DEVELOPMENT OF COMPACT H$^+$ ECR ION SOURCE WITH PULSE GAS VALVE

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Abstract

A compact H$^+$ ECR ion source is under development. For reduction of the gas load to vacuum evacuation systems, the gas flow into the plasma chamber is chopped by a piezo-electric gas valve. To achieve the enough short time constant of gas flow, a small plasma chamber with 50 cm^2 is adopted and the chamber is operated in 6 GHz TE111 mode. The magnetic field is generated by permanent magnet for reduction of the required volume. For the evaluation of the ion source performance, a Wien filter is fabricated and the ion species distribution is measured. As the result of experiments, the population of protons in the extracted beam was about 15 %.

INTRODUCTION

Ion sources using gas discharge eject not only ion beam but also neutral gas. Most of the neutral gas is evacuated by the vacuum system in Low Energy Beam Transport (LEBT) region and some of the gas diffuse into the accelerator tanks. For pulsed ion sources, the ion beams are extracted from the ion source in just pulse duration, while the neutral gas get out of the plasma chamber constantly. Considering the ion accelerator with high intensity, the length of the LEBT should be as short as possible to reduce the space charge effect. However, with the short LEBT, the quantity of the neutral gas flow into the accelerator tank would become large. The gas flow in the tank may lead discharge and disturb stable operation. For the reduction of the gas flow, the supply of the gas into the plasma chamber should be chopped.

COMPACT ECR ION SOURCE WITH PULSE GAS VALVE

For evaluation of the performance of the ion source with pulsed gas system, a prototype ion source is developed. Proton was chosen as the ions produced in the prototype, supposing that the ion source would applied to compact neutron sources. The ECR plasma production scheme was adopted intending to achieve high H$^+$ fraction in the extracted beam. A piezo-electric gas valve was developed to chop the gas supply into the plasma chamber. The volume of the chamber is about 50 cm^2 to set the time constant of gas filling and gas evacuation enough small. The chamber was designed to have resonance at the 6 GHz. The magnetic field for the ECR condition at 6GHz is about 2.2 kG and the magnetic field is generated by permanent magnets. The detailed description about the prototype ECR ion source can be found in Reference [1].

RECENT UPDATE ON THE ECR ION SOURCE AND THE TEST BENCH

RF System

The RF power is fed into the cavity through a coaxial line. To couple the coaxial line with the plasma chamber, the tip of the inner conductor inserted into the chamber as a antenna. The radius of the inserted antenna is 0.3 mm and the length of that is about 12.5 cm, which corresponds to the quarter wavelength of light at 6 GHz. The cross-sectional view of the plasma chamber is shown in Figure 1. For evaluation of the coupling condition, a frequency domain analysis with CST microwave studio was performed. The calculated S$_{11}$ parameter is shown in Figure 2. From the result, it was found that the chamber had resonance at 6.038 GHz and the mode of the resonance was TE111 mode.

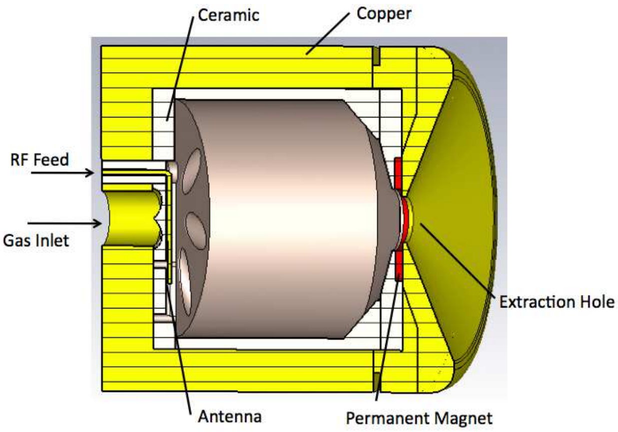

Figure 1: Cross-sectional view of the plasma chamber.

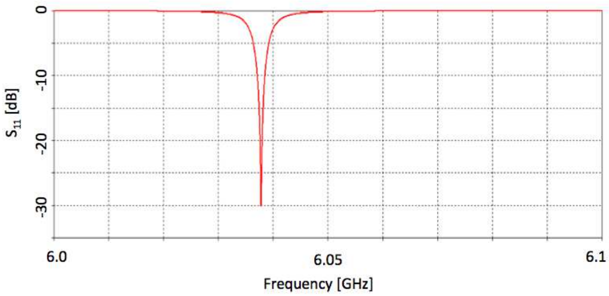

Figure 2: Calculated S$_{11}$ parameter. The plasma chamber has resonance at 6.039 GHz with TE111 mode.

