Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 17-18, 2018

Performance Study of Si PIN Photodiode for Radiation Detector

Ah Hyun Park, Chang Goo Kang, Jang Ho Ha, Young Soo Kim, Jeong Min Park,
Seung-Jae Lee, Hyojeong Choi, Han Soo Kim*
Advanced Radiation Technology Institute, Korea Atomic Energy Research Institute
**Corresponding author: khsoo@kaeri.re.kr*

1. Introduction

Semiconductor diode detectors are widely used as radiation detection in a variety of fields such as nuclear physics, dosimetry, medicine etc. Especially, the Si photodiode [1-4] are promising devices for high efficiency of radiation detection because of low cost, compact size, low power demand, and superior energy resolution.

In this study, the Si PIN photodiode was fabricated by in Radiation Equipment Fab. Center of KAERI (Korea Atomic Energy Research Institute) for measurement of low energy gamma and X-ray. We carried out performance of in-house fabricated Si PIN photodiode for the properties of electrical and radiation detection efficiency.

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. The schematic of important process of fabricated Si PIN photodiode is shown in Fig. 1. A double-side polished n-type 6 inch Si wafer of high resistivity (>10kΩ) with (100) orientation and 375 µm-thick was selected as a starting material.

Firstly, the 500 nm-thick SiO_2 layer was formed using oxide furnace equipment. The back-side (n-type) SiO_2 layer was removed by wet etching process using buffered oxide etchant (BOE). Phosphorous Oxychloride ($POCl_3$) diffusion process was implemented for the formation of n^+ doping layer by diffusion furnace equipment. For the guard ring and edge protection area of front-side (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 a metallization process, Al and Au were deposited on the front-side and back-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.

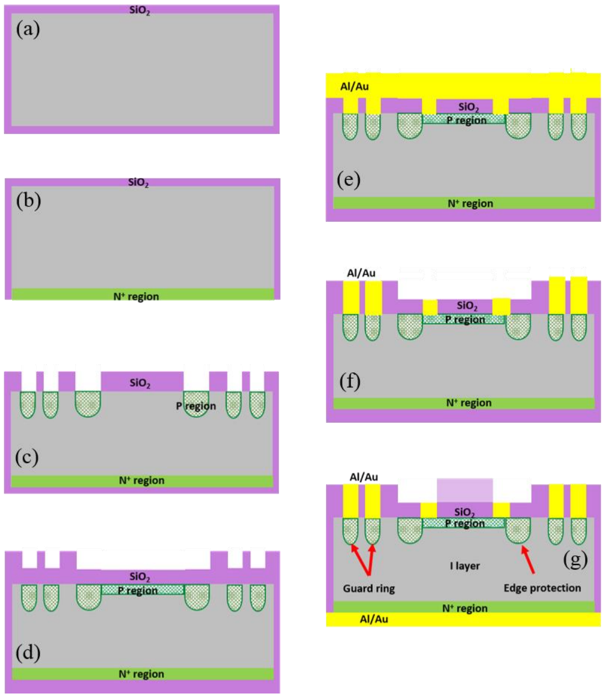

Fig. 1. Schematic of fabrication process flows of Si PIN photodiode: (a) Initial oxidation, (b) $POCl_3$ doping on back side, (c) ^{11}B implantation for an edge protection structure, (d) BF_2 implantation for a shallow active area and oxidation, (e) Al/Au deposition on front side, (f) Lift-off of an active area, and (g) Al/Au deposition on back side.

2.2 Electrical characteristics

Reverse leakage current consist of a thermally generated current and a current generated from defects in the Si and from the interface of SiO_2 layer. To confirm the reverse leakage current, the fabricated Si PIN photodiode was carried out measurement of the electrical characteristics as a function of reverse bias voltage at room temperature from 0V to -100V. The leakage current for the fabricated Si PIN photodiode is shown in Fig. 2. The leakage current density is observed to be ~ 18 nA at reverse voltage -70V. Because the low leakage current of device is extremely important to make the radiation detector having a very low noise level and high detection efficiency.

