DEVELOPMENT OF VERY SMALL ECR H^+ ION SOURCE WITH PULSE GAS VALVE

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Abstract

Neutrons are very interesting for scientists as new probes used for investigating inner structure of materials or even fundamental physics. But, there are few neutron science facilities available in the world for such purposes. To remedy a situation, we started to develop accelerator base small neutron source.

At present, we are working on a small H^+ ion source as the first step of development of a small neutron source. We have selected a type of ECR ion source with permanent magnets as a small and high intensity ion source.

A pulse gas valve made of a piezoelectric element was built-in in the ion source plasma chamber to reduce the gas loading of evacuation systems.

We have obtained in our test stand a beam current of more than 1mA at RF frequency of 5.74GHz and 25W RF power. The ratio of H^+ to other ion species was also measured with an analyzing magnet.

The 2nd model of the ion source was manufactured. This new model ion source is going to make improvements in several points such as better vacuum, and so on.

INTRODUCTION

We aim to develop a small and high intensity proton source for a compact accelerator based neutron source. Because this proton source shall be located close to RFQ for compactness, the ratio of H^+ to molecular ions such as H_2^+ or H_3^+ must be large. Therefore we have selected a type of ECR ion source with permanent magnet as a small and high intensity ion source. The ECR ion sources can provide high H^+ ratio because of their high plasma temperature. Utilization of permanent magnets makes the ion source small and running cost low. Because there is no hot cathode, longer MTBF is also expected.

Usually, gas is fed into ion sources continuously, even if ion sources run in pulse operation mode. But, continuous gas flow becomes a load to the vacuum system. So, we decided to install a pulse gas valve directly to the plasma chamber. Feeding the gas only when RF power is enabled reduces the gas load to the evacuation system and the vacuum level can be kept high.

PULSE GAS VALVE

We developed the pulse gas valve with commercial piezoelectric element (Kyocera Co. KBS-20DA-7A)[1]. Fig. 1 shows the piezoelectric element, which is used for developing a pulse gas valve. Table 1 shows the specifications of the element. This valve utilizes the piezoelectricity such that the elements warps by internal mechanical stress when a voltage is applied. As shown in Fig. 2, the application of a voltage opens a path under the element and the gas flows into the chamber.

This piezoelectric element has a hysteresis characteristic as shown in fig. 3. When negative voltage is applied the valve opens and the gas can flow. But because of hysteresis, applying only negative voltage reduce the displacement of the element. Therefore, a bipolar voltage pulse generator was prepared for driving the valve element. It reduces the quantity of leak gas at close position of the valve.

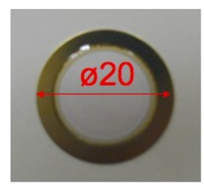

Figure 1: Piezoelectric Element.

Table 1: Specifications of the Piezoelectric Element

Diameter of metal base	20.0±0.1mm
Diameter of piezoelectric element	14.2±0.1mm
Total thickness	0.45±0.1mm
Thickness of metal base	0.20±0.03mm
Resonance frequency	6.6±1.0kHz
Capacitance	10±0.3nF
Electric strength(catalogue spec.)	$30V_{p\text{-}p}$

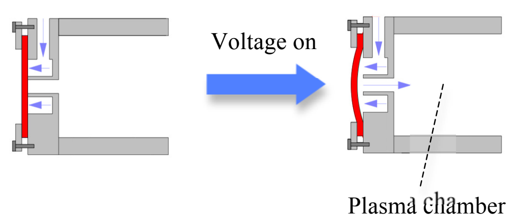

Figure 2: Operating principal of the valve .

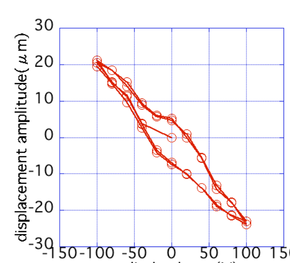

Figure 3: Hysteresis curve.

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THE 1ST MODEL OF THE ION SOURCE

Current Measurement

The current from the 1st model ion source[2] was measured. Fig. 4 shows the setup of test bench.

Total current including all ion species is measured with a Faraday cup set just downstream of the extraction electrode. Up to now, this ion source can supply ion beam of more than 1mA. Table 2 shows the fixed parameters for the measurement.

