DEVELOPMENT OF PIEZOELECTRIC PULSE GAS VALVE FOR SMALL ECR ION SOURCE

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Abstract

In a conventional ion source, the source gas is continuously fed even in its pulse operation. This requires a high load to a vacuum pumping system. The situation is prominent when the gas load is relatively higher in such a high current ion source. In order to improve this situation, the supply of the gas is synchronized with the timing of RF power feed by a valve that is installed directly in the plasma chamber. We have developed a small pulse-gas-valve using a commercially available disc-shape piezoelectric element. This valve is small enough to be mounted in our ECR ion source and is capable of very fast open-and-close operation of an order of kHz repetition.

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

We developed pulse gas valve with commercial piezoelectric element (Kyocera Co. KBS-20DA-7A). 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 chamber.

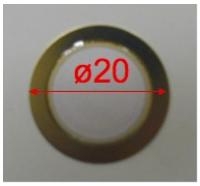

Figure 1: Piezoelectric element.

Table 1: Specifications of 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)	$30V_{P\text{-}P}$

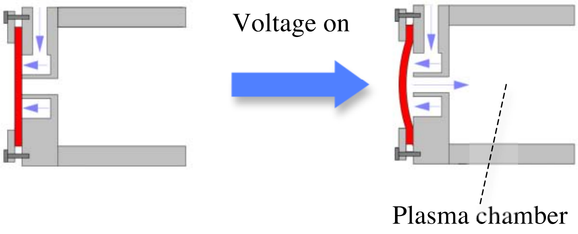

Figure 2: Operating principle of the valve.

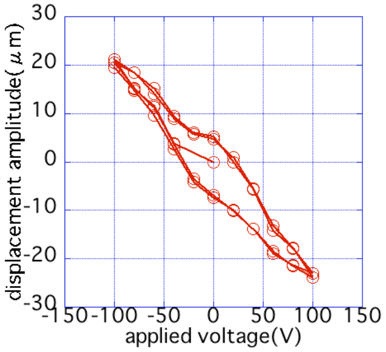

Figure 3: Hysteresis curve.

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 the valve element. It reduces the quantity of leak gas in close position of the valve. The shape of pulse for driving the valve is shown by Fig 4. The amplitude of signal is larger than the electric strength of the element. We preliminarily test how high voltage the element can bear,

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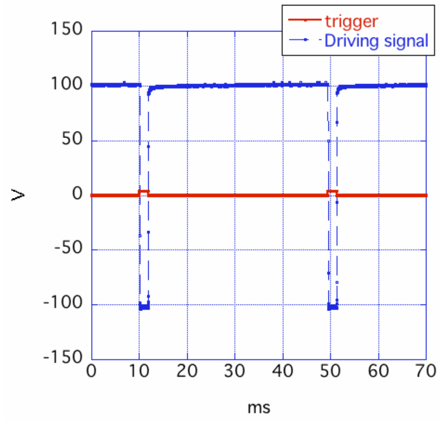

Figure 4: Shape of valve driving signal.

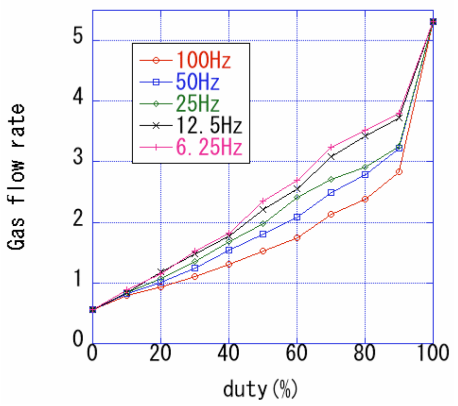

Figure 5: Change of flow rate for duty.

and it could bear about 150V. Therefore, to make allowance we selected the amplitude of the driving signal 100V. Fig 5 shows the change of flow rate as a function of the duty cycle of the valve operation. In this measurement, the frequency of the driving signal was varied from 6.25Hz to 100Hz, the pressure of the gas was 50 kPa (differential pressure).

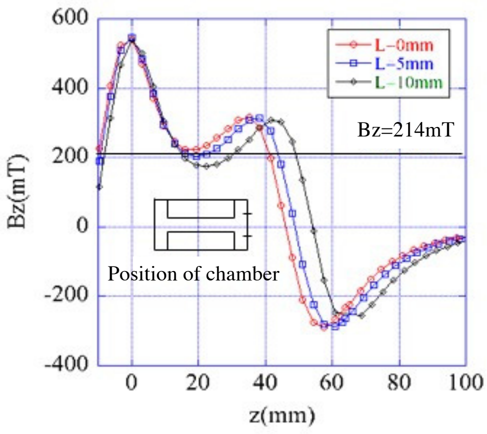

Figure 7: Distribution of axial magnetic field L means variation of distance between magnets

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 25keV. The optimal design of extraction electrode was like Fig 6. The density of plasma was $3.83 \times 10^{17}\mathrm{m}^{-3}$. This plasma density is proper for plasma frequency 5.56GHz. 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 6GHz.

