Apply the Light Guide to Improve the Light Collection Efficiency of the Gamma Ray Camera

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1. Introduction

Coded-aperture-imaging (CAI) systems are being developed for environmental monitoring and nuclear safety. In particular, portable devices can be used effectively in the fields of homeland security and the application of nuclear plants [1]. Cerium doped $Gd_2Al_2Ga_3O_{12}$(GAGG(Ce)) has a relatively high density (6.63 g/cm^3), excellent energy resolution, and high light yield. Silicon photomultiplier (SiPM) operates at a lower voltage than conventional PMT and can be compacted [2]. Therefore, it is considered a better choice to use SiPM when developing the imaging system.

In previous work, we obtain optimized scintillator pixel size from the coupling between SiPM in 12 x 12 pixel form and 12 x 12 scintillator arrays of varying pixel sizes. Thus, we developed a gamma-ray imaging system based on coupled 12 x 12-pixel SiPM with GAGG(Ce) scintillator array [3]. However, since the GAGG(Ce) pixel does not exactly match the SiPM sensor, the light generated in the scintillator may be lost to the gap area between the SiPM pixels, and the leaked light may react with the adjacent pixel to cause problems due to optical cross-talk [4]. In this paper, we conducted to apply a light guide to improve light collection efficiency and reduce optical cross-talk between adjacent SiPM pixels. We compared the peak channel (gain), energy spectrum, and image quality based on the application of the light guide.

2. Materials and Methods

Table I: Main parameter of the components.

Scintillator pixel size	4 x 4 mm^2
Detector pixel size	3 x 3 mm^2
Detector pixel gap	1.2 mm
Mask pixel size	0.42 x 0.42 cm^2
Mask material	Tungsten (ρ = 19.3g/cm$^{3)}$

Table I is for the main parameter of the components used in this experiment. Figure 1 shows GAGG(Ce) (Epic-Crystal Co. Ltd., China), a light guide (Epic-Crystal Co. Ltd., China), and SiPM (ArrayC-30035-144P, On Semiconductor) used in this study.

The light guide collects scintillation photons from crystal pixels [5]. The light guide used in this experiment is shown in Fig. 2 in order to avoid vacancy between the scintillator and pixel of SiPM. Figure 3 shows a comparison of the light loss in terms of the coupling of GAGG(Ce) and SiPM (left) and the application of the light guide (right) to GAGG(Ce) and SiPM combinations.

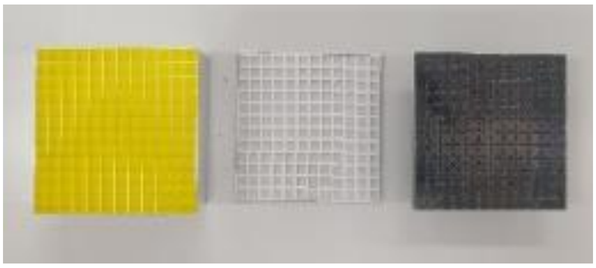

Fig. 1. Image of the GAGG(Ce) (left), light guide(center), and SiPM(right) used in the experiment.

Using a ^{137}Cs source (activity: 16.54 μCi), we compared the variation of peak channel, energy resolution (R), peak-to-valley ratio (PVR), and peak-to-Compton ratio (PCR). Also, peak signal-to-noise ratio (PSNR), normalized mean-square error (NMSE), and structure similarity (SSIM) were also evaluated with reconstructed images obtained under the same conditions to compare the quality of the images. As PSNR value approaches infinity, the NMSE approaches 0, and SSIM value approaches 1, the higher image quality is evaluated.

Fig. 2. Light guide side view and parameters.

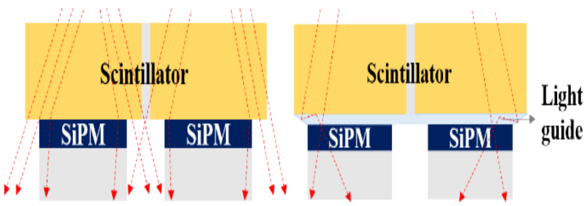

Fig. 3. Comparison of light losses by light guide application.