The current of each ion species was measured with analyzing magnet, while changing the frequency of RF. Fig. 5 shows the result. In all case the ratio of H^+ to the others is small. As RF frequency increases or gas flow decreases, the ratio of heavier ions decreases. Table 3 shows the fixed parameters for the measurement. The variable parameters were the RF frequency and gas flow rate. When the gas flow rate was 0.25 sccm, plasma did not generate at the RF frequency lower than 5.7GHz and higher than 5.78 GHz.

Redesign of Plasma Chamber

We designed a plasma chamber so that the resonance frequency became 6GHz. the shape of plasma chamber was determined by HFSS simulation[3]. Fig. 6 shows the plasma chamber designed by simulation. The size of this chamber is very small; being approximately ϕ40mm× 27mm. For realising the resonance frequency of the chamber, we insert the ring with ridges into the chamber. The distribution of the electric field in the chamber is shown in Fig. 7.

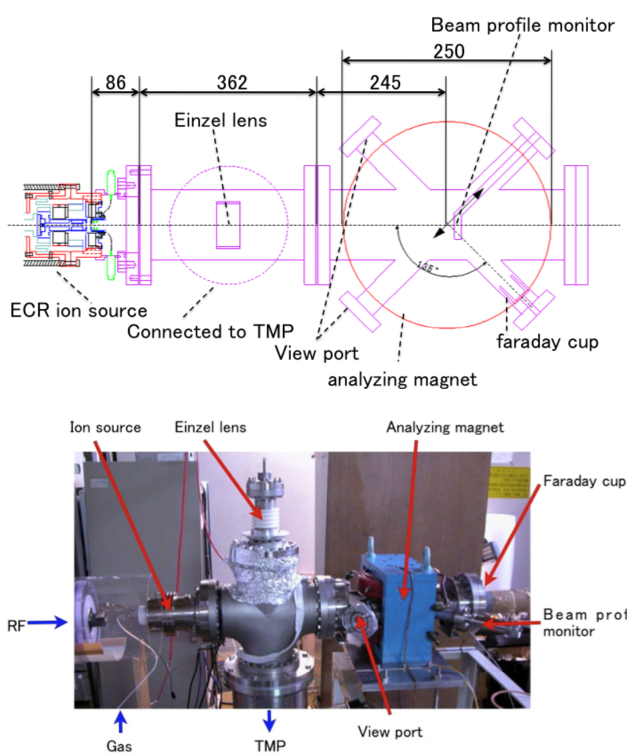

Figure 4: Upper; Horizontal profile of test bench (aperture of analyzing magnet is 60mm). Lower; Photo of test bench

Table 2: Fixed Parameters at Total Current Measurement

RF frequency	5.74GHz
RF power	25W
Extraction voltage	10kV
Repetition rate	25Hz
Duty factor of the driving signal	50%
Pressure of gas	400kPa

Table 3: Fixed Parameters at each Ion Species' Current Measurement

RF power	25W
Extraction voltage	5kV
Repetition rate	25Hz
Duty factor of the driving signal	50%

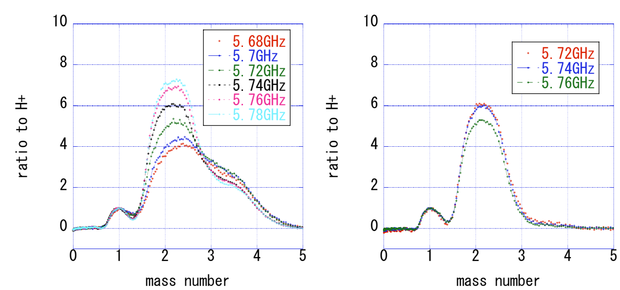

Figure 5: Ratio of each ion species current to H^+. Left: Gas flow rate was about 0.70sccm. Right: Gas flow rate was about 0.25sccm.

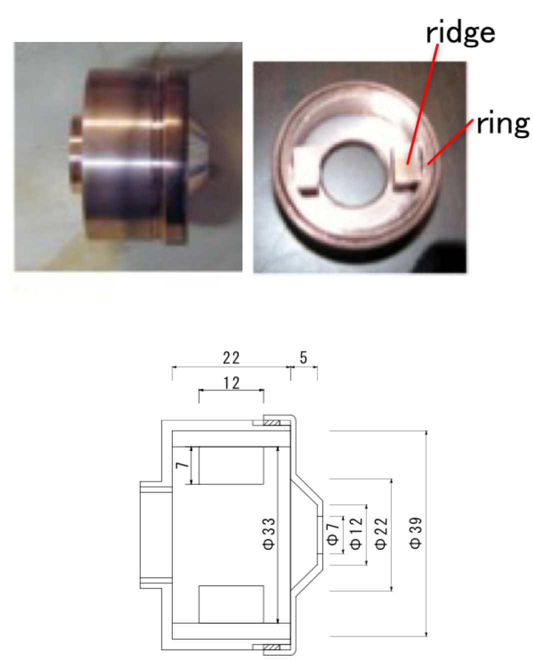

Figure 6: New plasma chamber. Upper; Photo of the chamber. Lower; Cross section of the chamber.

