

DEVELOPMENT OF A 2.45GHZ COMPACT HIGHER ORDER MODE ECR ION SOURCE

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Abstract

A new type of a compact ECR ion source has been designed and is being manufactured. It uses 2.45 GHz microwave frequency and has enough field strength to be operated at second harmonic mode in addition to the fundamental one.

The most remarkable feature of this source is that it is made of permanent magnets only; The required axial field had been realized by use of "mirror-field forming flanges" which are constructed by many rectangular magnets. We report this feature, the design parameters and the field configurations of the source.

Introduction

Many compact types of the ECR ion source have been developed recently because of its convenience in handling and its performance. So far as we use the solenoid system to make the magnetic mirror, however, it is difficult to reduce drastically the size and electric consumption. For this reason we have developed two kinds of compact sources by using only permanent magnets to form a confining field in both transverse and axial directions. One of them was constructed by the mirror field plus the sextupole field<sup>1)</sup> and the other the cusp field both in transverse and axial directions<sup>2)</sup>. In these cases, these ECR ion sources have clearly the following several merits:

- 1) They are lighter and smaller than those using the solenoids.
- 2) The electric power used to confine the plasma is unnecessary.
- 3) The space occupied by the source is very small.
- 4) The spare parts or alternative sources can be prepared economically.

On the other hand, we have experienced the following problems on the all-permanent magnet ECR devices which work in the range of 2-3 GHz.

- a) Dimension of WRJ-2 waveguide is rather large compared with the size of the plasma chamber.
- b) If permanent ring magnets are used for the mirror field, they limit the design of the shape and the axial length of the extractor electrodes.
- c) Necessity arises to optimize the mirror field distribution by other method in place of adjustment of the solenoid current.

It was found to be not difficult to work out these problems. In addition, it has been found that the realized maximum field intensity with permanent magnets (made of Neodymium-iron) is not only enough to make the first mode ECR zone but also to approach the value of 2B<sub>ecr</sub>, i.e., the field corresponding to the second-order mode ECR.

By confining both the first and the second mode ECR plasma in the chamber, it can be expected that we can increase the plasma density more than the attainable value by the first mode only. Thus, it is expected that the extracted beam current is more larger and the device can be used more widely both for single and for multicharged ions.

Then the authors had designed to make a new 2.45GHz compact higher order mode ECR ion source. The device is now in manufacture. We describe the design parameters and some of the results of the measurement on the magnetic field distribution.

Design parameters and main structure

Table 1 shows the main parameters of the compact ECR ion source. Ions to be extracted are N<sub>2</sub><sup>+</sup>, Ne<sup>+</sup>, Ar<sup>+</sup> and their multi charged one. The beam current density from plasma electrode is aimed over ~20 mA/cm<sup>2</sup> in case of single charged ion, because in case of our first mode source, the typical intensity of several mA/cm<sup>2</sup> is attained in Nitrogen ion beams at 28 kV.

If this source is used for the space charge experiments in a series acceleration tests of the 25.5MHz SCRFQ linac that has been developed at INS, the necessary least beam current is nearly the order of 2 mA in N<sub>2</sub><sup>+</sup> beam at 3mmφ aperture of the plasma electrode. This type of source is also expected to use for other purposes.

Fig.1 shows the main structure of the higher order ECR ion source. In this design work we took into account the problems a)~c) described in previous section:

a) Usually it is used a WRJ-2 waveguide in transmitting 2.45 GHz microwave power. But in order to select the more adaptive size to the compact ion source, we converted taperly the WRJ-2 waveguide to a WRJ-3 one and furthermore reduced the E-plane of the WRJ-3 guide.

As a result, the microwave power is injected from an inlet port of the cross section of 72×5mm<sup>2</sup> into the plasma chamber after transmitting the two steps tapered section.

As is shown in Fig.1, the ion source has the same two microwave ports. But the one side can be used to the observation of the ECR plasma in the chamber.

b) In order to realize the maximum magnetic field above 2B<sub>ecr</sub> in axial direction, the optimum diameter (usually, ≥50mmφ) and axial length of the ring magnet is considerably larger than the case of 1B<sub>ecr</sub>. It results in one or one and half order costs higher than the case of rectangular one. So we newly devised the "mirror-field forming flanges" in place of ring magnets (Fig.2).

