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# DEVELOPMENT OF JAERI 18-GHz ECR ION SOURCE

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### Abstract

An 18-GHz ECR ion source for multiply charged ions was constructed and is now in operation for development. A new distribution of the mirror field was adopted, of which minimum strength is varied by a solenoid coil installed between the mirror coils. Measured mirror field distribution is close to designed one and its maximum strength exceeds 1.4 T. The source is now being tuned by use of Ar ion generation. Relatively high base pressure in the plasma chamber has been improved by installing an additional vacuum pump. The source performance has been growing up gradually with the vacuum and Ar ions with charge states up to 13+ has been observed so far.

## 1. Introduction

The JAERI research programs on materials science and biotechnology using cyclotron beams require various heavy ion species including metallic ions in a wide energy range [1]. According to the requirement, a new ECR ion source was constructed to generate ions with M/Q (ratio of mass to charge numbers) of less than 6.5, highest limit of the JAERI AVF cyclotron acceptance, for all the stable atomic elements.

The basic design of the source design was reported at last symposium [2]. The detailed designs of the source, electric current supplies, a microwave power supply and a beam analyzing system were completed in October in 1993. After being manufactured, they were installed in the ion source room cited on the basement of the cyclotron building in Feburuary, 1994, and the first plasma was fired at the end of June. The source was named ECR-18 after the microwave frequency.

## 2. Source Description

We adopted a solenoid coil between a pair of the mirror magnets to vary the shape and the size of the ECR shell as shown in Fig. 1. The relative position of the ECR shell to the extraction hole is adjustable by moving the magnet assembly in the axial direction. This structure also allows easy replacement of the plasma chamber. The specification of the source is summarized in Table 1. Magnets were designed to obtain sufficiently strong fields so that a closed shell with the strength equal to twice the ECR field was produced (2ωce shell) [3]. The maximum mirror field strength over 1.4 T was obtained in the calculation. Two mirror magnets have the same structure with soft ion yoke of 8 cm in thickness. They are magnetically separated and the mirror ratio reaches 14. Figure 2 shows the calculated and the measured mirror fields and they are in good agreement.

In order to obtain a strong sextupole field, we examined various configurations and combinations of the

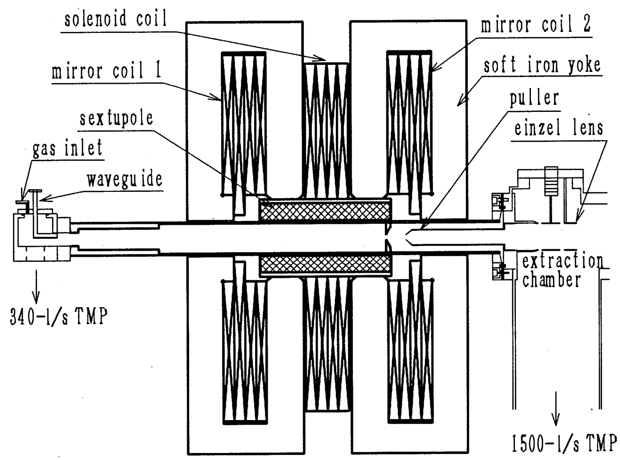


Fig. 1 Schematic drawing of the ECR-18.

Table 1 Specification and measured magnetic field of the ECR-18.

| | |
|---|---|
| mirror magnet (including yoke) | |
| number | 2 |
| outer diameter | 104 cm |
| inner diameter | 8.0 cm (smaller) |
| | 18.5 cm (larger) |
| length | 27 cm |
| number of turn | 224 |
| maximum field | 1.4 T (on axis at 700A) |
| solenoid coil | |
| number | 1 |
| outer diameter | 82 cm |
| inner diameter | 18.0 cm |
| number of turn | 206 |
| maximum field | 0.9 T (on axis at 700A) |
| sextupole magnet | |
| material | NdFeB |
| thickness | 4.5 cm |
| length | 30 cm |
| bore diameter | 8.0 cm |
| maximum field | 1.05 T (at 0.5 cm distance from inner surface) |
| plasma chamber | |
| length | 100 cm |
| outer diameter | 7.5 cm |
| inner diameter | 7.0 cm |
| klystron amplifier | |
| frequency | 18 GHz |
| maximum power | 2.5 kW |
| turbo-molecular pump | |
| evacuation speed | 1500 l/s (extraction chamber) |
| | 340 l/s (plasma chamber end) |

