Status of ECR ion sources at JAERI

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Abstract

There are four ECR ion sources at the Takasaki site of Japan Atomic Energy Research Institute. Tow of them are connected to an AVF cyclotron, one is installed in an electrostatic accelerator and the other one is under development for the cyclotron. The accelerator facilities are being improved in efficiency with these sources. This paper summarizes the present status, development and performance of the ECR ion sources.

Introduction

Ion beam irradiation facilities at the Takasaki site of JAERI, consisting of an AVF cyclotron and three electrostatic accelerators, supplies ion beams to various field of researches on biotechnology and materials science. To meet requirement from the researches, an ion source is a key device for efficient use of the facilities by supplying various ion species over a very wide energy range. Under this background, when the AVF cyclotron was constructed in 1989, it was equipped with OCTOPUS to generate ions from gaseous materials. As the researches progress, demands for highly charged heavy ions keep increasing. We started developing an 18-GHz ECR ion source (ECR-18) for the cyclotron and a full permanent magnet source (MINI-ECR) for an electrostatic accelerator. MINI ECR was installed in a 400 keV ion implantor for ion acceleration test. HYPERNANOGAN was installed as a metallic ion source of the cyclotron in March this year. With these ECR ion sources, we are pushing forward with efficient use of the facilities and beam time as well as expanding ion species and beam energy range. Figure 1 shows a schematic layout of the sources for the cyclotron.

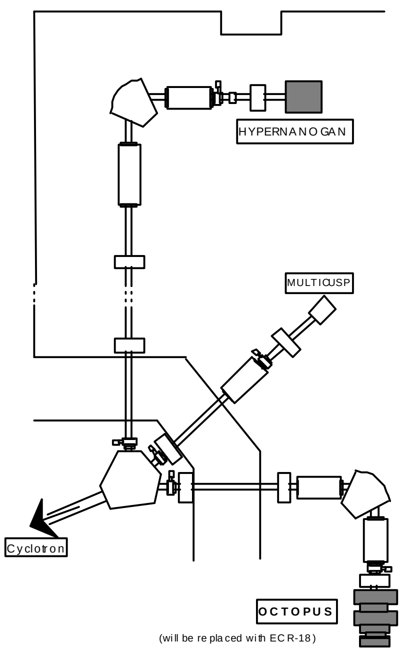

Fig. 1 Schematic layout of ECR ion sources for the cyclotron.

1. OCTOPUS

Frequent change of ion species or energy reduces beam time since one through two hours are taken for changing and optimizing all the parameters of the cyclotron system. Fast beam change without time loss is necessary for efficient use of the beam time. The cocktail beam acceleration technique [1] permit it. Cocktail beams of mass-to-charge (M/Q) ratio of 4 and 5 have been developed with OCTOPUS and its gas feed system was modified for the technique.

1.1 Cocktail beam acceleration technique

In this technique, mixture of different ion species having almost equal M/Q values produced by an ECR ion source, 'cocktail beam', is injected into the cyclotron and simultaneously accelerated. The cyclotron parameters are optimized for a specific M/Q value of one of the species in the cocktail to be fully accelerated under the isochronous condition. Ions with slightly different M/Q values are gradually shifted in acceleration phase and are phased out before reaching the extraction radius. But they can be extracted from the cyclotron by changing the frequency by $\Delta f_{RF}/f_{RF}$ or the magnetic field by $\Delta B/B$ proportional to $\Delta(M/Q)/(M/Q)$. Change of the frequency or the magnetic field is completed within a few minutes. As a matter of fact, however, finite M/Q-resolving power of the cyclotron arises intermixture of ion species in extracted beams.

1.2 Impurity problem and gas feed system modification

In the development of a cocktail beam acceleration with M/Q=4 using $^{12}C^{3+}$, $^{16}O^{4+}$, $^{20}Ne^{5+}$ ions, $^{12}C^{3+}$ and $^{20}Ne^{5+}$ ions were observed in the beam optimized for the $^{16}O^{4+}$. The reason for the intermixture is that $\Delta(M/Q)/(M/Q)$ of $^{12}C^{3+}$ and $^{20}Ne^{5+}$ from $^{16}O^{4+}$ are 3.2×10^{-4} and 0.6×10^{-4}, respectively, and are comparable to M/Q resolution of the cyclotron of about 3×10^{-4} which was experimentally and theoretically estimated[1]. The resolution can be improved if the turn number is increased by using the lower Dee voltage. However, considerable amount of time is necessary to optimize the parameters, contrary to the fast change of the beam.

For the practical operation, injection of a single ion species into the cyclotron is the easiest way for purification of the beam. In order to save the time for changing gases supplied to the ECR ion source, the gas feed system was modified as shown in Fig.2. The volume in the gas tubes was reduced as small as possible and nitrogen gas having an M/Q values sufficiently far from 4 is used as a common support gas to save the time for purging in the pipes. As a result, the ion species of cyclotron beam is changed within ten minutes.

