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Measurement of Ion Species Fraction of Hydrogen plasma in Cold Cathode Penning Ionization Gauge Ion Source in Pulsed Operation

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1. Introduction

Proton ion sources are widely used in various fields, the accelerators, the nuclear fusion energy, the neutron generators, etc. One of the important characteristics that determine the performance of proton ion source is the monatomic fraction. Higher monatomic fraction means that it can make more efficient proton beam. In previous study, we made the numerical model of hydrogen ion species and verified that with the hydrogen plasma cold-cathode PIG (*P*enning *I*onization *G*auge) ion source [1]. At that time, we operated the plasma source continuously and the discharge regime was the glow mode. So we cannot get high density plasma and high monatomic fraction. The monatomic fraction of that systems was under 20%. To get high monatomic fraction, the arc discharge regime is required, but it is hard to make that mode continuously. In many applications, pulse ion beam is widely and actively used. So in this study, short pulse discharge is adopted. For the continuous ion beam, the magnetic mass analyzer was used. But this method is not appropriate to short pulse beam because it takes time to change magnetic field. So we developed the time-of-flight (TOF) mass analyzer [2-5].

In this study, high current (~ 20 A) hydrogen arc plasma is discharged with cold cathode PIG ion source. The fraction of the hydrogen ion species H^+, H_2^+, and H_3^+ is measured by TOF mass analyzer. And the change of the ion species fraction by the change of the discharge condition is compared with the numerical model of the hydrogen ion species previously established [1].

2. Experimental Setup

The cold cathode Penning ionization gauge ion source is constructed as shown in Fig. 1. It consists of a tubular anode and 2 cathodes at each side. The inner diameter of anode is 25 mm, and its length is 40 mm, 25 mm diameter cathodes are set away from anode by 5 mm in each sides. So the discharge volume is 25 mm (D) × 50 mm (L).

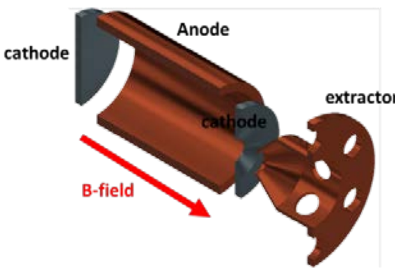

Fig. 1. Basic structure of cold cathode PIG plasma ion source.

There is a magnetic field, 500 – 1500 G, in the axial direction of the anode tube. The discharge gas is hydrogen and it is supplied at 5 – 15 sccm depending on the operating pressure. The arc initiation voltage is fixed at 3 kV. The arc current is adjusted with a current limit resistor, 75 – 600 Ω. The arc pulse duration is within 100 μs. In one of two cathodes, a beam extraction hole is formed, and an extractor is placed several mm apart from the hole. The ion beam is extracted with the acceleration voltage 10 kV.

The ion species fraction is analyzed by the time-of-flight mass analyzer. Fig 2 is the diagram of total system of the TOF with the ion source. By the gating device for short-pulse sampling and deflecting, ion beam from the source is sampled to a short pulse width within the difference of the flight time between the ion species.

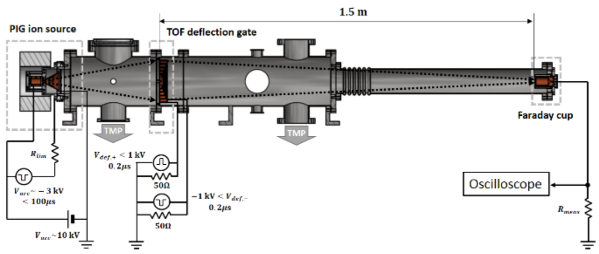

Fig. 2. Total system of the time-of-flight mass analyzer with the PIG ion source

The beam sampled to short pulse flies through the drift chamber of the length 1.5 m. At the end of the drift chamber, the ion current detector, Faraday cup is installed to measure the current of ion species respectively.

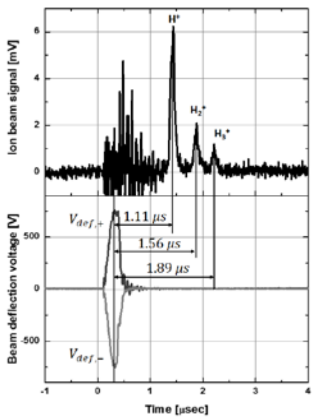

Fig. 3. A typical TOF signal: the consecutive arrivals of ion species

If ion beam is extracted with same energy and the charge state is all the same, the drift velocity depends on the ion mass. So light ion, H^+ arrives first to the detector, and H_2^+, H_3^+ arrive consecutively. Fig. 3 shows the arrivals of ions. The diagram in the lower part of Fig. 3 means the beam sampling pulse. The upper part shows the arrival peak of the respective ion species and the relative amount of ion species.

3. Results

According to the previous study, to increase the monoatomic fraction, the plasma density should be increased and the pressure should be lowered [1]. In order to check the change of the ion species fraction according to the discharge condition, the fraction of ion species was measured under various conditions.

