Development of Titanium Drive-in Solid Target for a Compact Fast Neutron Generator

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1. Introduction

A solid target developed for a compact fast neutron generator was fabricated with the OFHC-copper material including the water cooling structure to overcome the heatload by the injection of low energy deuterium ion beams (less than 100 keV/100 mA). The solid-target was shown in a shape of circular cone-type with a beam entrance diameter of 10 cm to reduce the heatload (per unit-area) of target. Beam-injected surface of the copper target was coated by a titanium layer with a thickness of 4~10 μm using the PVD plasma ion irradiation process of titanium to insert the injected deuterium ions into the target surface through the drive-in method. The coated thickness of titanium layer was evaluated for four samples of the coated debris by using the measurement of field emission-scanning electron microscope (FE-SEM).

The heatload performance of solid target was confirmed by the calculation of heatload distribution by using the commercial codes with an ion beam heat-power of 10.7 kW injected into the inner surface of beam target. A peak power density of 5.3 MW/m^2 was estimated with the cooling water flow. A maximum temperature of 73℃ (with an acceptable maximum temperature of 120℃) in the inner surface of target and a maximum cooling water temperature of 52℃ were also evaluated by the calculating result of commercial codes with a maximum flow-rate of 2.4 m/s at the entrance stage of cooling water.

2. Compact Fast Neutron Generator

A test facility of compact fast neutron generator was constructed in the KAERI, as shown in Figure 1. Main components of the test facility consist of a microwave wave power, a waveguide, an auto-matcher, a high-voltage DC breaker, an ECR plasma generator, a beam accelerator column, a beam transport/diagnostics section, and a titanium drive-in solid target. There is no neutron shielding structure in the test facility, until this time. Thus, hydrogen ion beams (a maximum beam power of 100 keV/100 mA) are extracted initially from the ion source and then irradiated on the surface of titanium drive-in solid target.

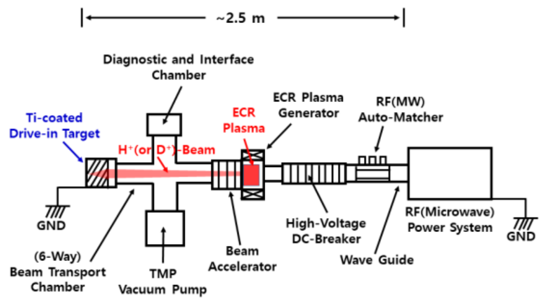


Fig. 1. Schematic structure of the test facility for a compact fast neutron generator.

2.1 ECR Ion Source

An ion source is used for the generation of high-density plasma with hydrogen (and/or deuterium) gases and to extract the positive ion particles from the plasma generator through the acceleration of ion beams. The ion source is composed of the ECR (electron cyclotron resonance with a frequency of 2.45 GHz) plasma generator and the ion beam accelerator, as shown in Fig. 2 [1, 2].

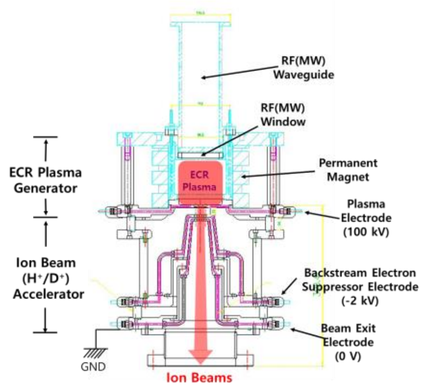


Fig. 2. Schematic structure of the ECR ion source.

2.2 Titanium Drive-in Solid Target

There are many structures of solid-target, depending on the neutron generation capability of neutron facility, for the production of fast neutrons in the compact fast neutron generators. The deuterium ions are generated in the plasma generator, and then the deuterium ion beams are accelerated and inserted on the titanium-coated surface of solid-target through the drive-in method to produce the fast neutrons (an energy of 2.45 MeV) through a D-D nuclear reaction [3-8]. The developed solid-target includes the water-cooled structure to overcome the heatload from the collision of deuterium ion beams on the surface of solid-target.

2.2.1 Simulation of SRIM Code

For the determination of titanium-coated thickness in the solid-target, it is necessary to use the SRIM code simulation [9, 10]. A SRIM-2008 code (2-D simulation) was used for the calculation of titanium-coated thickness. The injected depth of deuterium ion beams on the titanium target with a beam energy of 100 keV was less than 1.1 μm, as shown in Fig. 3. Therefore, the thickness of titanium coating on the solid-target can be determined about 10 μm considering the long-time operation of compact fast neutron generator.

