Journal of the Korean Nuclear Society
Volume 23, Number 4, December 1991

A Study on He^+ Ion Beam Extraction in the Duoplasmatron Ion Source

Myong-Seop KIM and Hae-iLL BAK
Department of Nuclear Engineering, Seoul National University
(Received April 30, 1991)

Duoplasmatron 이온원에서의 He^+ 이온빔 인출에 관한 연구

김명섭 · 박혜일
서울대학교 원자핵공학과
(1991. 4. 30 접수)

Abstract

The operational characteristics of the duoplasmatron ion source are investigated in order to obtain the maximum achievable extraction current of the He^+ ion beam with the small divergence. Under the variations of the gas pressure, the arc current, the magnet current and the extraction voltage of the ion source, the change of the extracted He^+ ion beam current is observed. An oxide filament, the mixture of BaO and SrO coated on Ni meshes, is used as the hot cathode, and its average lifetime is about 100 hours. The extraction current is linearly proportional to the arc current. As the magnet current of the ion source is increased, the extraction current increases, but the beam divergence becomes larger. The maximum extraction current is obtained at the source pressure of 0.084 Torr. The extraction current is proportional to the extraction voltage raised to the power of 3/2 as estimated from theory. At the extraction voltage of 5.72 kV, the maximum extraction current of 50 μA is obtained under the optimized extraction condition.

요 약

각확산도가 작은 He^+ 이온빔 인출전류를 최대로 얻기 위하여 Duoplasmatron 이온원의 동작특성을 조사하였다. 이온원의 기체압력, 아크전류, 전자석전류, 인출전압등을 변화시키면서 인출되는 He^+ 이온빔 전류의 변화를 관찰하였다. 열음극으로는 Ni망위에 BaO와 SrO의 혼합물을 코팅한 산화물 필라멘트를 사용하였으며, 그것의 평균수명은 약 100시간이었다. 인출전류는 아크전류에 선형적으로 비례했다. 이온원 전자석전류를 증가시킴에 따라 인출전류는 증가하였지만 빔의 각확산도가 커졌다. 최대의 인출전류는 0.084 Torr의 이온원압력에서 얻어졌다. 인출전류는 이론에서와 마찬가지로 인출전압의 3 / 2승에 비례하였다. 5.72 kV의 인출전압에서는 최적인출조건하에서 50 μA의 인출전류가 얻어졌다.

I. Introduction

In the present work, the extraction experiment of the He^+ ion beam from the duoplasmatron ion source of the SNU 1.5–MV Tandem Van de Graaff accelerator was performed in order to obtain the He^+ ion beam. The He ion beam is widely used in the RBS (Rutherford Backscattering Spectrometry) surface analysis because it has many advantages in the aspects of the mass and the depth resolutions of the RBS analysis(1). In the duoplasmatron ion source, the extraction process of the He^+ ion beam is as follows.

(1) The plasma generation from the He gas discharge.

(2) The constriction of the plasma.

(3) The extraction of the He^+ ion beam from the plasma boundary.

The He gas discharge experiment was performed in order to generate the plasma, then, the He^+ ion beam was extracted by the high voltage of the extraction electrode. The current and the divergence of the extracted ion beam depend on the arc current, the magnet current, the gas pressure and the extraction voltage of the ion source. Therefore, such parameters were varied in order to investigate the extraction characteristics of the ion source and to obtain the high current of the ion beam with the small divergence.

II. Experimental Method

Fig. 1 is the cross–sectional view of the duoplasmatron ion source(2).

