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Design Concept of Neutron Irradiation Basket for 12-inch NTD in HANARO

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1. Introduction

Neutron Transmutation Doping (NTD) facility is one of the most important facilities of the research reactor. HANARO has been providing commercial NTD services for 5, 6 and 8-inch Si ingots in the two vertical holes, NTD1 and NTD2. Recently, the demand for high power semiconductors is increasing in view of the supply for new power generation systems, such as EV, PFC, PV, wind and motor drive. In order to satisfy the sufficient supply of high power semiconductors, larger diameter Si ingot irradiation was requisite [1]. Wafer manufacturers around the world, such as Global wafers, Universal Wafer and Silitronic, continue to expand production of 12-inch Si wafers. Therefore, NTD facilities in the research reactors are considering commercial NTD services for larger diameter Si ingots. In the case of Kijang research reactor, the 300 mm diameter vertical hole was incorporated into the core design.

By increasing the Si-ingot diameter, the radial non-uniformity becomes larger due to the neutron attenuation effect, which results in a limit of the feasible diameter of the Si-ingot. In this study, the design concept of the neutron irradiation basket for the 12-inch Si ingot was proposed. Neutron screen and reflector for uniform irradiation in axial and radial direction of the Si ingot were designed and optimized. However, in the case of Kijang research reactor, since the final core design was not confirmed, this study assumed a pseudo 12-inch vertical irradiation hole in the HANARO core.

2. Methods and Results

In this work, we used MCNP code to simulate details of the irradiation basket. Since diameter of the NTD1 vertical hole of HANARO is 220 mm, NTD for 12-inch Si ingot is not possible at HANARO. To design an irradiation basket for 12-inch Si ingot, a pseudo core model that increases the size of the NTD1 irradiation hole to enable 12-inch Si ingot loading was created. Figure 1 shows the pseudo HANARO core model that increases the diameter of the NTD1 hole. The diameter of the NTD1 hole was increased from 220 mm to 323 mm. Distribution of neutron flux in axial direction varies depending on the position of the control rods. The control rods are withdrawn quickly at the beginning of the cycle (BOC) and slowly withdrawn at the middle of cycle (MOC). Therefore, it is assumed that the control rods are located at 450 mm from the bottom of the core where the control rods stay the longest in actual reactor operation. During operation, thermal power of the reactor was assumed to be 30 MW.

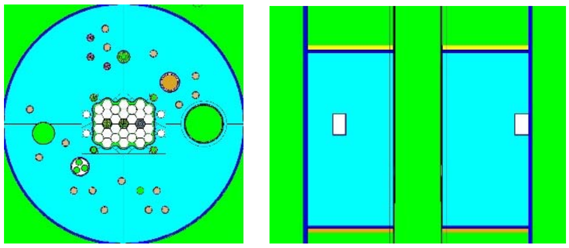

Fig. 1. Pseudo core model of HANARO with 12-inch vertical hole

Distribution of neutron flux in 12-inch vertical hole is shown in Figure 2. Inside of the hole is filled with water. The water inside the hole was divided into 70 segments in the axial direction, and was divided into 15 concentric circles for the radial direction. The axial neutron flux is highest at the center and decreases toward both ends. The highest position of the axial neutron flux is 3 cm below the center, and the neutron flux is 2.5×10^{13} n/cm^2/s. The radial neutron flux decreases toward center of the vertical hole. The neutron flux at the radial center is 5% of the neutron flux at the outermost.

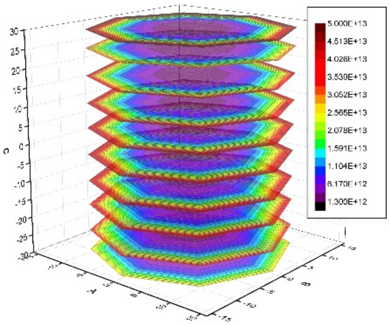

Fig. 2. Calculated neutron flux distribution in 12-inch vertical irradiation hole

Uniform radial and axial irradiation in the ingot is the main target in irradiation basket design. To realize axially uniform irradiation, the neutron screen method was chosen at HANARO. From preliminary analyses based on the thermal diffusion length of several kinds of materials, stainless steel (SUS) is chosen as the material for the screen. NTD simulations were performed to calculate the ^{30}Si(n,γ)^{31}Si reaction rate by the thickness and length of SUS. The axial reaction rate of 12-inch Si ingot by thickness and length of the neutron screen is shown in Figure 3. As the screen length increases, the reaction rate decreases. The reaction rate decreases even in the Si ingot where there is no SUS in axial direction. The effect of SUS spreads around and suppresses the transmission of neutrons. The most axial uniformity is when the length of the SUS is 29 cm and the thickness is 3 mm. In this case, however, since the reaction rate of the upper and lower ends is smaller than the axial center, it is necessary to increase the neutron flux at these positions by using a reflector above and below the Si.

