PIG TYPE H-/D- ION SOURCE

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Abstract

Negative ion cyclotrons have been recently required to accelerate both H- and D- beams for the purpose of various and flexible production of short-lived radionuclides. We have developed the negative ion cyclotron which can reliably accelerate both H- beams of 80μA and D- beams of 50μA which are sufficient enough for the purpose. It may safely be said that reliability and stability of a negative ion cyclotron mostly depend on performance of the ion source eqipped in the cyclotron. This paper mainly describes superior performance of the PIG type H-/D- ion source of the negative ion cyclotron.

1. Introduction

Because of an expanding market for short-lived positron emitting radioisotopes which are supplied for Positron Emission Tomography (PET), there is a need for a suitable cyclotron designed specifically for this purpose. Recent advances in target technology allow production of the four most commonly used positron emitters (^{11}C,^{13}N,^{15}O,^{18}F) using only low energy protons. However, the possibility of accelerating low energy deuterons offers special advantages : it removes the need for expensive ^{15}N enriched gas as target material for the production of ^{15}O and also enables the production of moderate amounts of $^{18}F_2$ by the $^{20}Ne(d,\alpha)^{18}F$ reaction.

From the above point of view we have developed the proto-type negative ion cyclotron which can reliably accelerate both H- beams of 80μA and D- beams of 50μA. The main features of the dedicated negative ion cyclotron for medical use are given in Table 1. The prototype cyclotron has been fully tested and now entered the final stage in order to obtain higher beam intensities and superior beam quality. This paper mainly describes characteristics and performance of the PIG type H-/D- ion source equipped in the prototype cyclotron.

2. PIG type H-/D- ion source

2.1 Source Structure

The developed PIG type H-/D- ion source illustrated in Figure 1 has 70mm in length and 20mm in diameter. It is very similar to a positive cold cathode PIG source used for protons and deuterons except that an anode recess is added at the extraction slit. This design is modified from the Dudnikov type PIG source which was originally designed and studied by Allison [1] and Leung et al [2]. It is conceivable that the anode recess of the source has the same role as the anode ribs of the Dudnikov type source [2]. They explain that the anode ribs essentially divide the source chamber of the Dudnikov type source into two regions ; the discharge and extraction region which contribute to facilitate the volume H- production.

Table 1 Main Features of BC1710N BABY CYCLOTRON

Beam		
Accelerated ions	H-	D-
Energy (MeV)	17	10
Beam Intensity (μA)	80	50
Number of targets	8	
Simultaneously extracted beams	2	
Electromagnet		
Number of sectors	4	
Average field (kG)	14.4	15.4
Magnet external diameter (m)	2.20	
Magnet external height (m)	1.37	
Weight (ton)	28	
RF System		
Number of dees	2	
Harmonic mode	2	4
Frequency (MHz)	43	47
Ion Source		
Type of source	PIG, Internal	
Insertion	Horizontal	
Beam Extraction		
Method	Stripping	
Stripping probes	2 sets, Adjustable	

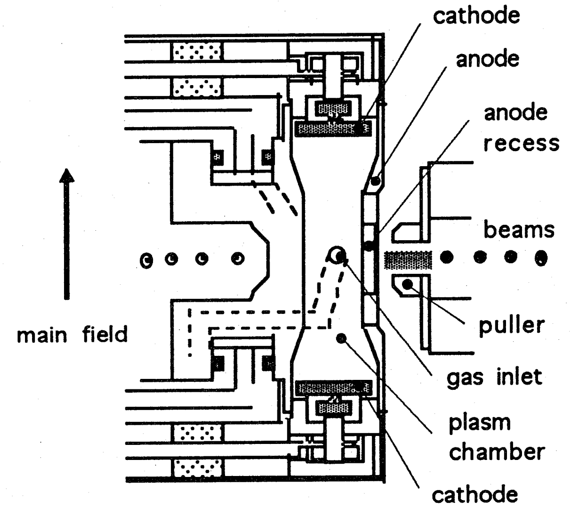

Fig. 1 The developed PIG type H-/D- ion source

It has been demonstrated by Allison that high-intensity H^- beams ($J^- > 2A/cm^2$) can be extracted from the Dudnikov type source if the proper amount of cesium is present. When the Dudnikov source is operated with cesium, the cathodes of the source may be severely damaged by positive ion sputtering. Further, cesium vaper migrating out of the source can cause voltage breakdown problems in the accelerating dee electrodes. Instead of employing cesium, we have operated the developed PIG type H^-/D^- ion source with boride ceramic cathodes which have low work function such as cesium has. we expected that high plasma density can be obtained in the arc column of the developed source, the hydrogen gas being readily ionized by sufficient primary electrons emitted from the boride ceramic cathodes.