It consists of many same rectangular magnets which placed radially with same polarity in each flange. By use of this type of flange, the limitation of dimension and shape of the extractor electrode was fairly released compared to the case of ring magnets.

The axial length of extractor electrode was reduced about several ten mm long and the choice of radial feature was more facilitated

Table 1

The design parameters of the higher order mode ECR ion source

Ions to be extracted	N <sub>2</sub> <sup>+</sup> , Ne <sup>+</sup> , Ar <sup>+</sup> and their multicharged ions		
Beam voltage	30	kVmax	
Beam current density	>20	mA/cm <sup>2</sup>	
Beam hole	2-3	mmφ (single)	
Beam emittance	~0.6π	mm · mrad (normalized)	
Microwave frequency	2.45	GHz	
Microwave power	1.0	kWmax (pulse)	
Microwave duty	0.2-20	% (variable)	
Inner dimension of plasma chamber	φ 38×72	mm <sup>3</sup>	
Outer dimension of return yoke	φ 140×150	mm <sup>3</sup>	
Magnetic mirror ratio	~2.3-2.8		

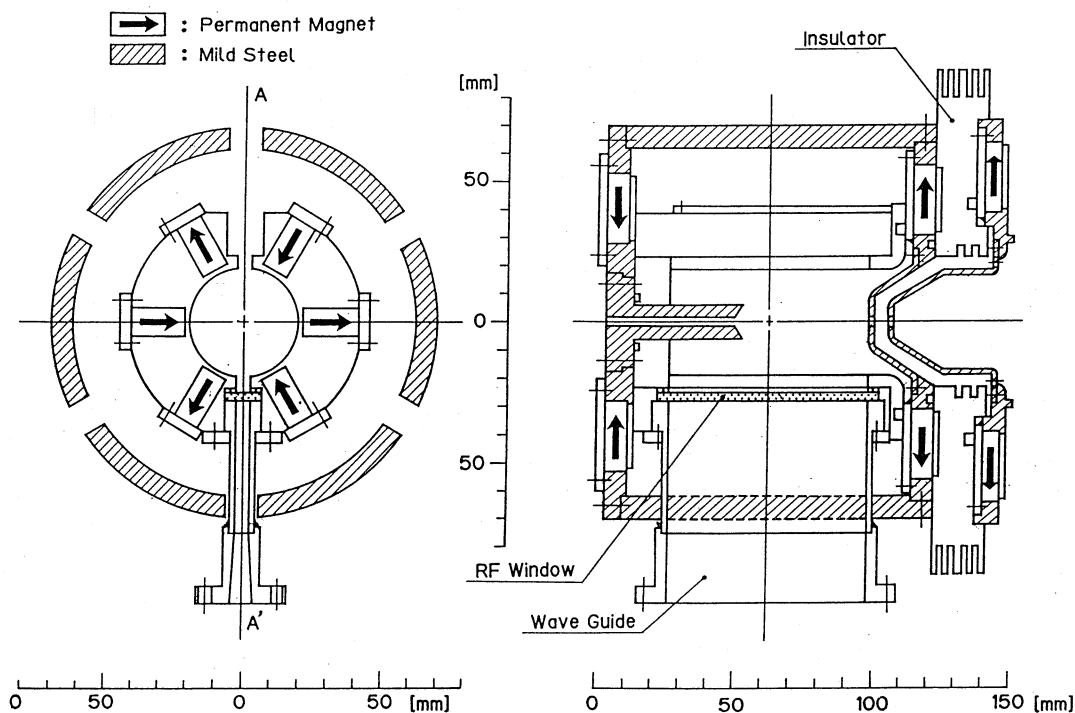


Fig.1 The construction of the 2.45GHz higher order mode ECR ion source

c) As for adjustment of the mirror-field distribution, an auxiliary ring magnet is set nearby the gas port side flange and by changing its position slightly on the axis, it is able to optimize the mirror field.

#### Magnetic field configuration and measured results

As for the axial mirror field, the basic configuration is constructed by the three sheets of "mirror field forming flange", which equips with the concentrated polepiece, the plasma electrode and the extractor electrode respectively, as shown in Fig.1.

