# HIGH CURRENT NEGATIVE ION SOURCE FOR PLASMA FUSION EXPERIMENT

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## 1. Introduction

It is experimentally confirmed that neutral beam injection heating is a most useful method of additional heating of plasma and as the size and the density of the plasma are increased in next stage device, the hydrogen neutral beam with high energy above 100 keV is required. In present type of injector using the positive ion, the neutralization efficiency rapidly decreases for ion energy above 60 keV due to the decrease of the cross section for electron capture by proton. However, negative ion of any energy can be neutralized with high efficiency. Especially for energies above 200 keV, negative-ion beams should be used to obtain higher neutralized efficiency. Therefore, high current negative ion source becomes important as the ion source of neutral beam injection in future fusion reactor.

## 2. Production of Negative Ion and Present Negative Ion Sources

There are two method to produce negative hydrogen ion beams. One of them is the direct extraction of negative ion from the discharge plasma. The other is the indirect production by charge exchange of extracted ions in a charge exchange cell.

The indirect method has the advantage that the production process of negative ion is clear and the negative hydrogen ion production efficiency depends on the output of well developed high intensity proton source and the charge exchange efficiency in cesium vapor. An example of experimental arrangement for the production of negative ion beam by this method is schematically in Fig.1.[1)]

The direct extraction of negative ion from a plasma has the advantage of compactness but the production processes of negative ion is rather complicate to understand.

Processes for $H^-$ creation and destruction in a hydrogen discharge are shown in the following table

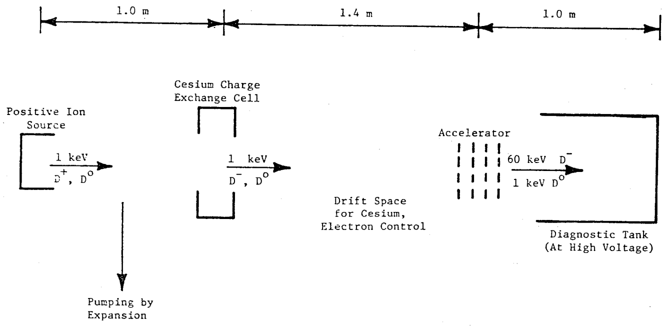



Fig.1 Schematic of the $D^-$ experiment

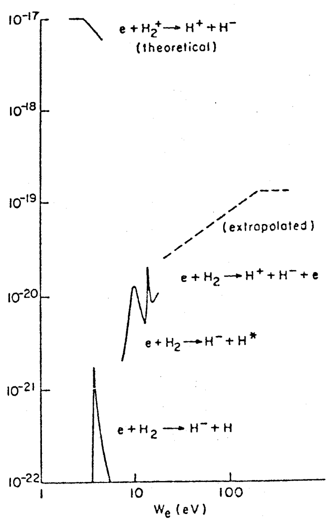
| creation | destruction |
|---|---|
| $e + H_2 \rightarrow H^- + H$ | $e + H^- \rightarrow H + 2e$ |
| $e + H_2 \rightarrow H^- + H^*$ | $H^- + H \rightarrow 2H + e$ |
| $e + H_2 \rightarrow H^- + H^+ + e$ | $H^- + H \rightarrow H_2 + e$ |
| $e + H_2 \rightarrow H^+ + H^-$ | $H^- + H_2 \rightarrow H + H_2 + e$ |
| $H^- + H \rightarrow H + H^-$ | $H^- + H^+ \rightarrow 2H$ |
| $e + H \rightarrow H^- + h\nu$ | $H^- + H_2^+ \rightarrow H + H_2$ |
| | $H^- + H_2O \rightarrow OH^- + H_2$ |

and the cross section of production and destruction are shown as a function of electron energy in Fig.2.[2] The cross sections for destruction are much larger than the cross sections for creation in a hydrogen discharge. To effectively extract the negative ion in direct method, the destruction of negative ion in traversing the plasma must be reduced by using thin plasma such as sheet.