3. Results

Figure 4 shows a 2D-flood histogram obtained by combining GAGG(Ce) and SiPM with a light guide between GAGG and SiPM. Figure 5 shows the 1D-sum profile, which shows a low edge intensity. Because the difference between the GAGG(Ce) and SiPM intervals causes light leakage, reducing the amount of energy accumulated. Comparing Fig. 5 (a) and Fig. 5 (b), it can be confirmed that intensity from both ends is 3.507% higher on average with a light guide applied. Figure 6 compares and displays the energy spectra obtained by the combination of the two sensors mentioned. The energy spectrum is obtained from the sensor incorporating the light guide observed that the peak center channel value of ^{137}Cs increased by about 16.03% from the previous value. This means that the peak center channel has increased due to increased light collection efficiency. At this time, it was confirmed that the peak-to-Compton ratio increased to 15.87, 16.45, and the peak-to-valley ratio increased to 8.67 and 8.64, respectively. Also, energy resolution has improved from 8.03% to 7.36%.

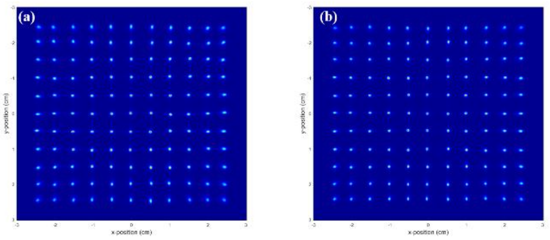

Fig. 4. The image of the 2D-flood histogram of the array coupled without the light guide (a), and with the light guide (b).

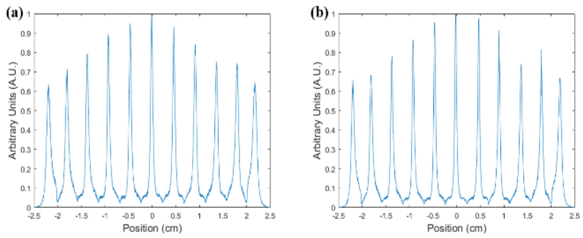

Fig. 5. The 1D-sum profile of the array is coupled without the light guide (a), and with the light guide (b).

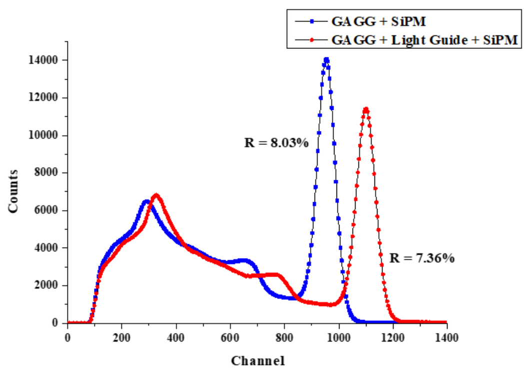

Fig. 6. Comparison of energy spectrum according to light guide application.

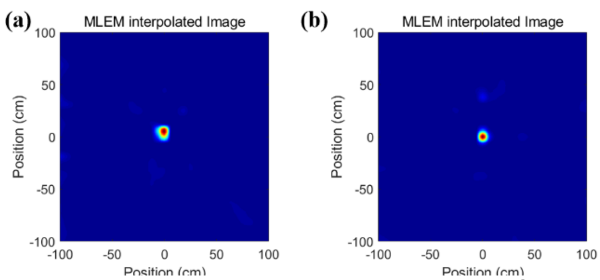

Fig. 7. Reconstructed image for a point source of ^{137}Cs at a distance of 0.5 m.

Figure 7 is reconstructed image by MLEM applying a centered-mosaic MURA mask based on tungsten. The results of the quality analysis of both images are shown in the Table II. As shown the Table II, the reconstructed image from the sensor equipped with the light guide has a higher value in PSNR, SSIM and lower in NMSE. This means that higher quality images were obtained when light guide was applied.

Table II: Comparison of metrics for image quality evaluation.

	GAGG(Ce) + SiPM	GAGG(Ce) + light guide + SiPM
PSNR	28.49	39.28
NMSE	9.07×10^{-4}	1.04×10^{-4}
SSIM	0.9157	0.9824

4. Conclusions

In this study, the effects of the light guide combined between scintillator and SiPM to increase the amount of light collection efficiency was investigated. By applying light guide, we confirmed that it can improve energy resolution with increasing amount of light, and improve metrics of quality for reconstructed images. In the future, while maintaining the area of the GAGG(Ce) scintillator array, we will adapt light guide into a 24 x 24 pixelated scintillator array. The light guide will be applied to help to minimize the effect of reducing effective active area and light loss.

Acknowledgements

This work was partly supported by Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government (MOTIE) (20181520302230) and by the Nuclear Safety Research Program through the Korea Foundation of Nuclear Safety (KoFONS) using the financial resource granted by the Nuclear Safety and Security Commission (NSSC) of the Republic of Korea (No. 1903011-0119-CG100).

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