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ISBN 978-3-95450-186-1

Charge-to-Mass Analyzing System

For measurement of the ion species distribution in the extracted beam, a charge-to-mass analyzing system with a Wien filter is fabricated. The analyzing system consists of the Wien filter, field clamp plates and a Faraday cup (see Figures 3 and 4). The length and the cross-section dimensions of the Wien filter are 30 mm and 60 mm × 40 mm, respectively. The area of the filter aperture is 25 mm^2. The magnetic field in the aperture is generated by permanent magnets and the strength of the field is 4 kG. The electrodes in the filter can be applied electric potential with ± 1 kV and the generated electric field is up to 400 kV/m. With the maximum applied voltages (± 1 kV), protons with up to 4.5 keV kinetic energy can be transported through the filter. The shapes of the magnetic pole tips and the electrode tips have grooved structure to flatten the transverse field distribution. The field clamp plates are made of iron plates with 1 mm thickness to form the fields in fringe region. The field clamp also collimate the beam. The field clamp at the upstream of the filter has slit with 1 mm gap. That at the downstream of the filter has aperture with 2 mm aperture. The Faraday cup is made of an SMA receptacle connector and the shape of detection surface is ϕ1.2 mm.

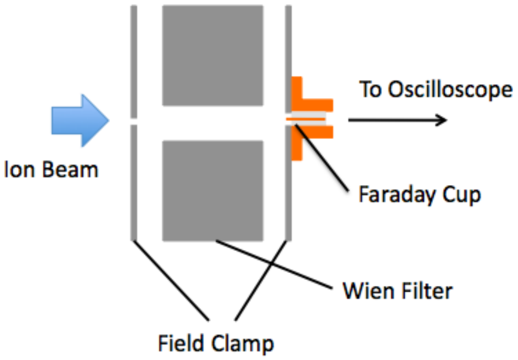

Figure 3: Schematic view of the charge-to-mass analyzing system.

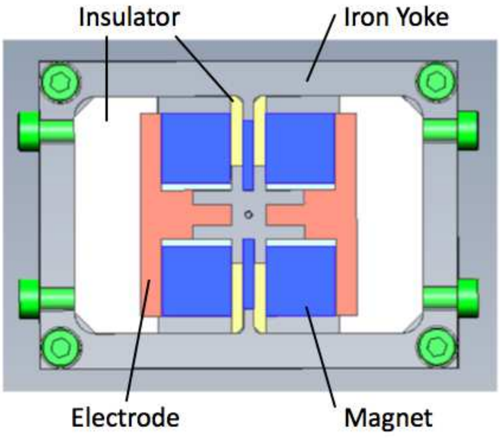

Figure 4: Cross-sectional image of the Wien filter. Magnets (blue part in the figure) are magnetized downward.

PRELIMINARY RESULTS

The ECR ion source was mounted on the test bench for evaluation of the beam production performance. The 6 GHz RF power was generated by a solid state amplifier with magnitude up to 30 W. The RF power was fed through a DC break between waveguides. Waveguide-to-coaxial adopters were attached at the end of the waveguide. The hydrogen gas was supplied from a hydrogen generator for gas chromatography and the gas was stored in a gas buffer tank to control the gas feed pressure to the pulsed gas valve. The gas flow into the plasma chamber can be tuned by the gas feed pressure. The gas flow can be estimated from the difference of the pressure in the test bench in cases pulsed gas valve is on/off. The estimated dependence of the gas flow (with 1 % gas pulse duty; 2 ms pulse duration with 5 pps) on the gas feed pressure is shown in Figure 5.

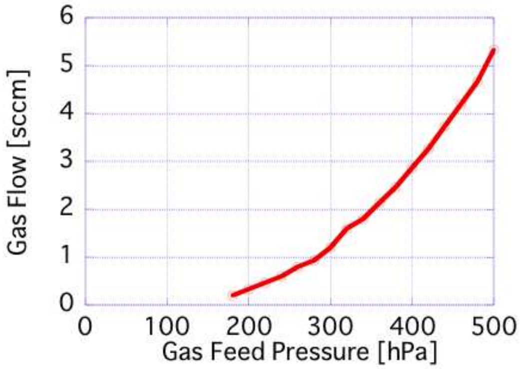

Figure 5: Estimated gas flow into the plasma chamber as the function of the gas feed pressure.

With the gas flow more than 0.2 sccm, the plasma was generated in the plasma chamber. Applying the extraction voltage, ion beams can be provided. The measured ion beam current with 3 kV extraction voltage is shown in Figure 6. The extracted current was saturated with increasing the RF power and the saturated value was increased as the gas flow increased. Figure 7 shows the saturated current value as the function of the gas flow. The extracted current as the

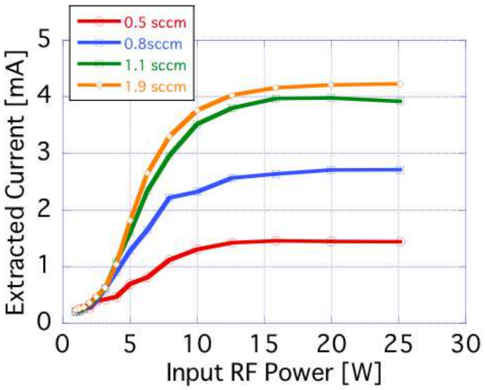

Figure 6: Extracted ion beam current with 3 kV extraction voltage.

