DEVELOPMENT OF VERY SMALL ECR 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. But, there are few neutron science facilities available in the world for such purposes. To remedy a situation, we started to develop linear 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 loading of evacuation systems.

We have obtained in our test stand a beam current of 1.13 mA at RF frequency of 5.74 GHz and 25 W RF power. The ratio of H^+ to other ion species was also measured with an analyzing magnet.

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. Using 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

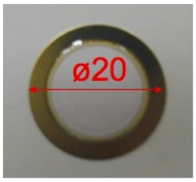

Figure 1: Piezoelectric element.

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.)	$30V_{p\text{-}p}$

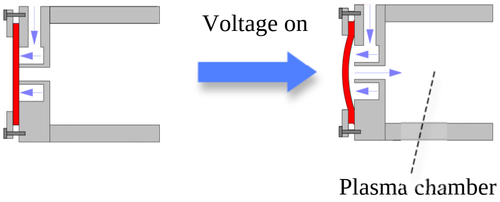

Figure 2: Operating principal of the valve .

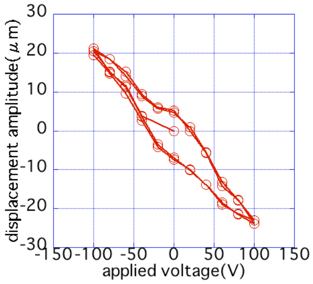

Figure 3: Hysteresis curve.

We developed 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 utilize 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 flow into the chamber.

This piezoelectric element has a hysteresis characteristic like Fig. 3. When negative voltage is applied the valve opens and gas can flow. But because of hysteresis, applying only negative voltage reduce the displacement of the element or its warpage. Therefore, a bipolar voltage pulse generator was prepared for driving

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the valve element. It reduces the quantity of leak gas in close position of the valve.

DESIGN OF THE ECR ION SOURCE

Extraction Electrodes

The optimal geometry of extraction electrodes were found by using a simulation soft PBGUNS[2]. Given extraction voltage was 25 keV. The optimal design of extraction electrode was like Fig 4. The density of plasma was $3.83\times10^{17}\mathrm{m}^{-3}$. This plasma density is proper for plasma frequency 5.56 GHz. The plasma has a property that if the frequency is lower than plasma frequency the RF can't penetrate into plasma. So, in order to supply RF power into plasma, RF frequency must be higher than plasma frequency. In this study we have chosen that RF frequency to be 6 GHz.

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 [3]. RF frequency is 6 GHz, so the optimal magnetic flux density becomes 0.214 T. The optimization of permanent magnets and iron yokes arrangement is done with PANDIRA code [4]. Fig. 5 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 1.3 T. It is capable to adjust the strength of magnetic field by varying the distance between the permanent magnets.

Plasma Chamber

We designed a plasma chamber so that the resonance frequency became 6 GHz. The resonance frequency of the TE_{111} mode in a tube is expressed in the following expression:

$$f_{111}=\frac{1.841}{\sqrt{\varepsilon\mu}}\frac{c}{R}\sqrt{\left(1+2.912\frac{R^2}{d^2}\right)} \qquad (2)$$

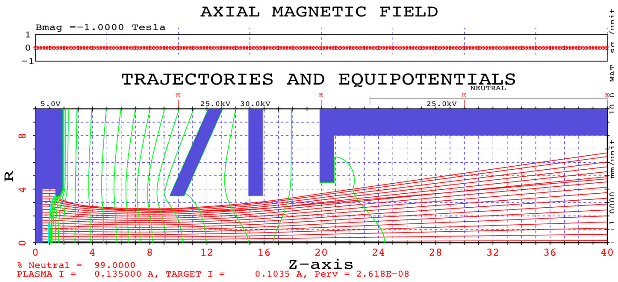

Figure 4: Result of PBGUNS simulation.

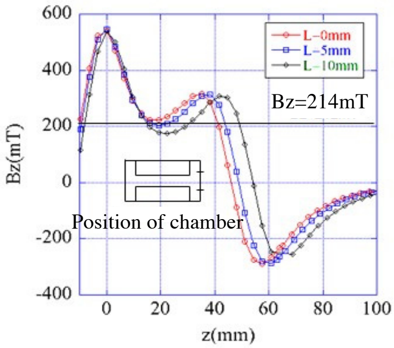

Figure 5: Distribution of axial magnetic field (L means variation of distance between magnets).

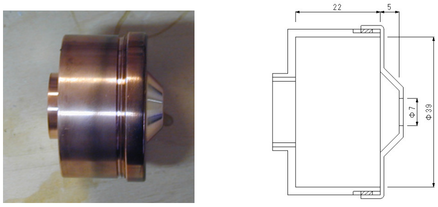

Figure 6: Plasma chamber.

where, f_{111} is frequency of RF, R is radius of plasma chamber, d is length of plasma chamber. On the basis of this, the shape of plasma chamber was determined by HFSS simulation [5]. Fig 6 shows the plasma chamber designed by simulation. The size of this chamber is very small; being approximately f40mm×27mm.

