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# Design of JAERI 18-GHz ECR Ion Source

W.Yokota, Y.Saitoh, Y.Ishii, T.Nara and K.Arakawa

Takasaki Radistion Chemistry Research Establishment
Japan Atomic Energy Research Institute
1233 Watanuki, Takasaki, Gunma 370-12, Japan

*Abstract*

An 18-GHz ECR ion source for multiply charged ions was designed and is now under construction. A new design of the mirror field distribution was adopted, of which the minimum strength is varied by a solenoid coil installed between a pair of mirror magnets. The field strength forming a closed shell for ωce and an open shell for 2ωce are obtained by the field calculation. The design characteristics of the source are presented in this paper. The source will facilitate acceleration of heavy ions by the JAERI AVF cyclotron.

## I. INTRODUCTION

An ECR ion source of OCTOPUS type has been in operation since 1991 in combination with the AVF cyclotron at JAERI[1]. Ion beams are supplied mainly for R & D on materials for space environment and nuclear fusion reactor, and for research on biotechnology and new functional materials[2]. The research programs require various kinds of ion species and a wide range of energy.

Only ions with mass to charge ratio (M/Q) less than 6.5 can be accelerated by the cyclotron, and Xe ion may be a limitation with the OCTOPUS source. The research plan requires heavier ion species and wider energy range. We designed a new ECR ion source with high performance in generating highly charged ions and metal ions.

We chose a microwave frequency of 18 GHz because it may be the highest that can be obtained by a commercially available klystron tube and applied for 2ωce mode operation in use of room temperature magnets. A single stage type was adopted for high magnetic field.

The mirror field has been discussed often by its strength on the axis so far. For further understanding of ECR ion source, however, it is important to know the shape and size of ECR shell from three dimensional field distribution including the multipole field[3,4] and make them controllable. Moreover, geometrical condition of the ECR shell and an extraction hole should be studied to effectively extract high charge state ions in plasma through magnetic confinement.

We installed a solenoid coil between a pair of the mirror magnets to vary the shape and size of the ECR shell to study their effect on the source performance. The distance from the ECR shell to the extraction hole is variable by sliding the magnet assembly in the axial direction, and a plasma chamber is of a straight cylinder to make the slide easy. This simple chamber also allows replacement and modification for mounting additional attachments such as an electron gun and a rod insertion mechanism for metal ion production. The schematic view of the source is shown in Fig.1 and the design parameters are summarized in Table 1.

Table 1 Design parameters of the ECR ion source.

| | | | |
|---|---|---|---|
| Microwave: | | | |
| | frequency | 18.0 | GHz |
| | max. power | 2.5 | kW |
| | resonance field | 0.64 | T |
| Mirror Magnet: | | | |
| | max. field on axis | 1.41 | T |
| | max. current | 700 | A |
| | length | 27 | cm |
| | outer diameter | 102 | cm |
| | inner diameter | 8 | cm |
| Solenoid Coil: | | | |
| | max. field on axis | 0.7 | T |
| | max. current | 700 | A |
| | outer diameter | 82 | cm |
| | inner diameter | 18 | cm |
| Sextupole: | | | |
| | material | NdFeB | |
| | length | 30 | cm |
| | thickness | 4 | cm |
| | bore diameter | 8 | cm |
| | max. field on surface | 1.4 | T |
| Plasma Chamber: | | | |
| | inner diameter | 7 | cm |
| | length | 100 | cm |
| Vacuum pump: | | turbo-molecular (1500l/s) | |

## II. MAGNETIC FIELD

Magnets were designed by use of ELF/MAGIC, a three-dimensional magnetic field calculation code. The most important point was to attain field strength forming a shell of 2ωce resonance.

Two mirror magnets have the same structure with a soft iron yoke of 8 cm in thickness. They are magnetically separated in order to attain high mirror ratio. The distribution of the mirror fields are calculated for soft iron with the saturation field at 2.3 T, and the result is shown in Fig.2. The peak strength of the mirror field is about 1.4 T, higher than the 2ωce field of 1.28 T, and the mirror ratio is 14. The additional field of the solenoid coil enhances the minimum of the mirror field. The peak strength of the mirror field increases slightly by the solenoid field. As seen in Fig.2, there are two undesirable dips of field between the solenoid coil and the mirror magnets, but we did not find a design solution without them. By varying the solenoid field, the minimum field strength at z=0 (Bz(0)) varies from 0.1 T to 0.75 T. The length of the ECR shell for ωce varies gradually from 22 cm to 17 cm with Bz(0) below 0.64 T. The ECR for ωce does not occur at higher field.

