CONSTRUCTION AND TEST OPERATION OF AN ALL PERMANENT-MAGNET ECR ION SOURCE AT CYRIC

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Abstract

A new electron cyclotron resonance (ECR) ion source has been designed and equipped with the new cyclotron at Cyclotron and Radioisotope Center (CYRIC), Tohoku University. The ion source consists of full permanent magnet system with the microwave frequency of 14.5 GHz. The source has three main features as follows: (1) V-style magnetization, (2) flat-bottomed magnetic field distribution, (3) field adjusting system. Measured magnetic field strength in the plasma chamber is about 8% weaker than calculated value. Extracted beam current is measured as the preliminary result.

1 INTRODUCTION

In 2000 a new cyclotron was installed in Cyclotron and Radioisotope Center (CYRIC), Tohoku University. The remarkable feature of the cyclotron is both positive and negative ion acceleration. It has an external ion injection system and three external ion sources stations. Positive ion source will be used for providing high energy beams of various ions including heavy ions. On the other hand, negative ion source will be used for providing high current proton and deuteron beams and is now in construction.

A new electron cyclotron resonance (ECR) ion source has been designed and installed as one of the positive ion sources. The role of this source is to ionize mainly gaseous materials up to argon and provide those to the cyclotron for acceleration.

The ion source is a full permanent magnet system. All-permanent magnet type ECR ion source has advantages of its simplicity and compactness. However, this type sources have several disadvantages in comparison with the type of electromagnets, (1) weaker magnetic field; (2) difficulty adjusting the distribution of magnetic field in the plasma chamber. For the field correction in permanent magnet ECR ion sources, electromagnetic coils have been used by the KEK group [1, 2]. On the other hand the present ECR ion source has been designed to overcome these disadvantages with only permanent magnets.

In this report we describe the geometry and characteristics of the source, and also report calculated and measured magnetic field distributions. In addition, we report preliminary results of beam extraction.

2 OUTLINE OF THE SOURCE

A cross sectional view of the ECR ion source is shown in Fig. 1. This source consists of two mirror magnets, a hexapole magnet, and three additional ring magnets outside of the hexapole magnet. All of the magnets are NdFeB permanent magnets which is 51.5 kg in total weight.

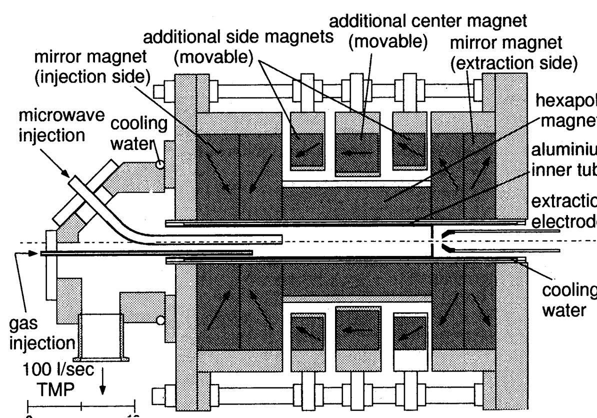

Fig. 1: Cross-sectional view of the new ECR ion source. Arrows represent magnetization directions of every permanent magnets.

The additional magnets consists of an additional "center" magnet and two additional "side" magnets with the same size. Magnetization directions are the same as that of the mini-ECR at JAERI [3]. We will describe the characteristics of the permanent magnet in the next section.

Microwave of 14.5 GHz frequency are generated by a klystron and fed from the rear end of the plasma chamber along the chamber axis. A Plasma chamber of 32 mm in inner diameter is made of stainless steel. An aluminum inner tube of 30 mm in inner diameter is inserted in the chamber to provide electrons for the plasma. An exit hole, which is made of stainless steel, is attached to the end of the aluminum tube and set at the position of maximum magnetic field. The diameter of the exit hole is 5 mm. An extraction electrode is made of stainless steel. The diameter of the electrode hole is 8 mm and the distance from the anode hole is adjustable by the rotary feedthrough. The electrode is isolated electrically from not only the potential of the plasma chamber but also the earth, so we can provide the high-voltage to the electrode. To avoid the degradation of the permanent magnet, plasma chamber is cooled by water. The vacuum sealing part of the microwave injection stage is also cooled by water to protect the O-rings from the heat of microwave waveguide. A 550 l/s turbo molecular pump is installed at the extraction stage and a 100 l/s turbo molecular pump is installed at the microwave injection stage.

3 CHARACTERISTICS OF THE SOURCE

Main feature of the present ECR ion source is slantingly magnetized permanent magnets as shown in Fig. 1 and the adjustable magnetic field distributions. OPERA-3d code is used for the magnetic field calculation and the arrangement of the magnets is searched based on the field calculation.

(1) *V-style magnetization*

Both the mirror magnets consist of a pair of thin ring magnets with the same size. These ring magnets are symmetrically magnetized at angles of 30 degrees with the radial direction of the plasma chamber. Maximum magnetic field on the chamber axis is 10% stronger than ordinary radial magnetization.

(2) *flat-bottomed magnetic field distribution*

Three additional ring magnets are placed between the mirror magnets. The angle between the magnetization direction and the chamber axis is ± 30 degrees. As a result these additional magnets form the flat-bottomed magnetic field distribution.

(3) *field adjusting system*

The additional magnets are fixed on six outside rods by locknuts, so they are movable along the chamber axis. By the movable system precise adjustment of the field strength is available around resonance zone.

4 CALCULATED AND MEASURED MAGNETIC FIELD DISTRIBUTIONS

Typical examples of the calculated magnetic field distribution are shown in Fig. 2. One (dashed line) is the case that additional side magnets are moved to the additional center magnet (setting I), and the other (solid line) is that they are set away from it (setting II). In the former case the strength of the minimum magnetic field is almost the same as the resonance value (5180 Gauss). On the contrary, in the latter case it is weaker than that of the former case and therefore a ECR zone of conventional shape is formed.

