Development of a Carbon Cluster Ion Source with a Hollow Cathode

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Abstract. Carbon cluster ion beams were produced utilizing a monoplasmatoron ion source with carbon cold hollow cathodes. Changing the gas injection position of the hollow cathode caused the difference in intensities and species of extracted ions. The pure carbon cluster ion beams were successfully produced at about 36 Pa Ar gas pressure in the ion source, 70 mA discharge current, 1 kV extraction voltage and focusing by an electrostatic lens system. The source operation was often limited by discharge extinction, possibly attributable to a rapid discharge pumping.

INTRODUCTION

Cluster ion beams have become a useful tool for processing surfaces of materials. Cluster beams of metals, semiconductors and insulating materials are formed mostly by either gas condensation or expansion of their vapors[1]. The methods to form clusters by sputtering and intense laser ablation are often used for high-temperature materials. Hollow cathode sputtering[2] is suitable for production of clusters due to a locally concentrated sputtered atom emission and can be utilized for many material preparation processes. Meanwhile an ion source utilizing a hollow cathode[3] can produce a stable and continuous ion beam. In this study, a monoplasmatron[4] ion source with a carbon cold hollow cathode was constructed in order to investigate the influence of cluster generation caused by the gas injection position and the gas line configuration of the hollow cathode. Two hollow cathodes with different gas lines, the straight and the branched gas flow hollow cathode, were examined.

EXPERIMENTAL

A schematic diagram of the experimental apparatus is shown in Fig. 1. The ion beam extracted from a monoplasmatron ion source travels about 70 mm from extraction aperture to reach the Einzel lens. The Einzel lens consists of three electrodes with a 60 mm inner diameter and a 30 mm length. The gaps between the lens electrodes are 20 mm. The ion beams converged by the Einzel lens are analyzed with a magnetic deflection type mass analyzer with the 285 mm Lamor radius. The ion beams change the direction by 90 degrees and further travel another 450 mm distance to reach the Faraday cup. The ions travel a total of 1555 mm.

Figure 2 (a) shows the schematic diagram of the monoplasmatron ion source. A 35.5 mm inner diameter, 40 mm long glass made tube serves as the side wall of the ion source. The source contains a carbon hollow cathode, a carbon anode and a carbon intermediate electrode. Two types of the hollow cathode are designed and tested in order to examine and compare the performance for generating carbon cluster ions. The hollow cathode shown in Fig. 2 (b) introduces gas into the source through straight conduit and the gas directly flows towards the extraction hole. On the other hand, the hollow cathode shown in Fig. 2 (c) supplies discharge gas into the source through bending the flow by 90 degrees at the point 30.5 mm from the entrance. This structure splits the flow to four directions for ejecting the gas from the side surface of the cathode. The cathode of this type is called the "branched type" in this paper. The hollow cathode has a 1 mm inner diameter, 5 mm outer diameter and 33 mm length in both straight gas flow type and branched gas flow type.

The electrically floated intermediate electrode condenses the discharge current flowing between the hollow cathode and the anode. The size of the intermediate electrode is 34 mm outer diameter and 9 mm height, with the plasma condensing cone having 22 mm diameter opening at the plasma side, and 4 mm diameter opening at the anode extraction electrode side. The slope of the cone is 45 degrees. A 21 mm inner diameter and 5 mm long Pyrex glass and alumina ceramic screws fix the intermediate electrode to the anode, while electrically insulate these electrode. The Pyrex glass for insulation keeps the distance 1 mm between the bottom of the intermediate electrode and the anode. The anode has 22 mm outer diameter and 1 mm length, and a conical hole with a center of 1 mm on the discharge chamber side and 3 mm on the extraction electrode side. The extraction system consists of two electrodes: anode and extraction electrode. The position of the 24 mm outer diameter 35.5 mm length extraction electrode can be adjust the position from the ion source anode. The distance between the anode and extraction electrode was varied from 0.5 mm to 2 mm at 0.5 mm intervals, the resolution of mass spectrum reached the maximum at 1.5 mm spacing, and the measurement was made at this spacing. The center hole of extraction electrode has a cylindrical shape with 1.5 mm diameter and 0.75 mm length. A conical shape extractor has the 0.75 mm diameter hole at the side of the extraction gap. The beam travels through the region of 45 degrees slope and that with 20 mm diameter and 25.5 mm length.