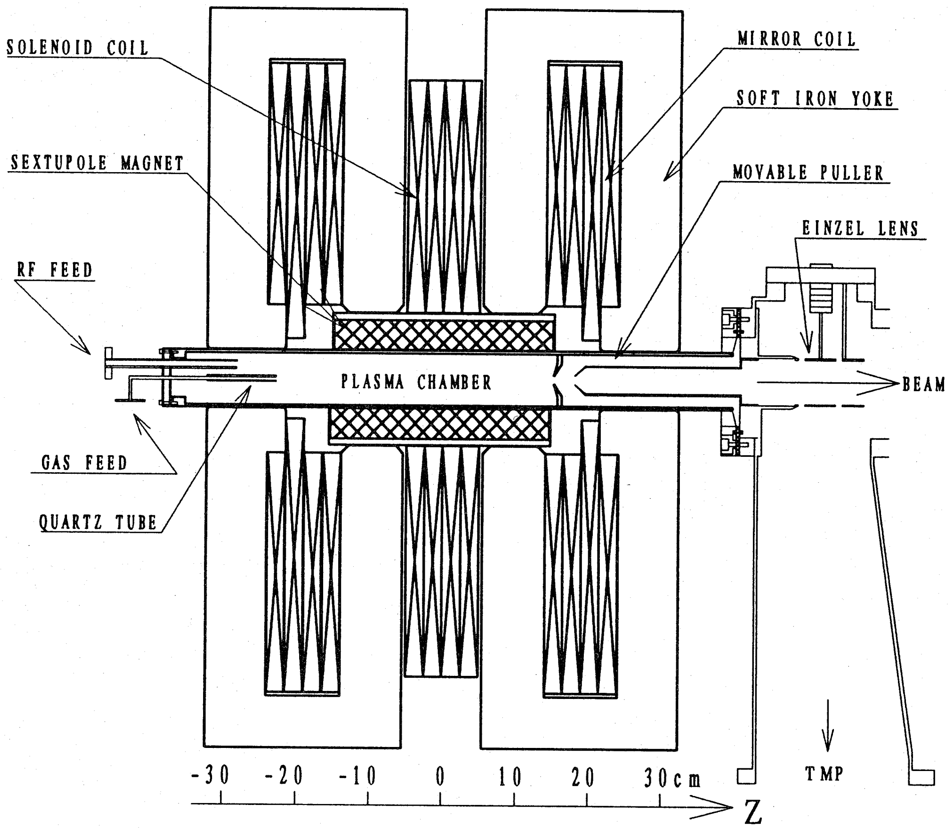

Fig. 1 Schematic drawing of the ECR ion source.

The thickness of sextupole magnets is limited by the existence of the solenoid coil, and was decided at 4 cm. In order to obtain a strong field, we examined various configurations of the shape and combination of magnetizing direction. The final configuration is shown in Fig.3. The maximum of the calculated field is beyond 1.4 T on the surface of the magnet as shown in Fig. 4. The strength is, however, 1.1 T on the inner wall of the plasma chamber because there is a 5 mm gap between the sextupole surface and the inner wall.

The shapes of the ECR shell are illustrated in Fig. 5. The shell for $\omega ce$ is closed and the size is 5.6 cm in diameter and 22 cm in length without the solenoid field. With increasing the solenoid field, the length decreases down to 17 cm and the diameter to zero, and the shell disappears for Bz(0) above 0.64 T.

In the absence of the solenoid field, the resonance of $2\omega ce$ is created only around the sextupole extremities. The resonance region appears along the inner wall of the chamber with the maximum solenoid field. Even in this case, however, the resonance shell is not closed in the chamber, as shown in Fig. 5. The area of the $2\omega ce$ will be extended by reducing the gap between the magnet surface and the inner wall in future.

## III. MICROWAVE AND PLASMA CHAMBER

The microwave is fed through wave guides from the end of the plasma chamber in the axial direction. The maximum power is 2.5 kW at an output flange of the generator. The $SF_6$ gas is filled to avoid arc discharge in the wave guide between the generator and the plasma chamber (about 2 m long) .

The plasma chamber is of a cylinder 7 cm in inner diameter and 100 cm in length, at the top of which an ion extraction system with a movable puller is mounted. Cooling water flows through 1 mm gap between the inner and the outer cylinders. The chamber is fixed and connected with the beam analyzing system. The magnet assembly slides on the rails in the axial direction without touching the chamber, and the extraction hole position is movable from an extremity of the $\omega ce$ shell to the peak of the mirror field.

In the first setting for generating gaseous ions, a wave guide and a quartz tube for gas feeding are mounted at the end flange of the chamber (Fig. 1). They will be rearranged when mounting a rod insertion mechanism for producting metallic ions and mounting an electron gun in next phase.

## IV. SUMMARY

An 18-GHz ECR ion source was designed and now in construction. A single stage type was adopted as the basic source configuration. The maximum mirror field beyond $2\omega ce$ resonance and a mirror ratio of fourteen were designed by field calculation. The sextupole field is above 1.4 T on the magnet surface and 1.1 T on the inner wall of the plasma chamber. By installing a solenoid coil between mirror magnets, the minimum mirror field was varied from 0.1 to 0.75 T. In accordance with this, the diameter of the ECR shell for $\omega ce$ varies from 5.6 cm to zero. An open shell for $2\omega ce$ appears with high solenoid field near the plasma chamber wall.

