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Preliminary Design of Compact Permanent Magnet Electron Cyclotron Resonance Ion Source for Neutron Generators

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1. Introduction

Korea Atomic Energy Research (KAERI) is presently developing a high-yield (> 10^{10} neutrons per second) movable deuterium – deuterium (D–D) neutron generator for various applications. As a part of development of the D–D neutron generator, we chose electron cyclotron resonance (ECR) plasma ion source as the ion source for the neutron generator and preliminarily designed a compact permanent magnet ECR ion source. [1~3] This ECR ion source will provide high beam current of D^+ ion for an acceleration (200 kV) tube inside the neutron generator. In this article, current status of the ECR ion source development and preliminary design of the ion source is presented and discussed.

2. Design Requirements of Ion Source for Neutron Generators

For the successful development of the high-yield movable D–D neutron generator, the ion source should fulfill requirements, i.e., (1) high D^+ current at low pressures, (2) compactness, and (3) stable long term operation.

After calculations on fusion reaction rate we have confirmed that D^+ ion current of over 50 mA is needed to meet the design value of neutron yield rate. Assuming the Bohm condition, plasma density as a function of beam current of ion source was investigated as shown in Fig. 1.

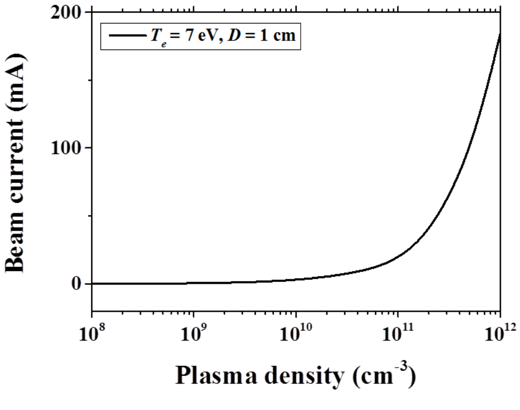

Fig. 1. The calculate plasma density as a function of ion source beam current. The diameter of a single hole of a plasma electrode and the electron temperature are assumed to be 1 cm and 7 eV, respectively. The deuteron fraction is set to 80%.

The graph shows that the required plasma density to achieve D^+ current of 50 mA is more than 3×10^{11} cm^{-3}. Since the ion source must be compact according to the second requirement, there is no room for a dedicated pump system of the ion source. This means that the ion source has to keep its pressure low. The ECR is one of the discharges which can provide high density plasma at low (sub-mtorr) pressures due to its electron heating favorable for the low-pressure condition. For this reason, we selected the ECR ion source equipped with permanent magnets. The small permanent magnets have an advantage over larger electromagnets for the compactness. They enable the neutron generator to be movable. We designed to use three neodymium iron boron (NdFeB) ring magnets for the permanent magnets.

For ensuring beam reliability and longevity of the ion source, cooling of the ECR ion source chamber heated by plasma itself and also backstream electrons is necessary. We designed the ion source taking account into the cooling system.

3. Magnetic Field Configuration and Preliminary Design of the ECR Ion Source

High-density plasma can be generated by enhancing the electron heating or by reducing loss through magnetic confinement. For the design of the high-density ion source we cannot help putting more focus on the electron heating rather than the magnetic confinement because use of the permanent magnets where their spaces are so limited that this restricts the magnetic field intensity and the confinement, compared to that of the electromagnets.

Wave frequency and the magnetic field intensity corresponding to the ECR zone, B_{ECR}, were designed to be 2.45 GHz and 875 G. The magnetic field configuration with 3 NdFeB ring magnets to maximize heating by ECR and right hand polarized wave (R-wave) mechanism was investigated using OPERA3D (Cobham plc). According to S. Gammino *et al.*, [3] high-density plasma can be generated when the magnetic field configuration along the axis is almost flat and the magnetic flux density ranges between B_{ECR} and 1.3 B_{ECR}. This was applied to the design, and the optimum configuration of magnets with two iron yokes and its magnetic flux density distribution along the axis were obtained as displayed in Fig. 2 and Fig. 3, respectively.