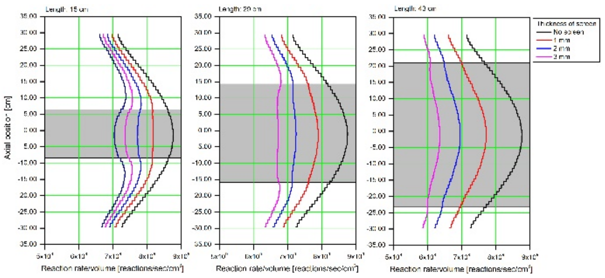

Fig. 3. Axial reaction rate of Si ingot by length and thickness of SUS screen

In order to increase the neutron flux and increase the radial uniformity at both ends of the Si, reflector is designed. The neutron reflector is advantageously a material having a small absorption cross-section and a large elastic scattering cross-section. In this study, graphite was considered as a neutron reflector. The graphite reflector is designed in the shape of cone to increase the neutron flux at the radial center of the Si ingot.

Based on the calculation results, the design of irradiation basket was optimized for the axial and radial uniformity as shown in Figure 4. The SUS screen is thick at the axial center of the Si ingot and gradually decreases in thickness as it goes to both ends. At both ends of the Si ingot, the screen is 1 mm thick. For the optimally designed irradiation basket, the axial and radial reaction rates are shown in Figure 5. The uniformity is defined as the difference between the maximum and minimum relative reaction rate. We achieved the axial uniformity of less than 3.4%, which is well within a usual requirement.

As mentioned above, when the water is filled in the vertical irradiation hole, the neutron flux at the radial center is 5% of the neutron flux at the outermost. On the contrary, Si is a transparent material to neutrons and thus neutrons can penetrate well into the center of Si. Radial uniformity of the resistivity in the Si ingot can be represented by the RRG (radial resistivity gradient) [2]. The resistivity of Si semiconductor was decided by the amount of ^{30}Si(n,γ)^{31}Si reaction, then RRG can be written as follows:

$$RRG = \frac{RR_{max} - RR_{min}}{RR_{min}} \quad (1)$$

where RR_{max} and RR_{min} are the maximum and minimum reaction rates, respectively. We achieved the radial uniformity of less than 4.9%, which is within a usual customer's requirement of 5%.

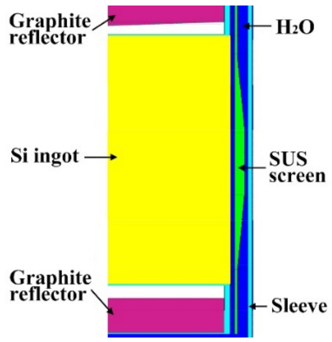

Fig. 4. MCNP model of the 12-inch Si ingot and the neutron irradiation basket

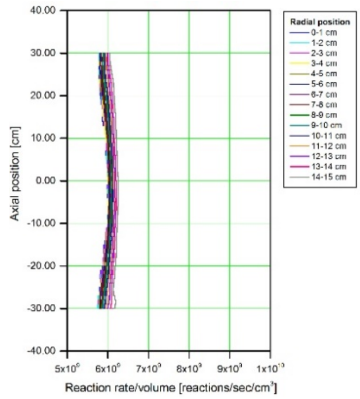

Fig. 5. Axial and radial reaction rate distributions of 12-inch Si ingot

3. Conclusions

The neutron irradiation basket was designed for 12-inch Si ingot irradiation in the NTD1 hole of HANARO, which is optimum in achieving a flat axial and radial distribution of resistivity in the irradiated Si ingot. To optimize the design of the irradiation basket, the ^{30}Si(n,γ)^{31}Si reaction rate for various geometries of the irradiation basket were calculated by using the Monte Carlo method. The fluctuations in the axial and radial distribution were estimated to be within 3.4%, 4.9%, respectively. It shows a good uniformity of axial and radial direction.

Acknowledgement

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