The experiment was conducted under the initial gas pressure of 1.0×10^{-4} Pa on the Einzel lens side and 4.5×10^{-4} Pa on the Faraday cup side. Introduction of Ar gas into the source up to about 60 Pa ignited a discharge in the ion source at about 700 V discharge voltage. The plasma discharge was controlled in the constant current mode of regulated negative voltage power supply (0~-6 kV, 0~100 mA). The discharge characteristics were obtained by setting the discharge current and measuring the discharge voltage in every 2 minutes. The ion beam was extracted at 1 kV and converged by 0.77 kV lens voltage. The spectral resolution of Ar was about 60 at 0.77 kV lens voltage. The magnitude of the ion beams current detected by the Faraday cup were amplified, and the digital multimeter measured the signal. A controlling program automatically sweeps the current of the magnetic deflection type mass analyzer and records the voltage value of the digital multimeter through connecting PC to power supply and the multimeter by data interface bus. The carbon cluster ions are investigated by measuring the peak value of obtained mass spectrum.

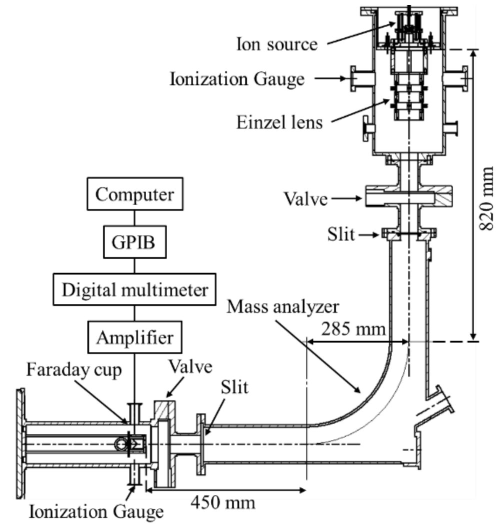
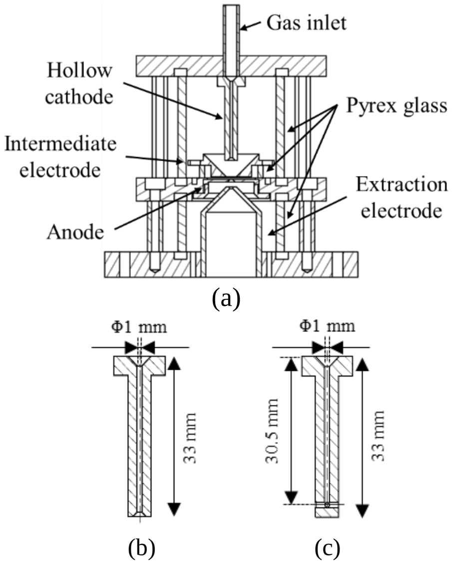


FIGURE 1. A schematic diagram of the experimental apparatus.



(a)

(b) (c)

FIGURE 2. (a) The schematic diagram of the ion source with a hollow cathode. (b) The straight gas flow hollow cathode. (c) The branched gas flow hollow cathode.

RESULT AND DISCUSSION

Figure 3 shows the discharge characteristics observed at 18 Pa and 36 Pa Ar gas pressure in the ion source. The discharge characteristics of both hollow cathodes showed a voltage descending region at about 10~30 mA discharge current and a voltage ascending region at about 30~80 mA. The decrease in discharge voltage was observed as the discharge was observed inside of the hollow cathode. The discharge voltage did not continue to decrease; it hit the lowest point then started to increase against discharge current. At 36 Pa Ar gas pressure in the ion source, both hollow cathodes took the lowest discharge voltage of 480 V at 30 mA discharge current. At 18 Pa Ar gas pressure in the ion source, the straight gas flow hollow cathode had the lowest discharge voltage of 560 V at a 30 mA, while the branched gas flow hollow cathode had the 490 V lowest discharge voltage at 20 mA. These lowest discharge voltages were expected to appear depending upon the discharge sheath structure like glow to arc transition. A discharge pumping often starts in this region of discharge, and the plasma could not be often maintained throughout 10~80 mA because the discharge voltage increased abruptly.