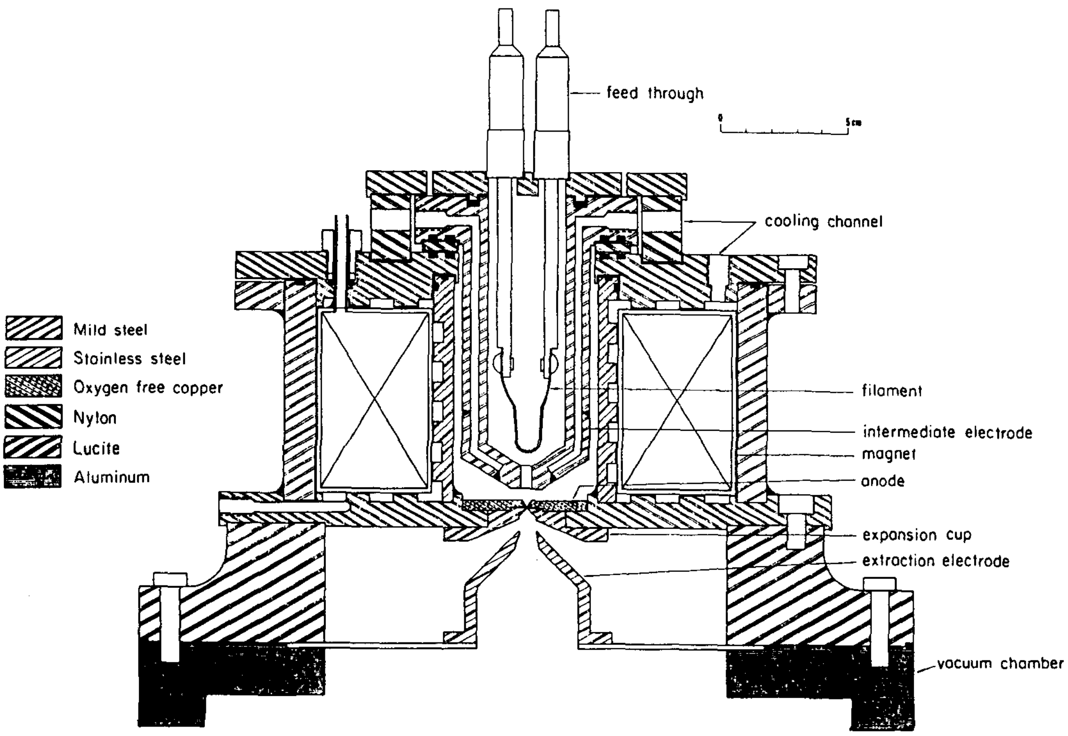

Fig. 1. Cross–sectional view of the duoplasmatron ion source.

An oxide filament, the mixture of BaO and SrO coated on Ni meshes, was used as the hot cathode(3). The fabrication process of the filament is described below.

The Ni meshes were baked up to the filament current of 35 A below the pressure of 2×10^{-2} Torr. The mixture, which was mingled with Ni powder, $BaCO_3$ and $SrCO_3$ in the mass ratio of 70 : 12.85 : 17.15, was suspended with the isoamylacetate solution(4). The baked Ni meshes were uniformly plastered with this mixture and baked up to the filament current of 40 A under the same pressure condition.

Since the anode aperture only plays the role to leak the plasma, the aperture diameter should be small so that the gas efficiency may be high. The two anodes whose aperture diameters were 0.6 mm and 1.05 mm, respectively, were employed in this experiment. The expansion cup plays the role to decrease the density of plasma for the small divergence. Since this expansion cup becomes the path of the magnetic field, it was made of the mild steel as in the case of the intermediate electrode. The geometrical shape of the extraction electrode was the same as that of the Pierce type electrode. The two einzel lenses were used in order to focus the extracted beam.

The ion beam current was measured with the Faraday cup which could minimize the effect of the secondary electrons.

The He gas discharge experiments were performed in the filament current of 30~40 A and below the ion source pressure of 8×10^{-3} Torr. The arc discharge was occurred in the range of the He gas pressure of 0.8~1.0 Torr and the range of the arc voltage of 300~380 V. The generated arc current had the value in the range of 2~3 A.

After the discharge state became stable, the source pressure was decreased to the optimum value for the extraction, and the ion beam was extracted by the extraction voltage. As the extracted beam current is the function of the arc current, the source magnet current, the gas pressure and the extraction voltage, such parameters were varied in order to investigate the extraction characteristics of the ion source and obtain the maximum extraction current with the small divergence.

Ⅲ. Results and Discussions

The filament lifetime was prolonged when it was fabricated in lower vacuum condition than 2×10^{-2} Torr. The average lifetime of the oxide filament was about 100 hours.

As shown in Fig. 2, the arc current increases with the arc power supply voltage but the arc voltage decreases, which is consistent with the general property of the arc discharge(5).

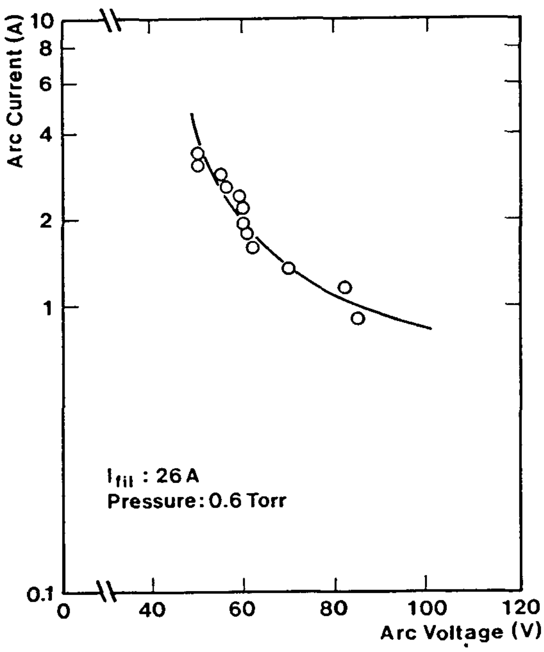

Fig. 2. Arc current vs. arc voltage.

