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Study of Si PIN Photodiode Coupled with a CsI(Tl) Scintillator for Radiation Detection

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1. Introduction

Semiconductor-based radiation detectors have been investigated for many applications such as nuclear physics, dosimetry, medicine etc. Especially, the Si-based semiconductor radiation detectors [1-3] were developed and commercialized in low-energy x- and gamma ray detection fields because of low cost, compact size, low power demand, and superior energy resolution.

A scintillator is a material that absorbs ionizing radiation such as x- or gamma-rays and has the ability to convert a fraction of the absorbed energy into visible photons. In particular, a thallium-activated cesium iodide (CsI(Tl)) scintillator coupled to Si PIN photodiode has been used to detect high energy gamma-rays.

In this work, the Si PIN photodiode was fabricated to match a CsI(Tl) scintillator by in-house process at the Radiation Equipment Fab. Center of KAERI (Korea Atomic Energy Research Institute) and the Si PIN photodiode coupled with CsI(Tl) scintillator for radiation detection was investigated.

2. Methods and Results

2.1 Fabrication Process Flows of Si PIN Photodiode

The Si PIN photodiode was fabricated by the clean room facility in Radiation Equipment Fab. Center of KAERI. A double-side polished n-type 6 inch Si wafer of high resistivity (>10kΩ) with (100) orientation and 675 μm-thick was selected as a starting material. The 500 nm-thick silicon oxide layer was formed using oxide furnace equipment. The n-type silicon oxide (SiO_2) layer was removed by wet etching process using buffered oxide etchant (BOE). Phosphorous Oxychloride diffusion process was implemented for the formation of n^+ doping layer by diffusion furnace equipment. For the guard ring and edge protection area of p-type layer, ^{11}B implantation was carried out after photolithography process and BOE wet etching. Also, the SiO_2 layer of active area was removed by BOE wet etching process for the active area open using photolithography process. The BF_2 was second implanted in active area followed by thermal annealing. The active area of fabricated Si PIN photodiode was about 10 x 10 mm^2. As metallization process, Al and Au were deposited on the n-type side and p-type side by using electron-beam evaporator equipment and lift-off was implemented. An anti-reflection layer was deposited to reduce surface reflection of the incident light.

For the formation of a single Si PIN photodiode, the arrays of Si PIN photodiode in 6 inch wafer was carried out by using dicing machine and then a single Si PIN photodiode was package on a ceramic substrate with wire bonding equipment. The final Si PIN photodiodes are shown in Fig. 1(a).

2.2 Fabrication of Si PIN Photodiode Coupled with a CsI(Tl) Scintillator

A CsI(Tl) scintillator was fabricated into 10 x 10 x 10 mm^3 size, which is identical with active area size of a fabricated Si PIN photodiode. It has an emission spectrum around 550 nm, which fits the absorption spectrum of Si. For radiation detection of Si PIN photodiode coupled with a CsI(Tl) scintillator, a Polytetrafluoroethylene tape was used. The matched Si PIN photodiode-CsI(Tl) scintillator radiation detector is shown in Fig. 1(b).

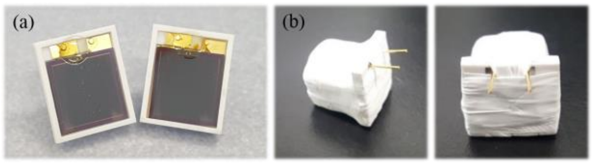

Fig. 1. The images of (a) finally packaged Si PIN photodiode by in-house process and (b) Si PIN photodiode coupled with CsI(Tl) scintillator for radiation detector.

2.3 Electrical Characteristics

The fabricated Si PIN photodiode was characterized by measurement of the leakage as a function of reverse bias voltage at room temperature. The reverse leakage current for the Si PIN photodiode in Radiation Equipment Fab. Center of KAERI are shown in Fig. 2. The reverse leakage current was observed to be ~20 nA at reverse voltage –70V. Because the low leakage current of device is very important to make the high radiation detection, the reverse leakage current of Si PIN photodiode can be further reduced by optimization of the fabrication condition.

