DESIGN OF NEW 18 GHZ ECRIS FOR RIKEN RIBF

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Abstract

In RIKEN Radio Isotope Beam Factory (RIBF), we plan to install a new 18 GHz electron cyclotron resonance ion source (ECRIS), which supply an intense beam of highly charged heavy ions into the RIKEN linear accelerator (RILAC). By equipping the RILAC with two ion sources, we expect to be able to develop new beams while producing a beam for experiments at RIBF. Based on the structure of existing 18 GHz ECR ion source which have been developed at RIKEN, this ion source has the following additional features: (1) Three solenoid coils have been installed to enable B_{ext} to be adjusted while B_{min} is fixed at an optimum value. (2) A variable frequency RF power source has been adopted. Therefore, further enhancement of the beam intensity is expected because the frequency band that is suited to the size of a plasma chamber can be selected. (3) The structure of the chamber has been improved to simplify maintenance work.

INTRODUCTION

For RIKEN Radio Isotope Beam Factory (RIBF) project [1], we constructed and developed several high-performance electron cyclotron resonance ion sources (ECRISs) [2–5]. One of the ion sources is the RIKEN 18GHz ECRIS used as an external ion source for the RIKEN linear accelerator (RILAC) [5]. The main role of the ion source is to produce an intense beam of multi-charged medium-heavy ions (e.g., $^{40}Ar^{8+}$ $^{48}Ca^{10+}$, $^{70}Zn^{15+}$, $^{84}Kr^{18+}$) for the RIKEN RIBF and the super-heavy element search experiment. For this purpose, we have improved performance using various methods [5]. However, we recently needed to develop new beams to meet the requirements for new beams and to extend the irradiation time (longer than one month) of the heavy ion beam, particularly the metallic ion beam, on target for the RIBF. To meet these requirements, we needed a new ion source. By equipping the RILAC with two ion sources for the RILAC, we could develop new ion beams while producing a beam for the experiment. Furthermore, when faced with problems of the ion source during beam production for the experiment, we can immediately switch to another ion source for producing the beam. This means that we can extend irradiation time by using two ion sources. For these reasons, we started to design and construct the new 18 GHz ECRIS as an additional external ion source for the RILAC.

In the present paper, we describe the structure of the new 18 GHz ECRIS. We present the structure of the solenoid coils used for producing a magnetic mirror along the axis and a hexapole magnet, the design of the plasma chamber, and the traveling wave tube (TWT) amplifier for producing 18 GHz microwaves, in the following sections.

SOLENOID COILS AND HEXAPOLE MAGNET

Figures 1 (a) and (b) show schematic drawings of the new 18 GHz ECRIS. It consists of three solenoid coils that produce a mirror magnetic field along the axis. Figure 2 shows a typical magnetic field distribution along the axis. The main parameters of the solenoid coils are listed in Table 1. By using this magnet system, one can independently control the magnetic mirror ratio and B_{min}. As described in several papers [4, 6, 7], beam intensities of highly charged heavy ions are strongly dependent on B_{min}. The optimum value of B_{min} for maximizing the beam intensity is nearly constant (70%~80% of B_{ecr}) for the high-performance ECRIS [4]. This may be due to the effect of the magnetic field gradient and the ECR zone

Table 1: Specifications of the Mirror Coil

	Solenoids I & III	Solenoid II
Number of turns	296	60
Maximum current	660 A	300 A
Maximum voltage	105 V	10 V
Maximum intensity of the mirror magnetic field	>1.3 T	
Minimum intensity of the mirror magnetic field	<0.5 T	

Table 2: Specifications of the Hexapole Magnet

Material	Nd-B-Fe permanent magnet
Inner diameter	85 mm
Outer diameter	186 mm (magnet only), 210 mm (including a holding jacket)
Length	250 mm
Number of divisions	36
Magnetic field intensity	~1.3 T at the surface of the cylinder with the size of 79 mmϕ × 150 mm

