Progress of Investigating the Characteristics of Neutron Irradiated Germanium

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1. Introduction

Bolometers have been used by the experiments measuring rare events (e.g. neutrino-less double beta decay, dark matter search) in particle physics field [1-7]. When incident radiations hit the local part of the bolometer's body, the temperature of the part increases. To measure these changes of temperature, bolometers are consequentially accompanied with thermistors. There are many types of thermistors, and neutron-transmutation-doped germanium (NTD-Ge) thermistors are used by many experiments [1-6]. Expecting the usages for search experiments, NTD-Ge thermistor is under development at Korea Atomic Energy Research Institute (KAERI).

The initial work for establishing NTD-Ge thermistor production is testing neutron irradiation to germanium samples. Neutron irradiation was carried out using High-flux Advanced Neutron Application Reactor (HANARO) at KAERI. In this work, the measured dose rates and doping levels of the germanium samples after neutron irradiation are presented. And, the results of checking radionuclidic impurities of the samples are also presented.

2. Methods and Results

In this section the process of testing neutron irradiation to Ge samples are described. And the results for various tests are presented.

2.1 Preparation of Germanium Samples

For the NTD-Ge thermistor production, commercial germanium wafers will be used. But in the testing phase, a high purity germanium (HPGe) HPGe crystal from malfunctional HPGe detector was used. The HPGe crystal was sliced and processed into a square shape (Fig.1). The size of square-shaped sample is approximately 10×10×1 mm. From one HPGe crystal, many square-shaped Ge samples were obtained. In addition, Ge powder was also prepared by grinding sliced Ge crystal. The Ge powder was used for analyzing radioactive nuclei just after the neutron irradiation with handleable dose rate.

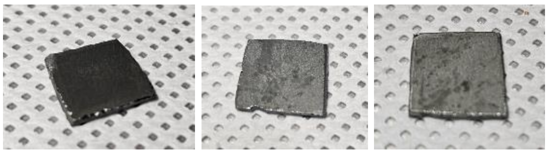

Fig. 1. Square-shaped Ge samples (Ge#3, Ge#5, Ge#6).

2.2 Neutron Irradiation using HANARO

In research reactor HANARO, there are many neutron irradiation holes with certain distances from the reactor core. Among them, the holes connected to pneumatic transfer system (PTS) were used. There are total 3 holes connected to PTS (PTS#1, #2, #3), and 2 holes (PTS#1 and #2) were used in the testing phase. The order of neutron fluxes of PTS#1 and #2 is 10^{13} /s/cm^2 for thermal neutron, when the thermal power of HANARO is 30 MW. In the testing phase, there were 2 operation cycles of HANARO, and the thermal power were 27 and 25 MW. But the orders of neutron fluxes were the same. Total 9 Ge samples were irradiated and 8 samples were used for the analysis. Among the used samples, 2 were the powder samples. The irradiation time of the samples were different (5 s to 4 hr). The details of the Ge samples are shown in Table I.

Table I: Detailed information for the Ge samples

Sample	Type	Weight	Irradiation	
			Hole	Time
Ge#1	Square	0.6 g	PTS#2	10 m
Ge#2	Square	0.7 g	PTS#2	30 m
Ge#3	Square	0.7 g	PTS#2	1 hr
Ge#4	Square	0.7 g	PTS#1	30 s
Ge#5	Square	0.8 g	PTS#2	2 hr
Ge#6	Square	0.8 g	PTS#2	4 hr
Ge#7	Powder	10 mg	PTS#1	10 s
Ge#9	Powder	0.08 mg	PTS#1	5 s

