Accuracy Adjustment for a Neutron Transmutation Doping of Si Ingots

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1. Introduction

HANARO provides two vertical irradiation holes in the D_2O reflector region for a Neutron Transmutation Doping (NTD). One of them has been used for a 5 and 6 inch NTD commercial service since 2003 and 2005 respectively. Excellent irradiation uniformity and high accuracy to a target neutron dose have been achieved from the early works of NTD. However, our expected resistivities have exhibited a slightly lower tendency when compared with the measured results by a semiconductor company. To achieve exact neutron irradiations corresponding to the actually measured resistivities, an old K value, which is a constant representing the relationship between the neutron fluence and target resistivity, was investigated and replaced with a new one by analyzing the measured results so far achieved. This paper describes the effects of changing the K value on the irradiation accuracy.

2. Prediction of neutron fluence

The irradiation uniformity and accuracy to a target neutron fluence are the most important factors in NTD. We confirmed that an excellent uniformity can be achieved by using our specially designed irradiation facility [1, 2]. For a high accuracy of the irradiation, two rhodium Self Powered Neutron Detectors and some zirconium activation thin foils are used for a real time neutron monitoring and confirming the actual neutron fluence during the irradiation, respectively.

The resistivity of a Si ingot is inversely proportional to the neutron fluence as follows;

$$\phi t = K(\frac{1}{\rho_t} - \frac{1}{\rho_i}) \qquad (1)$$

where, ϕt is a total neutron fluence, ρ_t and ρ_i are target and initial resistivity respectively, and K is a constant. In order to reach close to a target resistivity, therefore, the necessary neutron fluence should be predicted precisely. It can be calculated from the above equation if the K value is determined correctly.

Because K relates to an effective cross section of the $Si^{30}(n,\gamma)P^{31}$ reaction and the effective cross section is also varied with the neutron spectrum where the Si ingots are irradiated, thus it is not suitable for a fixed K value to be applied to all irradiation facilities. Even if some representative values can be estimated by using assumed spectra such as a Westcott or Maxwell average flux, eventually a characteristic empirical result for a facility will be used [3]. Furthermore, the K value can also be changed according to the suppliers or initial types of Si ingots.

3. Re-evaluation of K value

After an irradiation, the resistivities measured by a semiconductor company were fed back to updating a K value. We used K as a variable [$K=2.44 \times 10^{19}-1.98 \times 10^{17}\ln(\rho_t)$] until the beginning of this year. It reflected a preponderance of the distribution of the target resistivities collected until that time. The target resistivities of Si ingots were mostly within a range of 30- 50 Ω -cm and a small portion of them was around 100 Ω -cm. As shown in figure 1, our irradiation results well meet with the target resistivities within an allowable error of ±5% and also they are conformable with the Gaussian distribution with a standard deviation of 1.54. Few results are deviated from the boundary in the figure, but they were also acceptable because they are all unusual or test cases such as a Si ingot with a very big axial deviation of the initial resistivity or a Si ingot with a much higher target resistivity requiring a very short irradiation time. However, the figure shows that, our final results are biased toward under the irradiation by about 0.5~1.0 %. It means that the K value needs to be modified to increase the accuracy.

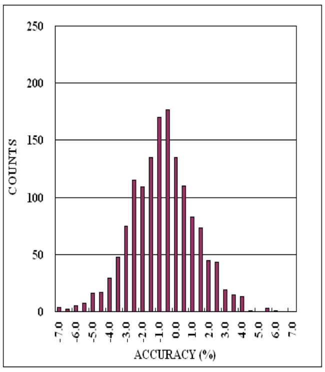

Figure 1. Accuracy distribution before changing K

Figure 2 indicates a distribution of the K values which are calculated reversely from equation 1 by using our measured neutron fluence and a company's measured resistivities. The most probable value of K appeared at around 2.41×10^{19}, while the average value was 2.37×10^{19} during the former works.

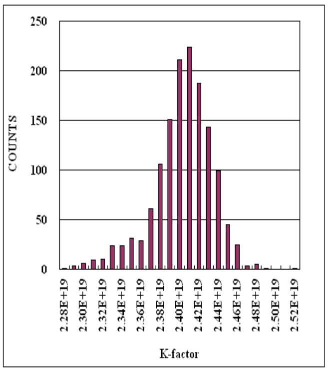

Figure 2. K value distribution before changing K

As the number of Si ingots with a variety of target resistivities is increasing, more information for the regions of a middle and high resistivity could be used for improving the K value. After analyzing all the irradiation results from the early stage of NTD works and considering our irradiation condition, we decided to use a constant value for a new K and it was determined as 2.40×10^{19}.

4. Result

Figure 3 represents an irradiation result after applying a new K value. It seems to be slightly over irradiated contrary to the former result, but the accuracy is improved to some extent. Before changing the K value the average accuracy was -1.0% over the 1,550 samples, while after changing it, it was +0.5% over 695 samples. In the figure most results can be found within a ±3% deviation from the target value. The standard deviation of the distribution is also decreased to 0.94. Of course there is not a lot of data on the current work, but it is expected that future works will produce better results.

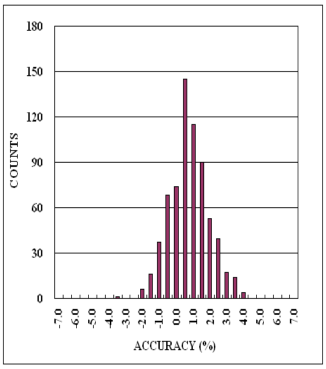

Figure 3. Accuracy distribution after changing K

K values were calculated again in the same way as above and their distribution is represented in figure 4. The center value of the distribution is round 2.4×10^{19} as expected.

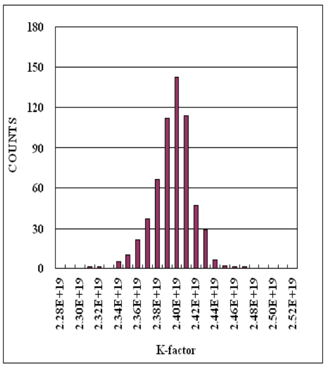

Figure 4. K value distribution after changing K

5. Conclusion

An uniform and accurate neutron irradiation is one of the critical factors in the NTD of Si ingots. In spite of short experience on NTD at HANARO, we could achieve the best results from the early stage through a careful preliminary preparation. Recently, we updated a proportional constant for the Si ingots of a company and as a result we confirmed an improvement in the quality of the NTD Si ingots. We also intend to update the K values for the Si ingots of other companies and to investigate the results of initially p-typed Si ingots in order to establish a correlation between the initial resistivity and neutron fluence.

Reference

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3. Myong-Seop Kim, et. al., “Relationship between Resistivity and Irradiated Neutron Fluence in Silicon Neutron Transmutation Doping,” *Proc. of Int. Sym. On Research Reactor and Neutron Science, Daejon, Korea, Apr. 2005.*