The measured result almost satisfied the condition  $B_{zmax} > 2B_{ecr}$ , where  $B_{zmax}$  is the maximum value of the axial magnetic field component and  $B_{ecr}$  (875G) is the value that generates the basic mode ECR at the given microwave frequency (2.45GHz).

More precisely, because of the effect of the each hole in the concentrated polepiece, the plasma electrode and the extractor electrode on the axis, the value of  $B_{zmax}$  amounts to 90-95% of  $2B_{ecr}$  in  $0 \leq r \leq 2$  mm region and only in  $3 \leq r \leq 6$  mm one the condition has realized.

Then an auxiliary ring magnet ( $\phi 71 \times 40 \times 18 \text{ mm}^3$ ) was set nearby the gas port side flange. The synthesized axial field pattern is shown in Fig.3(a). As a final result, the condition  $B_{zmax} > 2B_{ecr}$  realized in the range  $0 \leq r \leq 6$  mm. Furthermore, the mirror field ratio is variable by shifting the position of the ring magnet on the axis. The variable ranges of  $B_{min}$  and mirror ratio are 0.65-0.80 kG and 2.3-2.8 respectively.

Next, as for the transverse direction, the following two conditions must be considered:

1) Nearby the inner wall of the plasma chamber ( $r \leq 19 \text{ mm}$ ), it is necessary that

$$\sqrt{B_r^2 + B_\theta^2 + B_z^2} > 2B_{ecr}$$

where  $B_r$ ,  $B_\theta$  are the radial and the azimuthal component respectively.

2) Also at the position of RF window ( $r=25 \text{ mm}$ ), it is desirable that

$$\sqrt{B_\theta^2 + B_z^2} > 2B_{ecr}$$

The latter condition means the exception of an unstable ECR zone in the plasma chamber.

Fig.3(b) shows the measured results in two cases that is placed rectangular magnets which sizes are  $20 \times 10 \times 50 \text{ mm}^3$  and  $30 \times 10 \times 50 \text{ mm}^3$  respectively. (The sign  $\leftarrow$  denotes the direction of magnetization.) In each measurement, the three sheets of "mirror-field forming flange" and the auxiliary ring magnet were taken off. It is clear that the condition 1) is easily realized only with transverse field components in both sizes: the magnetic field amounts to  $B_{ecr}$  and  $2B_{ecr}$  at  $r=9.5-10 \text{ mm}$ ,  $14.5-15 \text{ mm}$  respectively.

The condition 2) is surely fulfilled only in the latter size, because the value of  $B_z$  at the position of the RF window is considerably low. Then, the aspect ratio of the rectangular magnet in the radial direction effects not only on the transverse field inside the plasma chamber but also on the optimum position of the RF window.

#### Conclusion

A new compact type higher order mode ECR ion source by using only permanent magnets has been designed at 2.45GHz. The required magnetic field configurations has been realized successfully by use of the "mirror-field forming flanges". The measured results of this magnetic field configuration suggests that this ion source is also able to convert to a 6GHz basic mode ECR ion source by a small increasing of the magnetic field strength, because the realized maximum field is nearly in the order of 2.14kG (=  $B_{ecr}$  at 6.0GHz) both in transverse and axial directions.

Hereafter it is intended the construction of this ion source and the first beam test in this year.