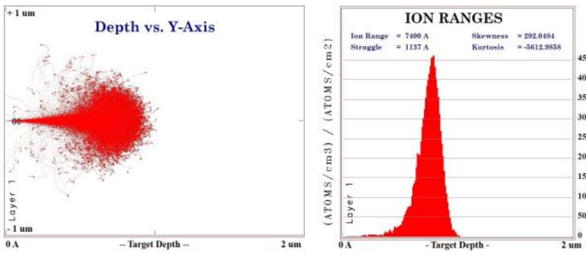


Fig. 3. Calculation results for the injected depth of deuterium ion particles inside the titanium layer by the simulation of SRIM code.

2.2.2 Design of Solid-Target

The water-cooled titanium-copper solid-target of compact fast neutron generator is composed of a beam target, a target supporter, a cooling water path, and a thermocouple hole, as shown in Fig. 4. Before the deuterium ion beam irradiation on the solid-target, the thermo-hydro-dynamic properties of headload performance were evaluated with an injected beam power of 10 kW by using the commercial codes.

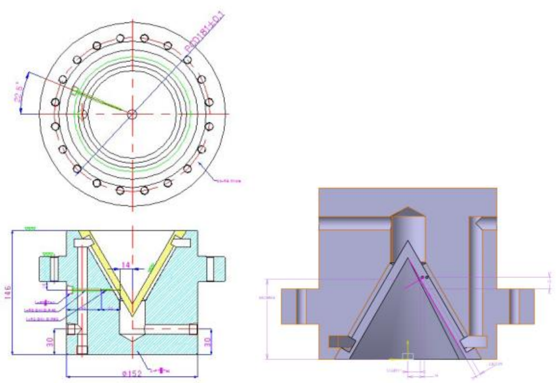


Fig. 4. Designed structures of water-cooled solid-target with a beam target, a target supporter, and a thermocouple hole.

The heatload properties of water-cooled solid-target were estimated with an injected deuterium beam power of 10 kW by using the commercial codes (CATIA P3 V5R20, ICEM CFD, CFX 17.0) under the following processes:

- CATIA P3 V5R20: Geometry Design
- ICEM CFD: Element Mesh Generation
- CFX 17.0: Thermo-hydro-dynamic Analysis

The calculated results of solid-target are shown in Fig. 5. For the deuterium ion beam irradiation of 10.7 kW, the maximum temperature of target surface is 73℃.

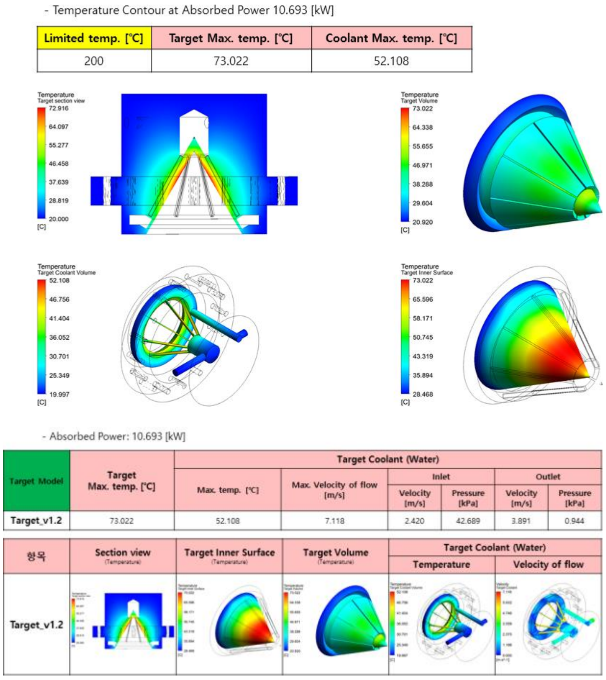
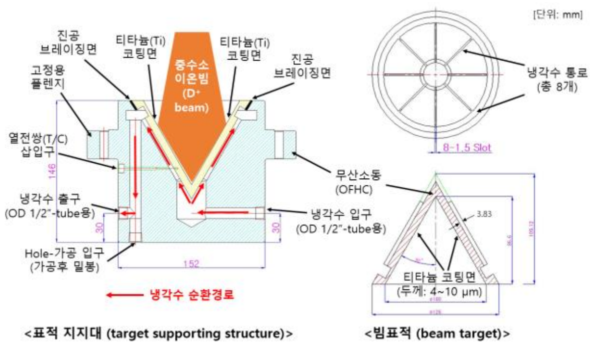


Fig. 5. Calculation results of solid-target for the heatload characteristics.

