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CVD Diamond Detector for Neutron Measurement

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1. Introduction

A diamond has several merits of high energy band gap, high carrier mobility, shot carrier lifetime, high radiation resistance and high conductivity, etc. Particularly, a diamond radiation detector was known at least 100 times stronger than a silicon detector. If fast neutrons irradiated into the diamond, ^{12}C in diamond layer generated electronics and holes by $^{12}C(n,\alpha)^{9}Be$ reaction. At this time, the ionization energy should be greater than 5.7 MeV. But if thermal neutron irradiated into the diamond, electronics and holes does not generated. So, the layer of energy converter need. As converting layer, materials such as ^{10}B, ^{6}Li, ^{157}Gd are used. Several studies have used ^{6}LiF, but another electrode is needed [1-4].

If a radiation detector is made by a single crystal CVD diamond, its electronics property is good, but it has weaknesses of high fabrication cost and difficulty fabrication method. In addition, noble materials as Au, Ag, Pt are used for sputtering but studies for the leakage current should be performed. Also, a high purity single crystal CVD diamond should be used because it effects quality change by temperature and repeatability. In development status of a CVD diamond detector, the dosimeter was developed and sold in medical fields and many studies are processing. But despite the development status of a CVD diamond detector, it is very poor in reactor use [11-13].

This study is about the development of neutron detector for irradiation test. In this paper, we refer to development for fast neutron and thermal neutron detector and detector experiment.

2. Design of Neutron Detector

Neutron detector for thermal and fast neutron detection for reactor should use MI (Mineral Insulator) cable and detector type is a small metal tube. Fig. 1 shows neutron detector. The sensor element used as a detector is CVD high purity diamond plate and applied the laser micro welding technology for stainless outer tube and MI cable sealing. Also, detector tube is sealed after filled with helium gas. The out tube diameter is ø5mm and MI cable of ø1mm is used. The size of CVD high purity diamond plate is 3.0x3.0x0.5mm and used Element6's electronic grade diamond. As Fig. 1 (right), electrode of diamond plate for fast neutron detector is used Ag and its thickness is about 750nm.

The diamond detector needs converting layer for thermal neutron detection. We chose ^{157}Gd among converting materials. The ^{157}Gd has the highest thermal neutron capture cross-section. The reaction of ^{157}Gd with thermal neutron is $^{157}Gd + n \rightarrow {}^{158}Gd + \gamma + 7.9$ MeV. The other merit of ^{157}Gd is that it is possible sputtering and it can acts not only converting layer but also electrode. The thickness of ^{157}Gd is informant factor. We refer to several data to determine the thickness of ^{157}Gd [6-7]. The design thickness of Fig. 1 (right) ^{157}Gd is about 4μm.

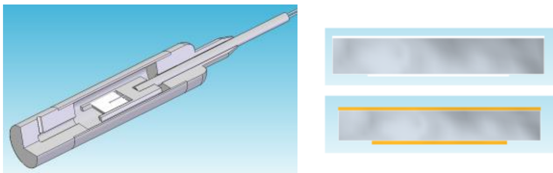

Fig. 1. Design of diamond neutron detector (left) and electrode of fast neutron detector/ electrode of thermal (right)

3. Response Experiment of Neutron Detector

The response experiment of neutron detector have done on MC-50 cyclotron at KIRAMS (Republic of KOREA). The 30 MeV proton beam at 10μA from MC-50 cyclotron bombarded a 0.5 cm thin beryllium target and neutron beams are generated. The generated neutron collimated by a graphite collimator irradiated to detector. Although there is a few thermal neutron in beam of MC-50, most of the beam is fast neutron [10-11]. So, 10cm HDPE (High Density Poly Ethylene) is used for the generation of thermal neutron. Also MC-50 is generated not only neutron but also the gamma ray. So, as Fig. 2, Pb block of 5cm thickness is used for gamma ray shielding and the Cd plate of 2mm thickness is used for thermal neutron shielding.

The response experiments of detector have conducted in four case as fellows.

Case 1 : Set up HDPE/Cd/Pb in front of collimator.
Case 2 : Set up HDPE/Pb in front of collimator (Cd

is eliminated in Case 1).

Case 3 : Set up HDPE in front of collimator (Pb is eliminated in Case 2).

Case 4 : No shielding in front of collimator (HDPE is eliminated in Case 3).

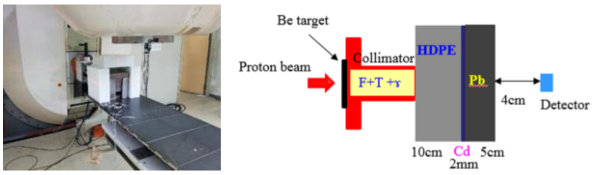

Fig. 2. MC-50 of KIRAMS (left) and detector experiment of HDPE/Cd/Pb shielding (case 4) (right).