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

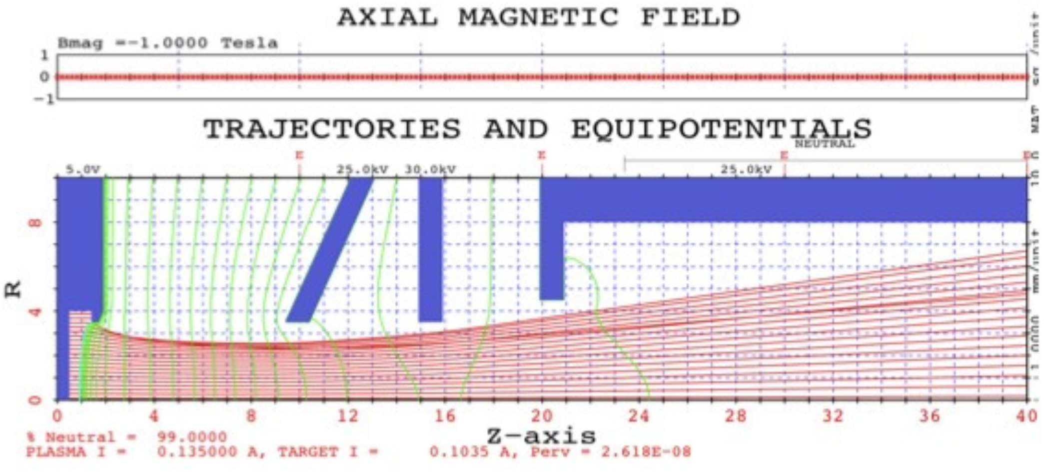

Figure 6: Result of PBGUNS simulation.

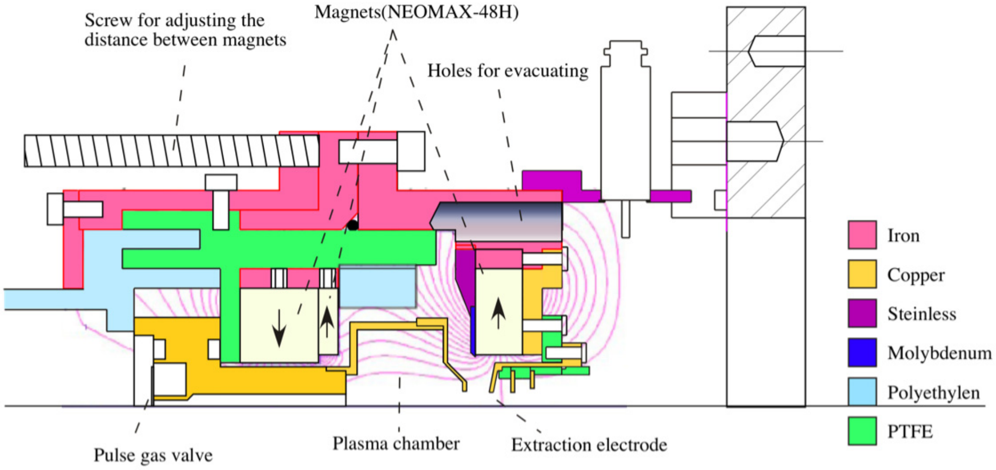

Figure 9: Schematic drawing of the ion source.

mass of electron, e is elementary charge, f is frequency of RF, ω is angular frequency of RF [1]. 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[3]. Fig 7 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.

Plasma chamber

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

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

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. Fig 8 shows the plasma chamber designed by simulation. The size of this chamber is very small; being approximately ϕ40mm×27mm.

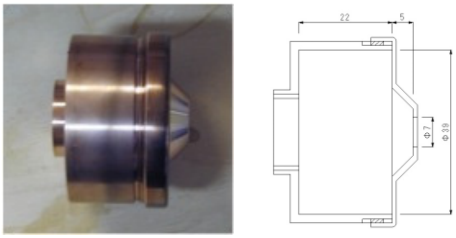

Figure 8: Plasma chamber.

Whole Ion Source

Fig 9 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 from it. The ion source we developed has the whole size of only about ϕ200mm × 300mm. To keep the vacuum in the ion source extraction region good, it has holes to evacuate (ϕ10mm × 30mm, 12places). The total conductance of the holes and extraction hole is 27.3 l/s. The conductance was calculated by a following formula:

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

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.

MEASUREMENT AND CONCLUSIONS

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 1.13mA. The parameters were that the frequency of RF was 5.74GHz, the RF power was about 25W, the extraction voltage was 10kV, the frequency of gas valve driving signal was 25Hz, the duty of it was 50% and the pressure of gas was 400kPa.

In future, we'll measure the beam current of the individual ion species using analyzer magnet, and investigate the ratio of H^+ to others. Then, we'll develop a second model of the ion source to increase beam current.

REFERENCES

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

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

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