Development of a Gamma Spectrometer using a Large NaI Scintillator and SiPMs

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1. Introduction

Scintillation detectors generally have been used in the gamma spectrometry, because of their high light yield and high gamma-ray detection efficiency compared to semiconductor detectors. A typical scintillation gamma spectrometer is composed of a NaI(Tl) scintillation crystal and a PM tube [1].

From last years, a Silicon Photomultiplier (SiPM) is being developed and expanding its application area as a substitute of PM tube due to its advantages like low operating voltage, small volume, and cheap production cost, MR compatibility [2].

In this research, the scintillation gamma spectrometer was developed using the array of SiPM instead of the PM tube. To preserve high detection efficiency, the NaI(Tl) scintillator of ordinary size was used. Instead, a light guide was used for the transport and collection of generated photons from the large scintillator to the small area SiPM without loss. This approach could make gamma spectrometer smaller, cheaper, easier to use, and these advantage are quite suitable to original purpose of scintillation gamma spectrometer.

2. Method and Results

2.1. Design of the gamma spectrometer

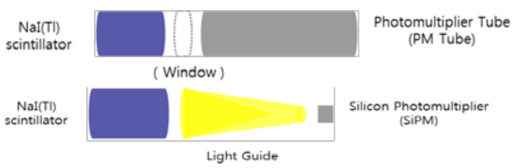


Fig. 1. Schematics of a general gamma spectrometer based on a PM tube and the proposed gamma spectrometer

Figure 1 shows the composition of the proposed SiPM-based gamma spectrometer compared to a general spectrometer. In a gamma spectrometer system, each component act as a source of fluctuation symmetrically and independently, therefore total fluctuation can be predicted statistically. Total FWHM is quadrature sum of the FWHM values for each individual source of fluctuation like the equation 1.

$$FWHM_{Total} = \sqrt{(FWHM_{Scint})^2 + (FWHM_{Detector})^2 + (FWHM_{Electric})^2} \quad (1)$$

Where the $FWHM_{Scint}$ is FWHM of the variation of the generated photons in a scintillator, the $FWHM_{Detector}$ is FWHM of the variance of the detector output, and the $FWHM_{Electric}$ is FWHM of the electric components output variation to the same detector signal.

The $FWHM_{Scint}$ is related to the number of generated photoelectrons N in the scintillator and the variation of that ΔN. There are several sources that make this fluctuation ΔN; the one of them is the photon generation point in the scintillator. According to the photon generation point in the scintillator, there are difference in the transport probability to detector ($\sigma_{Transport}$). This variation makes the photoelectric peak wide, energy resolution worse.

In the proposed gamma spectrometer which includes a light guide, parts of photons could be lost during transport to the sensor. As the effect of this loss, the number of generated photoelectrons decrease, and it leads to degradation of energy resolution. Conversely, this degradation of energy resolution due to variance of transport probability could be reduced by the design of the light guide.

2.2 Light transport and collection simulation

Before fabrication of the light guide, a series of computer simulation was performed for the effective design of the light guide. For the light transport from a scintillator and collection to SiPMs, DETECT 1997 was used. Two objectives of this simulation is 1) the comparison between the current PM tube-based system and the proposed system, 2) the prospection of characteristics of the light guide in the SiPM based system. Figure 2 and 3 are summaries of the whole process of DETECT simulation and simulated systems.

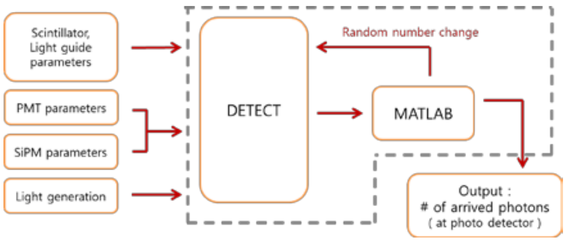


Fig. 2. Summary of the whole process of DETECT simulation

For realistic simulation, the parameters required to design scintillator, PM Tube, SiPM were from the actual products. PMMA(poly(methyl methacrylate)), which is usually used to make lens or window, was selected as a material of the light guide due to its low attenuation coefficient and high refractive index. Surface of the light guide was assumed as two type; the normal polished surface and the surface coated with reflective material.