4. Results

The detectors was irradiated radiation from collimator for 20 sec and the current of detector was measured by the KEITHLEY 6487 picoammeter. The applied bias voltage is 50 volts. Fig. 3 and Fig. 4 show the measurement results about Ag electrode detector and Gd electrode detector for 4 cases. The calculation by MCMP for 4 cases have done and table 1 shows sum values of thermal neutron (<0.025eV), epithermal neutron and fast neutron (>1 MeV). In each cases, gamma ray contribute to the current of detector. So, table 2 is the result of calculation by MCNP for gamma ray flux.

Table 1. A result of MCNP for neutron flux

Neutron (n/cm²·s)	Case 1	Case 2	Case 3	Case 4
Thermal neutron (<0.025 eV)	4.54E+05	5.50E+05	7.09E+05	4.26E+05
Epithermal Neutron	1.40E+06	1.79E+06	2.52E+06	1.25E+06
Fast Neutron (>1 MeV)	8.52E+07	8.61E+07	1.01E+08	2.53E+08

Table 2. A result of MCNP for gamma ray flux (Gy/h)

	Case 1	Case 2	Case 3	Case 4
Gamma ray	0.3364	0.33921	1.7326	2.0658

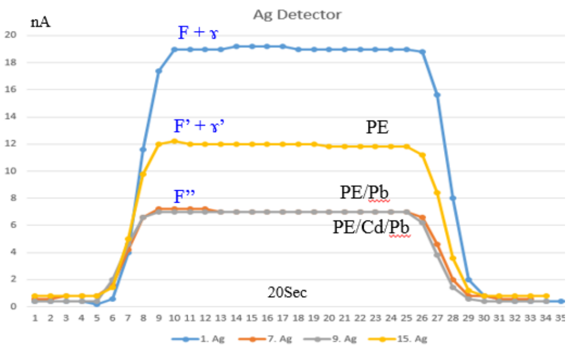

Fig. 3. Current measurement of Ag Electrode Detector.

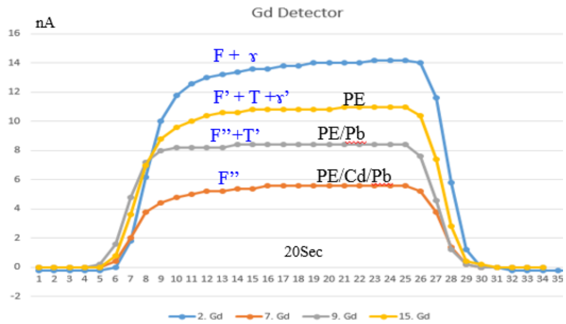

Fig. 4. Current measurement of Gd Electrode Detector.

4.1 Fast neutron

As you can see in Fig. 3, the experiment detector is Ag electrode. So the Ag electrode detector can be measured the current generated by the fast neutron and the gamma ray. The current of case 4 is greatest because there is no shield in front of detector. But as in case 3, the current value by fast neutron and gamma ray gets smaller by HDPE moderator. Also, as in case 2, the detector is measured only the current by fast neutron. Pb brick acts well the role of gamma ray shielding. But as the result of case 1, there is no change by the Cd plate. From the results of case 1 and case 2, the Ag electrode detector can measured fast neutron.

4.2 Thermal neutron

Fig. 4 is the results of Gd electrode detector. In Fig 3, the current of case 4 is 14.2 nA by fast neuron and gamma ray as in case 4 of Fig. 3. But the measured current is rather small. It is considered the sensitivity of Gd electrode detector is low compared to Ag electrode detector because of the thick Gd layer of detector. If you compare to the result of case 1 and case 2 in Fig. 3 and Fig. 4, you can see the Cd plate's effect. In case 2, both thermal and fast neutron have measured (8.4 nA). But In case 1, only fast neutron has measured (5.6 nA). Gd detector has measured 2.8 nA of thermal neutron from different of case 2 and case 1. Therefore, Gd electrode detector can measure thermal neutron and fast neutron.

4.3 Gamma ray

The measured current values by detector include current by gamma rays. Even though we know the computed gamma flux as Table 2, the current by gamma flux should be known for the exact neutron value. The detector has irradiated at high Co-60 gamma source in Jeonguo. The sensitivity of Ag detector is 0.5917 nA/(Gy/h) and the sensitivity of Gd detector is 0.3535 nA/(Gy/h). So, the current by gamma ray can be known. In case 4, the current of Ag detector is 1.2 nA and the current of Gd detector is 0.65 nA.

5. Conclusions

The neutron detector has developed for reactor irradiation test. The sensing element of neutron detector use high purity CVD diamond plate. The detector of ø5mm stainless tube type is sealed by laser micro welding from external environment protection. The electrode of diamond for fast neutron detector has used Ag about 750nm thickness. Also, the electrode of diamond for thermal neutron detector has used Gd about 4µm. The developed neutron detectors have tested on the MC-50 cyclotron. The HDPE, Cd and Pb was used for moderator and shielding. The Ag electrode detector has measured the current generated by fast neutron and gamma ray. Although sensitivity is small, Gd electrode detector has measured the current generated by thermal neutron as well as fast neutron and gamma ray.

Acknowledgements

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