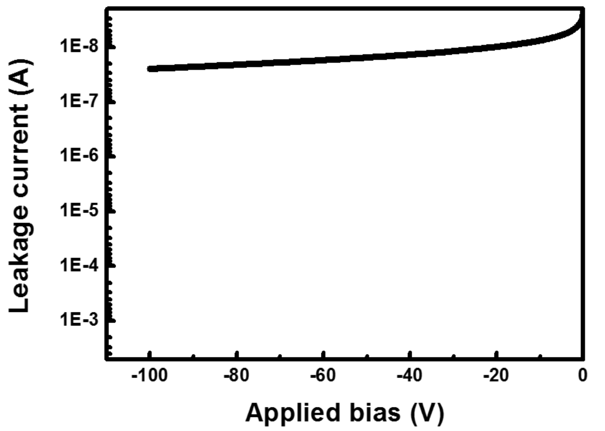

Fig. 2. Leakage current density as a function of the reverse bias voltage for a single Si PIN photodiode.

2.3 Radiation detection characteristics

The energy resolution of the fabricated Si PIN photodiode was measured at room temperature from the pulse height spectrum of radiation response measuring system by using ^{133}Ba source. The measured result of the Si PIN photodiode is shown in Fig. 3. The energy resolution for 30 keV and 81 keV were about 23.2% and 9.8%, respectively.

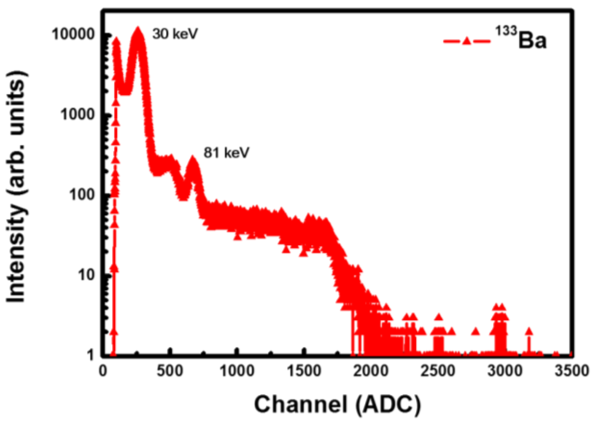

Fig.3. The pulse height spectrum of the Si PIN photodiode radiation detector measured using ^{133}Ba source.

3. Conclusions

In conclusion, we have studied the fabrication and radiation detection characteristics of Si PIN photodiode. From the current-voltage and radiation response characteristics, we confirmed the leakage current of ~18 nA at reverse voltage -70V and good radiation responsivity for a 10 x 10 mm^2 active area. Further optimization is needed to find out fabrication process of Si PIN photodiode to reduce the reverse leakage current.

ACKNOWLEDGEMENTS

This work has been carried out under the nuclear R&D program of the Ministries of Science and ICT (MIST) (NRF No. 2017M2A2A4A05018259, No. 2013M2B2B1075775) of Korea. It is also technically supported by Radiation Equipment Fabrication Center in KAERI.

REFERENCES

[1] G. F. Dalla Betta, G. U. Pignatel, G. Verzellesi, and M.Boscardin, Si-PIN X-ray detector technology, Nuclear Instruments and Methods in Physics Research A, Vol.A395, p.344 (1997).
[2] F. J. Ramirez-Jimenez, R. Lopez-Callejas, A. Cerdeira-Altuzarra, J. S. Benitez-Read, M. Estrada-Cueto, and J. O. Pacheco-Sotelo, PIN diode-preamplifier set for the measurement of low-energy gamma- and X-rays, Nuclear Instruments and Methods in Physics Research A, Vol.A497, p.577 (2003).
[3] H. S. Kim, M. Jeong, Y. S. Kim, D. H. Lee, S. Y. Cho, and J. H. Ha, Characteristics of fabricated Si PIN-type radiation detectors on cooling temperature, Nuclear Instruments and Methods in Physics Research A, Vol.A784, p.131 (2015).
[4] S. C. Lee, H. B. Jeon, K. H. Kang, and H. Park, Study of Silicon PIN diode responses to low energy gamma-rays, Journal of the Korean Physical Society, Vol.69, p.1587 (2016).