Design of the 14.5 GHz ECR Ion Source for the 100 MeV Superconductor Cyclotron

Byung-Hoon Oh, Sang-Ryul In, Kwang-Won Lee and Seong Ho Jeong
Korea Atomic Energy Research Institute 1045 Daedeok St., Yuseong-gu, Daejeon 305-353

1. Introduction

An ECR ion source is being developed as an intensive injection source of a 100 MeV superconductor cyclotron constructed newly in Korea.

ECR plasma is characterized with highly charged states of ions, which is come from its large population of high temperature electrons and good plasma confinement by a strong mirror magnetic field. To obtain a large intensity ion beam of highly charged states, the ECR wave should have a high frequency and a large power. A high frequency wave requires again a large magnetic field for the resonance.

In this paper, the general specifications of our ECR ion source, which is determined according to the performance requirements, are introduced, and some design details of the components comprising the ion source are described.

2. General specifications

In the past 10 years, leading ECR ion sources have used a 14.5 GHz frequency, but nowadays, 18 GHz ECR sources are widely constructed and operated, and even 28 GHz ECR sources are being developed. The sources using the frequencies higher than 18 GHz have to be equipped with superconducting magnets to provide required mirror magnetic fields. Although detailed requirements for desired ion beams of the injection source are not determined yet, a tentative goal of the ECR source may be a few tens of μA for C^{+6} beams. Considering the fact that this is a powerful ECR ion source developed for the first time in Korea, the 14.5 GHz frequency is chosen, because it does not need superconducting magnets, and is expected to result in a good performance of the source if designed carefully.

Table 1 summarizes the requirements for the ECR ion source at a physical aspect, and Table 2 introduces the specifications of the source.

Table 1. Physical requirements for the ECR ion source.

Parameters	Requirements
M/Q	12/6
$(I.P)_{C+6}$	490 eV
$(T_e)_{opt}$	2.5 keV
$n_e\tau_i$	7×10^9 cm^3/s
$(n_e)_{max}$	2.5×10^{12} /cm^3
$(\tau_i)_{min}$	2.8 ms
$(n_eT_e)_{min}V_{plasma}$	0.1 J
$(n_eT_e)_{max}V_{plasma}$	2 J
$(P_{RF})_{min}$	100 W (when τ_E~1 ms)
$(P_{RF})_{max}$	2 kW (when τ_E~1 ms)

Table 2. Specifications of the ECR ion source

Parameters	EM-type	PM-type
Frequency	14.5 GHz	14.5 GHz
Power	2 kW	1.2 kW
B_{ECR}	0.52 T	0.52 T
B_{inj}	1.7 T	1.15 T
B_{ext}	1.1 T	0.9 T
B_{rmax}	1 T	1 T
R_{inj}	3.3	2.2
LECR	90 mm	50 mm
V_{plasma}	85 cm^3	25 cm^3
$ID_{chambe}r$	70 mm	40 mm
$L_{chamber}$	300 mm	150 mm
D_{ext}	8 mm	8 mm
V_{ext}	20 kV	20 kV
I_{C+6}	75 eμA	35 eμA

The ECR ion source is composed of a plasma chamber made of aluminum, RF system, axial-field magnet assembly, Hexapole magnet assembly, beam extraction-acceleration assembly, and several auxiliary devices for delivering high voltage, vacuum pumping, gas fueling, and cooling. Some diagnostics are also installed.

Table 3. Construction of the ECR ion source.

Items	Remarks
1. Plasma Chamber	Aluminum
2. Solenoid Magnet- Axial field	(Coil)§/NdFeB
3. Hexapole Magnet- Radial field	NdFeB
4. RF Source	Klystron
Wave Guide	
RF Window	
5. Extraction Assembly	2 electrodes
6. Bias Disk	Movable
7. Magnet P/S	(85 kW) §
8. HV P/S	50 kV, 1 kW
9. Vacuum Pump	2 × 30 L/s TMP
10. Vacuum Gauge	CIG
11. Gas (main + mix)	VLV
12. Cooling	(100 kW) §/3 kW
13. Diagnostics	

§ ( ) is for only EM-type.