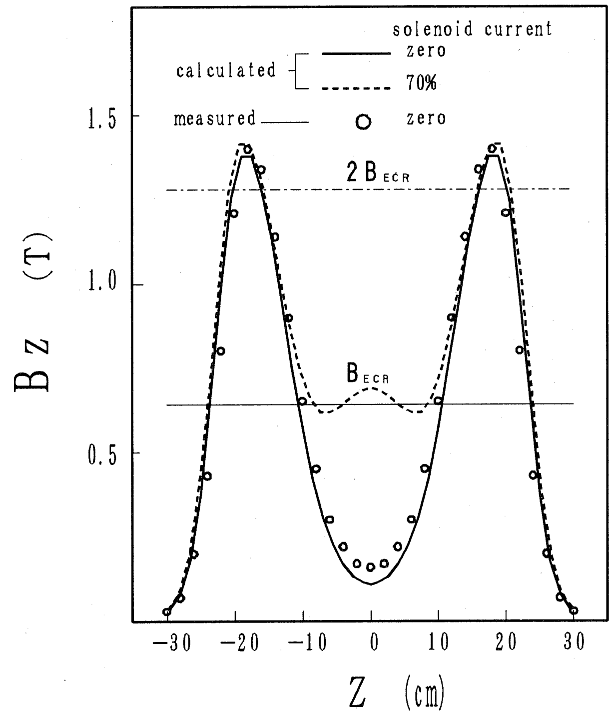


Fig. 2 Mirror distribution on the axis.

magnetization direction of permanent magnets in the calculation. Since the field strength of permanent magnets increases as a function of a permeance, the strongest field can be produced, in principle, by a configuration in which magnetization directions gradually change from one pole to the next. The best result was obtained by the configuration in which the pieces magnetized in the radidal and the azimuthal directins have the angular size of $10^{\circ}$ and the intermediate pieces $20^{\circ}$, and the maximum field was over 1.4 T on the magnet surface. The configuration is similar to that proposed by Halbach [4] and realized by Schiemenz et al. [5]. The angular size of all the pieces were finally fixed at $10^{\circ}$, of which magnetization direction rotates by $30^{\circ}$ from one piece to the next, as shown in Fig. 3, for smoother change of the direction and the convenience of manufacture. The measured field is about 95 % of the calculated value on the inner surface of the plasma chamber.

The calculated field without the solenoid current has a closed ECR shell of 5.6 cm in diameter and 22 cm in length at full excitation of mirror coils, and the length and the diameter decrease down to 17 cm and zero, respectively, with increasing solenoid current. The ECR shell disappears at the solenoid currents over 70 % of the maximum because the field strength exceeds the resonance value everywhere inside both peaks of the mirror field distribution. The shell of $2\omega ce$ appears around the sextupole extremities and expands with the increase of the solenoid field. However, the shell is not closed in the plasma chamber even at the highest solenoid current.

The microwave is fed through wave guides from the rear end of the plasma chamber in the axial direction. It is generally considered from many experiences that a microwave power of a few hundreds watts is enough for a small ECR plasma[6] In our design, the plasma size is relatively large and the higher frequency is apt to result in larger power loss in the waveguides. Therefore the maximum power was fixed at 2.5 kW.

The outer surface of the sexupole is cooled by air to avoid conduction of heat from the coils of which temperature rise up to $45^{\circ}$ C, because the temperature leads to 1.5 % reduction of the permanent magnet field and the heat cycle may deteriorate the magnet. The air is fed from an opening between a mirror coil and the solenoid, passes through narrow gaps about 3 mm between the coils and the sextupole, and goes outside from an opening between the mirror coil and the plasma chamber. Air flow rate of 10 l/min keeps the sextuple temperature lower than $30^{\circ}$ C.

Ion beams extracted from the source are focused by an einzel lens in the extraction chamber and analyzed by a $90^{\circ}$ bending magnet with the trajectory radius of 40 cm.

