Transactions of the Korean Nuclear Society Virtual Autumn Meeting
October 21-22, 2021

Effects of Improved Light Collection on Coded-aperture based Gamma-ray Imager

Suyeon Hyeon, Jihwan Boo, Seoryeong Park, and Manhee Jeong*
Nuclear & Energy Dept., Jeju National University, 102 Jejudaehak-ro, Jeju-si, Jeju-do, 63243
**Corresponding author: mhjeong@jejunu.ac.kr*

1. Introduction

The coded-aperture gamma-ray imaging equipment developed through previous work, the *Energy Particle Sensor for the Identification and Localization of Originating Nuclides (EPSILON-G)*, can perform a 2-D position (x, y) of radiation sources, ambient gamma dose rate measurement, and simultaneously with an energy spectrum [1,2]. Important components in the detector module are scintillators and photo sensors. Previous studies have shown that using silicon photomultiplier (SiPM) with the same pixel pitch but an effective area of 3 × 3 mm^2 and pixelated scintillators with an effective area of 4 × 4 mm^2 causes light loss and cross-talk, which affects location resolution [2]. As a result, it was determined that it had a negative impact on the identification of fast localization and gamma sources and that it was overcome by software and hardware methods. In this study, we propose a method to match the effective area of SiPM with a scintillator with SiPM with an effective area of 4 × 4 mm^2 to increase the light collection efficiency. For quantitative evaluation of the proposed methods, spatial resolution, energy spectrum analysis, and image quality analysis such as peak signal-to-noise ratio (PSNR), the normalized mean square error (NMSE), and the structural similarity (SSIM) were conducted.

2. Methods and Results

2.1 GAGG(Ce) scintillator

The cerium doped $Gd_2Al_2Ga_3O_{12}$ (GAGG(Ce)) has a higher light field than NaI(Tl), and the effective atomic number is 54.4 and a relatively high density of 6.63 g/cm^3 [3]. The GAGG(Ce) scintillator (Epic-crystal Co. Ltd., China) consists of 144 pixels of 4 × 4 × 20 mm^3.

The reason why the effective area was determined to be 4 × 4 mm^2 is to optimize the energy resolution as the thickness of the reflector used can affect the energy resolution (R) of the energy spectrum and the effective response volume of the scintillator [4].

2.2 SiPM array

Figure 1 shows SiPM produced to improve existing SiPM and light collection. To increase the light collection efficiency of gamma-ray imaging equipment, a 12 × 12 pixels array was produced by assembling it on a printed circuit board (PCB) substrate with SiPM pixels of the same size as the scintillator pixel effective area. The conventional SiPM used in previous study is MicroFC-30035(C-type). C-type SiPM has low dark count rate, high photo detection efficiency (PDE). It also has high gain, low operating voltage, excellent temperature stability, high output uniformity, and single-photon sensitivity from UV to visible light wavelength.

The customized SiPM array is made of 144 MicroFJ-40035(J-type) which has lower dark count rate, higher PDE, higher fill factor, and higher sensitivity than that of C-type SiPM array.

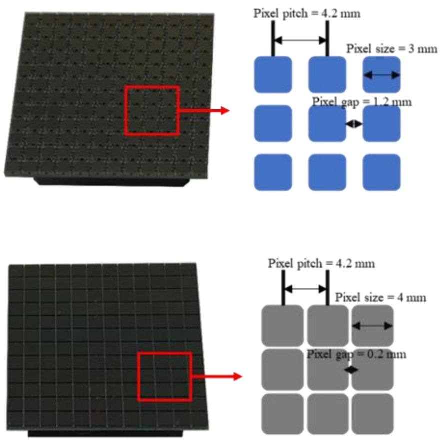

Fig. 1. Example of SiPM and pixel structure of ArrayC-30035-144P with 4.2 mm pixel pitch, 3 mm pixel size, and 1.2 mm pixel gap (top), example of SiPM and pixel structure of ArrayJ-40035 with 4.2 mm pixel pitch, 4 mm pixel size, and 1.2 mm pixel gap (bottom).