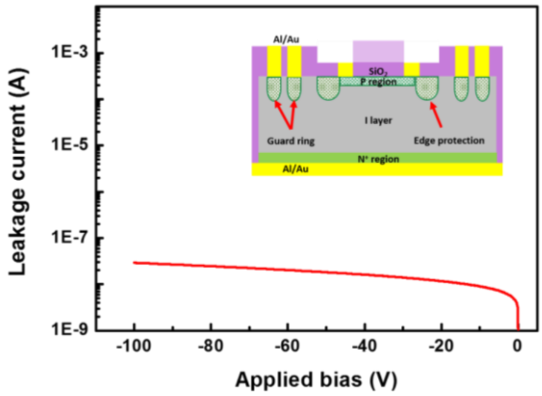

Fig. 2. Leakage current distribution as a function of the reverse bias voltage for Si PIN photodiode fabricated in Radiation Equipment Fab. Center of KAERI.

2.4 Radiation Detection Characteristics

We was performed the radiation characteristics of Si PIN photodiode by using radiation response measuring system. The energy resolution of the in-house fabricated Si PIN photodiode was measured at room temperature using ^{133}Ba source. The measured results of the Si PIN photodiode is shown in Fig. 3. The energy resolution for 30 keV and 81 keV were about 20.6% and 7.9%, respectively.

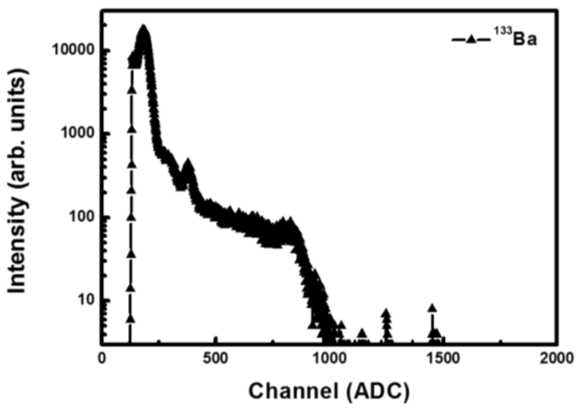

Fig. 3. The pulse height spectrum of Si PIN photodiode measured using ^{133}Ba source.

Figure 4 shows the pulse height energy spectrum of Si PIN photodiode coupled with Si PIN photodiode measured using ^{137}Cs source. The energy peak was observed for 662 keV. However, Si PIN photodiode-CsI(Tl) scintillator shows low energy resolution, which is not separate from various peak. Therefore, Si PIN photodiode is need to further optimize fabrication process having low reverse leakage current for high efficiency of radiation detection.

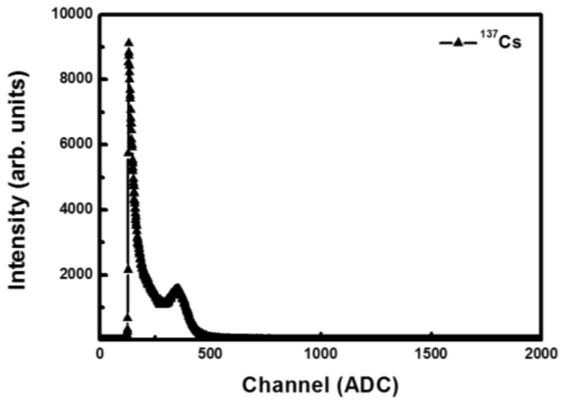

Fig. 4. The pulse height spectrum of CsI(Tl) scintillator coupled with Si PIN photodiode measured using ^{137}Cs source.

3. Conclusions

We have studied the radiation characteristics of Si PIN photodiode coupled with a CsI(Tl) scintillator in fabricated Radiation Equipment Fab. Center of KAERI. From the characteristics of current-voltage and radiation detection, we established the leakage current of ~20 nA at -70V and the respectable radiation responsivity. However, the performance of Si PIN photodiode for high efficiency of radiation detection should be further improved to optimize the fabrication process conditions.

ACKNOWLEDGEMENTS

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