2.3 Dose Rates of the Neutron Irradiated Germanium Samples

The irradiated samples were transferred to lead shielded case in the PTS control room, and stored until the dose rates of the samples decreased to handleable level. The handleable dose rate is 10 μSv/hr or under. The dose rates of the samples were measured using the gamma survey meter. The dose rates of the early 2 Ge samples were measured several times, for evaluating the storing (cooling) time in the lead shielded case. Figure 2 shows the dose rates over time, of the 2 neutron irradiated Ge samples. The data points for one sample in Fig.2 were fitted using two exponential functions, for describing short- and long-lived radioisotopes. Using the results, the changes of dose rates over time for 1 g Ge sample with 1-hour neutron irradiation time was estimated, for the two different neutron irradiation holes (Table II). Using the estimated dose rates, the cooling time and related dose rates of the 4 Ge samples with long irradiation time (0.5-4 hr) were calculated and applied. The dose rates of the 4 samples were measured over time, and the results agreed with the calculated values.

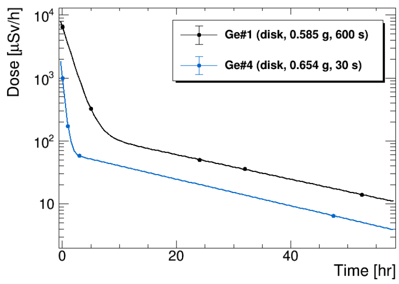

Fig. 2. Dose rates of Ge samples over time, after neutron irradiation. Ge#1 is irradiated in the neutron irradiation hole PTS#2, while Ge#4 is irradiated in the PTS#1.

Table II: Estimated dose rates over time, for 1 g Ge sample (1-hour irradiation), for different neutron irradiation holes

Cooling time [day]	Dose rate [µSv/hr]	
	PTS#1	PTS#2
0	188,000	67,200
1	3,750	520
2	1,170	177
3	363	61
4	113	21
5	36	7
6	11	3
7	4	1

2.4 Checking Radionuclidic Impurities

For the production of the NTD-Ge thermistor, germanium wafers will be processed and it's suspected that the Ge wafers may become contaminated during processing. Thus, the radionuclidic impurities was checked after the neutron irradiation. In the testing, the radionuclidic impurities of the 6 Ge samples were checked analyzing the gamma spectra of the samples. Figure 3, 4, and 5 show the gamma spectra of the neutron irradiated Ge samples with different irradiation time. The amplitudes of the gamma peaks were changed over time, as shown in Fig.3. Almost all gamma peaks that were distinguished were analyzed, and the results showed that all the analyzed gamma peaks were Ge related. In particular, just after the neutron irradiation (whose cooling time is less than 10 min.), there were several gamma peaks (Fig.4) related to the meta state of the ^{75}Ge or ^{77}Ge. In contrast, in Fig.5, there are gamma peaks for Ge and related NTD-isotopes were shown after 2-week cooling time. As shown in the results, there's no considerable radionuclidic impurities after processing Ge samples, and the neutron transmutation doping was occurred in the Ge samples.

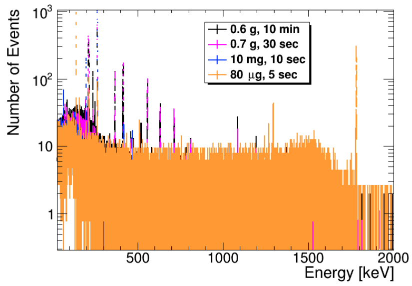

Fig. 3. The gamma spectra for neutron irradiated Ge samples with different irradiation time. These spectra were measured when the dose rate of each sample decreased to 10 µSv/hr (thus the cooling time is different for each sample).

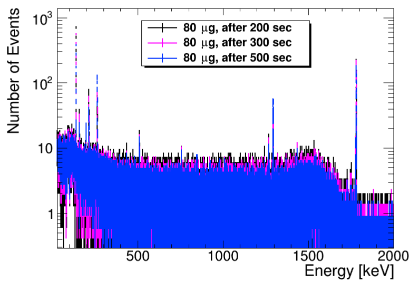

Fig. 4. The gamma spectra for Ge sample Ge#9, with different cooling time. There are no distinguished differences in cooling time within 10 minutes.