The relation between the He gas pressure and the extracted beam current is shown in Fig. 3. The maximum beam current was measured at the He gas pressure of 0.084 Torr, which coincides with the result of other experiment(6). In high gas pressure, the breakdown by the extraction voltage and the electron loading(7) made the beam current unstable. But if the gas pressure was too low, the intensity of the ion beam decreased because of the lack of the discharge source.

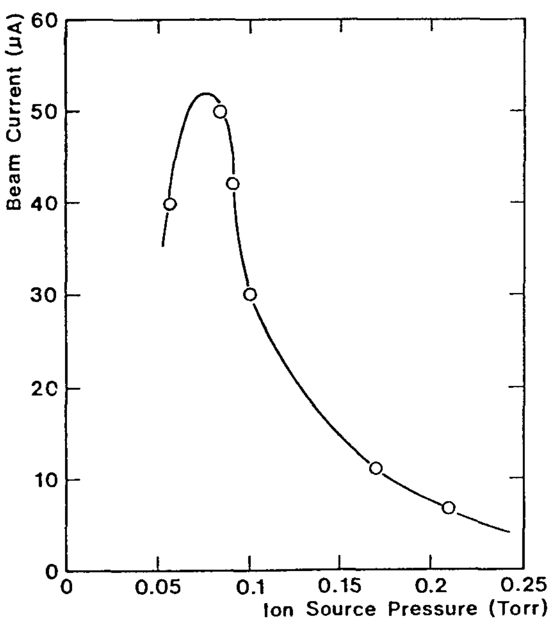

Fig. 3. Beam current vs. ion source pressure.

In the case of the anode with the aperture diameter of 1.05 mm, the beam current was very unstable because of the large gas leakage. When the anode with the aperture diameter of 0.6 mm was used, the stable beam was obtained.

The relation between the arc current and the extracted beam current is shown in Fig. 4. The beam current was linearly proportional to the arc current. It could be expected that the beam current would be saturated in the high arc current. This result was consistent with P. Ciuti's result(8).

If the potential difference between the plasma and the metal electrode is V, the distance between

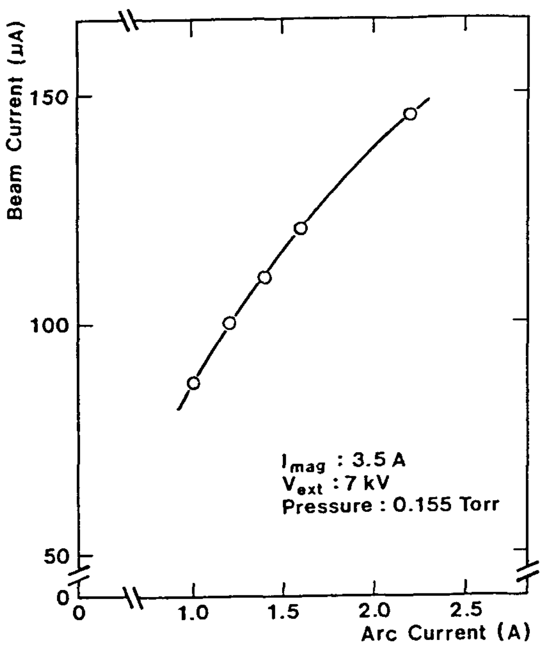

Fig. 4. Beam current vs. arc current.

the electrode and any point M on the plasma boundary, d(M), is given by

$$d(M)=\frac{2}{3}\epsilon_0\left(\frac{2e}{m}\right)^{1/4}\left(\frac{V^{3/4}}{J_p^{1/2}}\{1+k(M)\}^{1/2}\right), \quad (1)$$

where k(M) is the correction factor that is related to the shape of the electrode and m is the ion mass and J_p is the maximum current density that can be emitted from the plasma(9). According to Eq. (1), the increase of the arc current makes the plasma boundary convex. Accordingly, the beam divergence becomes larger, which limits the beam current.

The relation between the source magnet current and the beam current is shown in Fig. 5. As the magnet current was increased, the electron diffusion to the wall decreased in the magnetic field which was parallel to the electric field. So, the plasma was compressed and the beam current increases as shown in Fig. 5. In the range of the high magnet current, the beam divergence became larger by Eq. (1) and the beam homogeneity became worse due to the increase of the residual magnetic field in the expansion cup(10).