2.3 Spatial Resolution

To comparison spatial resolution, a ^{137}Cs (379.62 kBq) source was placed 30 cm away from the detector, which is used for confirming the 2D flood map. Figure 2 shows the 2D flood map obtained using both conventional and customized SiPM array which have the same effective area of scintillator pixels.

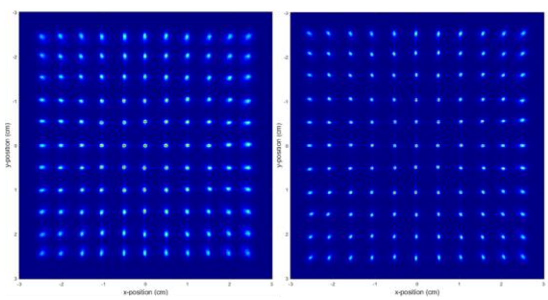

Fig. 2. 2D flood histogram derived from GAGG(Ce) scintillator array coupled with 3 × 3 mm^2 SiPM array (left) and 4 × 4 mm^2 SiPM array (right). The ^{137}Cs is centered 30 cm away from the face of the detector.

For quantitative evaluation, 1D-sum profile analysis was conducted. Figure 3 shows the full width at half maximum (FWHM) of peaks located at each center in the acquired 1D-sum profile, showing 607.19 μm and 460.16 μm, respectively, and confirmed that pixel identification capability is improved.

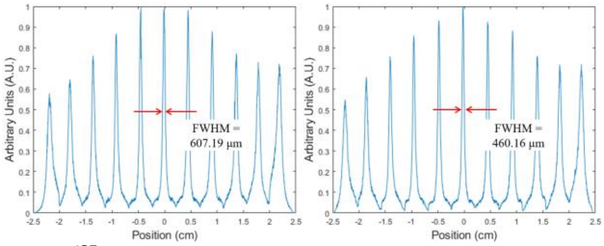

Fig. 3. ^{137}Cs 1D-sum profile across row axis of 2D flood map of Fig. 1 for GAGG(Ce) scintillator array coupled with 3 × 3 mm^2 SiPM array (left), 4 × 4 mm^2 SiPM array (right).

2.4 Spectrum Analyze

Figure 4 shows a comparison of energy spectra when using conventional SiPM array and newly fabricated SiPM array. The energy resolution obtained by using customized SiPM array was 6.49% which was better than the 7.84% energy resolution obtained by using conventional one.

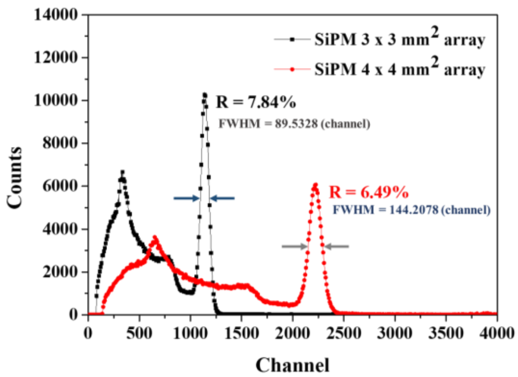

Fig. 4. Comparison ^{137}Cs gamma ray spectrum obtained from GAGG(Ce) scintillator array coupled with 3 × 3 mm^2 pixel SiPM array, 4 × 4 mm^2 SiPM array.

Table I: Comparison of central channel values of PVR, PCR, energy resolution, peak based on energy spectrum obtained in each experiment case.

	3 × 3 mm^2 pixel array	4 × 4 mm^2 pixel array
PVR	10.183	11.286
PCR	4.791	5.59
R @662 keV [%]	7.84	6.49
Centered peak channel	1142	2222

In addition to the peak-to-valley ratio (PVR), peak-to-Compton ratio (PCR), and central peak channel values are measured from the energy spectra. Table 1 summarizes the comparison of results.

