Design of a Compact ECR Ion Source with Ku Band *

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Abstract

The electron cyclotron resonance (ECR) ion sources are increasingly popular for producing highly charged ions. With worldwide proposals to build the Isotope Seperator On-Line (ISOL) facility being at hand, it becomes important to design a high efficiency ion source as a charge breeder for the secondary beam. A novel type of ECR ion source based on a flat magnetic field configuration has been proposed by Alton et al. [1, 2] This source provides a large, on-axis electron cyclotron resonance region, "ECR-volume". Due to a larger ECR zone, absorptivity of microwave power into plasma is much increased, thereby electron becomes so hot. And hot electron population of the plasma could result in higher charge states and higher beam intensity. Two sloenoids are used to produce axial mirror magnetic field. Twelve permanent magnets (NdFeB) are designed for confining the hot electrons in the radial direction. Moreover, specially designed iron yokes are added to create the flat central field region. The single injected microwave frequency is tunable in the range of 6.45 to 14 GHz covering the range of the Ku band. We shall present the design report concerning the field mapping obtained by POISSON and OPERA-3D together with and mechanical design.

1 INTRODUCTION

ECR ion source (ECRIS) was first proposed by R. Geller and H. Postma in late 1960's for fusion plasma studies. Since then, ECRIS has improved continuously in many fields of sience. Specially, The ECRIS is a very efficient tool providing highly charged ions for atomic and nuclear research, material science, and surface physics. The most important factors in ECRIS are the electron density, the electron temperature and the confinement time of plasma to produce highly charged ions. In a conventional ECRIS, the magnetic mirror makes a parabolic shaped field and the ECR zones are ellipsoidal-shaped surfaces which occur when microwave frequencies have the same value with electron cyclotron frequencies. There have been various attempts to increase beam intensity and charge state. The multi-frequency heating has proved an effective way to increase both the number and width of the ECR zone [3]. Wall coating [4] in the inner wall of plasma chamber was attempted in order to supply more electrons. The afterglow effect drastically improved beam intensity by one order of magnitude through injection of a pulsed microwave [5]. Despite of these attempts, the only small fraction of the whole plasma still participates in the resonance of microwaves and electrons in this case. Therefore, electrons can be accelerated only in this ECR zone. In addition, because the size of ECR zone is smaller than that of plasma volume, that is, $n_e/n_0 < 1$ [6], it has a small ionization volume, and therefore, the absorptivity of microwave is limited by the size of ECR zone. To produce more highly charged ions, first of all, the ECRIS is preferred to have a larger ECR zone. The volume type ECRIS proposed by Alton et al. [1, 2] is a very efficient means for enlarging the size of ECR zone. In present work, we use two solenoid coils for mirror field and iron return yoke for producing flat magnetic field in the central region of plasma chamber. Simultaneously we tried to minimize the amount of electrons which are intended to escape into the wall of plasma chamber, with twelve NdFeB permanent magnets in a multicusp magnetic field.

2 MAGNETIC SYSTEM DESIGN

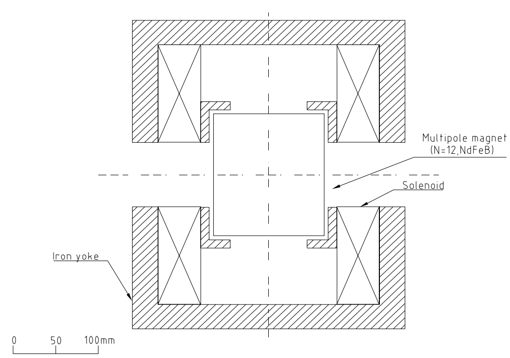

Figure 1: Schematic view of magnetic system

2.1 Axial mirror field

In this ECRIS, we use two solenoid coils (inner radius $40\ mm$, outer one $160\ mm$, thickness $50\ mm$) to make a variable mirror magnetic field. The schematic view of magnetic system is shown in Fig.1. There is also an added $30\ mm$-thick return yoke in order to reduce power consumption and to produce a flat magnetic field inside the plasma chamber. The ratio of a maximum and a minimum magnetic field, mirror ratio, is $B_{max}/B_{min} \sim 2.4$ at $14\ GHz$ microwave. This large ECR volume is able to heat more electrons distributed throughout the whole area of plasma. And the population of hot electrons can produce

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more highly charged ions. Fig. 2 and Fig. 3 are the results of simulation using by the POISSON code [7].