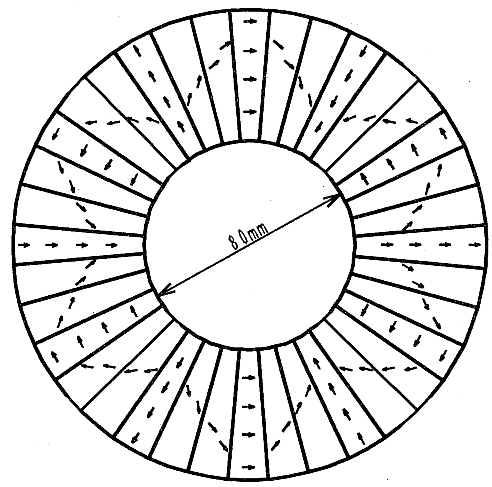


Fig. 3 Configration of the sextupole magnet. Arrows show magnetization direction.

### 3. Operational Experience

We have been tuning the source by generating Ar ions. In the initial operations, the ions with higher charge state than 11+ were not observed. This was considered to be due to relatively high base pressure which was $1.8\times10^{-5}$ Pa in the extraction chamber and was assumed to be higher by ten times or more in the plasma chamber. For improvement of the vacuum, an additional evacuation port equipped with a 340 l/s TMP was installed at the rear end of the plasma chamber. Consequentrly the base pressure went down below $5\times10^{-6}$ Pa in the extraction chamber, and ions with charge states up to 13+ were observed.

Oxygen gas is fed into the plasma chamber as an support gas for Ar ion generation, however, it does not work effectively. This suggests that the plasma chamber is still filled with too much outgas and the oxygen pressure can not be optimized. The charge state distribution of Ar ion, shown in Fig. 4, has the highest intensity for $Ar^{8+}$ and the similar results have been observed for the conventional ECR ions sources. However, the intensity decreases more rapidly at higher charge states. The rapid decrease may be also attributed to the relatively high pressure in the plasma chamber.

The optimum solenoid currents for highly charged Ar ions is about 55 % of the maximum and show a tendency to increase slightly with charge state, for example, the difference between the optimized currents for $Ar^{8+}$ and

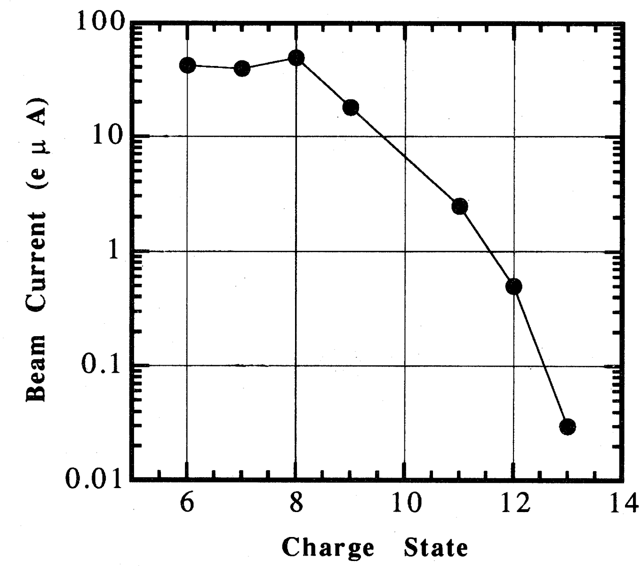


Fig. 4 Charge state distribution of Ar ions.

$Ar^{12+}$ is about 4 %. The mirror ratio at the optimum current is estimated at 2.4, which is close to that of the Caprice-type sources.

## 4. Conclusion

The 18-GHz ECR ion source was constructed at JAERI and is now in test operation by generating Ar ions since June, 1994. The source performance has been improving with vacuum in the plasma chamber, and the charge states up to $Ar^{13+}$ have been observed so far. The optimum currents of the solenoid coil, mounted between the mirror coils to vary the mirror ratio, show a tendency to increase with charge states. Further investigation is necessary for an appropriate explanation on a rule of the solenoid. The source performance will still grow by further optimization of the magnetic field, the position of the extraction hole and the improvement of the vacuum in the plasma chamber. After goal performance is attained by using Ar ions, the metallic ions will be generated in the next stage.


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