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Design of the compact permanent-magnet ECR ion source

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1. Introduction

The Electron Cyclotron Resonance Ion Sources (ECRIS) for multiply charged ion beams keep regularly improving and expanding since the pioneer time of R.Geller and his coworkers about twenty years age[1]. It has been widely utilized in a variety of research areas ranging from atomic and nuclear physics to material sciences. Because of the unique capability of producing highly charged ion beams, the ECR ion source has become increasingly popular in heavy-ion accelerators where the principle of acceleration sensitively depends on the charge-to-mass ratio (q=M) of the injected positive ion beam.

The potential usages of beam based research development is still developing and there are plenty of rooms to be part of it. On the basis of ECR ion source technology, we will explore possible applications in the field of plasma technology, radiation technology, plastic deformation, adding more and new functionality by implantation, MEMS applications, developing new generation mass analysis system, fast neutron radiography system, etc.

2. Design of ECR ion source

ECR ion sources can be classified into two different types; with electromagnets or with only permanent magnets. Advantages of all-permanent magnet type ECR ion source are simple power supply, simple cooling system, low cost of operation and compactness of total size. We plan to develop the 2.45GHz ECR ion source with all-permanent magnet. ECR ion source use two types of magnetic fields referred to as mirror and hexapole magnetic fields[2-7]. The mirror fields axially confine the ECR plasma while the hexapole fields radial confine it. A schematic view of the all-permanent magnet ECR ion source is presented in Fig.1. It consists of 3 kind of permanent magnet. Two ring magnets at side with inner radii of 40 mm, outer radii of 100 mm and thicknesses of 30 mm are used to make a mirror magnetic field. Hexapole magnet with inner radii of 30 mm, outer radii of 50 mm and thicknesses of 150 mm is used to make a radial magnetic field. Center ring magnet with inner radii of 80 mm, outer radii of 100 mm and thicknesses of 20 mm provides a flat magnetic field at the center region to make of "volume-type" ECR Ion Source. The magnetization of each permanent magnet is shown in Fig.1.

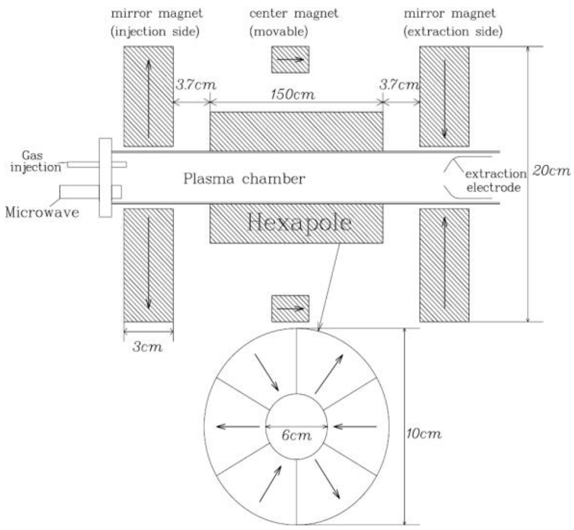

Fig. 1. Schematic view of Prototype of ECRIS at 2.45 GHz

Table I lists typical parameters of the KBSI-ECR compared with those of other all-permanent ECR. The KBSI-ECR has better mirror ratio (B_{ratio}) with low Radio Frequency (RF) as comparing.

Table I : Typical parameters of KBSI-ECR compared with those of other ECR.

	RF [GHz]	B_{max}[T] B_{min}[T]	B_{ratio} (B_{max}/B_{min})	Power [W]	HV [kV]
NANOGAN	10	0.8 0.34	2.24	100	25
NANOGAN2	14.5	0.88 0.373	1.70	200	19
TUNL	2.45	0.1 0.05	1.14	310	0.45
LAPECR2	14.5	1.28 0.43	2.47	450	25-30
LECR2	14.5	1.5 0.39	2.47	1100	25
KBSI-ECR	2.45	0.23 0.0875	2.63	1000	

3. Magntic Field Measurement

We measured magnetic field strengths(B_z) in every 5mm along the axial direction. A gauss meter was movable along the axial and radial direction by using a stepping-motor controller. Measured magnetic field distributions (symbols) are overlaid with an OPERA-3D simulation result (solid line) in Fig.2. The measured field distribution with the simulation geometry (triangles) is found to be slightly off the simulation result. It could be due to non-uniform magnetization of permanent magnets. Reducing the distance between two solenoid magnets makes the field distribution fit more with the design, as displayed by circles. It should be noted that the ECR zone of B_{min}=0.0875T is achieved over the length of 50mm. The maximum field (B_{max}) was measured to be 0.22T with the mirror ratio (B_{max}/B_{min}) of 2.5. We also measured the uniformity of axial magnetic fields along the radial direction. The axial field is found to be uniform over the radial volume to a few percent.

