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Development of Personal Dosimeter Using Electronic Dose Conversion Method

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Abstract

Personal dosimeters based on PIN detectors have been widely used because of their simplicity and real time operation. In this paper, the optimal filter thickness and material designed by the Monte Carlo method is 1.0 mm Al plus 0.2 mm Cu. From the results of radiation characteristic analyses, the developed dosimeter has good performance when it is compared with the other conventional those as described below; The linearity due to the change of radiation intensity is kept within 8 % in 10 μSv 4 Sv, and the relative energy response to ^{137}Cs is almost constant within $\pm$10 % for above 65 keV. Generally the relative energy response of conventional dosimeter using a PIN diode is within $\pm$20 %. For minimizing the non-linear sensitivity on energy, dose conversion algorithm was presented, which was able to consider pulse number as well as pulse amplitude related to absorbed energies. When dose conversion algorithm was used, the linearity of sensitivity was better about 38 % than that of dosimeters without usage of the electronic dose conversion algorithm.

1. Introduction

A PIN semiconductor detector has been studied and widely used as a detector of personal dosimeter [1-3]. Solid state detector for personal dosimeter has intrinsic problem that the atomic number of the detector is higher than that of tissue. Thus the response of such a solid detector is largely different from that of tissues in the low energy region and depends strongly on the energy.

One method overcoming this disadvantage, which designs the energy compensated filter for making the uniform response due to energy, has widely been studied in some papers [4-5]. Another problem of conventional solid-state dosimeters is operating in pulse mode. Therefore the amplitude of dose depends only on the number of pulses irrelative to pulse height proportional to the absorbed energy in a detector.

A weight function proportional to the pulse amplitude was introduced by M. Slapa et al [6]. This method had been researched in several groups for the scintillation detector and semiconductor detectors [7-8]. The weight function introduced in their papers was applied under assumption that the pulse amplitude is almost linear due to the absorbed energy at silicon PIN detector. But its amplitude is not directly proportional to the absorbed energy and is saturated above limit energy.

For improving the conventional dosimeter based on the silicon PIN photodiode, we proposed a new method in this paper.

2. Materials and methods

2.1 Optimum filter design

The energy compensated filter, which makes the response function of detector similar to that of tissue in all energy range, was optimally designed by Monte Carlo method [9] because the response of solid detector is largely different from that of tissues in the low energy region and depends strongly on the energy [10-11]. MCNP 4B code is used for calculation of energy deposition due to change of the incident energy from 10 keV to 3 MeV, under assumption that a perpendicular photon beam to PIN detector plane is uniformly entered. Filter materials used in this paper are aluminum and copper. The response on the gamma energy was calculated with the thickness of 0.5 mm copper, 1.0 mm aluminum, and 1.0 mm aluminum plus 0.2 mm copper respectively[12]. Fig. 1 shows the Monte Carlo simulation geometry.

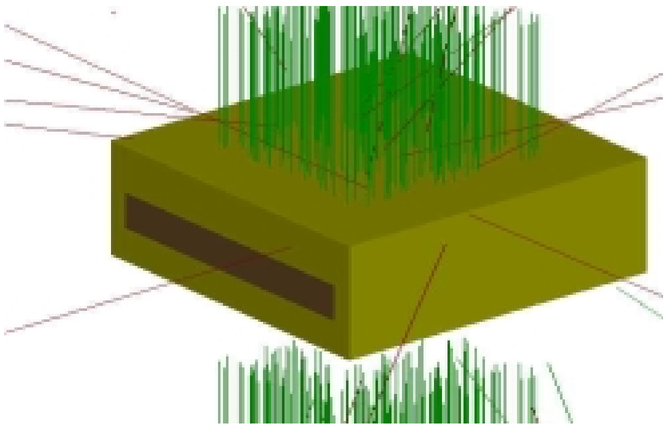
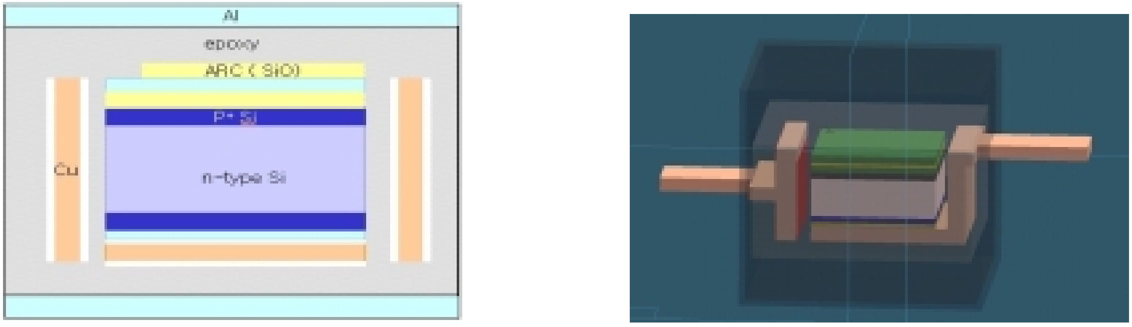


Figure. 1. Monte Carlo simulation geometry of silicon PIN photodiode for filter design.

