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Study of Temperature Effect on Ion Implanted Silicon Detector for In-containment Radiation Monitoring System

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1. Introduction

There has been studied to develop an in-containment radiation detection system for detecting small coolant leakage. The system could detect charged particles of radioisotope from the leaked coolant and a silicon semiconductor detector could be applied as a sensor of the system due to its compactness and good detection capability for charged particles with simple detector design.

But, well-known fact about the silicon semiconductor detector is that a dependency of temperature is high, especially in the low channel because of leakage current noise, which could be increased on high temperature conditions. Therefore, researchers have been studying how temperature could make a change in functional states of silicon semiconductor detectors.

Udaykumar *et al.*[1] reported effects on the performance of a silicon surface barrier detector observed by studying the spectra of 28.4 MeV protons recorded at different temperatures over the range from 270 to 313 K.

Kim *et al.*[2] showed the effects of temperature on silicon PIN photodiode radiation detectors. The experimental temperature was approximately in the range from 266 to 297 K using a Peltier device.

As one of the most advanced charged particle detectors, an ion implanted silicon semiconductor detector has a good resolution and good efficiency for detecting alpha and beta particles, because of an extremely thin dead layer compared with other detectors such as a silicon PN junction detector, silicon PIN photodiode detector, and even a silicon surface barrier detector. In order to investigate an effect of temperature on the behavior of an ion implanted silicon semiconductor detector (hereafter Si detector) for an in-containment coolant leakage detection system, we studied Si detector of 300 μm thickness depletion depth over the temperature range 283 to 323 K, which the range is a design basis temperature of an annulus zone of a nuclear power plant, by recording the spectrum of a Po-210 alpha source (5.3 MeV).

2. Experiments

2.1 Detector and Electronics

In the present experiment for investigating effects by temperature change, ULTRA ion implanted silicon detector CU-037-1200-300 (ORTEC) was used. The Si detector had 300 μm thickness of depletion depth and 1200 mm^2 of an active area. And, the detector was configurated by N-type silicon implanted arsenic and implanted boron as P-type. The Si detector was mounted in lead shield that will be installed in containment, and the shield was composed of a cylinder as 11 cm inner diameter, and 5 cm thickness lead except for one side. 142A preamplifier, 460 amplifier, 428 bias supply, 928 MCB, and MAESTRO® 7 application software made by ORTEC were used as electronics for identifying spectrum during temperature changes. The block diagram of the electronics system is shown in Fig. 1.

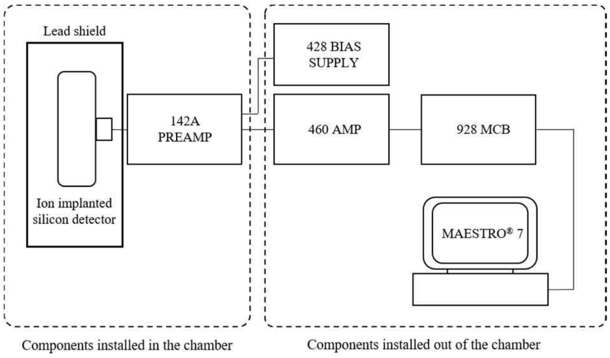

Fig. 1. Block diagram of the setting of detector and electronics system

2.2 Setting of Experiment Conditions

For the temperature test on the Si detector, International Certification Registrar Corp. (ICR)'s equipment (environmental test chamber) was used. The Si detector and Preamp were installed in the equipment, and other electronics were equipped out of the chamber. The temperature inside the chamber was controlled from 283 to 323 K and relative humidity was fixed by about 60% while the test was conducted. During the experiment, the alpha energy spectrum from Po-210 and noise was recorded for 1 minute at room temperature, 283 K, 293 K, 313 K, and 323 K.