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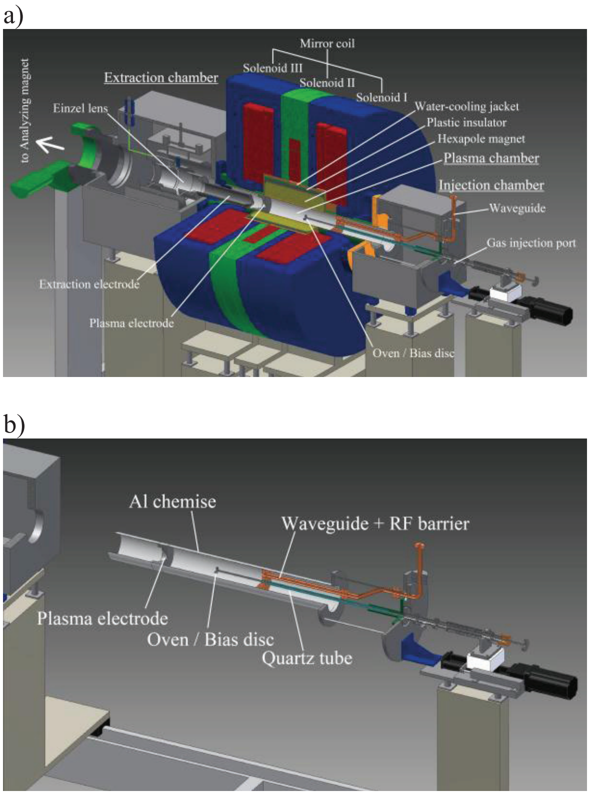

Figure 1: (a) Schematic drawing of the new 18 GHz ECRIS for the RIKEN RIBF. (b) Schematic drawing of the plasma chamber of the new 18 GHz ECRIS for the RIKEN RIBF.

size [8, 9]. On the other hand, the charge state in the plasma is dependent on the mirror ratio, because a longer confinement time for the plasma is obtained by a higher mirror ratio. To achieve these results, we can realize an optimum magnetic field distribution to maximize the beam intensity for the required charge state of the heavy ions as follows: (1) B_{min} should be maintained at 70%~80% of B_{ecr}, (2) the mirror ratio should be changed to maximize the beam intensity for the required charge state of the heavy ions while maintaining the optimum value for B_{min}.

In Fig. 3, the area enclosed by the blue line is the

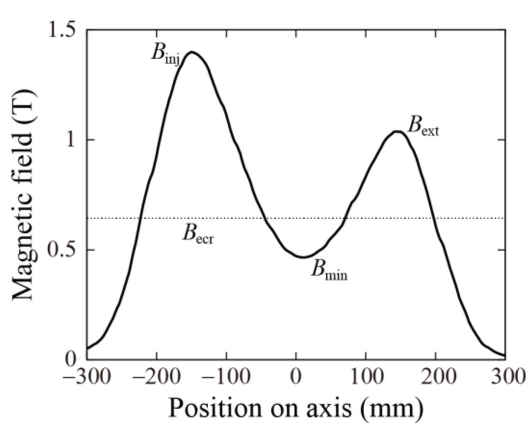

Figure 2: Typical magnetic field distribution along the axis.

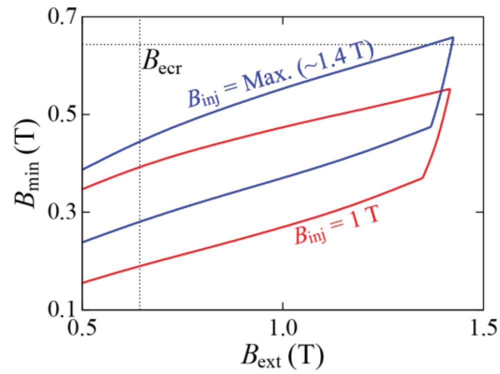

Figure 3: B_{min} vs. B_{ext}. Areas surrounded by the blue and red lines are the possible combination of B_{min} and B_{ext} for B_{inj} = 1.4 T (blue) and 1.0 T (red).

possible combination of B_{min} and B_{ext} when B_{inj} = 1.4 T is selected. In this figure, it is clear that B_{ext} can be changed from 0.8 to 1.3 T while maintaining B_{min} at 0.45~0.5 T.

Table 2 lists the main parameters of the hexapole magnet. The inner and outer diameters of the Hexapole are 85 mm and 186 mm, respectively. It consists of 36 segments of Nd-B-Fe permanent magnets (N48M, Shin-etsu Kagaku Co.). Figure 4 shows the schematic drawing of the hexapole magnet. The arrows in this figure show the direction of magnetization. The remanence (B_r) and coercivity ($H_{c,J}$) are 1.42~1.47 T and 16,000 Oe, respectively. The maximum energy product is 44~49 MGOe. The radial magnetic field strength at the inner surface of the plasma chamber (which is 79 mm in diameter) is ~1.3 T, which is sufficiently strong for 18 GHz microwave operation.

