Design and Experiment of a Cylindrical Neutron Generator

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1. Introduction

Various types of plasma sources have been made and tested at the Ion Source Group in Seoul National University. Ion sources based on helicon plasma—one of the most efficient rf-driven plasmas with magnetic field—have successfully demonstrated that the helicon plasma ion sources are suitable for generating high neutron yield because they can generate high-density plasmas with high monatomic fraction. For instance, hydrogen ion beams with high monatomic fraction of 94 % were measured with a compact helicon ion source [1]. Also, with diode extraction system, the ion beam current density up to 175 mA/cm^2 was obtained [2]. Recently, hydrogen ion beams of energy of 34 keV and current of 50 mA were successfully extracted using an upgraded triode extraction system.

A beam-target D-D neutron facility has been set-up and tested. Helicon ion source with diode extraction system was adopted as an ion source for the neutron generator. Various targets were prepared to occlude deuterium ions within them and generate neutrons through the D-D fusion reactions. Neutron yield of 6.5x10^7 n/s was achieved with an ion beam current of 4.0 mA and beam energy of 88.0 keV in CW mode [3].

In parallel, a cylindrical neutron generator which has a radially-convergent ion beam extraction configuration was proposed and has been developed. Cylindrical-type sources can easily increase beam currents by increasing the length of extraction slits. Moreover, the radially-convergent configuration makes neutrons to be generated at the focused region, i.e., center of the machine. Hence, samples located inside the central target can be irradiated with high neutron dose so that the activation time can be reduced. In this paper, the configuration the cylindrical neutron generator and the experimental results of beam extraction are presented.

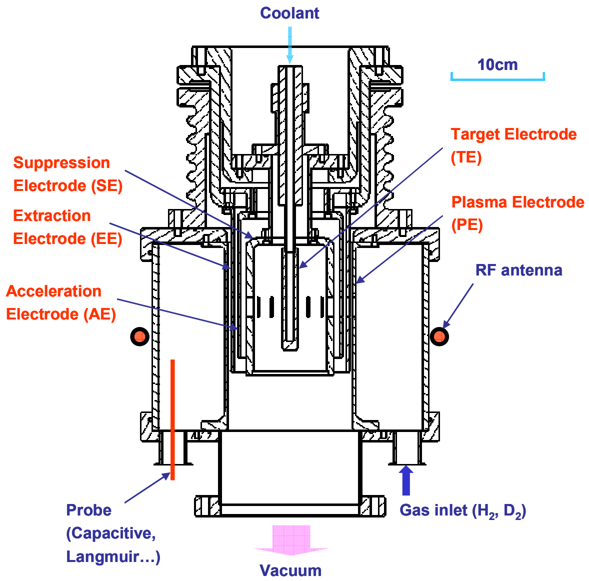

Fig. 1. Schematic diagram of cylindrical neutron generator.

2. Design of Cylindrical Neutron Generator

In radially-convergent extraction configuration, source plasmas are located outside of beam extraction systems such as plasma electrode, extraction electrode, target electrode, and so on. The plasmas are generated within a cylindrical quartz tube of 295 mm in diameter and 200 mm in length through induction heating by a single-turn loop antenna located outside the tube. Radio-frequency power of 13.56 MHz is delivered to the antenna to ignite and sustain the discharge.

For the extraction and acceleration of ion beams from the plasma, tetrode extraction system was adopted as shown in Fig. 1. The ion beams are extracted from the plasma through slits by low extraction voltage applied to an extraction electrode (EE). The slit of a plasma electrode (PE) is 2 mm wide and 20 mm long, and twelve slits are fabricated around the electrode. The extracted ions are accelerated radially inward by high voltages applied to an acceleration electrode (AE) and target electrode (TE). To suppress secondary electrons from the surface of the target electrode, a suppression electrode (SE) is biased with a slightly negative voltage with respect to the potential of the target electrode. To relieve thermal loadings of the target electrode by ion impact, distilled water is supplied inside the target. Various jigs were used to align the slits as well as the center of electrodes. Alignment was examined by observing the beam trajectories when the target electrode was got rid of. Figure 2 shows the picture of the beam trajectories which was taken at the bottom of the

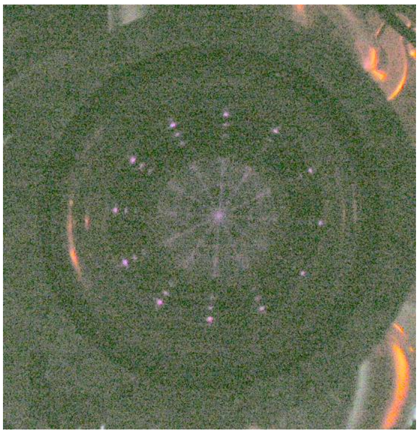

Fig. 2. Picture of ion beam trajectories (bottom view).

neutron generator.