2.5 Image comparison

Figure 5 shows reconstructed images using the Maximum-Likelihood Experiment Maximization (MLEM) methods using a tungsten-based centered-mosaic MURA mask for centered gamma-ray source. Table 2 shows the results of PSNR, NMSE, and SSIM, which are evaluation indicators of image quality, for reconstructed images obtained by using both type of SiPM arrays.

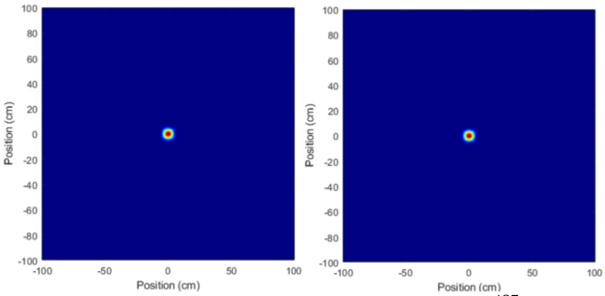

Fig. 5. Reconstructed image for a point source of ^{137}Cs at the distance of 0.5 m, acquired by GAGG(Ce) scintillator array coupled with 3 × 3 mm^2 SiPM array (left), 4 × 4 mm^2 SiPM array (right).

Table II: Comparison of metrics for image quality evaluation

	3 × 3 mm^2 pixel array	4 × 4 mm^2 pixel array
PSNR	54.74	66.93
NMSE	3.3×10^{-5}	8.07×10^{-7}
SSIM	0.997	0.999

If the PSNR is 30 dB or higher, it is considered to be an excellent quality [5], so in both cases, the reconstructed images could be considered that they have good image quality and there are no significant differences in image quality metrics.

3. Conclusions

In this study, we identified how improving light collection efficiency on developed *EPSILON-G* equipment affects spatial resolution, energy resolution, and image quality. Improved spatial resolution and energy resolution were obtained when the method of matching the effective area of the scintillator pixel with the effective area of the SiPM pixel was applied compared to the conventional SiPM pixel. Although image quality does not show significant improvement, it is believed that it will be helpful in terms of nuclide analysis capability of coded-aperture based gamma-ray imaging equipment.

In this conference, we will announce the impact of gamma-ray imager with improve the light collection by additionally conducting field-of-view (FOV), angular resolution, and sensitivity tests.

Acknowledgement

This work was partly supported by Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government (MOTIE) (20181520302230), 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).

REFERENCES

[1] M. Jeong, M. Hammig, Development of hand-held coded-aperture gamma ray imaging system based on GAGG (Ce) scintillator coupled with SiPM array, Nucl. Eng. Technol., Vol.52, pp.2572-2580, 2020.
[2] S. Park., J. Boo, M. Hammig, & M. Jeong, Impact of aperture-thickness on the real-time imaging characteristics of coded-aperture gamma cameras. Nucl. Eng. Technol., Vol.53, pp.1266-1276, 2020.
[3] M. P. Taggart, M. Nakhostin, P. J. Sellin, Investigation into the potential of GAGG:Ce as a neutron detector, Nucl. Instrum. Methods A, Vol.931, pp.121-126, 2019.
[4] M. Jeong, B. Van, B. T. Wells, L. J. D'Aries, and M. D. Hammig, Comparison between Pixelated Scintillators: CsI(Tl), LaCl 3(Ce) and LYSO(Ce) when coupled to a Silicon Photomultipliers Array, Nucl. Instrum. Methods A., Vol.893, pp.75–83, 2018.
[5] Y.A. Syahbana, Herman, A.A. Rahman, K.A. Baker, Aligned-PSNR(APSNR) for Objective Video Quality Measurement (VQM) in Video Stream over Wireless and Mobile Network, World Congress on Information and Communication Technologies (WCIT), pp.330-335, 2011.