The relation between the extraction voltage and the extracted beam current is shown in Fig. 6. According to the O. Almen's equation(10), extraction current was proportional to the extraction voltage raised to the power of 3/2. As shown in Fig. 6, in the low extraction voltage, the extraction current is increased with larger slope than that of the power of 3/2 due to the change of the plasma boundary by Eq. (1), and it is saturated in higher extraction voltage due to the removal of the space charge effect. In very high extraction voltages the extraction properties were unstable due to the breakdown phenomena by the high voltage.

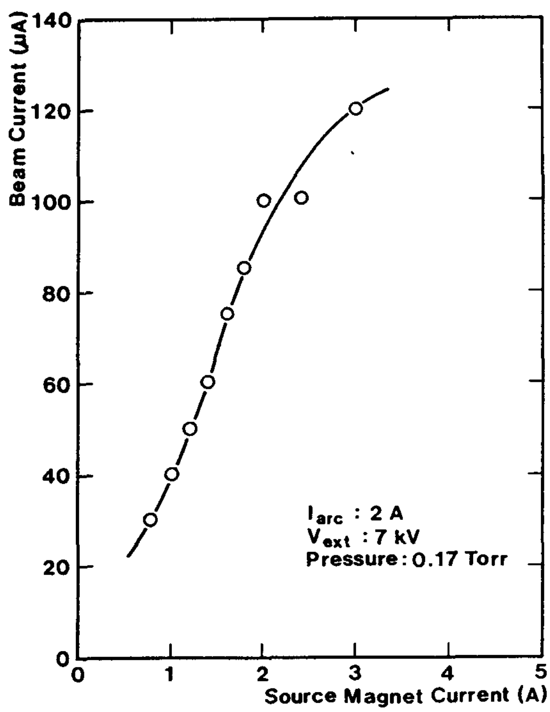

Fig. 5. Beam current vs. source magnet current.

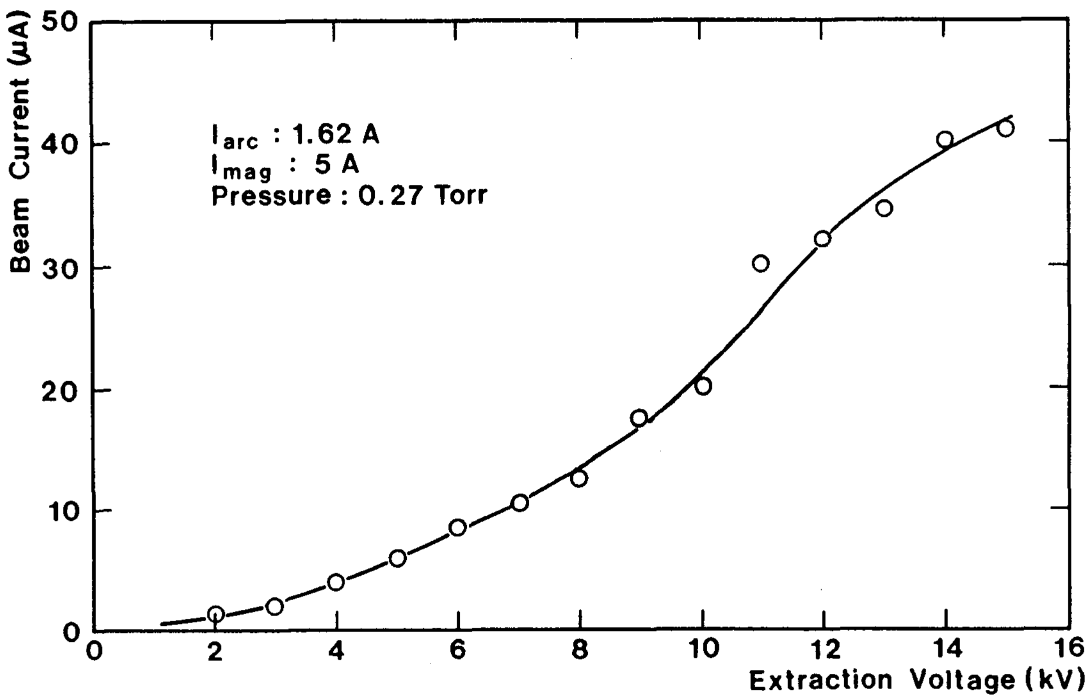

Fig. 6. Beam current vs. extraction voltage.

Ⅳ. Conclusion

The overall operational characteristics of the duoplasmatron ion source were investigated, and the optimum extraction condition of the He^{+} ion beam was found. Thus it is concluded that the duoplasmatron ion source can be applied to the RBS analysis system. Since the diameter of the anode aperture and the geometry of the expansion cup have a great influence on the beam current, their improvements are the main subjects which must be studied in order to increase the beam current.

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