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# Neutron Transmutation Doping in the HANARO Reactor in 2008

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## 1. Introduction

After we started the NTD (Neutron Transmutation Doping) service of the 5 inch silicon ingot in 2002 and 6 inch in 2005 respectively, we completed the test irradiation of 8 inch silicon ingot in 2008, which is the biggest diameter in the current NTD-Si market [1].

In 2008, we have produced total 12 tons of NTD-Si semiconductor including 5 and 6 inch diameters, while the HANARO was operated with full power for 106 days. Total number of irradiation was 650 and the net irradiation time was 2,200 hours. Especially the demand for the higher resistivity over hundreds Ω-cm was much increased in this year. The quality control becomes more difficult for the higher resistivity because of very short irradiation time. However, we can get the great favorable notices from the customers for the excellent quality of high resistivity NTD-Si production.

This paper summarizes the production of the NTD-Si semiconductor at HANARO in 2008 for the 5 and 6 inch irradiated ones at NTD2 hole.

## 2. Irradiation results

In 2008, the HANARO was operated with full power for 106 days. The 2,200 hours was assigned to the irradiation of 5 and 6 inch silicon ingots at NTD2 hole, which records a beam utilization factor of 86%. Considering the time needed for the preparation and change of the irradiation target, the NTD2 hole was utilized almost 100% as in other years. The total 650 times of irradiation were done and around 12 tons of NTD-Si was produced. Fig. 1 shows an annual record of NTD-Si production at NTD2 with operation time of HANARO. In spite of shortage of operation time and decreasing of 6 inch irradiation comparing with the former years, the total production registered the similar level as in 2007 due to the increase of demand for the higher target resistivity.

Fig. 2 compares the irradiation volume and the target resistivity by operating cycle of HANARO. We had four normal cycles and one shortened cycle in 2008. The average irradiation volume was about 2.5 tons per cycle. Up to recently the leading product in the NTD-Si market was changing towards 6 inch from the 5 inch, however the demand for 6 inch was decreased in this year because the worldwide economic stagnation suspended the development and investment for the 6 inch processing facility of the companies producing the power devices.

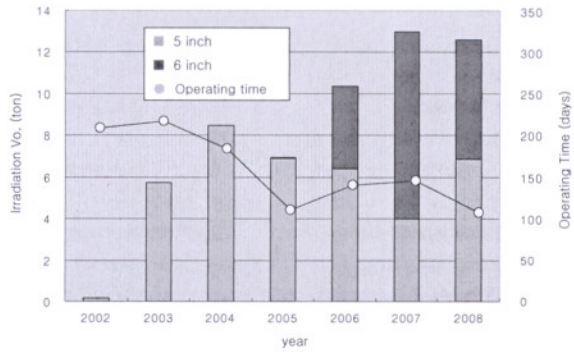


Fig. 1 Annual records of NTD-Si production at NTD2

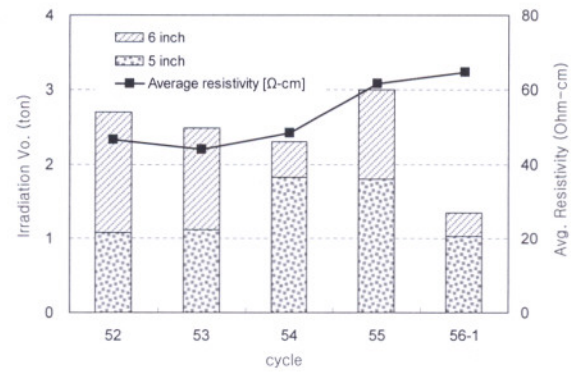


Fig. 2 Irradiation volume by cycle

The NTD-Si is rapidly replacing the conventional power discrete of the various industrial applications which require higher electric power such as electric driving engines, power plants, industrial robots, etc. As a result, the market is also changing to the higher resistivity over hundreds Ohm-cm. In 2008, the demands for higher resistivity NTD-Si over 100 Ohm-cm took up about 37 % in volume, which was increased almost twice as high as in 2007. If we count the number of irradiation for the higher resistivity, then it took more than 50 % of all our production. During the first cycle in 2009, more than 80 % was for the higher resistivity NTD-Si and it is expected to be continued for the time being.