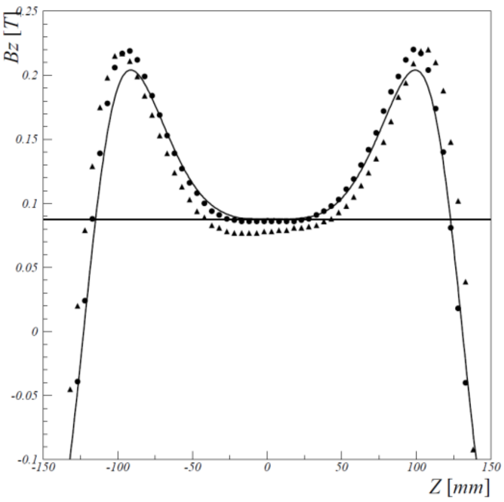

Fig.2. he measured field distribution (triangles) is compared with the OPERA-3D simulation result (solid line). Closed circles indicate the magnetic field distribution measured with a shorter distance between solenoid mirror magnets, which fits more with the simulation result.

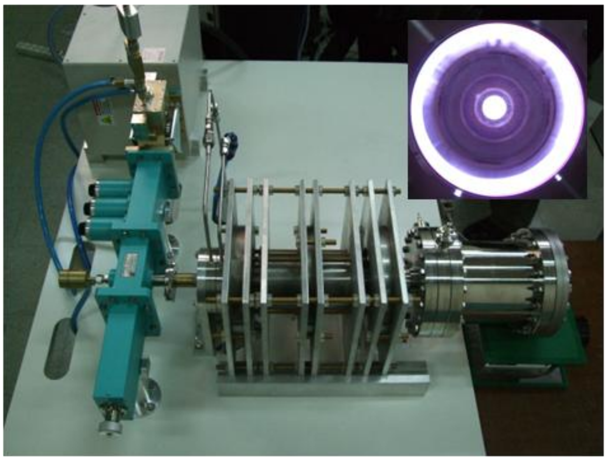

Fig.3.The figure shows 2.45GHz ECR ion source and small figure shows test result of plasma ignition.

Figure 3 shows All permanent-magnet ECR ion source at Korea Basic Science Institute(KBSI). It consists of 2.45GHz Microwave, permanent-magnets and plasma chamber. Specially, the microwave is injected by antenna from microwave generator to plasma chamber.

4. Conclusions

We performed magnetic field design of the “volume-type" ECR ion source in resonance with a microwave frequency of 2.45 GHz. The magnetic system in the present ECR ion source consists of two ring magnet for the mirror field, hexapole magnet for radial field and center magnet for flat-B field. We measured magnetic field and make the ECR ion source at 2.45GHz.

We plan to extract various heavy ions by using KBSI-ECR and accelerate these with Van de Graaff accelerator. Fig.4. shows the schematic view of radioactive ion beam line.

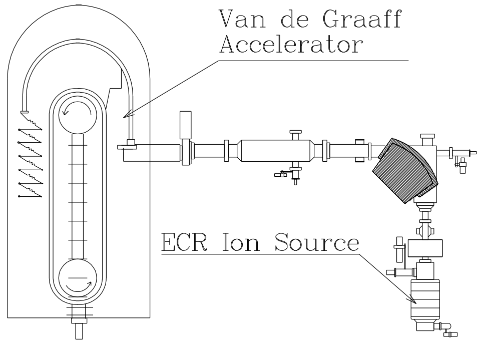

Fig.4. Schematic view of radioactive ion beam line with KBSI-ECR ion source and Van de Graaff Accelerator.

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