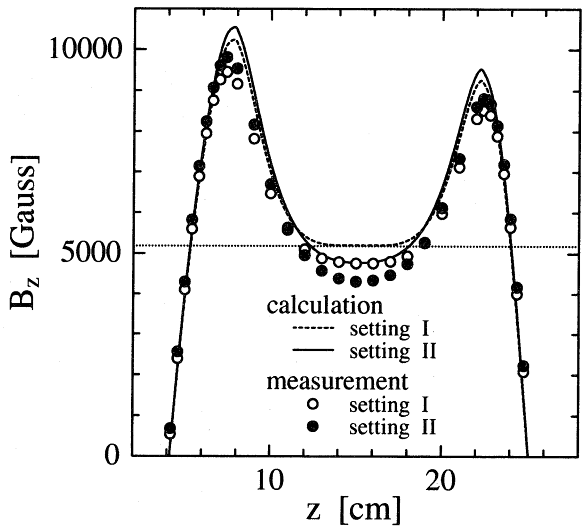

Fig. 2: Magnetic field distribution on the symmetry axis of the chamber. A dashed line and a solid line represent the calculated field at the setting I and II, respectively. Measured field strength at the setting I (open circle) and the setting II (filled circle) are compared. A dotted line indicates the resonance field strength of 5180 Gauss.

In addition to the calculated value, Fig. 2 shows the measured magnetic field on the chamber axis with the setting I (open circle) and setting II (filled circle). The measured field strength is about 8% weaker than the calculated value. Therefore ECR-volume is not formed. We suppose that one of the reasons of this disagreement is the influence of the residual magnetism in stainless steel constructing the plasma chamber.

The specifications of the source are summarized in Table I.

5 PRELIMINARY TEST OPERATION

The ion source was installed at one of the high voltage terminals of the injection lines. The first plasma was ignited by hydrogen gas. The layout of the beam analyzing line, which is a part of the injection line, is shown in Fig. 3. Extracted beam is analyzed by a bending magnet with a bending angle of 40 degrees. Analyzed beam current is measured on a vertical slit which is used for a Faraday cup. A horizontal slit is in front of the vertical one and it has an aperture of 20 mm. A glazer lens is used for focusing the extracted beam on the vertical slit.

The aim in the operation is to produce multi-charged ions with less than 4 or 5 of the mass-

Table I: Specifications of the designed ECR ion source

microwave frequency	14.5 GHz
maximum microwave power	2 kW
plasma chamber length	282 mm
plasma chamber diameter	32 mm
ECR zone length	30[55] mm
ECR zone diameter	6[16] mm
maximum extraction voltage	20 kV
material of permanent magnet	NdFeB
total weight of magnet	51.5 kg
cooling	water
maximum magnetic field (injection side)	10260[10550] Gauss
minimum magnetic field (extraction side)	5170[4770] Gauss

[ ] is the case of the setting II.

to-charge number ratio and to provide to the new cyclotron for accelerating. Test operation and commissioning have been started to obtain highly multi-charged ions on argon beams.

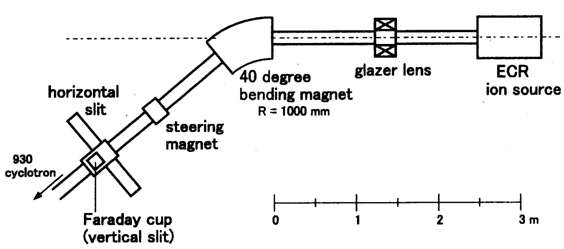

Fig. 3: The layout of the beam analyzing line.

Figure 4 is the preliminary result of the charge state distribution of the extracted beam from the argon plasma. Extra magnets setting of type II was used at this test. The overall resolution of the system is about 1/65 and every charge state argon ions can be resolved from any other impurities with the different mass-to-charge state ratios. Multi-charged argon ions up to 9+ were observed but the current of the high-charged ions were smaller than low-charged ions. Another test operation with the setting I was held. The results were almost the same as that with the setting II.

6 DISCUSSION

The base pressure is 5×10^{-7} Torr and the operating pressure is about 1×10^{-6} Torr at the extraction stage. This value is about five or ten times higher than the designed value. It suggests that the plasma chamber has not attained best conditions of vacuum yet. Further conditionings for vacuum are necessary.

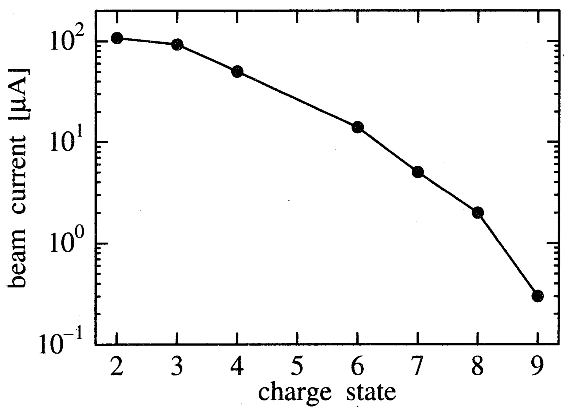

Fig. 4: Charge state distribution of the extracted beam from argon plasma. Operation conditions are optimized for Ar^{8+} ions. Gas-mixing method is not used.

In summary, we have constructed an all-permanent magnet ECR ion source with characteristically arrangements of the permanent magnets. The calculated magnetic field distribution was flat-bottomed shape and form ECR-volume. An Ar^{9+} ion was extracted in the preliminary operation but the current was low. Further effort to obtain the best operating condition is necessary and is in progress.

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