The characteristics of the carbon ions beam as a function of the discharge current are shown in Fig. 4 (a). The conditions were 36 Pa Ar gas pressure in the ion source and 1 kV extraction voltage. The typical mass spectrum shown in Fig. 4 (b) shows C_1, C_2, C_3, C_4, C_5 and C_6 ion peaks as pure carbon clusters. It was often difficult to accurately measure the spectral peaks of C_3 and C_6 ions due to the large Ar ion skirt and huge peak at mass 78 to 80. The characteristics had the difference in the amount of carbon cluster ions in hollow cathode glow at 30~80 mA. The amount of C_2 ion beam produced by the straight gas flow hollow cathode did not change with increasing discharge current, however the amount of C_4 and C_5 ion beam tend to decrease. On the other hand, the amount of C_2, C_4, and C_5 ion beam produced by the branched gas flow hollow cathode showed a tendency to rise as the discharge current increased. As a result of comparison between the branched gas flow hollow cathode and the straight gas flow hollow cathode in their performance at about 36 Pa Ar gas pressure and 70 mA discharge current, the branched gas flow hollow cathode produced 120 % of C^+, 182 % of C_2^+, 200 % of C_4^+ and 192 % of C_5^+. By resolving the problem of discharge extinction due to rapid discharge pumping in the discharge mode transition, the source may produce more cluster ions at a better operation condition.

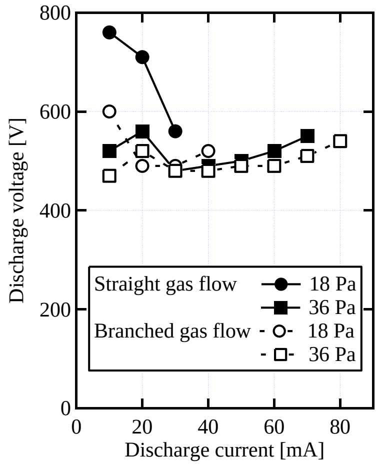
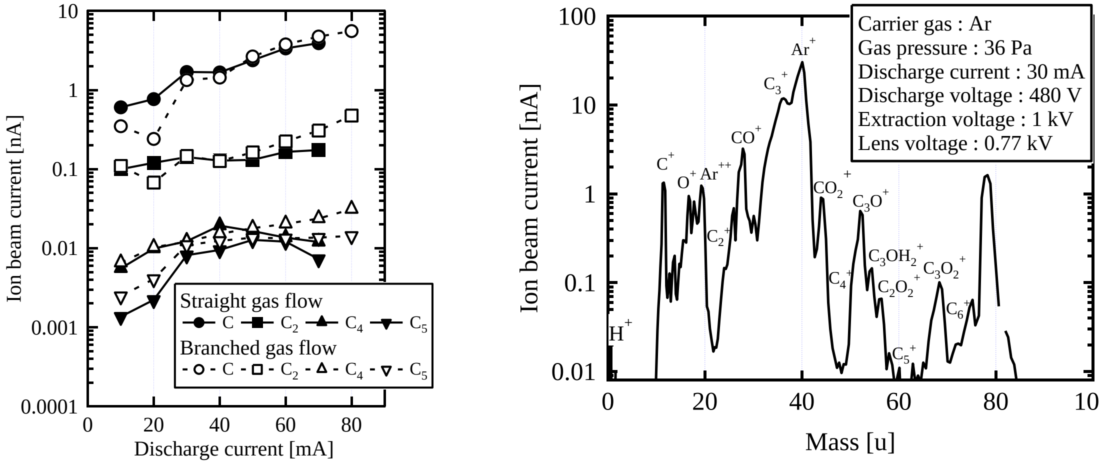


FIGURE 3. The discharge characteristics of the ion source when using each hollow cathode.



(a) (b)

FIGURE 4. (a) The carbon ions beam characteristics as a function of discharge current. (b) A typical mass spectrum obtained by the branched gas flow hollow cathode.

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