A compact neutron source by a high voltage ring cathode discharge

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1. Introduction

The neutron is one of elementary particles, which constructs with an atomic nucleus. It has a capacity of the very high transmittance of materials, because the neutron has no net electric charge. In addition, the neutron has a high reactiveness with light elements because the mass of the neutron is almost same as that of the hydrogen nucleus. From above reasons, the neutron beam is so effective tool for wide range of application field of the medical engineering, the industrial development or the nuclear engineering. For example, the non-destructive inspection by using a neutron beam becomes a detection system of the light element. The neutron radiography becomes an effective method, which is more sensitive than that of X-rays. The capture gamma ray and backscattering peculiar to the neutron are used a mine detection. Nuclear reaction between boron and the neutron will be applied to a cancer treatment (BNCT). However, such applications of the neutron beam is still under development. This is because that there is no simple, small-sized and low-coat neutron beam source. It is important for spread of neutron applications to develop a simple and compact neutron source with low cost and high controllability. The purpose of our research is to develop the compact and low-cost neutron source by a simple high voltage ring-shaped cathode discharge.

The inertial electrostatic confinement fusion (IECF) is one of concepts of the compact neutron source. This concept of electrostatically confining the electron was first conceived by Elmore[1] and by Hirsch[2,3]. After that many concepts of the inertial electrostatic confinement fusion by a spherical gridded cathode was advanced in the whole world[4-12]. Characteristics of the IECF are as follows. (1) Required device is relatively simple and compact. (2) Therefore, the portability is high. (3) The energy of radiated neutron is almost monochromatic, for example it is approximately 2.45 MeV by D-D nuclear reaction. (5) The cost of the device is relatively low. (4) Controllability of a neutron radiation by applied voltage and discharge current is high.

However, the structural disadvantage of these IECF neutron sources by using the gridded cathode also exist. For the occurrence of nuclear reaction between deuterons, it is necessary to apply a high voltage to the glow plasma. Since the gridded cathode is located inside the deuterium glow discharge plasma, the thermal damage of the gridded cathode is a serious problem in experiments of a general spherical gridded IECF. To solve such a thermal problem, we propose here a new type of the compact IECF neutron source by a high voltage ring-shaped cathode discharge. Figure 1 shows the schematic drawing of our compact neutron source. In our neutron source, the ring-shaped cathode is used for the convergence of deuterons. As the deuterium glow discharge plasma is generated by the high voltage ring-shaped cathode, the glow plasma cannot touch to the ring-shaped cathode. Hence, (5) Durability of the electrode becomes high in this compact neutron source. This is also a advantage of the compact and low-cost neutron source.

2. Experimental device and setup

Our compact neutron source mainly consists of the one cathode and two anodes as shown in Fig. 1. The ring cathode is located at the centre of the vacuum vessel. The cathode is exchangeable of different sizes of diameter and width. In this experiment, the ring-shaped cathode, which outside and inside diameters are ϕ=36 mm and ϕ=26 mm respectively, is used for the convergence of deuterons. The width of the ring-shaped cathode is 10 mm. Two conical anodes are also located at the both side of the ring cathode and are connected to the electrical earth. The turbo molecule pump creates the high vacuum field inside the vacuum

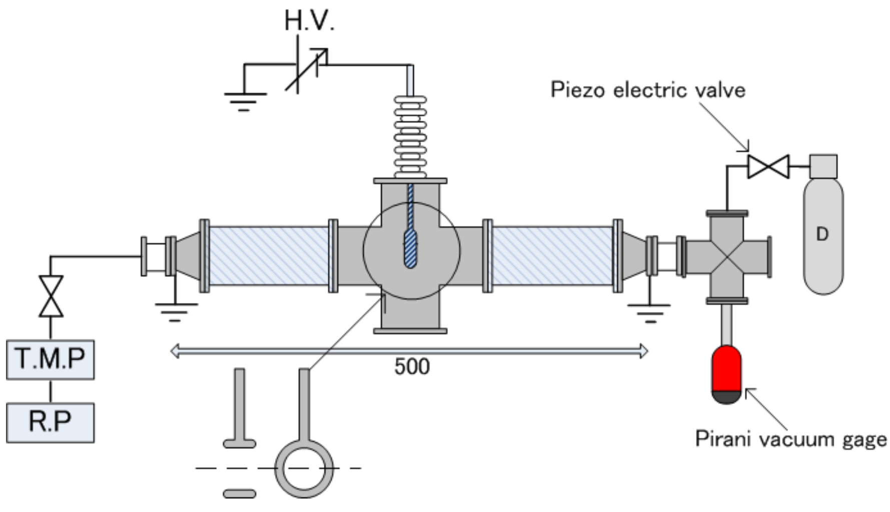

Figure 1: Schematic drawing of a compact neutron source by a high voltage ring-shaped cathode discharge. The ring-shaped cathode is located between two conical anodes.

vessel and the deuterium gas pressure is controlled by piezo electric valve. The degree of vacuum is measured with a Pirani and ionized vacuum gauges. In this experiments, the high voltage applies between the ring-shaped cathode and two anodes and glow discharge is formed around the ring-shaped cathode. In this experiment, maximum voltage and current of the power supply are -30kV and 10 mA respectively. The working gas is deuterium. Deuterons inside the glow discharge converges and accelerate on the centre of the ring-shaped cathode. Consequently, the nuclear reaction occurs under the condition of the high applied voltage to the ring-shaped cathode. The discharge voltage is measured by high voltage meter and the neutron emission is measured by the neutron counter.