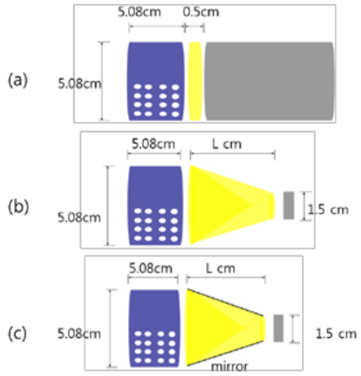
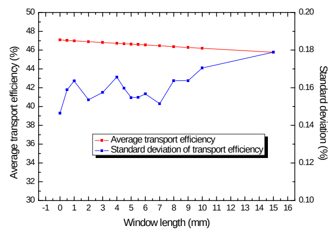


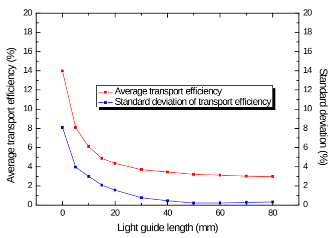
Fig. 3. 2D schematic of three systems in the simulation (a) a PM tube-based system, (b) a SiPM with normal light guide-based system (c) a SiPM with reflective light guide system White circles are the position of light generation

2.3 Simulation result

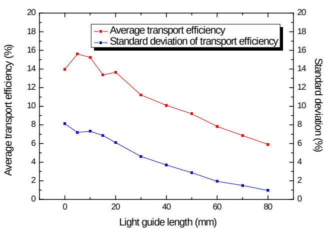
Figure 4 is the simulation results of each system; the average transport efficiency and their standard deviation. In the light guide-SiPM based system, the average transport efficiency was lower than that of general PM tube-based system, but the standard deviation of transport efficiency was also lower. These two results will makes negative and positive effect both to the energy resolution of gamma spectrometer. Therefore energy resolution change depends on relative effects from them.



(a)



(b)



(c)

Fig. 4. The average and standard deviation of transport efficiency in the simulation of system (a), (b), (c)

2.4. Test of the composed gamma spectrometry system

Figure 5 shows fabricated light guides with different length and coating materials in Table I. Before the test of the gamma spectrometer system which includes light guide and SiPM both, the characteristic of light guide was measured. Figure 6 shows the composition of test system for light guide only and light guide/SiPM both. From comparison between results in the (1) and (2), the effect from light guide only could be acquirable. This effect will be used to consider effect from each component in the result of (3).

The comparison between results in the system of (1) and (2) is shown in the figure 7. Of the all energy peaks, Teflon coated light guide(17mm, 60mm) shows less degradation, 60mm normal light guide (not coated) shows worst energy resolution. The energy resolution increase generally (means worse) in the range of 4~8%, but certain systems with light guides (17, 60mm Teflon coated), it is enough value for the gamma spectrometer.

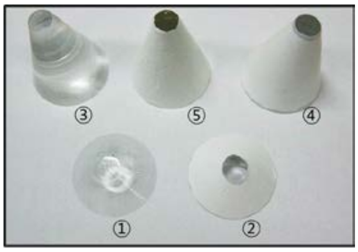


Fig. 5. Figure of the fabricated light guides

	②	②	③	④	⑤
Length	17mm	17mm	60mm	60mm	60mm
Coating	None	PTFE	None	PTFE	TiO_2

Table I. Details of the fabricated light guides

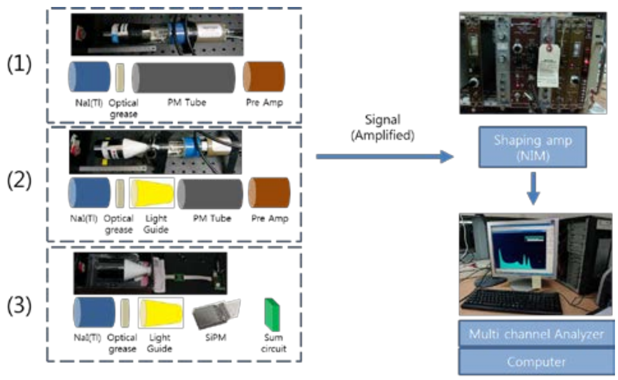


Fig. 6. Composition of test setup

The main reason of this degradation of energy resolution is loss of the generated photons in the light guide. Figure 8 is comparison of the number of generated photoelectron in PM tube. In the system with light guide, the number of generated photoelectron is only 20% of that of PM tube. Almost 80% of generated photons are lost before they reach the sensor.