Whole Ion Source

Fig. 7 shows the schematic drawing of the ion source. In this ion source, the plasma chamber is at the high voltage potential and the iron yokes are electrically insulated by insulators. The ion source we developed has the whole size of only about f200 mm × 300 mm. To keep the vacuum in the ion source extraction region good, it has holes to evacuate (about f10 mm × 30 mm, 12 places). The total conductance of the holes and extraction hole is 27.3 l/s. The conductance was calculated by a following formula:

$$C\left[\frac{m^3}{s}\right]=0.523\frac{r[cm]^3}{M^{1/2}L[cm]} \qquad (3)$$

where r is radius of holes, M is the molecular weight of the gas particles (in this time, Hydrogen) and *L* is length of holes. The pumping speed of our turbo molecular pump is 1500 l/s, so that the vacuum level in the plasma chamber is poorer by factor of about 100 than the pump head.

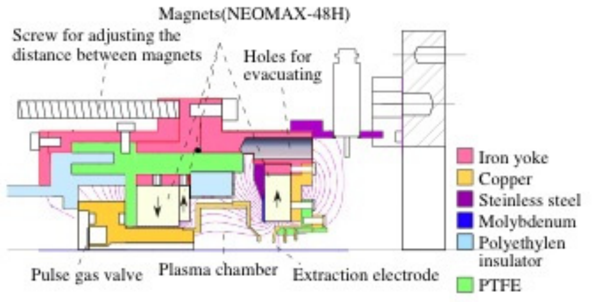

Figure 7: Schematic drawing of the ion source.

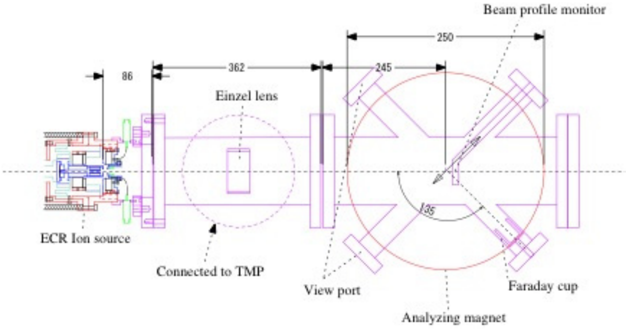

Figure 8: Horizontal profile of test bench (aperture of analyzing magnet is 60mm).

Table 2: Fixed parameters at total current measurement.

RF frequency	5.74 GHz
RF power	25 W
Extraction voltage	10 kV
Frequency of thepulse gas valve driving signal	25 Hz
Duty of the pulse gas valve driving signal	50%
Pressure of gas	400 kPa

MEASUREMENT

The current from the ion source was measured. Fig. 8 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 1 mA. Table 2 shows the fixed parameters.

The current of each ion species was measured with analyzing magnet, while changing frequency of RF. Fig. 9 shows its result. In all case the ratio of H^+ to others is small. As RF frequency increases or gas flow decreases, the ratio of heavier ions decreases. Table 3 shows the fixed parameters. The variable parameters were the RF frequency and gas flow rate. When the gas flow rate was 0.25 sccm, plasma did not appear at the RF frequency lower than 5.7 GHz and higher than 5.78 GHz.

Table 3: Fixed parameters at each ion species' current measurement

RF power	25 W
Extraction voltage	5 kV
Frequency of the pulse gas valve driving signal	25 Hz
Duty of the pulse gas valve driving signal	50%

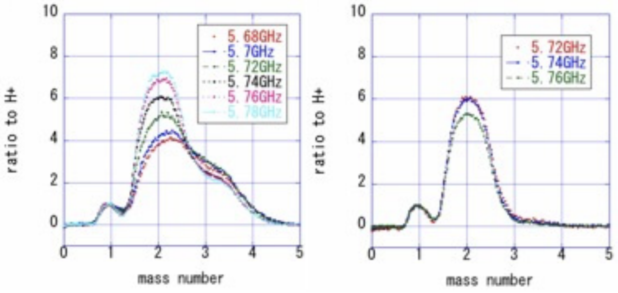

Figure 9: Ratio of each ion species current to H^+. Left: Gas flow rate was about 0.70 sccm. Right: Gas flow rate was about 0.25 sccm.

CONCLUSIONS

We consider that to increase the ratio of H^+, the RF frequency should be higher and the gas flow as little as possible. Because in the current magnets arrangement we can't increase RF frequency a new magnets arrangement is being searched.

In the near future we'll develop a second model of the ion source to increase total beam current and the ratio of H^+ ions.

REFERENCES

[1] M. Ichikawa, "Development of Piezoelectric Pulse Gas Valve", Proceedings of 4th Annual Meeting of Particle Accelerator Society of Japan and 32nd Linear Accelerator Meeting in Japan, August 2007, http://www.pasj.jp/

[2] J. E. Bores, "A digital computer code for the simulation of electron and ion beams on a PC", IEEE Cat. No. 93CH3334-0 (1993) 213.

[3] I. Blown, "The Physics and Technology of Ion Sources Second, Revised and Extended Edition", WILEY-VHC Verlag GmbH & Co. KGaA, 2004.

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

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