3. Experimental results and discussions

Figure 2 shows the photograph of the deuterium discharge by a high voltage ring-shaped cathode discharge. The formation of a thin linear beam plasma discharge can be confirmed. We can also see the main plasma discharge does not touch to the cathode directly. Therefore, a loss of the charged particles of deuterium ions and electron can be reduced and the thermal damage of the cathode does not become a serious problem in this neutron source.

The nuclear reaction occurs in our experiment under the condition that applied voltage to the ring-shaped cathode exceeds approximately ten kilo voltages. Figure 3 shows dependence of the discharge current on the neutron generation at the applied voltage of -25 kV. We can see that the neutron production rate increases with increasing the discharge current. The neutron production rate reaches approximately 10^4 n/s under the condition of the discharge current 5 mA. It will be possible to increase the number of neutrons by the stabilization of the discharge at the more high voltage and high current experimental regions.

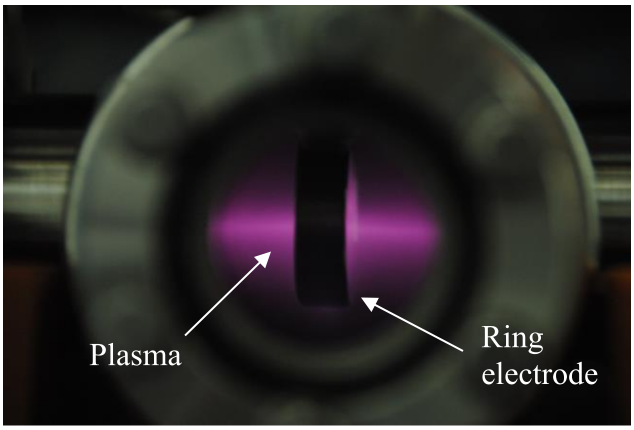

Figure 2: Photograph shows a high voltage ring cathode discharge. It is clear that the thin linear beam plasma discharge is formed by the electric potential distribution.

4. Conclusions

For the development of neutron sciences, a compact and low-cost neutron source by a ring-shaped cathode is proposed in this research. To product the neutron radiation by a D-D nuclear fusion reaction, the deuterium glow discharge was formed and deuterons were converged by a high voltage ring-shaped cathode. The neutron production rate is approximately 10^4 n/s under the condition that the cathode voltage is -25kV and discharge current is 5 mA. The neutron production rate will be able to increase with the stabilization of the discharge at the more high voltage and high current experiment.

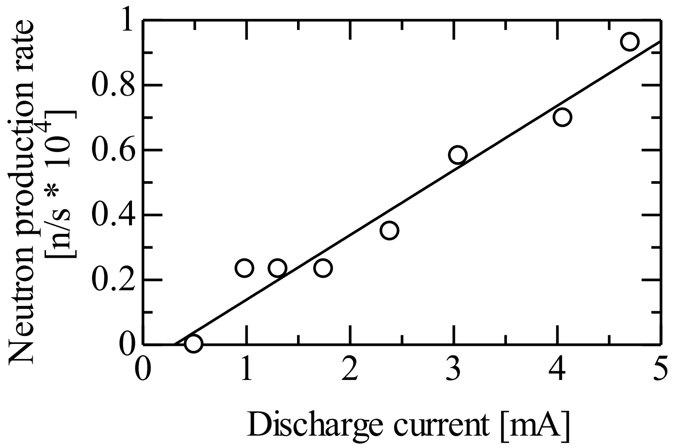

Figure 3: Dependence of the discharge current on the neutron production rate. The number of generated neutrons increases with increasing the discharge current.

References

[1] Physics of Fluids, 2, 239 (1959).

[2] Journal of Applied Physics, 38, 4522 (1967).

[3] Physics of Fluids, 11, 2486 (1968).

[4] AIP Conference Proceedings, 217, 67 (1991).

[5] IEEE Transaction on Plasma Science, 25, No. 4, 733 (1997).

[6] Review of Scientific Instruments, 71, 1210 (2000).

[7] Review of Scientific Instruments, 74, 975 (2003).

[8] Physical Review Letter, 95, 015003 (2005).

[9] Nuclear Instruments and Methods in Physics Research, B 261, 299 (2007).

[10] Physics of Plasmas, 22, 070701 (2015).

[11] Review of Scientific Instruments, 84, 033501 (2013).

[12] Physics of Plasmas, 22, 082701 (2015).