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Characteristics of Fabricated SiC Neutron Detectors for Neutron Flux Monitoring

Han Soo KIM [a*], Jang Ho HA [a], Se-Hwan PARK [a], Kyu Hong LEE [a], Cheol Ho LEE [b]
[a] *Korea Atomic Energy Research Institute.,1045 Daedeok-daero,Daejeon, Korea*
[b] *Department of Nuclear Engineering, Hanyang Univ., Seoul, Korea*
[*] *Corresponding author: khsoo@kaeri.re.kr*

1. Introduction

An SPND (Self-powered Neutron Detector) is commonly used for neutron detection in NPP (Nuclear Power Plant) by virtue of un-reactivity for gamma-rays. But it has a drawback, which is that it cannot detect neutrons in real time due to beta emissions (about > 48 s) after reactions between neutrons and ^{103}Rh in an SPND. And Generation IV reactors such as MSR (Molten-salt reactor), SFR (Sodium-cooled fast reactor), and GFR (Gas-cooled fast reactor) are designed to compact size and integration type. For GEN IV reactor, neutron monitor also must be compact-sized to apply such reactor easily and much more reliable.

The wide band-gap semiconductors such as SiC, AlN, and diamond make them an attractive alternative in applications in harsh environments by virtue of the lower operating voltage, faster charge-collection times compared with gas-filled detectors, and compact size.[1)]

In this study, two PIN-type SiC semiconductor neutron detectors, which are for fast neutron detection by elastic and inelastic scattering SiC atoms and for thermal neutron detection by charged particle emissions of 6LiF reaction, were designed and fabricated for NPP-related applications. Preliminary tests such as I-V and alpha response were performed and neutron responses at ENF in HANARO research reactor were also addressed. The application feasibility of the fabricated SiC neutron detector as an in-core neutron monitor was discussed.

2. Methods and Results

2.1 Methods

Two PIN-type SiC neutron detectors were designed for fast and thermal neutron detection. Figure 1 shows the design schematic of a SiC thermal neutron detector. For a fast neutron detector, 9 μm-thick ^{6}LiF was not designed. Depletion depth of the designed SiC was 29.7 μm with no biasing. An epitaxial layer on an N-type SiC wafer was grown by Cree Company. Thickness and doping profiles can be found in figure 1. H_2SO_4, HNO_3, and 1% HF were used to cleaning the processed wafer. Ni was evaporated at 0.03 μm-thickness to enhance adhesion of Au electrode to the wafer. In thermal neutron detection, MeGregor et al. showed that percentage of thermal neutron detection efficiency increased up to 35 μm-thicknesses when evaporating ^{6}LiF. 35 μm-thick ^{6}LiF film cannot be encapsulated in our experiments[2)]. In our experiments, ^{6}LiF was evaporated by using a thermal evaporator at 9 μm thickness. To encapsulate ^{6}LiF, another Au evaporation process was performed immediately in a vacuum to eliminate the reaction of ^{6}LiF and air. The processed PIN-type neutron detectors were cut and mounted on a ceramic die.

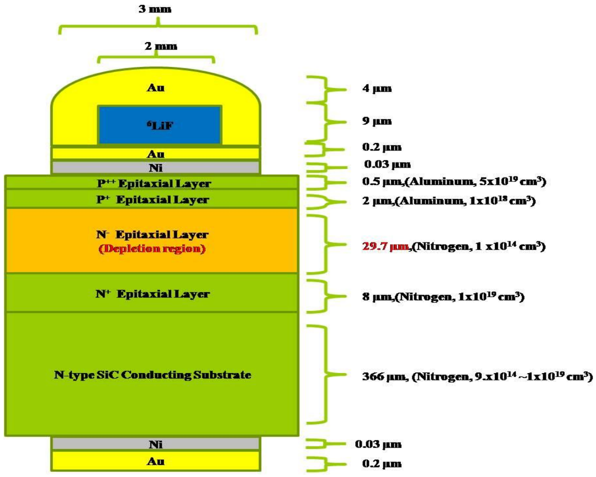

Fig. 1. A schematic of PIN-type SiC thermal neutron detector.

2.2 Results

I-V characteristics were measured with a Keithley® Semiconductor characterization system 4200. Diode characteristics are shown in figure 2. A thermal neutron detector (PIN-type SiC semiconductor with ^{6}LiF film) showed slightly higher leakage currents than a fast neutron detector. This is not yet fully understood, but is most likely related to the ^{6}LiF film. I-Vs of two neutron detectors were below 0.3 μA up to -100 V and these values were affordable since the neutron detectors were a non-biasing operation in neutron detection.

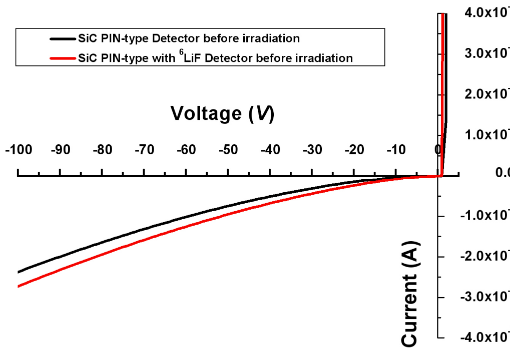

Fig. 2. I-V characteristics of PIN-type SiC neutron detectors.