2.2 Experimental Results

We fabricated three different sources each of which has an anode diameter of 6, 8 and 10 mm respectively. The space between two cathodes can be altered among three different values of 35, 44 and 50 mm. We searched for the optimum combination between anode diameter and cathode space. The D^- beam is best with the combination between the diameter of 6mm and the space of 35mm with the anode recess fixed at 0.5mm. The experimental results shown in Figures 2 through 5 were obtained with the optimum combination. The beams plotted in Figures 2 through 6 were measured at the radius of 24cm in the developed cyclotron.

Fig. 2 shows the H^- beams and arc voltage as a function of arc current with a fixed gas flow of 7sccm. The optimum arc current to obtain the maximum H^- is around 0.9A and the corresponding arc voltage for that is about 135V. Beyond that, the decrease of H^- might be due to the over supply of electrons with destructive energy and the increased percentage of positive ions.

Fig. 3 shows the D^- beams and arc voltage as a function of arc current with a fixed gas flow of 6sccm. It can be seen that the optimum arc current is around 2.3A. Beyond that, the decrease of D^- would be explained as abovementioned H^- beams.

Fig. 4 shows another H^- beams curve and arc voltage as a function of gas flow with a fixed arc current of 1.0A. The maximum H^- production is reached at 7sccm. Beyond that, the high gas pressure inside the source decreases the survival of the H^- already produced and the increase of stripping loss before reaching 24cm also contributes to the trend of decrease.

Fig. 5 shows another D^- beams curve and arc voltage as a function of gas flow with a fixed arc current of 2.2A. The saturation of the D^- at gas flow above 5.5sccm might be due to the insufficient supply of gas molecules. However, the decline of the D^- at higher gas flow will be inferred from that of the H^- as abovementioned.

Fig. 6 shows the difference between the two sources with and without anode recess. The H^- beam current for the source without anode recess is reduced to about 70 percent of that for the source with anode recess in the range of arc current above 0.9A. The effect of the anode recess might be explained here-