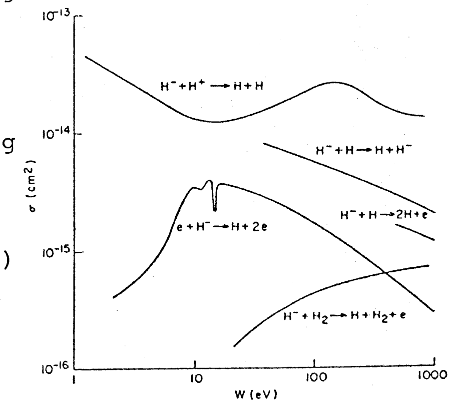
One of the most promising ion source by the direct extraction of negative ion from the plasma discharge is a magnetron type ion source originated in Novosibirsk group, as shown in Fig.3.[3] In this source, $H^-$ ion fluxes of greater density have been obtained after adding cesium vapor to the discharge. Parameters of present negative hydrogen ion sources is summarized in Table 1.[4] In order to develop more intense negative ion source, it is necessary to experimentally and theoretically invistigate the production processes of negative ion in hydrogen-cesium discharge.

## 3. Experiment on Magnetron type Negative Ion Source

Figure 4 shows the cross sectional view of the ion source along with the schematic circuit of the power supply and the gas feed system. The ion source is similar to the magnetron type ion source developed in Novosibirsk group.[5,6] The anode block and the extraction slit (0.5 mm × 10 mm) are made of stainless steel and the cathode is made of stainless steel or molibdenium. Applied magnetic field strength can be varied up to 2 kG in the source region and it decays to one tenth of the value in the source at a distance of 3.5 cm from the extractor. Extraction electrodes are made of copper or stainless steel blade. Collector electrode for the escaping electron from the source is not provided. Hydrogen gas is introduced into the source chamber by an electromagnetic pulsed valve through the needle valve. Pulsed power for arc is supplied by a pulse forming network. The pulse forming network can be charged up to 1 kV and its impedance is of 3 Ω. The




(a)




(b)

Fig.2 a) Negative hydrogen creation cross section
b) Negative hydrogen destruction cross section

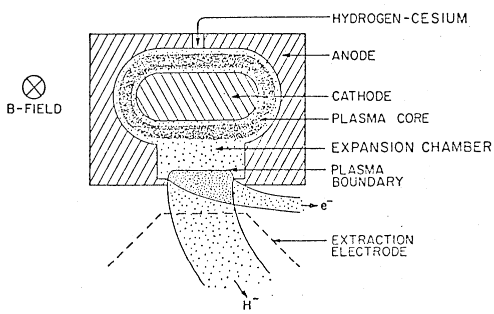



Fig.3 Magnetron negative ion source

TABLE I

| Parameter \ Source | | BNL Magnetron $H_2$ | BNL Penning $H_2$ | BNL Penning $D_2$ | Novosibirsk Magnetrons, $H_2$ | | Novosibirsk Penning without emitter, $H_2$ | Novosibirsk Penning with emitter, $H_2$ | BNL cooled cathode source, design values: Penning | BNL cooled cathode source, design values: Magnetron | 10 A scaled-up Magnetron |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $H^-$($D^-$) current | A | 0.9 | 0.44 | 0.2 | 0.9 | 1 | 0.15 | 0.2 | 0.9 | 1.8 | 10 |
| $H^-$($D^-$) current density | A/cm$^2$ | 0.7 | 0.44 | 0.2 | 2.9 | 3.3 | 3 | 5.4 | 0.5 | 0.5 | 0.5 |
| Pulse length | ms | 10 | 3 | 6 | 1 | 1 | 0.2 | | 25-50 | 25-50 | dc |
| Discharge current | A | 260 | 65 | 40 | 450 | 150 | 180 | 450(80*) | 150 | 500 | 2000 |
| Cathode current density | A/cm$^2$ | 20 | 33 | 20 | 110 | 50 | 300 | (90) | 20 | 20 | 20 |
| Discharge voltage | V | 120 | 220 | 400 | 100 | 120 | 100 | 100(100) | 200 | 120 | 100 |
| Total discharge power | kW | 30 | 14.3 | 16 | 45 | 18 | 18 | 45(8) | 30 | 60 | 200 |
| Cathode power density | kW/cm$^2$ | 1.5 | 4.8 | 5.3 | 7.5 | 4 | 20 | (9) | 2.7 | 1.6 | 1.3 |
| Power efficiency | mA/kW | 30 | 30 | 12 | 20 | 56 | 17 | 3.8 | 30 | 30 | 50 |

* a. Values in parenthesis refer to emitter parameters.

source is mounted by frange to the vacuum chamber (about 100 ℓ), which is evacuated by an oil diffusion pump (2000 ℓ/sec). The pressure in the source chamber cannot be measured, but it is estimated at the order of 1 Torr. A high negative voltage is applied to the chamber and the extraction electrode is grounded. Beam current is measured with movable Faraday cup, and E×B velocity filter is used to confirm that extracted beam is negative hydrogen ion.