2. Magnetic Field Design

The magnetic field of the ECR ion source is composed of an axial field and a radial field. The most of the radial field of the 14.5 GHz source is made by permanent magnets, but the axial field is made by permanent magnets of solenoid coils depending on the main application of the ion source. Two possibilities are considered in the design.

(1) ECRIS with All Permanent Magnets

The target of the magnetic field strength with all permanent magnet is 1.1 Tesla at the center of the wave entrance position and 0.9 Tesla at the center of the beam exit position. Fig. 1 shows the calculated axial magnetic field along the center axis of the beam extraction direction. The mirror ratio could be controlled by two trim solenoid magnets.

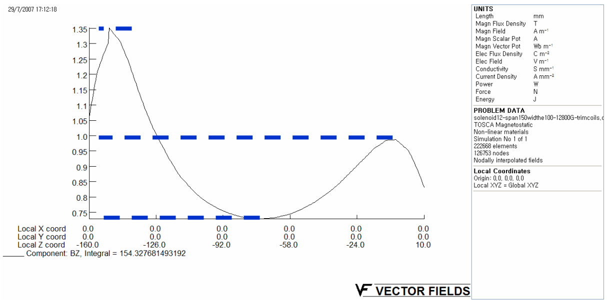

Fig. 1 Magnetid field configualtion with all permanent magnets.

(2) ECRIS with Solenoid Coils

The target of the magnetic field strength with solenoid coils for the axial field is 1.7 Tesla at the center of the wave entrance position and 1.1 Tesla. Fig. 2 shows the calculated axial magnetic field along the center axis. The needed fields could be earned with two solenoid coils, which has the dimension of 450 mm outer diameter, 200 mm inner diameter and 250 mm length, with a current density of 7 A/mm^2, and carefully designed yoke structure. The mirror ratio could be controlled by a trim solenoid coil.

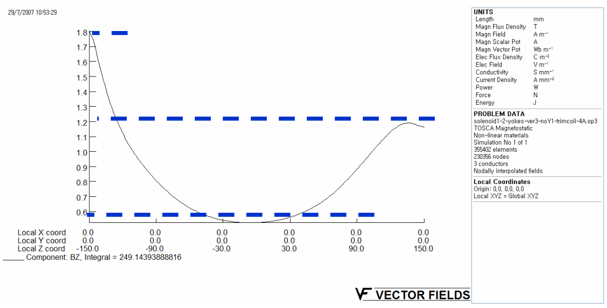

Fig. 2 Magnetid field configualtion with solenoid coils for the axil field.

3. Beam Extraction Systems

The detailed extraction geometry and extraction filed are optimized by the help of IGUN code. Fig. 3 shows an example of the beam extraction results with various species such as from O^{+} to O^{7+} and from Ar^{6+} to Ar^{16+}. Well defined beam could be extracted by changing the extraction voltage and the gap length even without an electron reflection electrode. The electrode of the beam extraction-acceleration assembly is made as a movable type to control easily the beam divergence of the ions with many different masses and charge states.

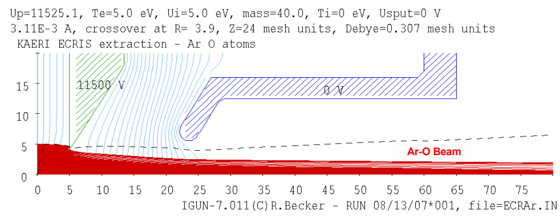

Fig. 3 Beam extraction results with IGUN code.

5. Other Systems

The plasma chamber is a cylinder with cooling holes in the chamber wall, which will effectively suppress a local temperature rise of Nd magnets, otherwise the depletion of the magnetic field enhances the particle loss which again raise the temperature. Krystron(2kW) is used as a 14.0 – 14.5 GHz microwave generator, and the wave is injected axially.

6. Summary

An ECR ion source which is going to be used in the 100 MeV superconductor cyclotron has been designed. Two types of the magnetic field configurations are considered; one with all permanent magnets for the axial and radial fields, and the other with solenoid coils for the axial field. Also to guarantee several operational parameters, movable electrode and trim coils are considered in the design.

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