For the verification of simulation results, the experiments on the energy response of the personal dosimeter was experimented for irradiation distance 2 m using ISO narrow series' X-ray field [13].

2.2 Development of personal dosimeter

The schematic geometry of PIN detector and the designed dosimeter are shown in Figure. 2.



(a) (b)

Figure. 2. (a) A schematic geometry of PIN detector and (b) the designed dosimeter.

This dosimeter is composed of detector, charge sensitivity preamplifier, amplifier, and displayer contained microprocessor. For performance test, this developed dosimeter was irradiated within the energy range between 50 keV and 1.25 MeV, the test dose rate range between in 10μSv and 4 Sv.

2.3 Dose conversion algorithm

For minimizing the strong dependence of the sensitivity on energy, a dose conversion method, which is able to consider the absorbed energy, is introduced and applied on dosimeter of silicon PIN photodiode. A principle of dose conversion unit (DCU) was described in Figure. 3. While the dose rate of a conventional dosimeter depends only on the pulse number without consideration of pulse amplitude proportional to the energy, the concept of dose conversion algorithm considers the pulse number as well as its amplitude simultaneously.

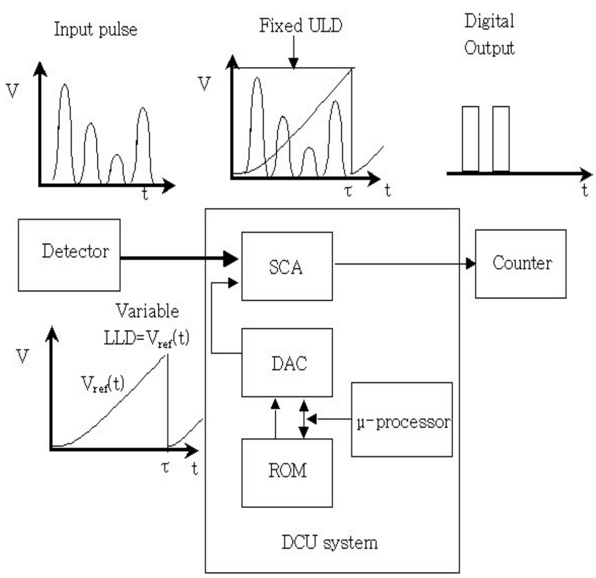


Figure. 3 A principle of dose conversion method.

The DCU is consisted of a single channel analyzer (SCA), a read only-memory (ROM), a digital-to-analog converter (DAC), and a microprocessor. The dose conversion values are stored in the ROM and is converted into a modulation waveform as a function of period and fed into the comparator within the SCA as low-level discriminator (LLD) values. The DCU was first applied in the scintillation detector for environmental radiation monitoring system, and so its principle was explained in detail at reference papers [14]. Here we will describe briefly the principle of the DCU.

While fixing the upper level discriminator (ULD) to the voltage level equivalent to 3 MeV, which is the level usually used in an environmental radiation monitoring system as the maximum energy range, the low level discriminator (LLD) based on the dose conversion function is modulating. If the voltage level of the input signal is located between the ULD and the LLD, the DCU generates digital pulses, of which count rates are directly proportional to the exposure dose rate in air. The generation probability of output pulse in DCU was controlled by the pulse amplitude and so this method can consider the pulse height as well as the pulse numbers. The important tasks of the system using the DCU are to calculate the exact dose conversion function. Because a basic calculation method of dose conversion function at semiconductor detector is similar with that at scintillation detector and is explained in reference paper, we will not describe this method [15].

3. Results and summary

Sensitivity of silicon PIN detector depends strongly on the energy as shown in Figure. 4 and is almost uniform about above 300 keV.

