Development and performance characteristics of personal gamma spectrometer for radiation monitoring applications

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1. Introduction

Gamma-ray spectrometry analysis methods can be classified into direct and indirect detection methods, according to the manner in which the gamma-rays are converted into an electrical signal. The direct detection method uses a semiconductor device that generates an electrical signal immediately, with no intermediate stage, through gamma-ray absorption. The indirect detection method is a scintillation detection system, in which a photoelectric device detects photons having wavelengths in the visible region, which are produced through interactions between gamma-rays and the scintillator, as electrical signals.

HPGe, CdZnTe, CdTe, and HgI_2 are primarily used in semiconductor devices employing the direct detection method [1]. These materials are preferred in gamma-ray spectrometry analysis because of their excellent energy resolution compared to that of the scintillator detector. However, the maintenance of materials with this composition is relatively expensive compared to that of scintillator crystals, and reduction in sensitivity and resolution as a result of radiation damage within a highly irradiated environment can prove problematic. Currently, compound semiconductor materials are more expensive than scintillator crystals. On the other hand, NaI(Tl), CsI(Tl), and LYSO are primarily used as scintillator crystals in the indirect detection method. These materials have low energy resolution compared with semiconductor detectors, but they have excellent sensitivity. Because of the specific characteristics and limitations of each of these analysis methods, continual development of scintillator detectors with semiconductor detectors is necessary and on-going. Thus, scintillator detectors remain promising candidates for use in homeland security (HLS) and environmental radiation monitoring systems (ERMS).

In this study, a personal gamma spectrometer is developed and its feasibility is evaluated through analysis of its energy resolution of ^{133}Ba, ^{22}Na, ^{137}Cs, and ^{60}Co, which are standard gamma ray sources. The personal gamma spectrometer is composed of a scintillator comprising cerium-doped gadolinium aluminium gallium garnet (Ce:GAGG) with enhanced physical characteristics, such as superior light yield, florescence, decay time, and energy resolution in response to gamma ray energy, compared to conventional scintillators and Si photomultipliers.

2. Methods and Results

The prototype utilizes a Hamamatsu multi-pixel photon counter (photosensitive area: 3 × 3 mm^2) for minimization of the overall system dimensions. The developed prototype contains a Ce:GAGG (3 × 3 × 20 mm^3) crystal. Ce:GAGG has a peak wavelength of 520–530 nm, which fits the spectral response range of the SiPM. Furthermore, as this material has a density of 6.63 g cm^{-3}, it has effective stopping power. Also, the decay time (90 ns) obtained for the proposed device was higher than that of the other scintillator. The light yield (46,000 photons/MeV) of the developed scintillator was very high. In order to maximize the light output from the Ce:GAGG and to match it to the SiPM photosensitive area, the crystal geometry was optimized using a Monte Carlo n-particle extended (MCNPX) code. Fig. 1 shows the detector head of the designed prototype. The SiPM is coupled to a Ce:GAGG scintillator covered with five layers of a white diffusive (Teflon) reflector in order to optimize the scintillation light collection. The optical coupling is obtained through application of optical grease (n = 1.465) as the coupling medium. The coupled detector is then covered and sealed using an Al tube to prevent background noise from external light.

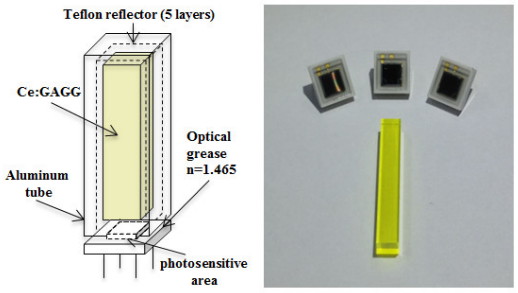

Fig. 1. Structure of 3 × 3 × 20 mm^3 Ce:GAGG detector (left). 3 × 3 mm^2 Hamamatsu S12572-100C MPPC (right).

Fig. 2 shows the personal gamma spectrometer and the overall spectroscopy system that were designed in this study. The overall system is composed of the scintillation-detection, signal-processing, voltage-supply, signal-analysis, and display units. The fabricated Ce:GAGG-SiPM detector and electronics were installed in an experimental shielding box to prevent background noise from external electromagnetic waves.