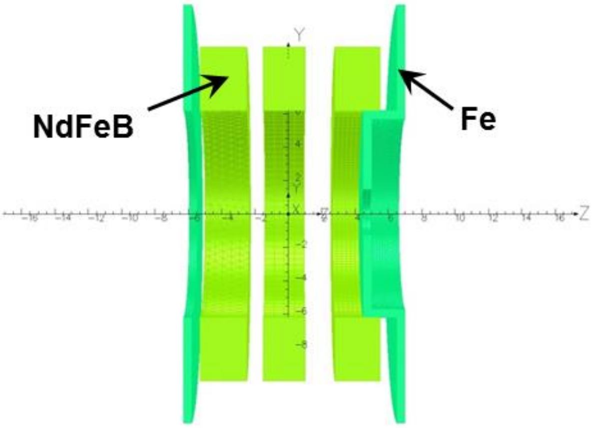

Fig. 2. The optimum configuration of magnets with two iron yokes.

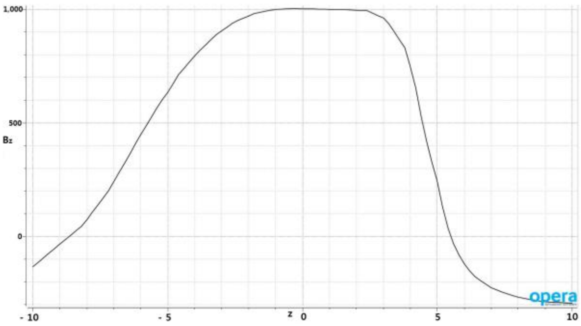

Fig. 3. The magnetic flux density distribution along the axis in the ECR ion source design. The rf window and the plasma electrode hole are located at z = -4.5 and 5.5 cm, respectively.

The ECR was designed to have a plasma chamber of 10 cm in inner diameter and 10 cm in inner length. The region where $B_{ECR} < B < 1.3\ B_{ECR}$ covers about 70% of the inner chamber length. Note that the iron yoke near the plasma electrode plays an important role in reducing the magnetic field at the plasma electrode to zero. This enables one to prevent extracted ions from being deflected by the magnetic field. We designed to keep the magnetic field distribution stiff at the position close to the plasma electrode.

Based on the optimum magnetic field configuration, the ECR ion source was designed as illustrated in Fig. 4.

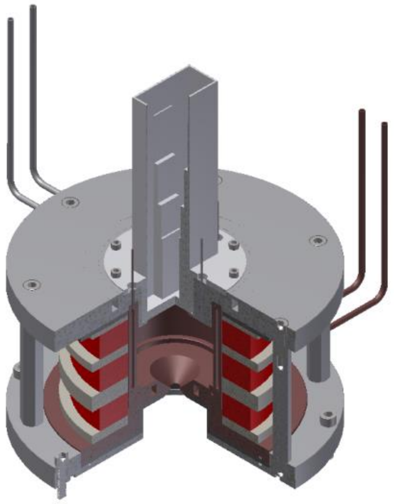

Fig. 4. The preliminary design of the ECR ion source for the neutron generator.

The ion source chamber and the plasma electrode were designed to be made of copper, and it includes a water-cooling jacket for protection of the bodies and magnets from heat by the plasma ion irradiation. A quartz plate together with a boron nitride (BN) plate is used as the RF window. The BN plate prevents the RF window from thermal shock damage by backstream electrons. In order to improve the coupling between microwave fields to the plasma, a double ridged waveguide was introduced in the design. More details on the design will be reported.

4. Summary

The investigation of the optimum magnetic field configuration for obtaining high-density plasma and preliminary design of the ECR ion source for neutron generators was completed. Based on the design, the ion source is being fabricated at present. The plasma density and beam measurement will be carried out soon.

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