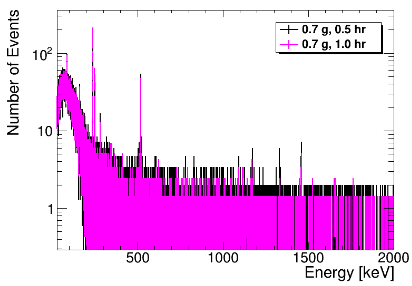

Fig. 5. The gamma spectra for Ge samples with 2-week cooling time. Most gamma peaks are related to doped isotopes (^{77}As, ^{75}Se)

2.5 Measuring Doping Level of the Germanium Samples

From the results of analyzing gamma spectra for neutron irradiated Ge samples, it was found that the neutron transmutation doping was occurred in the Ge samples. Among the Ge samples, the 3 samples irradiated in the same hole (PTS#2) were selected and the doping level of the samples was evaluated using a Hall effect measurement system (HEMS) at KAERI. For the Hall effect measurements, the soldering was carried out on the surface of the samples and the electric contact was done to each sample, as shown in Fig. 6. The used samples for doping level measurements are Ge#3, #5, and #6. The doping levels of each sample were measured with 10 different supply current values and averaged. Figure 7-9 show the results of measuring doping levels of the 3 samples. The results show that the doping level increases as the neutron irradiation time increases.

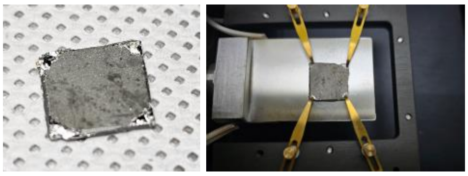

Fig. 6. Soldering on the surface of Ge sample (left), and electric contact for Hall effect measurement (right).

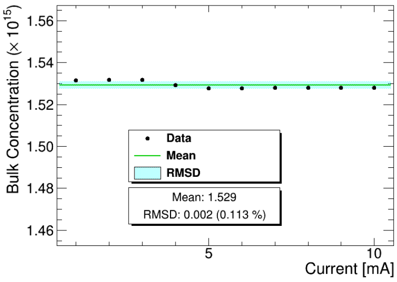

Fig. 7. Doping level of the Ge#3 (27 MW thermal power, 1-hr neutron irradiation).

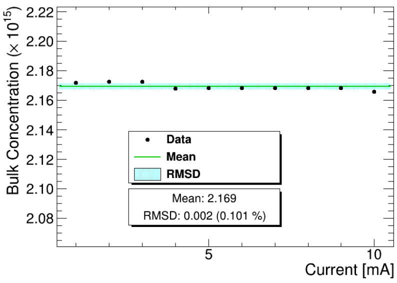

Fig. 8. Doping level of the Ge#5 (25 MW thermal power, 2-hr neutron irradiation).

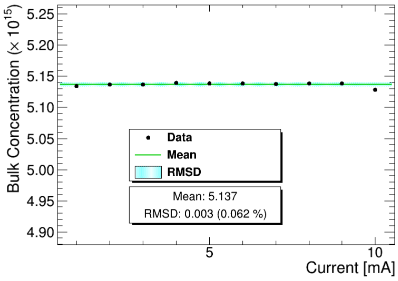

Fig. 9. Doping level of the Ge#6 (25 MW thermal power, 4-hr neutron irradiation).

3. Conclusions

For the production of NTD-Ge thermistor, the process of the neutron irradiation to germanium samples was tested, and the characteristics of the samples after the neutron irradiation were checked. The testing results show that the samples have no significant radionuclidic impurities, and the neutron transmutation doping was done to the samples as expected. The measured doping levels of the samples will be validated with various methods, and the neutron irradiation to other Ge samples with longer irradiation time will be tested until the doping level reaches the aimed level.

Acknowledgements

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