The ion source will be completed in February, 1994, and the first beam will be generated next spring.

## V. REFERENCES

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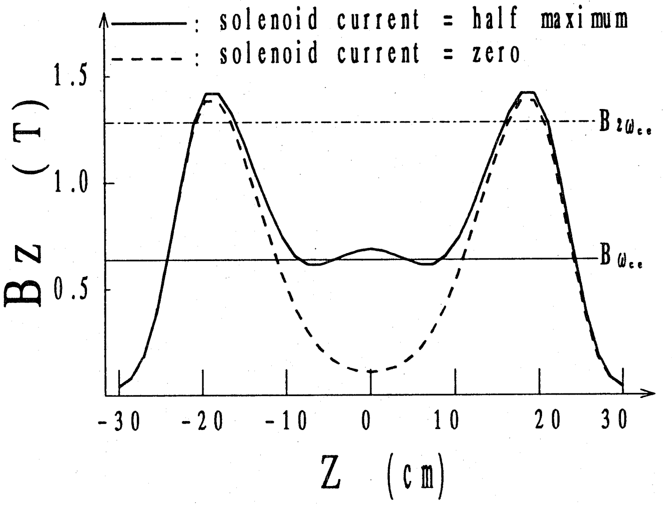

Fig. 2 Distribution of mirror and solenoid fields on the axis.

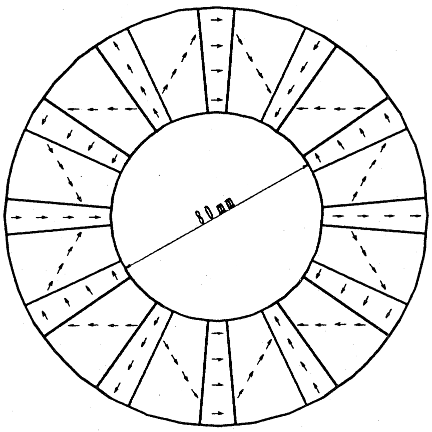

Fig. 3 Configuration of the sextupole magnet. The arrows indicate the magnetization.

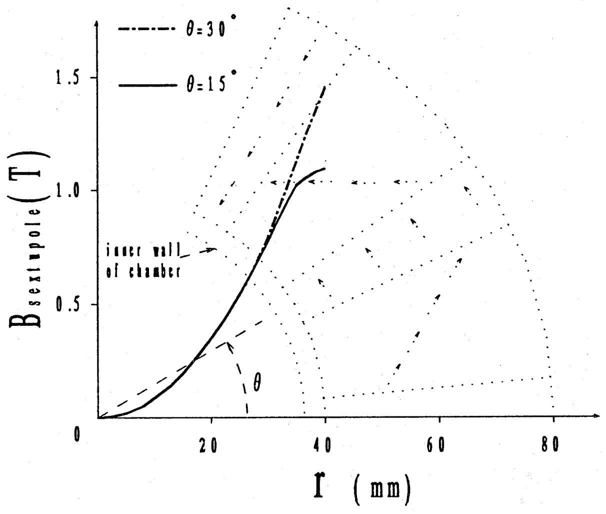

Fig. 4 Sextupole field distribution at z=0 cm.

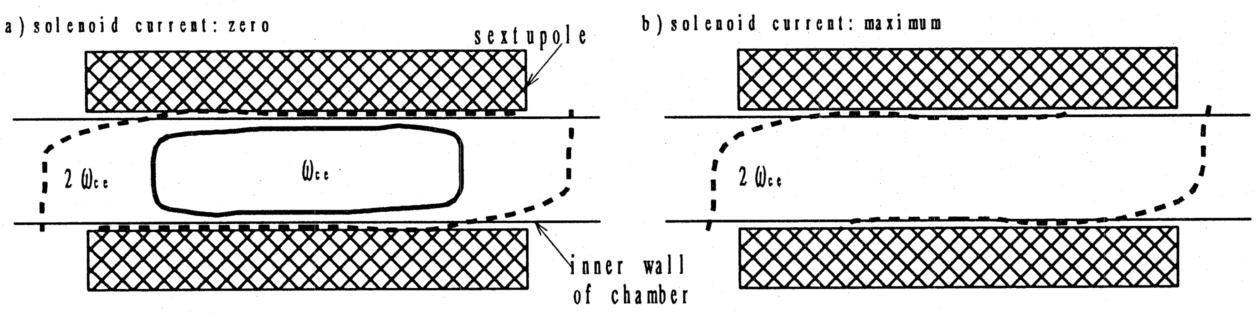

Fig. 5 ECR shell in the plane at θ=30° with maximum mirror coil current. Azimuthal angle θ is defined in Fig. 4.