# **DEVELOPMENT OF VERY SMALL ECR H<sup>+</sup> ION SOURCE**

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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 have 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.

The 2<sup>nd</sup> model of ion source was manufactured and we measured the beam current. Up to now, the maximum current at the Faraday cup is about 1.5mA and the maximum current at the just downstream of the extraction measured by DC current transformer is about 2mA.

To increase the ratio of  $H^+$ , we painted Boron Nitride paste on the inner surface of the plasma chamber. As a result, the ratio of  $H^+$  to  $H_2^+$  increased about twice and  $H^+$ became major part of the beam.

## **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-27DA-5A)[1]. Fig. 1 shows the piezoelectric element, which is used for a pulse gas valve. Table 1 shows the specifications of the

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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	27.0±0.1mm
Diameter of piezoelectric element	20.2±0.1mm
Total thickness	0.53±0.1mm
Thickness of metal base	0.25±0.03mm
Resonance frequency	4.6±0.5kHz
Capacitance	20±0.3nF
Electric strength(catalogue spec.)	30V <sub>p-p</sub>







Figure 3: Hysteresis curve.

# THE 2<sup>ND</sup> MODEL OF THE ION SOURCE

Fig. 4 shows the schematic drawing of the  $2^{nd}$  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  $\phi 200 \text{mm} \times 250 \text{mm}$ .

#### Magnets Arrangement

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

$$B_{ecr}[T] = \frac{m_e \omega}{e} = \frac{2\pi m_e}{e} f \cong \frac{f[GHz]}{28}$$
(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,  $\omega$  is angular frequency of RF [2]. RF frequency is 6GHz, so the optimal magnetic flux density becomes 0.214T. The optimization of permanent magnets and the iron yokes arrangement is done with PANDIRA code[3]. 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 1.3T. It is capable to adjust the strength of magnetic field by varying the distance between the permanent magnets.

# Improvement in the 2<sup>nd</sup> Model of the Ion Source

To achieve a better vacuum, we improved conductance by leaving space around the magnet located downstream. To prevent an electric discharge, the space around the extraction electrode was made wider. In the 1<sup>st</sup> model the ion source extraction electrode was close to the nearest magnet. Consequently, the distance between the plasma chamber and the extraction electrode varied when the distance between magnets was adjusted. In the 2<sup>nd</sup> 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.

### Total Current Measurement

The total current from the 2<sup>nd</sup> model ion source[4] was measured by two methods. Fig. 6 shows the setup of test bench.

The first measuring method is to measure the total current including all ion species with a Faraday cup (FC) set just downstream of the extraction electrode. Up to now, this ion source can generate ion beam of more than 1.5mA. Table 2 shows the fixed parameters for the measurement.

The second method is to measure the extraction current by looking the current of the high voltage power supply using DC current transformer (DCCT). The insert position of DCCT can be found in Fig. 7. Up to now, more than 2mA was measured at the parameter shown in Table 3. Fig. 8 shows the measured current values by FC and DCCT.







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



Figure 6: Upper; Horizontal profile of test bench (aperture of analyzing magnet is 60mm). Lower; Photo of test bench.



Figure 7: Block diagram of the ion source and peripheral equipments.

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### Improvement of the Ratio of $H^+$ Ion

The current of each ion species was measured with analyzing magnet. Fig. 9 shows the result. The ratio of  $H^+$  to the others is small. Therefore, to increase the ratio of  $H^+$  ion to the others we painted Boron Nitride (BN) paste on the inner wall of the plasma chamber. The improvement of the ratio of  $H^+$  by using BN is described in past experiment[6]. The BN paste is made from BN powder with ethanol solvent. Fig. 10 shows the ratio of ion species after painting BN paste. The ratio of  $H^+$  to the others improved, especially the ratio to  $H_2^+$  was increased about twice.

### **CONCLUSIONS**

The 2<sup>nd</sup> model ion source was fabricated to solve some problems which the first model had and the performance test has been done.

The maximum beam current we got from the  $2^{nd}$  model ion source is about 1.5mA by FC and about 2mA by DCCT at the RF power of 25W. Where we considered the current of high voltage power supply measured by DCCT as extraction beam current.

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

By painting the BN paste on the inner surface of the plasma chamber the ratio of  $H^+$  ion to other ion species was increased.

To increase the beam current, we are going to introduce the resonant frequency matching tuner in the plasma chamber. And to improve the ratio of  $H^+$  much more, where to apply the BN paste will be studied.

### REFERENCES

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Table 2: Fixed parameters at current measurement using FC.

RF frequency	6.39GHz
(Peak) RF power	25W
Extraction voltage	12.5kV
Repetition rate	25Hz
Duty factor of the driving signal	50%
Pressure of gas	400kPa

Table 3: Fixed parameters at current measurement using CT.

RF frequency	6.42GHz
(Peak) RF power	25W
Extraction voltage	10kV
Repetition rate	25Hz
Duty factor of the driving signal	50%
Pressure of gas	400kPa



Figure 8: Currents measured by DCCT and FC at the parameters of table 3.



Figure 9: Inner surface of chamber without BN.



Figure 10: inner surface of chamber with BN.