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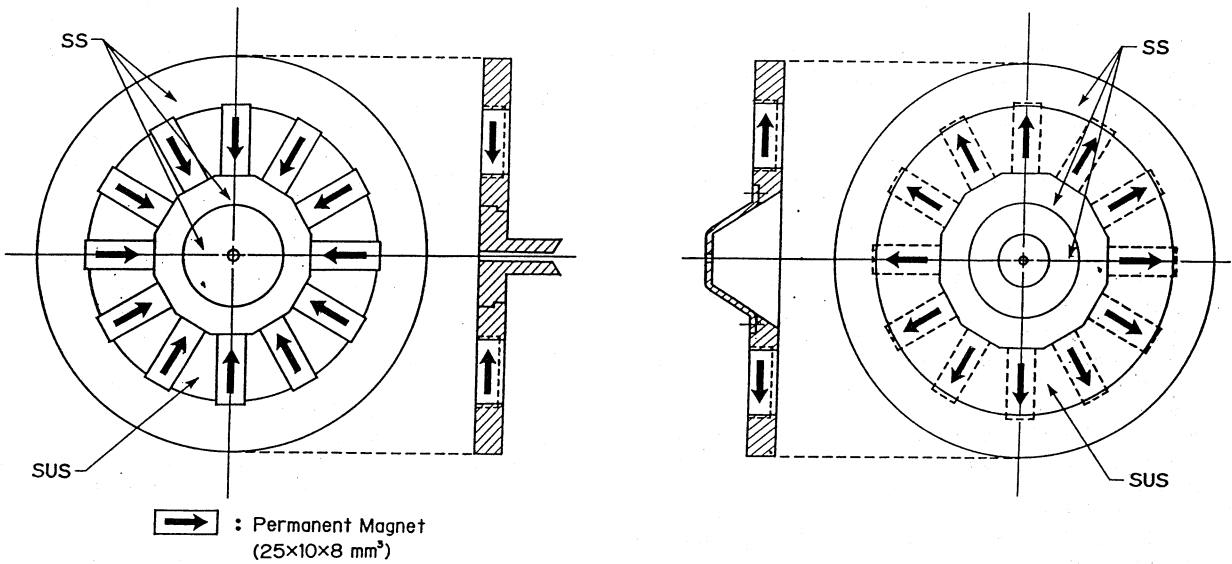


Fig.2 The mirror-field forming franges with radially placed rectangular magnets

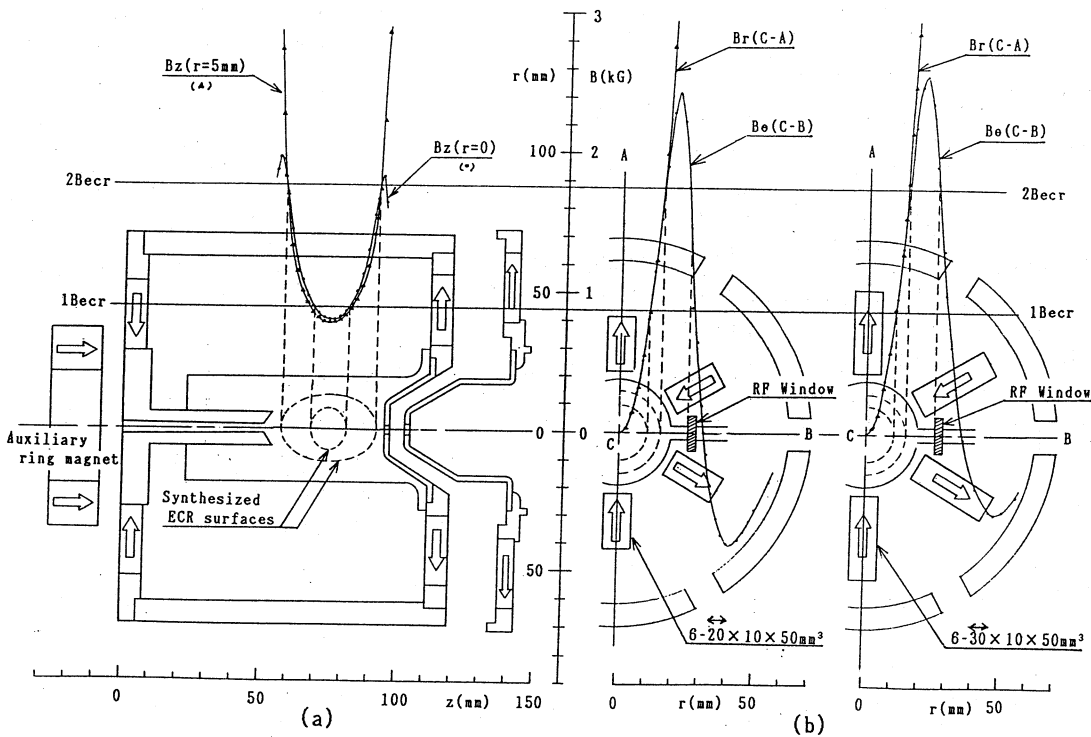


Fig.3 The magnetic field distributions of the 2.45GHz higher order mode ECR ion source