3. Results and Discussion

3.1 Influence of Temperature in a High Channel Region

In a high channel region that could ignore the noise energy spectrum (above 105 channels), It is confirmed that the gross count rate (hereafter cps) of alpha is little change with temperature. 105 channels could be calibrated as 0.82 MeV. At room temperature (about 300 K), the gross cps of the alpha spectrum is 62.87. Under room temperature, 283 K and 293 K, each gross cps of alpha spectrums are 62.1 and 61.32, respectively, that are almost the same gross cps with room temperature. Over room temperature, 313 K and 323 K, each gross cps of alpha spectrums are 60.82 and 61.53, respectively, that are slightly decrease but almost the same with gross cps with room temperature. The relative error with respect to the gross cps is less than ± 3.3 % based on the room temperature. In the case of Full Width at Half Maximum (hereafter FWHM) of channels, when it is higher than the room temperature, the performance degradation is identified. The FWHM of room temperature is 60.67 channels. But FWHMs of 313 K and 323 K are 63.41 and 63.88, respectively. The Change in temperature of gross cps and FWHM is shown in Fig. 2.

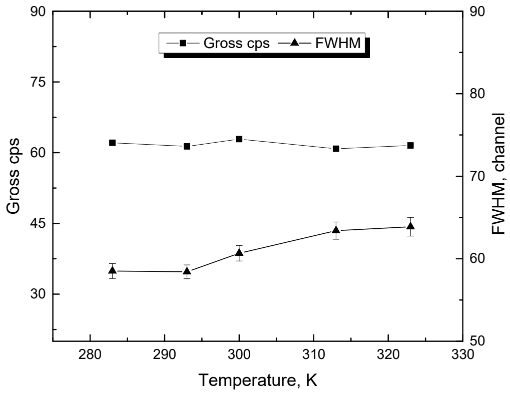

Fig. 2. Change of gross cps and FWHM (for channels) of the alpha energy spectrum according to the temperature change from 283 to 323 K.

3.2 Influence of Temperature in a Low Channel Region

Because of noise in a low channel region (under 104 channels) by leakage current from thermal electrons, the influence of temperature in low channels is bigger than high channels. Theoretically, the probability per unit time that an electron-hole pair is thermally generated is given by [3]

$$p(T) = CT^{\frac{3}{2}}\exp\left(-\frac{E_g}{2kT}\right) \quad (1)$$

where T is the absolute temperature, E_g is the bandgap energy, k is the Boltzmann constant, and C is proportionality constant characteristic of the material. According to the equation, the number of electron-hole pairs should be exponentially increased with the temperature, causing increasing noise which appears in a low channel region of the energy spectrum. The result of the change of gross cps in the low channel region is shown in Fig. 3. When temperature increase, the probability of generation of electron-hole pairs also are increased. And, thermally generated electron-hole pairs could make leakage current which can make noise energy spectrum in a low channel region. In the experiment, we can identify an increase of gross cps by leakage current in the Si detector while the temperature becomes high. However, it is not exactly fit with the theoretical value of the probability of thermally generated electron-hole pairs because of other influences like a change of electronics noise from the preamplifier which equipped inside the test chamber with the Si detector.

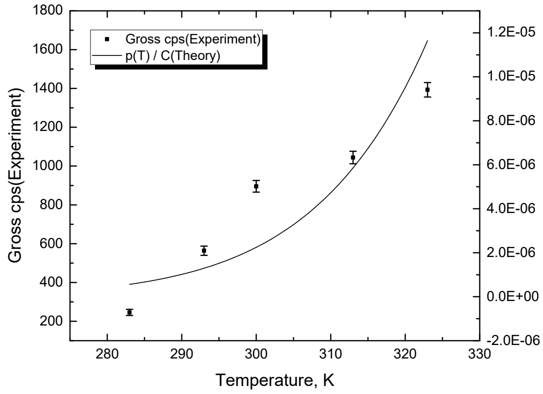

Fig. 3. The gross cps change in noise energy spectrum and the probability of electron-hole pair's generation as a change of temperature

3. Conclusions

The effect of temperature on the Si detector by recording the energy spectrum was studied. We confirm that temperature could make just little influence in a high channel region. On the other hand, in the case of a low channel region, because of the increasing of thermally generated electron-hole pairs, while the temperature becomes higher, the gross cps could be increased. It indicates that the in-containment Si detector should be cooled and the level discrimination of should be determined carefully depending on target radiation energy and species.

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