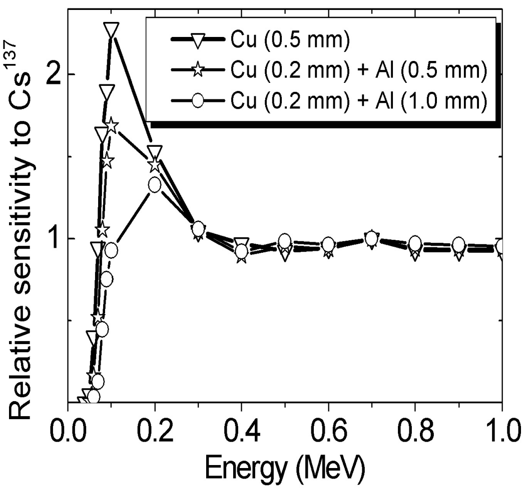
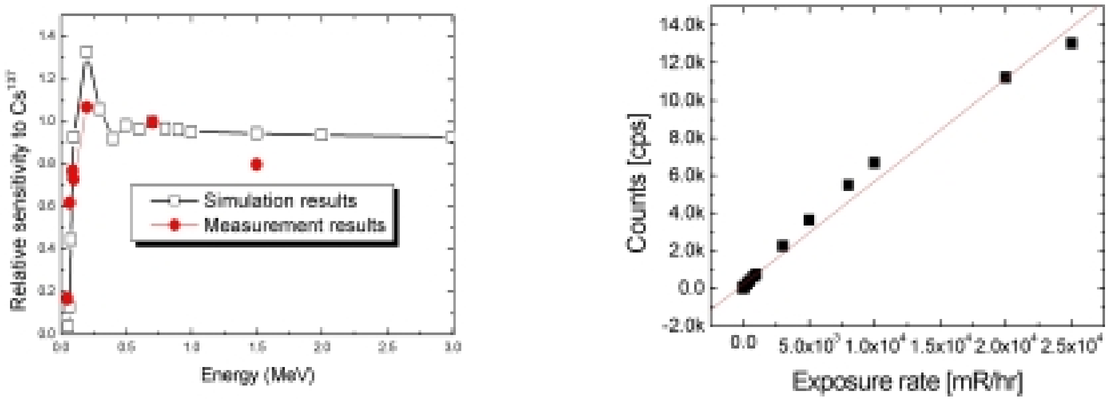


Figure. 4 Relative energy sensitivity to Cs-137 due to change of filter thickness and materials.

In order to design optimally the energy compensated filter, we calculated the relative sensitivity to Cs-137 by MCNP code simulation. For usage of the designed dosimeter above

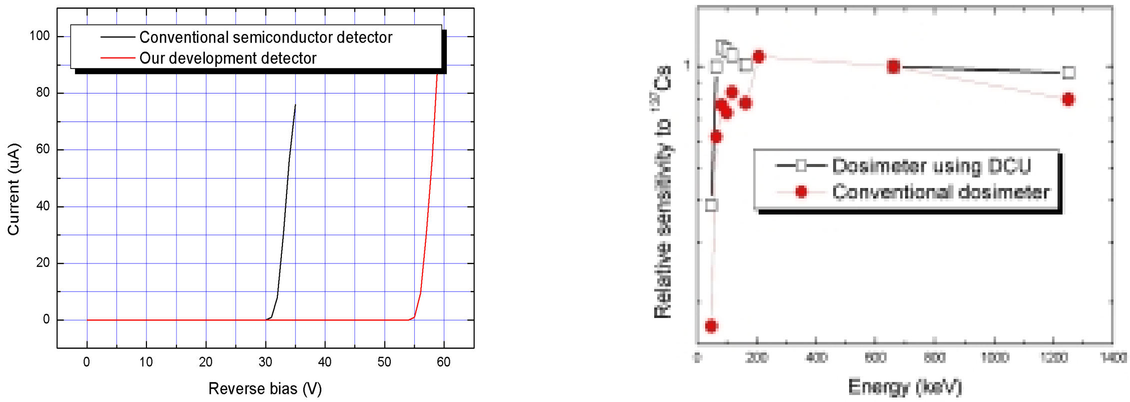
65 keV, the thickness of 0.2 mm Cu and 1.0 mm Al was determined by simulation results. The performance analysis of the designed filter was carried out with KAERI X-ray beam.



(a) (b)

Figure. 5 (a) Comparison of relative energy sensitivities between MCNP simulations and measurements with KAERI x-ray beam and gamma source and (b) counts rate due to the variation of exposure dose rate.

We acquired the simulation results similar to measurement values as shown in Figure. 5(a). The developed dosimeter was irradiated in order to test its linearity due to the change of dose rate from 3 mR/hr up to 25 R/hr. Figure. 5(b) shows a good linearity about exposure rate.



(a) (b)

Figure. 6 (a) Electronic analysis and (b) comparison of the relative energy sensitivity to Cs-137 using the conventional method and that using dose conversion algorithm.

The comparison of electronic characteristics was shown in Figure. 6(a) and the breakdown voltage of the developed detector was a 55 V. Figure. 6(b) shows that the relative sensitivities to Cs-137 by conventional method and dose conversion method are compared. Sensitivities were almost constant for above 65 keV when dose conversion method was used.

4. Conclusion

The personal dosimeter improved by the optimal filter design. It has good performance about the dark current and noise when it was compared with the conventional detector. The non-linearity still remains especially near low energy region and so we proposed the DCU for minimizing the non-linearity response of energy. The realistic dose conversion factor as a weight function was used in the DCU system. The optimum filter thickness is 0.2 mm Cu and 1 mm Al and the energy response of this developed dosimeter is almost constant within ± 10 % for above 65 keV. The electronic performances such as breakdown voltage are better than that of conventional dosimeter.

Acknowledgement

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