Performance of a Multi-purpose Compact Fast Neutron Generator

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1. Introduction

There is a Multi-purpose Compact Fast Neutron Generator (MCFNG) in the Korea Atomic Energy Research Institute (KAERI). The MCFNG device was developed initially by the Plasma and Ion Source Technology Group at Lawrence Berkeley National Laboratory (LBNL) for material analysis group at the KAERI for the purposes of neutron activation analysis (NAA) and prompt gamma activation analysis (PGAA) applications [1]. The NAA/PGAA system of MCFNG device equipped with a compact D-D neutron generator was developed for fast detection of explosives and chemical warfare agents in the KAERI [2]. The MCFNG device was built with a fully high-voltage shielded and axially assembled D-D neutron generator including a radio frequency (RF)-driven ion source. The ion beam current of MCFNG was determined as a function of accelerating voltage at various RF powers. The performance of MCFNG device was investigated by studying the characteristics of hydrogen discharge and ion beam extraction prior to the deuterium ion beam irradiation on the TiD drive-in Cu-target.

2. Structure of Compact Fast Neutron Generator

Fast neutrons are produced by the D-D nuclear fusion reactions in an axially assembled D-D neutron generator (called as the MCFNG) composed of three main components: a radio frequency (RF)-driven ion source with an external antenna for the ICP (inductively coupled plasma) generation (a maximum RF power of 2.0 kW), an electrostatic D^+-ion beam accelerator column (a maximum beam power of 100 kV/10 mA through a single hole of 4 mm diameter), and an explosively bonded titanium drive-in copper target including a water-cooled path. The schematic layout of D-D neutron generator is shown in Fig. 1.

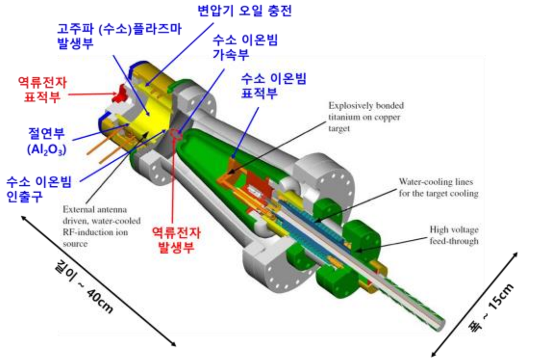

Fig. 1. Detailed structure of the D-D neutron generator.

Atomic and molecular deuterium (or hydrogen) ions are produced by an RF discharge in the MCFNG device. The ions are accelerated on the titanium target through a single gap accelerator column to produce a monoenergetic 2.5 MeV fast neutrons by the reaction shown in the following equation:

$$ {}_1^2H + {}_1^2H \rightarrow {}_2^3He + {}_0^1n \; Q\text{-value} = 3.27\,\mathrm{MeV} $$

The main body of MCFNG device placed in the center of a radiation shield/moderator structure consisting of three layers of 300 mm-thick polyethylene, 7 mm-thick polyethylene doped with 9% boron, and 1.5 mm-thick lead sheet in order to shield both neutrons and secondary gamma-rays, as shown in Fig. 2.

Fig. 2. Assembly of KAERI MCFNG system.

3. Results of Hydrogen Ion Beam Extraction

The performance of MCFNG device was investigated by studying the characteristics of hydrogen discharge and ion beam extraction prior to the deuterium ion beam extraction and then the fast neutron production.

2.1 Expected Hydrogen Ion Beam

Extractable hydrogen ion beams of the MCFNG device are shown in Fig. 3. A maximum extractable hydrogen ion beam current should be increased with the effect of particle mass (a factor of root 2) compared to the deuterium ion beam current of 10 mA.

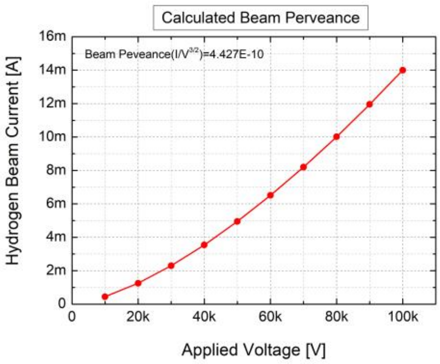

Fig. 3. Extractable beam currents of hydrogen ions for the ICP-discharge ion source of MCFNG device.