In normal operation that ion can be extracted, the voltage drop across the discharge increases from 300 to 350 V as the current increases from 10 to 100 A. The distribution of ion current density transvers to the magnetic field is shown in Fig. 5. Two peaks appear at the distance of 13.5 cm from the extractor. The vertical position of lower peak and that upper peak correspond to the displacement evaluated by the calculated trajectory of $H^-$ and that of heavy ion, respectively. The identification for ion species is also done by E×B filter. Total beam current is calculated from the current distribution and its dependency on the extraction voltage is shown in Fig.6. At the case of the extraction voltage of 10 kV, the source current of 80 A and the magnetic field of 2 kG, the total beam current is of about 5 mA, which gives about 2 mA of $H^-$ and about 3 mA of

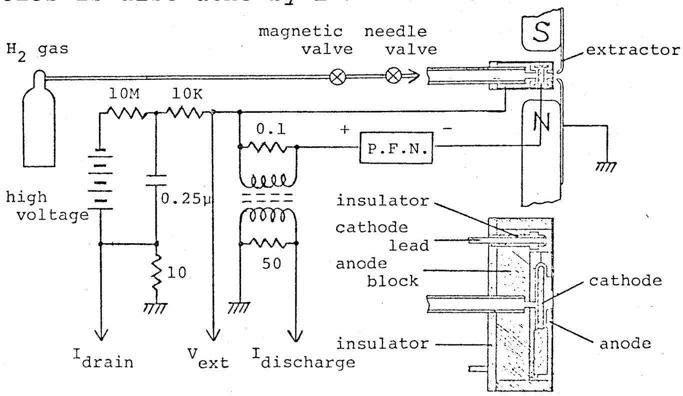



Fig.4 Cross sectional view of the ion source

heavy ion. The ratio of heavy ions to $H^-$ obtained from the peak value is 1 to 1.5. This ratio is not changed by using the different cathode material, stainless steel and molibdenium, but it decreases as shown in Fig.7 as the arc current is decreased. The ratio of heavy ion in the present experiment is large as compared with that in Belchenko's paper.[7] A new improved model and a feeding system of Cs is being prepared now.

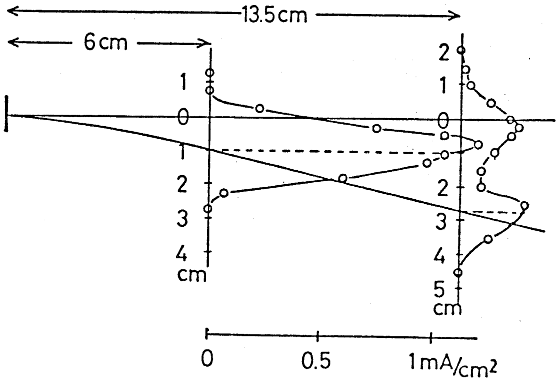



Fig.5 Beam profile

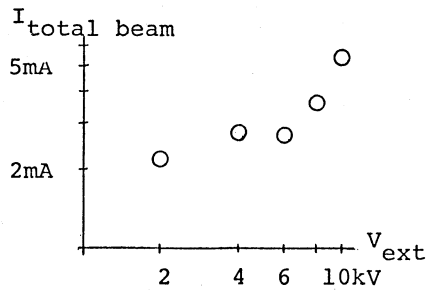



Fig.6 Total beam current vs. extraction voltage

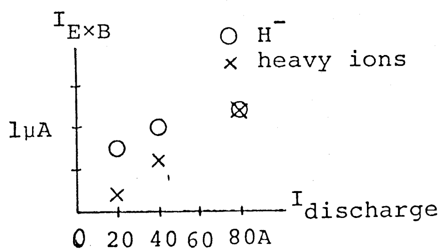



Fig.7 Beam current detected with E×B filter at peak point

References

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