Firstly, we measured the change of the ion species fraction according to the change of the arc current. The arc current is considered to be a physical quantity proportional to the plasma density. So, in Fig 4. the measurement of the ion species fraction change by the arc current is compared with the numerical model result by the plasma density. The two results fit well, and we can see that as the arc current increase, that is, as the plasma density increases, the monatomic fraction increases. Unlike the continuous glow discharge in previous study, in this pulsed arc discharge the monatomic fraction can be over 60%.

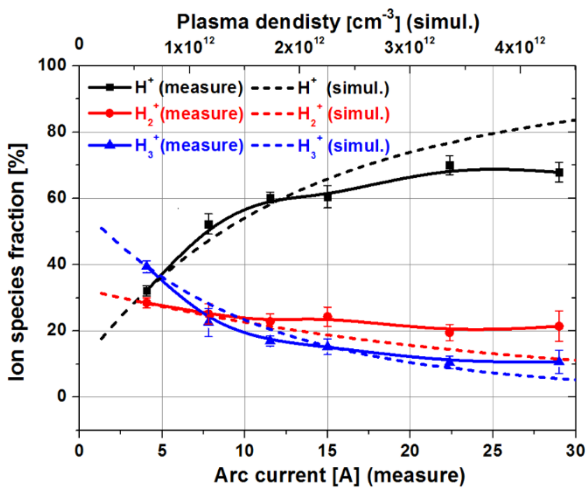

Fig. 4. Change of the ion species fraction according to the arc current (measurement, solid line) and the plasma density (numerical model, dotted line). The operating pressure is set at 10 mTorr.

Next, the change of the ion species fraction is measured according to the change of the operating pressure. The electron temperature is a value that depends on the operating pressure within a fixed discharge volume, so in the numerical model, the electron temperature was applied with the magenta solid line in Fig. 5. The measurement and the numerical model were also compared for the changes in the operating pressure in Fig. 5. In the numerical model, the plasma density is fixed, but in the measurement, the plasma density can be changed, so the comparison between the measurement and the calculation doesn't fit very well. However, the trend that as the operating pressure decreases, the monatomic fraction increases, can be seen well.

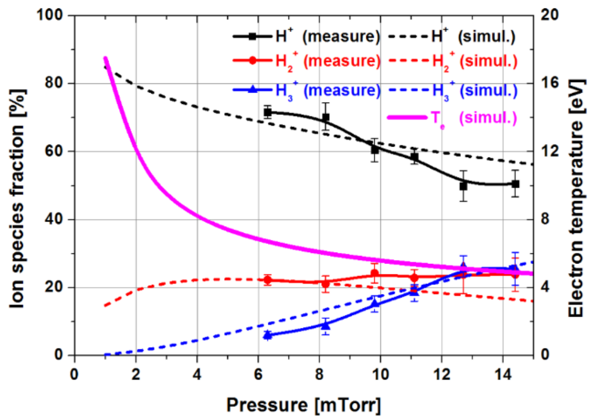

Fig. 5. Change of the ion species fraction according to the operating pressure: solid line – measurement, dotted line – numerical model. The arc current is set at 15 A in measurement, and the plasma density is set 2×10^{12} cm^{-3} in the numerical model.

Lastly, the change of the ion species fraction is measured according to the change of the axial magnetic field. In the numerical model, the consideration of the magnetic field is not included yet. Just a measurement is shown in Fig. 6.

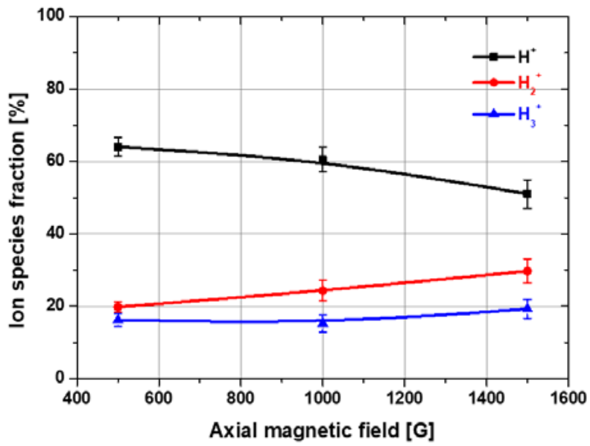

Fig. 6. Change of the ion species fraction according to the axial magnetic field. The arc current is 15 A, and the operating pressure is 10 mTorr.

The monatomic fraction is higher as the axial magnetic field is lower. The effect of the magnetic field will later be implanted in the numerical model and compared with this measurement result.

4. Conclusions

The ion species fraction of a hydrogen cold cathode PIG ion source in puled operation is measured. To measure the mass state of pulsed ion beam, the time-of-flight mass analyzer was developed and fabricated. Previously developed numerical model of hydrogen plasma estimated the tendency of the ion species fraction change according to the change of the discharge conditions. The measurement was compared with this calculations and the results fit well. The monatomic fraction reached 60 – 70% or more at this pulsed arc discharge. In order to obtain a proton beam with a high monatomic fraction, the plasma source should be operated with a pulsed arc mode. By controlling the operating conditions such as arc current, operating pressure and magnetic field, a higher monatomic fraction can be obtained.

ACKNOWLEDGEMENTS

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