Investigation of Radial Uniformity of Neutron Irradiation in Neutron Transmutation Doping for 5 and 6 Inch Silicon Ingots

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1. Introduction

Neutron transmutation doping (NTD) for producing N-type silicon is based on the conversion of the Si-30 isotope into phosphorus atom by the absorption of neutron. This method can produce silicon semiconductors with extremely uniform dopant distributions [1,2]. HANARO, a 30 MW research reactor, has two vertical holes in the heavy water reflector region for the NTD - NTD1 and NTD2 of which the diameters are 22 and 18 cm, respectively. It has been confirmed that the two holes are very good for the NTD from the viewpoints of neutron quality and size [3]. And now, commercial NTD service for 5 inch silicon ingot is going on at NTD2 hole, and the irradiation facility for 6 inch ingot is being developed for the NTD1 hole. Uniform irradiation in the ingot radially as well as longitudinally is the prime target of the irradiation device design. The neutron screen method was chosen in HANARO for the uniform irradiation. From the previous study, the optimum neutron screen was searched so as to give an axial flux uniformity within ±2% [4].
The radial uniformity of the resistivity can be represented by RRG(radial resistivity gradient),

$$RRG = \frac{\rho_{\max} - \rho_{\min}}{\rho_{\min}} \qquad (1)$$

where $\rho_{\min}$ and $\rho_{\max}$ are the minimum and maximum resistivity in a silicon wafer, respectively. Generally, the NTD customer demands that the RRG of an irradiated NTD silicon should be lower than 4~5% for 5 inch ingot. The radial uniformity cannot be perfect because the neutron flux of the inner part of silicon is slightly lower than the periphery due to the neutron attenuation by silicon and the initial resistivity distribution. In this work, we checked the radial uniformity of the neutron irradiation for 5 and 6 inch ingots with calculation and experiment.

2. Calculation and Experimental Methods

We used VENTURE code to compare the flux distribution inside the 5 inch natural silicon ingot with that in the single crystal loaded at NTD2 irradiation hole. Figure 1 shows the calculation model for an irradiation. The pitch of a hexagonal cell is 1.1561 cm. For this analysis, the cross-section of single crystal silicon is added into the 69 group WIMS library.

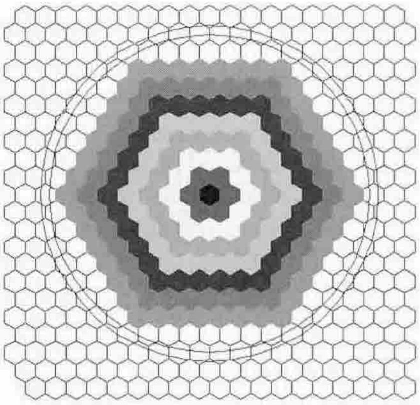

Fig. 1. Calculation model for 5 inch silicon loaded at NTD2 hole.

The calculation of radial distribution of 6 inch silicon reaction rate is performed using MCNP. The model simulating the real neutron screen for 6 inch silicon irradiation is used.
The Au wire activation method is used for the flux distributions measurement [5]. The Au wire with a diameter of 0.1 mm is attached at each plane of the two pieces of 6 inch ingot with a 30 cm length, and irradiated at NTD1 hole at the reactor power of 30 kW. The activity of the irradiated Au sample is measured using a high purity germanium detection system by the gamma-scanning method. The lead slit size of the gamma-scanning system is 4 mm.

3. Results

Figure 2 shows the relative neutron flux at each hexagonal ring of figure 1. The neutron flux is obtained by averaging the cell flux in each ring. The differences in neutron flux between ring 1(center) and ring 8 are 4.26% for natural silicon and 1.76% for single crystal silicon, respectively. It is because the scattering cross-section of a single crystal is less than the non-crystal [6]. Since the scattering cross-section of a single crystal is larger at a higher temperature, the RRG is larger if the crystal temperature is higher during a irradiation. In the calculation, 300 K cross-sections are used.

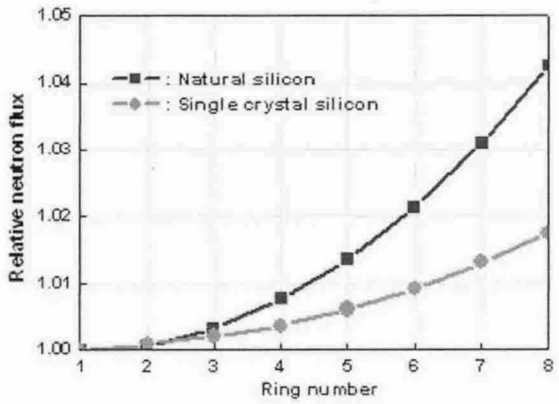

Fig. 2. Relative neutron flux at each hexagonal ring.

Figure 3 shows the relative neutron flux calculated by MCNP as a function of radial distance from center of 6 inch silicon ingot. The radial distribution of irradiation is obtained by calculation assuming the rotation of the ingot during the irradiation. The calculated flux is lowest at the center and highest at the periphery of the ingot, and the difference is less than 2.5%. The three radial neutron flux distributions are similar to each other.

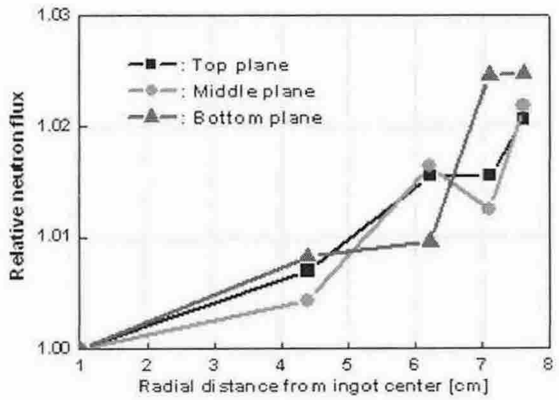

Fig. 3. Relative neutron flux calculated by MCNP for 6 inch silicon ingot.

Figure 4 shows the relative neutron flux measured by Au wire activation in the irradiation experiment for 6 inch ingot. The difference between the measurements is bigger than the calculation, and the maximum value is 4.4%.

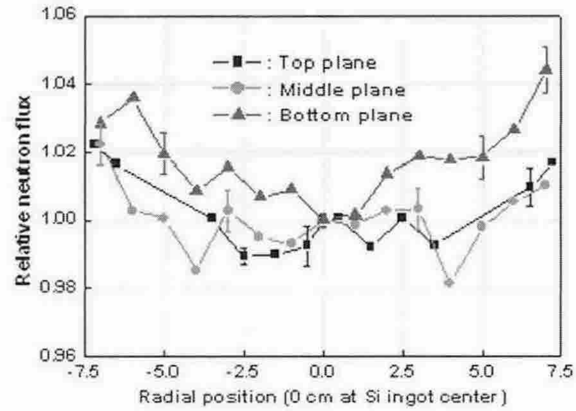

Fig. 4. Relative neutron flux measured by Au wire activation for 6 inch silicon ingot.

4. Conclusion

We confirmed the radial uniformity of irradiation by calculations and experiments. For 6 inch ingot, the measured maximum difference between the neutron fluxes at the center and periphery is 4.4%, which is acceptable. However, we are not sure whether we can meet the customer's RRG requirement for larger ones, for instance, 8 inch ingot if the RRG requirement is the same.

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