## 3. Irradiation quality

The most important factor in producing NTD-Si is to control the total neutron fluence and uniformity over whole silicon ingots very accurately. Our quality standards of NTD-Si are based on those from the

customers. The deviation from the target resistivity (demanded resistivity by the customers) is ±5% and axial deviation of the resistivity distribution in an ingot is 5%. The radial uniformity (RRG, Radial Resistivity Gradient) is normally required the different standards depending on the crystal size, 5% for 5 inch, 6 % for 6 inch and 8% for 8 inch ingot.

The irradiation accuracy which is based on the measured data by customers is shown in Fig. 3 according to their target resistivity. For the lower target resistivity, it shows a good distribution within ±5% and the average accuracy is less than ±2 %. However, the distribution is getting wide and average resistivity is getting bigger as the target value is increasing. The thermal neutron flux at the NTD hole in HANARO is much higher than in other reactors where the NTD service is carrying out. In HANARO, it takes only 10 minutes to get a resistivity of 700 Ω-cm, while about 1 minute is needed to fully insert and withdraw a silicon batch of 600 mm long into or from the irradiation hole. Therefore, the bottom and top side of a silicon batch have to undergo the different irradiation time and it makes the worse accuracy distribution as show in the figure. More than 95%, however were within ±5 %.

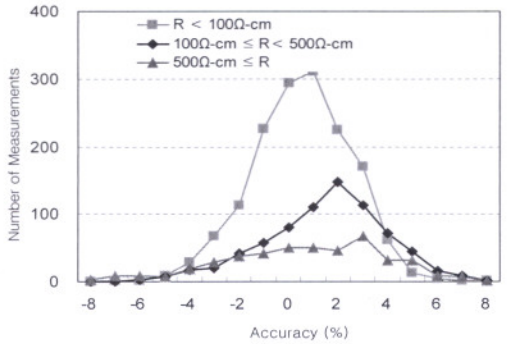


Fig. 3 Irradiation accuracy by target resistivity

The axial uniformity is also less than 5% for all the cases including 5 and 6 inch as shown in Fig. 4. And the average RRGs are 2.4% and 2.8% for 5 and 6 inch ingots respectively.

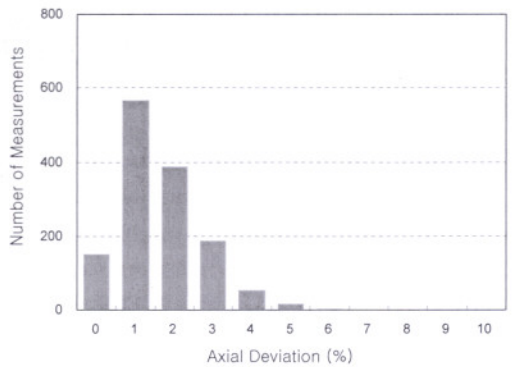


Fig. 4 Axial uniformity

## 4. Conclusions

In 2008, we had a total 650 irradiations at NTD2 and produced total 12 tons of NTD-Si semiconductors including 5 and 6 inch. We were subject to restriction in production due to the shortage of operating time of the HANARO, however we utilized almost the 100% of available time. As we also introduced the ISO quality control system for NTD works in 2008, we could maintain the world best NTD supplier.

From the end of 2008, the demand of NTD-Si with higher resistivity over hundreds Ω-cm is rapidly increased in the market as the application fields of NTD-Si is getting wide in the various industrial applications. And this tendency will be more intensified in the future.

HANARO has provided the neutron irradiation service for a NTD-Si production since 2003. We started with 5 inch silicon ingot and added 6 inch ingot from 2005. In order to increase irradiation capacity and acceptable crystal diameter, we developed the new irradiation equipment utilizing the other irradiation hole in 2008. Now we are making every effort for a full scale production of 8 inch NTD-Si in 2009.

## REFERENCES

[1] S. J. Park, et. al., "Characteristics and Operation of Neutron Transmutation Doping in HANARO Reactor", Proceedings if the 17-th International Conference on Nuclear Engineering, ICONE17 July 12-16, 2009, Belgium. (to be published)