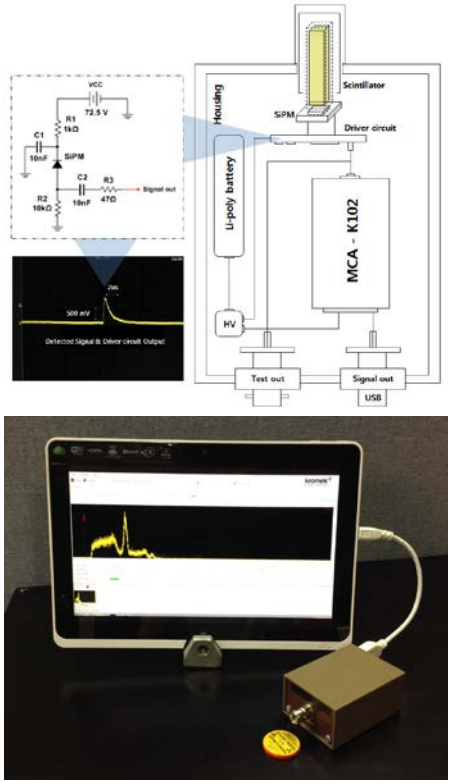

Fig. 2. Personal gamma spectrometer structure (top) and overall spectroscopy system (bottom).

Previously, charge-sensitive preamplifiers that convert scintillation detector charge signals into voltage signals, as well as shaping amplifiers that amplify the converted voltage signals and simultaneously shape them into Gaussian forms, were designed and used for signal processing in γ-ray spectrometry. However, such signal processing procedures cause signal attenuation due to impedance mismatch, decrease the signal-to-noise ratio through the amplification and shaping processes, and cause output signal loss due to detected signal overlap from the dead time.

Therefore, in this study, the previous signal processing stage was excluded considering the high electron amplification gains of SiPMs, and only the driver circuit of the scintillation detector was designed and built to analyse the output signal of the circuit. The left-hand side of Fig. 2 shows a 700 mV pulse signal with 2 μs pulse width that was generated by a ^{22}Na source and measured using the driver circuit. The voltage-supply unit consists of the main power supply and boosting voltage units. The boosting voltage unit was designed so that there is a boost input voltage of 7.2 V up to 73± 1.5 V, which is the input voltage of the SiPM. A Li-poly battery (7.4 V, 850 mAh) is used as the main power supply unit with a DC-DC converter module (UltraVolt, Inc.). The signal-analysis unit performs spectrometry analysis through a tablet PC, which constitutes the display unit, and also uses a miniature 4906-channel K102 Multichannel Analyser (Kromek Ltd., UK).

Energy spectra for various standard sources were measured using the fabricated personal gamma spectrometer. The live time was set to 300 s for all experiments. The standard sources were positioned 10 mm from the surface of the developed device. Fig. 3 shows the energy spectra obtained for the ^{133}Ba, ^{22}Na, ^{137}Cs, and ^{60}Co standard sources.

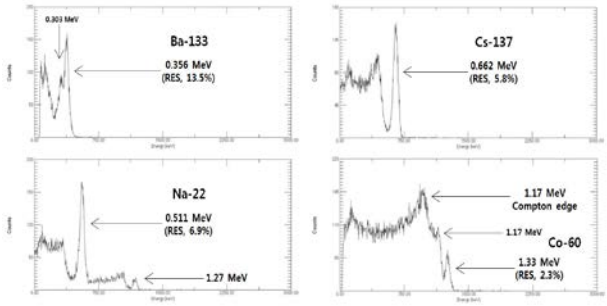

Fig. 3. Measured energy spectra for ^{133}Ba (0.356 MeV), ^{22}Na (0.511 MeV), ^{137}Cs (0.662 MeV) and ^{60}Co (1.33 MeV).

For the 0.356-MeV area of the ^{133}Ba source, 13.5 % energy resolution was obtained. In the case of the 0.511-MeV energy generated through positron annihilation during ß decay, 6.9 % energy resolution was obtained. For the 0.662-MeV energy region of the ^{137}Cs spectrum, 5.8 % energy resolution was obtained while, in the case of ^{60}Co, 2.3 % energy resolution was observed at 1.33-MeV energy. Peaks of 1.17 and 1.33 MeV could be clearly observed.

3. Conclusions

A personal γ spectrometer was fabricated and evaluated for application in radiation monitoring applications. The fabricated device exhibited good performance, as confirmed by the spectra obtained for several standard γ sources. The compactness, low-voltage supply, and high resolution of the developed prototype are very useful features as regards its application in a variety of fields, such as homeland security (HLS) and environmental radiation monitoring systems (ERMS).

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REFERENCES

[1] S. D Sordo *et al*, Progress in the development of CdTe and CdZnTe semiconductor radiation detectors for astrophysical and medical applications, Sensors, Vol.9(5), p. 3491, 2009.