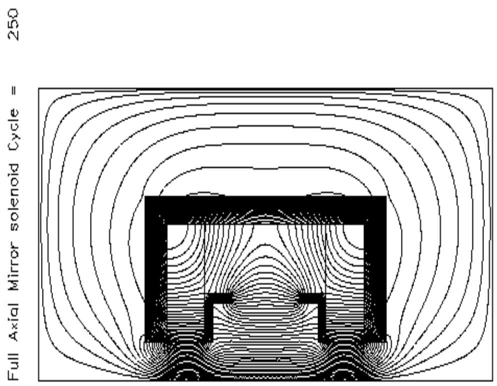

Figure 2: Simulated result of the full axial mirror magnetic field distribution

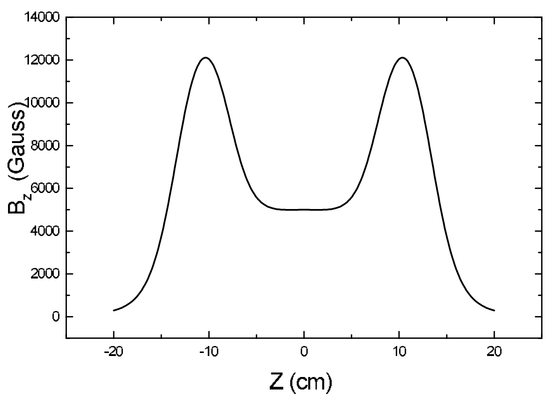

Figure 3: Simulated result of axial mirror magnetic field along the symmetric axis

2.2 Radial magnetic field

Twelve permanent magnets (NdFeB) are employed to make the volume type realized, instead of the hexapole field, which is composed of six permanent magnets usually used in conventional ECRIS for plasma confinement along the radial direction. As is well known, the magnetic field along the radial direction is expressed $B_r = B_0 r^{N/2-1}$ [8]. Thus, the magnetic field can be produced flat as the number of magnets is increased. Then, the ECR volume along the radial direction gets easily attained. The magnets comprise twelve NdFeB-its horizontal and vertical size are $14\ mm$ and $30\ mm$, respectively. Fig. 4 and 5 is a three dimensional field distribution and cross-sectional field obtained by OPERA-3D[9], respectively.

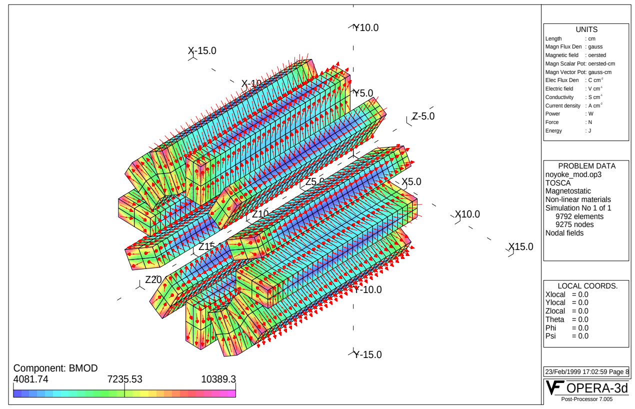

Figure 4: Magnetic field distribution of radial multicusp magnets

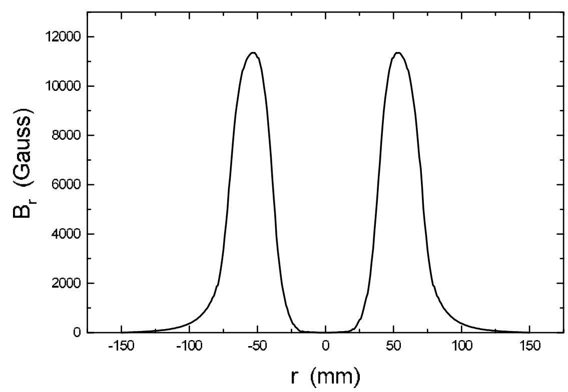

Figure 5: B_r along the radial direction

3 MICROWAVE SYSTEM

The microwave system is designed to be variable in the range of 6.45 to $14\ GHz$ with a single injection port along the axial direction. With the present magnetic system shown in Fig. 1, the flat ECR region can be maintained for this range of microwave frequency. Fig. 6 shows axial magnetic fields corresponding to the microwave frequenies, where the relation that $\omega_{ce} = eB/m = \omega_{rf}$ leads to a simple expression as $f_{ce} = 2.8B_{ecr}\ (GHz)$ with B_{ecr} in units of kilogauss.

4 DISCUSSION

To extend the size of the ECR zone is a very efficient method for producing highly charged ions. Multi-frequency heating, broadband frequency [2] and volume type ECRIS are used for this purpose. In future work, we will construct the volume type ECRIS which successfully worked out by Alton et al. [2] and Heinen et al. [10] In addition two solenoids are used for varying flat magnetic fields. In the present work, we carried out the mechanical

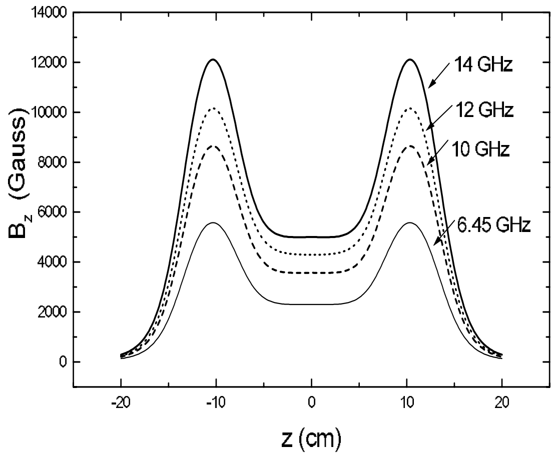

Figure 6: Various axial magnetic fields

design and simulated magnetic fields.

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