1,690 Bq ^{241}Am (5.486 MeV alpha) was used to measure radiation response of the SiC semiconductor neutron detectors without a collimator. Alpha responses of a thermal neutron detector with respect to the biasing voltage were shown in figure 3. Energy spectra at high biasing voltage in both cases show the high energy resolution due to sweep electron fast in the high applied electric fields. In the case of an SiC thermal neutron detector, 3.39 MeV energy loss occurred due to 4 μ m-thick Au electrode and 9 μm-thick ^{6}LiF film. Deposited energies in active volume of two detectors were approximately 4.1 and 2.1 MeV, respectively. In figure 3., a peak of about 4.1 MeV due to an Au electrode (D=3 mm) and about a peak of 2.1 MeV peak due to another ^{6}LiF film (D=2 mm) were observed.

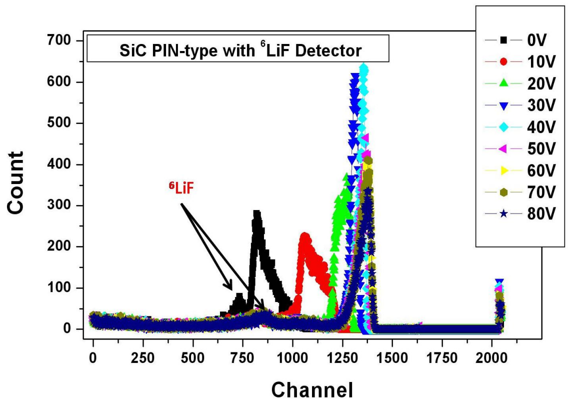

Fig. 3. Alpha response of a thermal neutron detector at various bias voltages.

Neutron responses of the PIN-type SiC neutron detectors were measured at ENF in HANARO research reactor in KAERI. The maximum neutron flux (n/cm^2·s) for the fast neutron (>0.82 MeV) and the thermal neutron (< 0.635 MeV) are 2.8 x 10^{12} and 1.8 x 10^{14}, respectively. For thermal neutron detection, ^{6}LiF was commonly and the ^{6}Li(n, α)^{3}H reaction resulted in the following products :

^{6}Li + n → ^{3}H (2.73 MeV) + α (2.05 MeV),

Figure 4 and 5 shows experimentally observed energy spectra, which were detected by a fast and thermal neutron detectors, respectively. Total neutron flux were varied from 1.6×10^6 to 1.9×10^7 n/cm^2·s to confirm linear response on the basis of thermal neutron flux. Neutron fluxes were determined by using Au wire activation analysis. In thermal neutron detection, tritium (2.73 MeV) and alpha particles (2.05 MeV) were clearly observed. The neutron detection was about 3.3 % using the measuring time and active area of the detector. In fast neutron detection, continuum energies from the elastic and inelastic scattering of SiC atom were observed. The linear response for fast neutron was also obtained (99%) by using the neutron flux and their observed counts. From the results, the fabricated SiC neutron detector can be applied in an NPP in case of appropriated package such as water-proof.

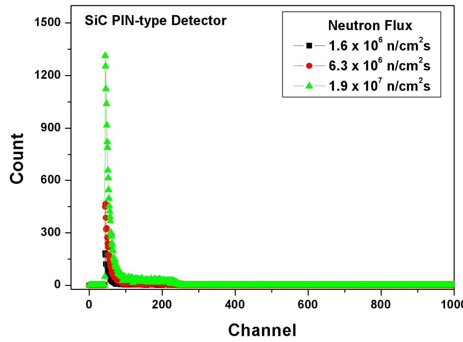

Fig. 4 Experimentally observed energy spectrum by using a fast neutron detector.

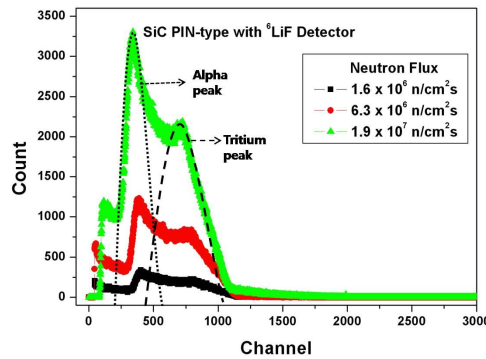

Fig. 5 Experimentally observed energy spectrum by using a thermal neutron detector.

3. Conclusions

Neutron responses were measured at ENF in HANARO research reactor with varying neutron fluxes. For thermal neutron detection, ^{6}LiF neutron converter was evaporated and encapsulated. Linearity was obtained both with a fast neutron detector and a thermal neutron detector. In future work, the developed SiC neutron detectors will be experimented at in-core at the HANARO reactor and the results will be also presented for GEN IV reactor application.

Acknowledgements

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