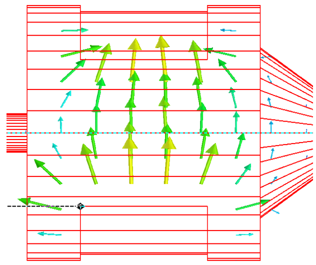

Figure 7: Distribution of electric field.

THE 2ND MODEL OF THE ION SOURCE

Fig. 8 shows the schematic drawing of the 2nd model ion source. In this ion source, the plasma chamber is at the high voltage potential and the iron yokes are electrically insulated by PTFE insulators. The ion source we developed has the whole size of only about ϕ200mm × 250mm.

Magnets Arrangement

The magnetic flux density optimal for ECR condition is given by a following formula:

$$B_{ecr}[\mathrm{T}] = \frac{m_e \omega}{e} = \frac{2\pi m_e}{e} f \cong \frac{f[\mathrm{GHz}]}{28} \qquad (1)$$

where B_{ecr} is magnetic flux density at ECR point, m_e is mass of electron, e is elementary charge, f is frequency of RF, ω is angular frequency of RF [4]. RF frequency is 6GHz, so the optimal magnetic flux density becomes 0.214T. The optimization of permanent magnets and iron yokes arrangement is done with PANDIRA code[5]. Fig. 9 shows the distribution of axial magnetic field in the optimal arrangement. The magnet material we used is NEOMAX-48H, whose magnetic flux density is about 1.3T. It is capable to adjust the strength of magnetic field by varying the distance between the permanent magnets.

Improvement in the 2nd Model of the Ion Source

To achieve a better vacuum, we improved conductance by leaving space around the magnet located downstraem. To prevent an electric discharge, the space around the extraction electrode was made wider. In the 1st model the ion source extraction electrode was close together with the magnet nearest by it. Consequently, the distance between the plasma chamber and the extraction electrode changed when the distance between magnets was adjusted. In the 2nd model ion source the extraction electrode can be moved independently from the downstream magnet, so that the distance between the chamber and the electrode can be adjusted regardless of the distance between the magnets.

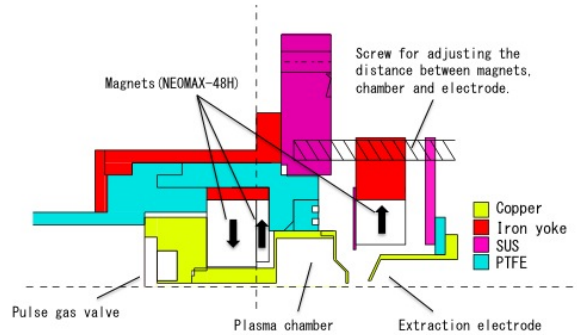

Figure 8: Schematic drawing of the ion source.

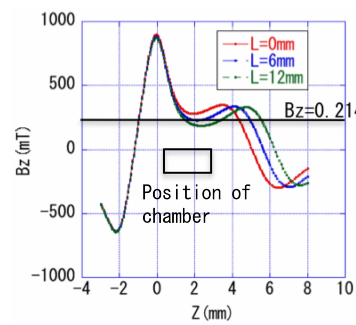

Figure 9: Distribution of axial magnetic field (L means variation of distance between magnets).

CONCLUSIONS

Up to now, the maximum beam current from the 1st model ion source is about 1.13mA at the RF power of 25W. But, the major part of RF power doesn't seem to be absorbed into plasma because of incorrect resonance mode of the plasma chamber.

The magnet arrangement was modified to match the ECR frequency and the chamber resonance frequency, while the vacuum conductance should be also improved.

The 2nd model is under fabrication to increase total beam current and the ratio of H^+ ions.

REFERENCES

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[3] Ansoft, http://www.ansoft.com/products/hf/hfss/.

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[5] Reference Manual for the POISSON/SUPERFISH Group of codes, No. LA-UR-8712.