PLASMA CHAMBER

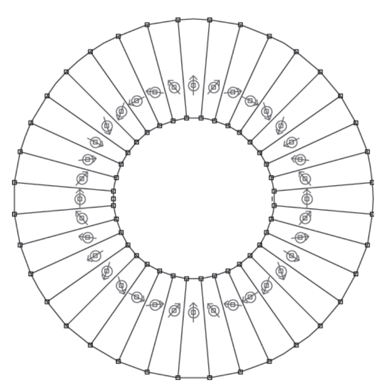

Figure 4: Schematic drawing of the hexapole magnet. Arrows indicate the direction of the magnetization.

The inner diameter of the plasma chamber is 79 mm, which is slightly larger than the old RIKEN 18 GHz ECRIS. There are two turbo-molecular pumps, ~500 L/s, placed at the RF injection side and beam extraction side to maintain a high vacuum in the plasma chamber (on the order of 10^{-8} Torr). The maximum extraction voltage is 20 kV. The position of the extraction electrode is remotely controlled to optimize the beam trajectory. The high-

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temperature oven is inserted from the RF injection side. To set the oven in the optimum position, its position is also remotely controlled. The position and negative voltage of the biased disc are important parameters for increasing the beam intensity of the highly charged heavy ions [5]. For this reason, we install a movable negatively biased disc in the plasma chamber. The position and disc voltage are remotely controlled.

The Nd-B-Fe permanent magnet is easily demagnetized by high temperature. For this reason, we must maintain it at a low temperature (i.e., at room temperature or lower) against the heat load from the ECR plasma. To maintain this temperature, the chamber consists of double-wall stainless steel tubing with a water cooling channel in the gap (~1 mm). The flow rate of the cooling water in the channel is ~6 L/min, which is sufficient to maintain the temperature against the heat load from the plasma when we inject an RF power of 700 W. The temperature of the injected cooling water is 20 °C.

To maintain the high voltage for the plasma chamber, 3 mm thick plastic insulators are placed between the chamber and the solenoid coils. The maximum extraction voltage is 20 kV. For example, the extraction voltage for a Zn^{15+} ion beam is 16.6 kV for the accelerator of RIKEN RIBF.

THE 18 GHZ MICROWAVE GENERATOR

Recently, changes in the ECRIS performances have been achieved by slightly varying the microwave feed frequency ("frequency tuning") [10, 11], which produces strong fluctuations in the beam intensities even for frequency variations in the megahertz range. Simulations based on the particle-in-cell code have shown that the ECR heating efficiency depends on the electromagnetic field distribution in the plasma chamber and on the electric field distribution on the resonance surface. It has been reported that the beam formation process and the beam shape are strongly affected by frequency variations. The explanation for these results is strictly linked to the electromagnetic field pattern inside the chamber; the heating and the ionization processes change with the electric field distribution on the resonance surface. In the case of strongly corrugated plasma surfaces, the scattering effect shortens the ion lifetime. In this case, the beam brightness decreases and is mostly populated by ions at low charge states. If we have "good" matching between the microwave frequency and the geometry of the plasma chamber and ECR zone, a smooth plasma surface can be created. In this case, the ion confinement time and brightness of the extracted beam are increased.

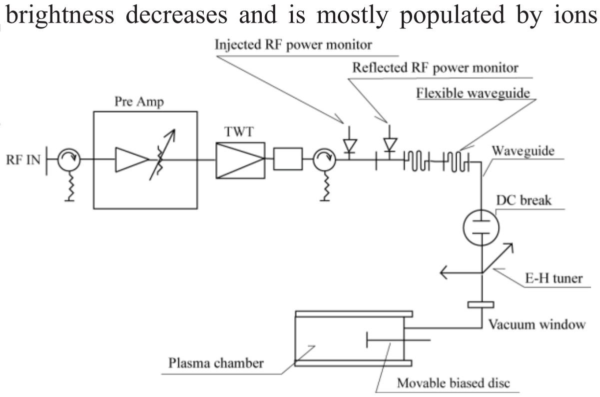

Figure 5: RF power line from the TWT amplifier to the plasma chamber of the ECRIS.

Following these experimental and theoretical results, we use the TWT amplifier for microwave generation to optimize the microwave frequency for the plasma chamber of the ion source. The frequency range is 17.2~18.4 GHz, and the maximum power is ~700 W. Figure 5 shows a schematic drawing of the RF injection system from the TWT to the plasma chamber. The rectangular waveguide is directly connected to the plasma chamber. We also use an E-H tuner to minimize the reflected power.

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