2.2 Simulation of Ion Beam Trajectory

Before the test of hydrogen beam extraction, the ion beam trajectories of accelerator column are simulated for the ion source of MCFNG device by using the IGUN 2D code. The IGUN numerical simulation has been extensively utilized for the design of ion source accelerator. From the IGUN simulation, it was found that the trajectories of hydrogen ion beam was focused well in the ion source accelerator with a beam current of 15 mA and a beam voltage of 100 kV, as shown in Fig, 4.

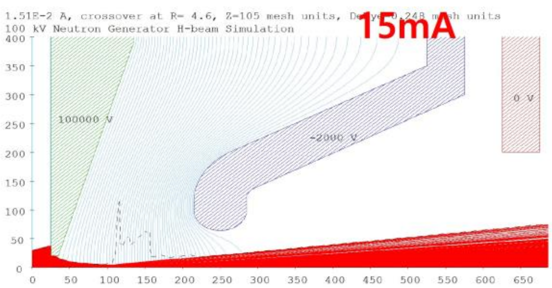

Fig. 4. Calculated hydrogen ion beam trajectories of ion source accelerator with a beam current of 15 mA and a beam voltage of 100 kV.

2.3 Discharge of ICP Ion Source

For ICP-discharge of the ion source with a maximum RF power of 2 kW, the beamline vacuum chamber is pumped through a TMP (turbo molecular pump) with a pumping speed of 700 LPS. Hydrogen gases are injected on the ICP generator through an MFC (mass flow controller) instruments (a maximum flow rate of 5 sccm). A base pressure of NG (neutron generator) vacuum enclosure (chamber) iss ~E-7 mbar, and the operational region of gas injection is shown in Fig. 5. The operation region of hydrogen gas pressures are fixed 2~5E-3 mbar to minimized the high voltage breakdowns inside the beam accelerator column.

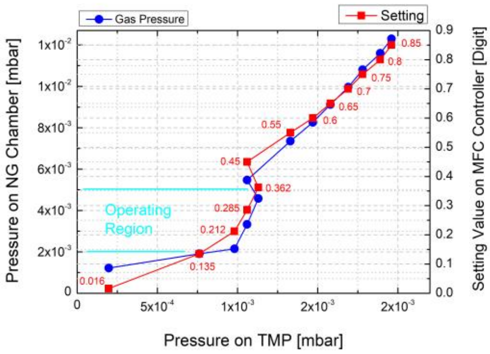

Fig. 5. Operating region of hydrogen gas injection through an MFC controller for ICP-discharge of ion source in the MCFNG device.

2.4 Extraction of Hydrogen Ion Bs

The extracted hydrogen beams of MCFNG device was tested initially up to 120 kV/5 mA by Plasma and Ion Source Technology Group at LBNL [1]. The extracted hydrogen beam currents as a function of accelerator voltage is plotted in Fig. 6.

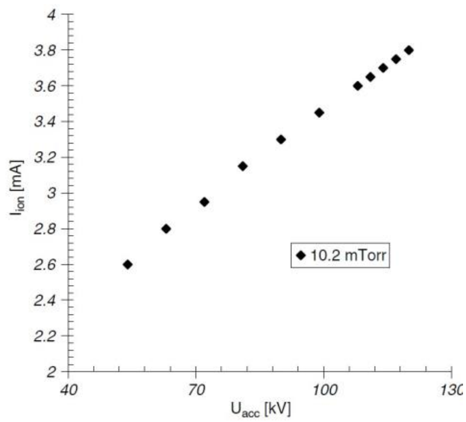

Fig. 6. Extracted hydrogen beam currents from the MCFNG device with an extraction aperture diameter of 4 mm and an RF power of < 2 kW (Predicted D–D neutron yield is > 5E8 n/s).

The extracted hydrogen ion beams at the KAERI will be introduced finally in the presentation to compare the original beam extraction results obtained from the LBNL.

3. Conclusions

The performance of a multi-purpose compact fast neutron generator (MCFNG) was investigated at the Korea Atomic Energy Research Institute (KAERI). Stable operation regions of RF-discharge and hydrogen ion beam extraction were developed for the MCFNG device. The fast neutron generation of MCFNG device will be proven by D-D reactions with the deuterium ion beam extractions, afterwards.

REFERENCES

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