2. ECR-18

This ion source has a unique coil arrangement which varies a mirror ratio in a wide range with a solenoid coil mounted between the mirror coils [2]. A weak bump appeared between the mirror field peaks at a mirror ratio lower than 3 in the original magnetic field distribution, as shown in Fig.3. The source performance in generating highly charged ions improved after a number of minor changes, and the maximum charge state of Ar ion was 16+ with 2 enA beam current. Some of observed phenomena may be peculiar to this field distribution;

1. Cylindrical aluminum plate attaching on the plasma chamber wall (copper) enhanced the beam intensity at high charge states by factor 2 or 3, but a bias probe had little effect.
2. After optimizing source parameters to maximize specific charge state intensity, increasing the solenoid coil current resulted in decreasing intensity at high charge states.

We assumed that the plasma was divided into two regions by the bump and larger bump weakened the connection between two regions. Under this assumption, electrons fed from the bias probe into a region on the microwave-injection side might not be easy to move to the other region from which ions were extracted. On the other hand, the aluminum plate surrounding the whole plasma could increase electron density in the both region.

We made a field calculation with a code of TOSCA to find an axial magnetic field profile without a bump. It turned out that the bump could be removed simply by halving the solenoid coil length and the gap between the mirror coils. The new design of the source and the axial field profile is shown in Fig.3 in comparison with the original ones.

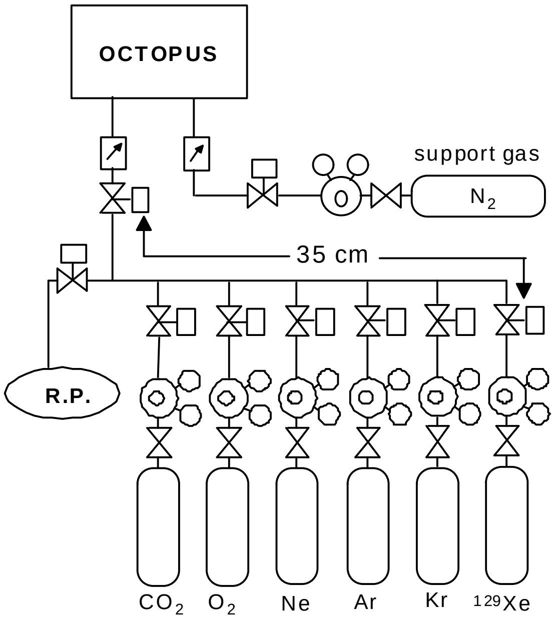

Fig.2 Modified gas feed system of OCTOPUS.

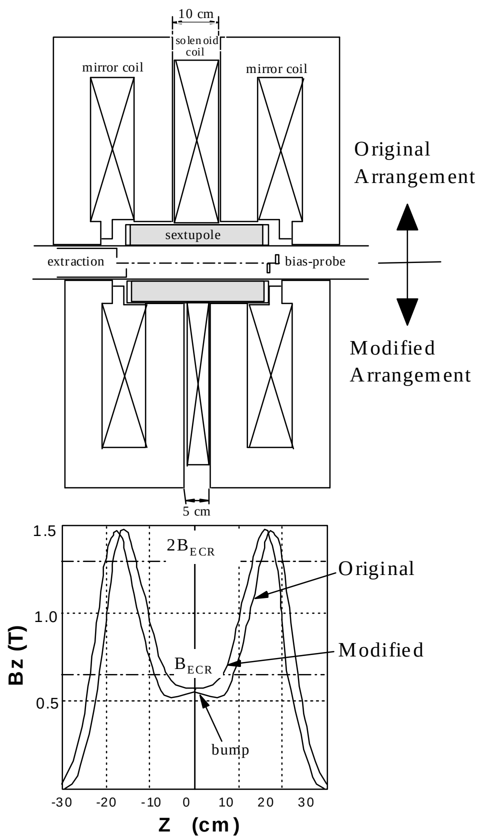

Fig.3 Modification of the solenoid coil and the axial magnetic field profile of ECR-18.

After the modification, test operations were made with a cylindrical aluminum plate covering the plasma chamber wall and with a bias probe. The charge state distributions of Ar ions before and after the modification is shown in Fig.4. Ion beam intensity increased for all charge state. Improvement at high charge states was significant and Ar^{16+} intensity increased by three orders of magnitude.

3. HYPERNANOGAN

This source was purchased from PANTECHNIK s.a. and connected to the injection line of the cyclotron this year . The extracted beam is focused by a Glazer lens, analyzed by a 90°-analyzing magnet and transported into the injection line of the cyclotron. All the focusing elements are solenoid lenses.

