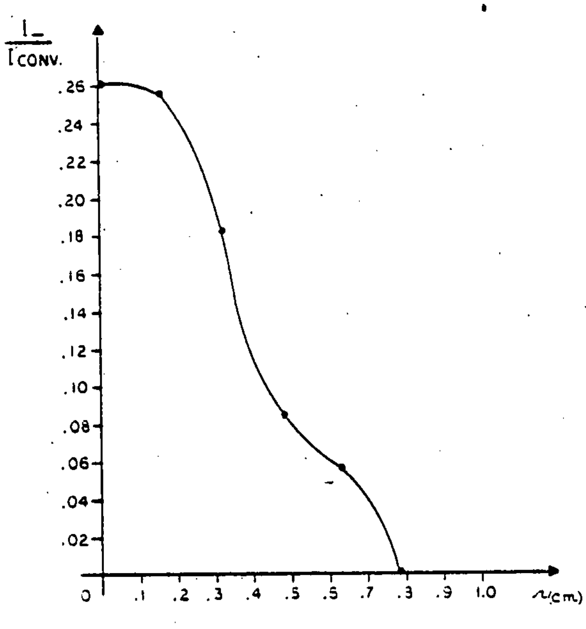

Fig. 5: The ratio of negative ion current to converter current versus the radial position of the converter. With the collector in the "top" position, the current collected by the collector was constant regardless of the converter position.

(6) LaB$_6$ converter doped with cesium. The previous experiment was repeated with a LaB$_6$ converter doped with cesium. This converter was exposed to air for a prolonged period of time before it was used. Therefore, it had to be immersed and baked in the plasma to remove surface oxidation. Initially, 0.8 Amp of current were drawn by the collector with the plate in either the top or the bottom position. After 1.5 hours of baking the collector current with the plate at the bottom started to incrase and reached a value of 1.5 Amp, while the current collected with the plate in the top position remained constant.

IV. Conclusion

This set of experiments strongly suggests that a substantial H^- current was produced by the converter from the plasma injected from the HCD. The strongest evidence comes from the fact that the H^- current collected is consistent with the field direction and strength and from the appearance of the H^- signal only after the oxidation was removed from the LaB$_6$ surface. Also, in the case of the Cs coated Mo surface, the effect reduced in time as the Cs was depleted. It was not measured quantitatively since the Cs depletion could only be observed visually through a window. The remaining question, which cannot be solved without a radical alteration of the device, is what fraction of the negative ion current is due to H^-. The system is dirty and F^- and O^- currents are possible. However, it is hard to imagine that they would amount to more than 10-20%.

Nevertheless, these experiments indicate that a negative ion source based on plasma injection from a hollow-cathode discharge may work well at the expected parameters. Furthermore, due to low background pressure and high gas efficiency, a source based on this principle seems ideal for the production of $_3H_e{}^-$ and T^- ions.

V. Design of a 2 Ampere Negative Ion Source

Our next step is to build a dc negative ion source based on HCD plasma injection as it was previously suggested.[7] For our purpose, a desired plasma is to be shaped into thin sheet which is very differenct from the shape of the plasma in the MIT device. To reach this objective, five tantalum cathodes are to be mounted inside a pole piece which is shaped to produce a magnetic field configuration designed to form the plasma into a sheet of 3 cm x 10 cm with a thickness of 0.5 cm. If the planned experiment is successful, Mark V magnetron will be modified to include plasma injection. Figure 6 is a possible design of such a source. The cathode in the original Mark V becomes a converter.

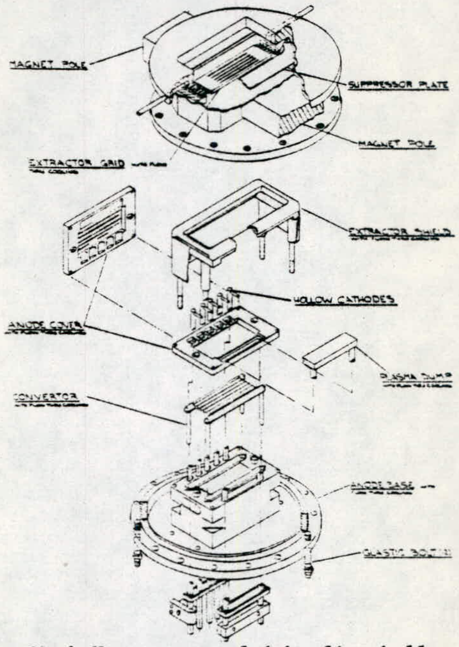

Fig. 6: Mark V magnetron fed by five hollow cathodes.

In a plasma density of 10^{13} cc^{-1} , 2 Amp/cm^2 can be easily drawn by a cesiated converter as we have shown experimentally. Since we have 30 cm^2 of surface area, 60 Ampere of ion current can be drawn on the converter surface. This can be accomplished by plasma injection from five cathodes each yielding 50 Ampere. If we assume conservatively a conversion efficiency of 10%, converter area utilization of 50% and 30% losses in transport, the H^- current extracted from such a source should reach 2 Ampere.

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