ISBN 978-3-95450-186-1

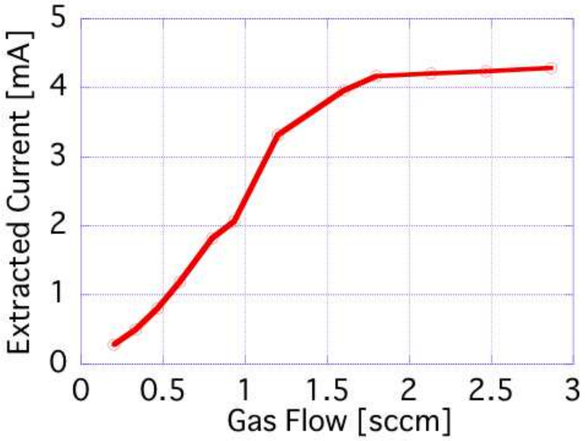

Figure 7: The extracted beam current with 25 W RF power as the function of gas flow.

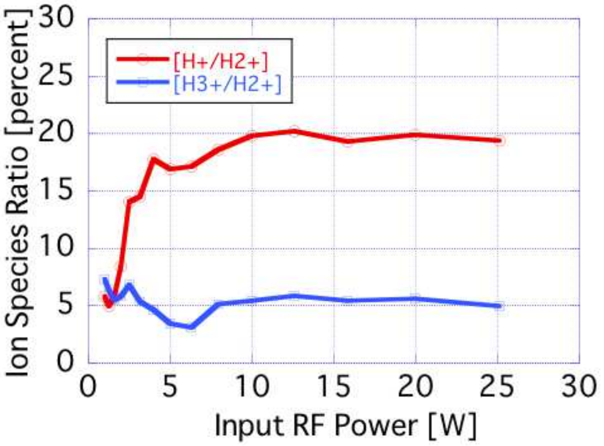

Figure 8: The current of H^+ beam and H_3^+ beam normalized by H_2^+ beam current.

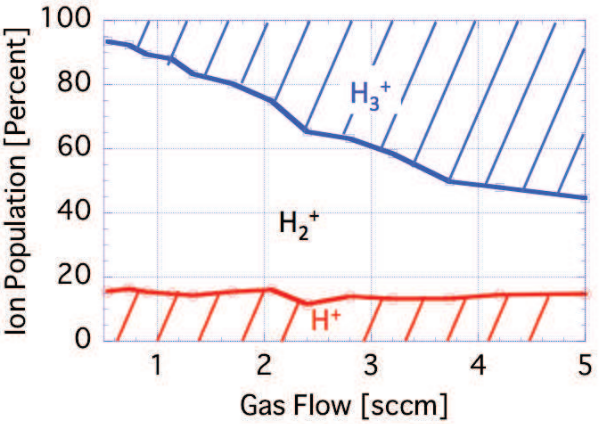

Figure 9: The current of H^+ beam and H_3^+ beam normalized by H_2^+ beam current.

function of of the gas flow is also saturated to 4.2 mA beyond the 1.8 sccm gas flow.

The charge-to-mass analyzing system was installed in the test bench at about 15 cm downstream from the extraction electrodes. Changing the applied voltage on the electrodes in the Wien filter, current of H^+, H_2^+, H_3^+ was measured. Figure 8 shows the measured current of H^+ and H_3^+ normalized by H_2^+ current with 0.8 sccm gas flow. With RF power more than 10 W. The ratio of the population of the ions in the beam become constant. The measurements with other gas flow value also showed that the population of the ions was constant with RF power up to 25 W. Figure 9 is the result of the ion population measurements as the function of gas flow. The population of the H^+ was almost constant as 15 %, and the population of the H_3^+ was increased as the gas flow increased.

DISCUSSION

Considering the practical operation of the ion source, the gas flow should be set as 1 sccm. From the experimental result, the extracted current with about 2 mA with the gas flow condition. Because the 15 % of the total current is the proton current, the extracted proton current would 300 µA. For the application of the ion source to the compact ion sources, the proton current should be more than 1 mA. The result of the ion species population measurement, the temperature of the plasma is suggested to be too low to generate the large amount of protons. To generate more protons in the ion source, more heating of the plasma is needed. For more efficient plasma heating, the modification of the magnet seems to be effective. In the current ion source test model, the magnetic field distribution is almost uniform to make the volume of the ECR zone large (see Ref. [1]). However, the high temperature electrons are supposed to hit the chamber wall due to the absence of the mirror field. The performance test with additional magnet to generate mirror field is planned.

REFERENCES

[1] Y. Iwashita, H. Tongu, Y. Fuwa, and M. Ichikawa, *Rev. Sci. Instrum.* 87, 02A718 (2016).