3. Hydrogen Ion Beam Extraction

Ion beam extraction experiments were carried out in low-density hydrogen plasma. Figure 3 shows the beam current measured at the target electrode as a function of beam energy. In this experiment, hydrogen plasma was generated by rf power of 600 W, which is too low to obtain high-density plasma. The plasma density was estimated as low as 1×10^{10} cm^{-3}. The pressure in the plasma generation region was fixed at 6.5 mTorr and the pressure in the beam extraction region was measured to be 1.5 mTorr. The extraction voltage (voltage of EE in Fig. 1) and acceleration voltage (voltage of AE in Fig. 1) were fixed at -3 kV and -10 kV, respectively. Then, the currents flowing into the target electrode were measured as the energy of ion beams increases with higher target voltages (voltage of TE in Fig. 1) in negative sense. During the experiments, the suppression voltage (voltage of SE in Fig. 1) was always negatively biased by 1 kV with respect to the target voltage in order to suppress the secondary electrons ejected from the target surface by ion impact. Hydrogen ion beams with current of 1 mA at the energy of 25 keV were achieved in this experiment.

It is noted from Fig. 3 that the loss current always exceeds the target current. The loss current is decreased with increasing beam energy or target voltage, but still higher than the target current. Here, the current losses through the other electrodes were measured to be negligibly small. Large loss through the suppression electrode is considered to be due to bad design of beam optics. As shown in Fig. 1, since the thickness of the suppression electrode is much thicker than other electrodes, ion losses through it are much larger than those through other electrodes. Therefore, the improvements of beam optics, especially for the suppression electrode, are required in order to increase the target current. Reducing the diameter and thickness of the suppression electrode while enlarging the width of the slits is expected to increase the maximum target voltage (beam energy) as well as the target currents since the electric field strength between acceleration electrode and suppression electrode can be reduced by increasing the gap distance. Furthermore, the increase of plasma density by increasing rf power can provide higher beam currents.

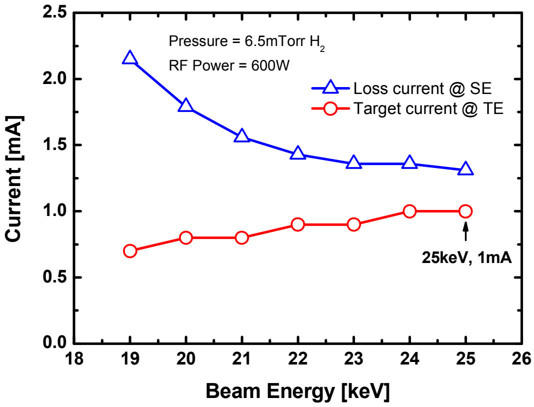

Fig. 3. Beam currents measured at target electrode (circle) and suppression electrode (triangle) with increasing beam energy.

4. Conclusion

A novel neutron generator with cylindrical configuration was made and tested. Ion beam extraction experiments were carried out with low-density plasma. Hydrogen ion beams with energy of 25 keV and current of 1 mA was extracted with plasma generated by rf power of 600 W and pressure of 6.5 mTorr. Improvements of the electrode structure are now progressing to increase beam current and energy for higher neutron generation yield.

ACKNOWLEDGMENTS

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REFERENCES

[1] H. D. Jung, M. J. Park, S. H. Kim, and Y. S. Hwang, “Development of a compact helicon ion source for neutron generator,” Rev. Sci. Instrum., vol. 75, pp. 1878-1880, May 2004.

[2] M. J. Park, A Study on a Compact Hydrogen Ion Source using Helicon Plasma, Ph. D thesis, Seoul National University, 2005 (in Korean).

[3] I. J. Kim et al., “Development of a D-D neutron generator and investigation on the characteristics of neutron generation,” 52nd Annual Radiobioassay & Radiochemical Measurements Conference, Chicago, USA, October 2006.