Test operation was carried out using Ar ion generation and 10 eμA of Ar^{14+} was obtained 6 days after the first plasma. Successively, Pb and Ta ions were obtained using an oven and an elemental wire, respectively. Beam of Pb^{23+} with 0.5 eμA and Ta^{19+} with 0.9 eμA were observed tow days after the tuning started for each metal. Further tuning is necessary to generate metallic ions for higher charge state, higher beam intensity and stable operation. As to Ar ions, on the other hand, intensities for all charge states are comparable to the nominal values. The charge state distribution of Ar ion is shown in Fig.5.

The source will begin to supply ion beams to the cyclotron this autumn after developing generation of various metallic ions using an oven, rod insertion and MIVOC method.

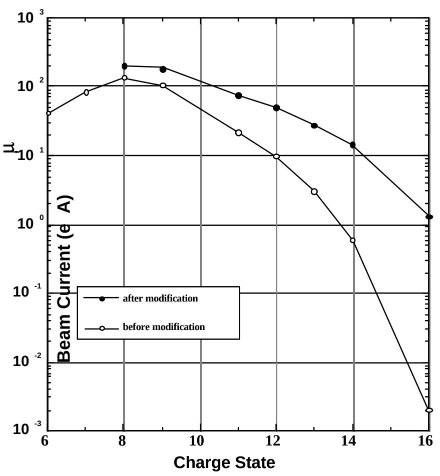

Fig.4 Improvement in charge state distribution of AR ios by means of ECR-18 modification.

4. MINI-ECR

The MINI-ECR has been developed to install in a 400 kV ion implanter to allow MeV implantation. Since, on the implanter, the space and available electric power is limited, all the magnet of the source is made of permanent magnet and a transistor amplifier is used to supply the 10 GHz microwave with the maximum power of 20 W. The details of the source were described elsewhere [3].

4.1 Application of bias-probe

In MINI-ECR, microwave is emitted from the waveguide into the plasma chamber. Application of a disc-shaped probe downstream of the waveguide end increased reflection of microwave and decreased beam currents. The 22.9 mm × 10.2 mm cross section of the waveguide was comparable to the plasma chamber of 28 mm diameter. Instead of a disc shape, a simple wire works well as a bias probe. As shown in Fig.6, a copper wire is extended out from front of the waveguide end toward the median of the chamber. The tip of the wire is set close to the plasma surface. This may work as converter from waveguide to coaxial guide, and microwave reflection became nearly zero.

The bias voltage is effective at high charge states and Ar^{9+} increased by two orders of magnitude, as shown in Fig.7.

4.2 Metallic ion generation technique using SF_6 plasma

Many metallic fluorides have a vapor pressure higher than 1×10^{-3} Pa. We made use of this nature to generate ion of refractory materials [4]. In this technique, an annular sample metal is set in the plasma chamber of the ion source to fit to the wall with an extraction hole as

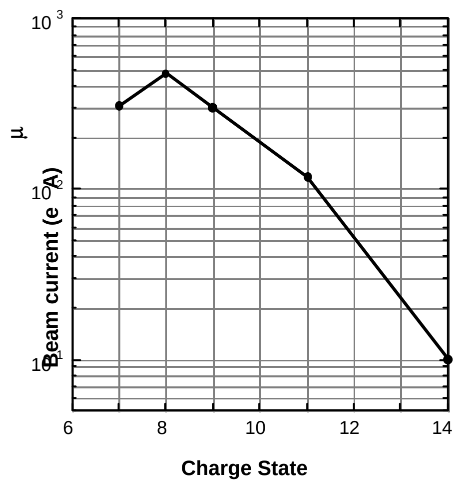

Fig.5 Charge state distribution of Ar ion from HYPERNANOGAN.

shown in Fig.6. For producing boron ions, a sample of boron nitride (BN) is used because of good machinability. The SF_6 plasma, which is generated by simply feeding SF_6 gas into the source, contains fluorine ions, sulfur ions, and their neutral gases. The sample in the chamber is fluorinated by the SF_6

plasma. The fluorides with sufficiently high vapor pressure are vaporized and dessociated into metallic ions and fluorine ions. The observed beam currents of examined samples are summarized in Table 1.

This method was tested for three months and no corrosion has been observed for the ion source. This means that the amount of corrosive gases generated in this method is quite small and the sample metal fluoride is ionized much more effectively in comparison with conventional methods in which the metal gases fed from outside.

Table 1 Ion beam current for each metal in eμA generated by SF_6 plasma method.

Charge state	1+	2+	3+	4+	5+	6+	7+	8+
^{11}B 6.0	2.5	0.3						
^{93}Nb	0.46	1.84	2.0	1.38		0.66	0.30	0.18
ΣMo	0.49	1.85		1.75				
^{181}Ta	0.20	1.43	1.75	2.13	2.28		1.0	0.31
ΣW	0.27	1.07	1.09	1.50	1.69		1.20	0.67

Σ : summation of isotopes

Fig.6 Sectional view of MINI-ECR. Setting of a bias probe and a metal sample is shown.

Fig.7 Intensity dependence of Ar ions on bias voltage for MINI-ECR.

5. Acknowledgment

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