For the case of maximum water flow rates with 2.4 m/s (42.6 kPa) and 3.8 m/s (0.9 kPa) at the inlet and outlet positions of solid-target, respectively, a maximum temperature of target surface was 73℃, and a maximum temperature of cooling water was 52℃.

2.2.3 Fabrication of Solid-Target

The fabricated and assembled water-cooled solid-target is shown in Fig. 6, including a thermocouple hole.



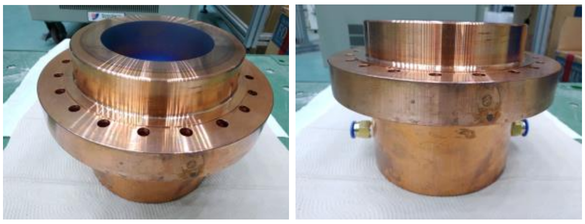
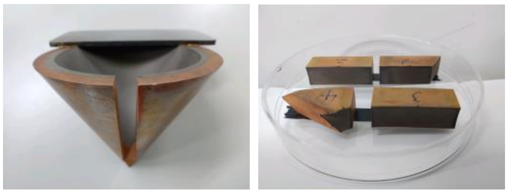


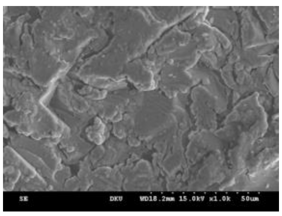
Fig. 6. The structures of fabricated and assembled water-cooled solid-target.

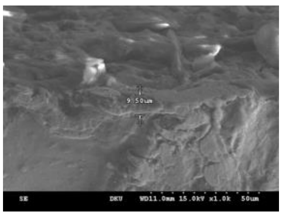
The titanium layer of approximately 10 μm was coated on the surface of deuterium beam injection by using the PVD (physical vapor deposition) process with the method of plasma ion irradiation technology, as shown in Fig. 7. The thickness of coated layer was measured by the FE-SEM (field emission-scanning electron microscope), as shown in Fig. 8, and estimated previously with four samples of titanium-coated layer before the fabrication of solid-target.

Fig. 7. A photo of titanium coated beam target.

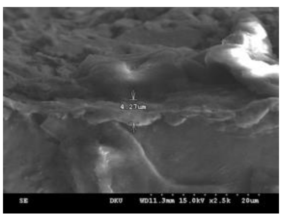


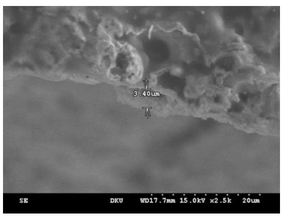
(a) Sample Target





(b) Sample-1 (Not measured) (c) Sample-2 (t~9.5 μm)





(d) Sample-1 (t~4.27 μm) (e) Sample-2 (t~3.4 μm)

Fig. 8. The measured thickness of titanium-coated layers for four samples through the F-ESES technology.

3. Conclusions

A solid-target developed for a compact fast neutron generator in the KAERI was fabricated by OFHC-copper including the water cooling structure to overcome the heatload caused by the injection of deuterium ion beams. The solid-target was shaped in a circular cone-type with an entrance diameter of 10 cm to reduce the heatload (per unit-area) of target. Beam-injected surface of the copper target was coated as a titanium layer with a thickness of 4~10 μm using the PVD plasma ion irradiation process of titanium to insert the injected deuterium ions into the solid-target surface through the drive-in method. The coated thickness of titanium was confirmed for four sample targets by the measurement of FE-SEM.

The heatload performance of solid-target was confirmed by the calculation of heatload distribution with the commercial codes including an ion beam heat-power of 10 kW injected into the inner surface of beam target. A peak power density of 5.3 MW/m^2 was estimated with the cooling water-flow, and a maximum temperature of 70℃ was also evaluated in the inner surface of target with a maximum flow-rate of 2.4 m/s at the entrance of cooling water.

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