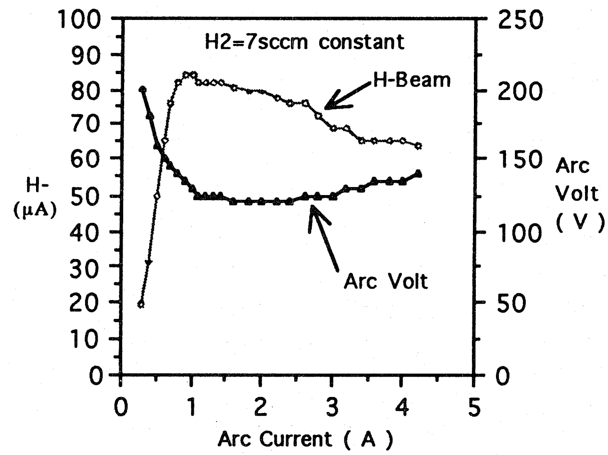

Fig. 2 H^- beams as a function of arc current

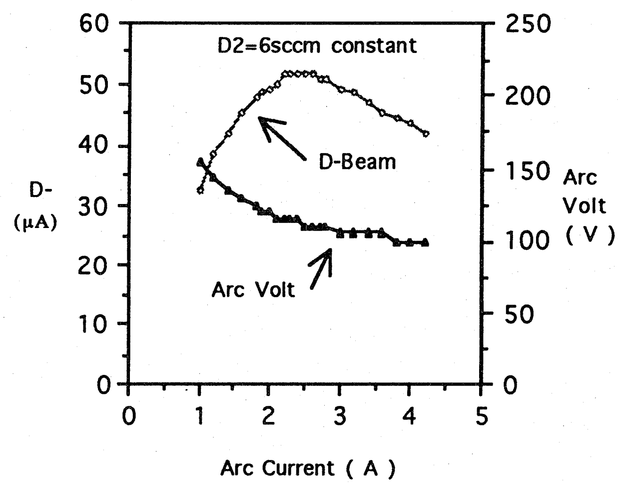

Fig. 3 D^- beams as a function of arc current

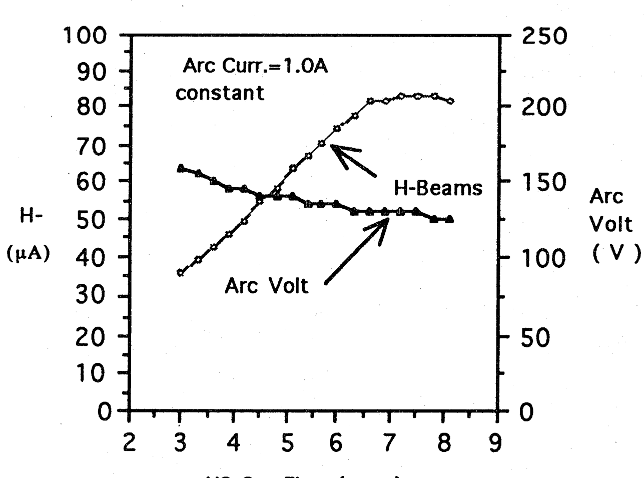

Fig. 4 H^- beams as a function of H_2 gas flow under by the volume-production process of H- ions. The anode recess devides the source chimney into two regions ; the discharge and the extraction region. In the discharge region,energetic primary electrons ionize or vibrationally excite the background gas, forming a dense arc plasma column. The plasma in the extraction region is colder than that in the discharge region. H- ions may be formed in this cold plasma region by dissociative attachment of low energy electrons to the vibrationally excited molecules.

2.3 DC Equivalent H-/D- Output

Fig. 7 shows the radial dependence of H- beams in the prototype cyclotron. The RF phase acceptance is estimated to be approx. 20 degrees at the extraction radius. The DC equivalent H- output of the source is then inferred to be 1.4mA without taking account of stripping loss. Likewise the inferred DC equivalent D- output is about 0.9mA.

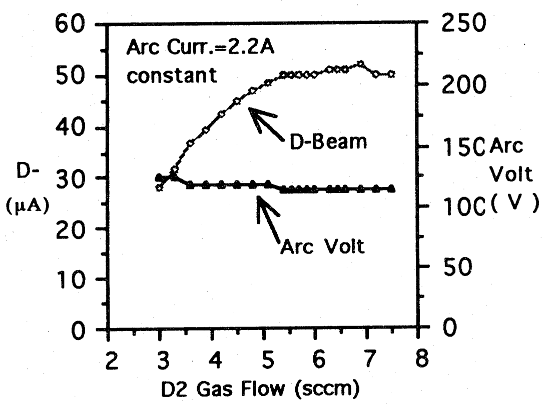

Fig.5 D⁻ beams as a function of D2 gas flow

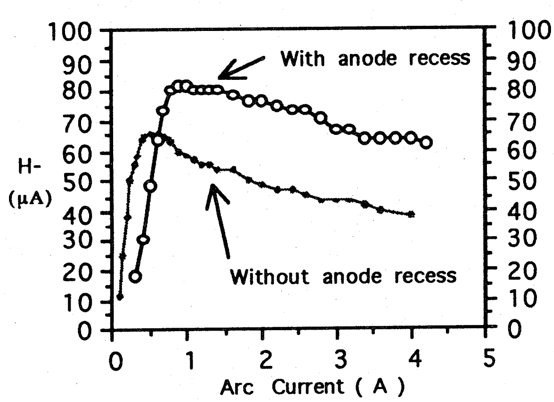

Fig. 6 The difference between the two sources

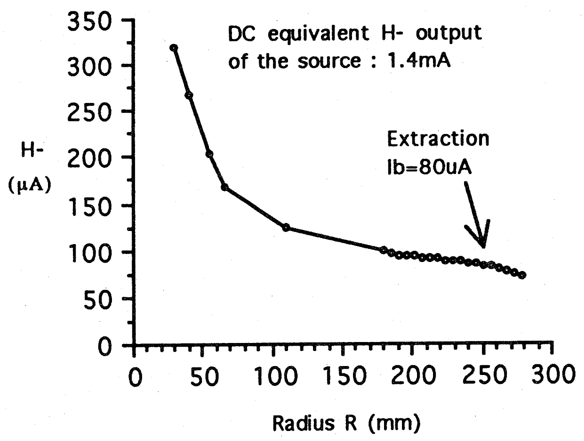

Fig.7 The radial dependence of H^- beams

3. Conclusions

The test results are summarized as follows : H- beams of 80μA are obtained with the arc power of 120W and the H_2 gas flow of 7sccm. D- beams of 50μA are obtained with the arc power of 280W and the D_2 gas flow of 6sccm. Although it would be possible to obtain larger beam current by increasing the size of the ion extraction slit and the vaccum pumping speed, it will be necessary to learn how to operate the source at lower pressures.

Acknowledgements

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References

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[2] K. N. Leung et al., Rev. Sci. Instrum., Vol. 58, No. 2, 235 (1987).