This loss could be also verified in Table II. In the table II, the calibrated (with the Na-22 source) energy values of Cs-137 photoelectric peak in the systems including the light guide is similar with that of Co-57 photoelectric peak in the system directly coupled to the PM tube. It means the number of reached photons is similar even the energy of gamma-ray from Cs-137 (662keV) is much larger than that of Co-57 (122keV).

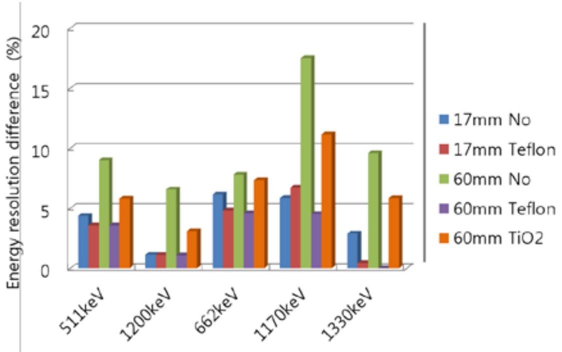


Fig. 7. The degradation of energy resolution at each energy peaks with difference light guides

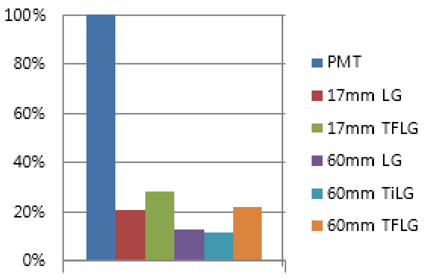


Fig. 8. Comparison of the relative number of generated photoelectron in PM tube

	PMT only (Co-57)	PMT & 17mm light guide (Cs-137)	PMT & 17mm PTFE light guide (Cs-137)	PMT & 60mm PTFE light guide (Cs-137)
Calibrated Energy (keV)	143.31	136	183	144
Resolution (%)	13.3	11.781	10.43	10.21

Table II. Comparison of between the systems in the same energy-channel calibration

Finally, the last system including an array of SiPM and a light guide was tested. The test results are summarized in Table III. The samples of light guide which shows good characteristics was chosen. At the 660keV, the system had the best energy resolution of 25%. (Figure 9.) The light guide which of length of 17mm and are coated with TPFE showed the best result. The reason of such poor resolution is being analyzed.

Energy	17mm light guide	17mm PTFE light guide	60mm PTFE light guide	60mm TiO_2 light guide
511 keV	54.4 %	31.16 %	44.68 %	59.48%
662 keV	43.81 %	25.09 %	35.4 %	41.04%

Table III. Energy resolution in the each light guide and SiPM

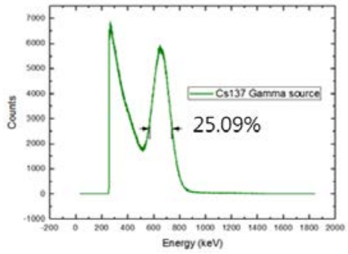


Fig. 9. The spectrum of Cs-137 with the SiPM and 17mm light guide coated with PTFE

3. Conclusion

Gamma spectrometry and gamma spectrometer is used to analyze gamma source in nuclear science, geochemistry, and astrophysics. In this research, gamma spectrometer which uses SiPMs instead of PM tube is proposed. The proposed gamma spectrometer has advantages of low cost, small volume, low operation voltage; but it has disadvantages of performances. To reduce this loss in performances, a light guide of effective structure is required. (Material, reflection type, tapering angle) For design of the light guide, DETECT simulation was performed. And through DETECT simulation, the characteristics of light guide could be prospected. Actual light guide was manufactured on the basis of this simulation result. Using the light guide, gamma spectrometer system was composed and tested. In the test result, gamma spectrometer using SiPM shows degraded energy resolution. The reason of this degradation is being analyzed and the test system is under modification.

REFRERENCES

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[2] B. Dolgoshein et al., Status report on silicon photomultiplier development and its applications, Nucl. Instrum. Methods. Phys. Res. A 563, pp 368-376, 2006.

Acknowledgement

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