Image quality comparison for different type of SiPM coupled with GAGG(Ce) scintillator arrays for the coded-aperture gamma ray imaging

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1. Introduction

Recently, silicon photo-multipliers (SiPMs) have demonstrated the necessary gain and dark current levels for single-photon detection, enabling them to replace PMTs in many applications [1-2]. SiPMs have other features that improve their robustness and usability compared to traditional PMTs; namely, they are compact, operate on low voltage (typically under 50 V), and are insensitive to magnetic fields. The photo-detection efficiency (PDE) is typically higher than PMTs, with recent devices having a maximum PDE of ~50% [3]. In particular, On semiconductor offers two types of SiPMs that are used in radiation applications, the C-series and the J-series that both have high PDE with low dark count rate. The C-Series SiPM possesses a high gain, a low operating voltage, excellent temperature stability, high output uniformity, and a single photon sensitivity from UV to visible wavelengths. The J-series, on the other hand, shows higher sensitivity in the blue wavelengths, a higher fill-factor, a similarly low operating voltage and is optimized for fast timing applications such as time-of-flight positron emission tomography (PET). When the pixel size is the same as in Fig. 1, but the pixel pitch and the pixel gap are different, we would like to know how it will affect detection effectiveness and spectral information decisions, and how this affects the image quality in the final coded-aperture imaging system.

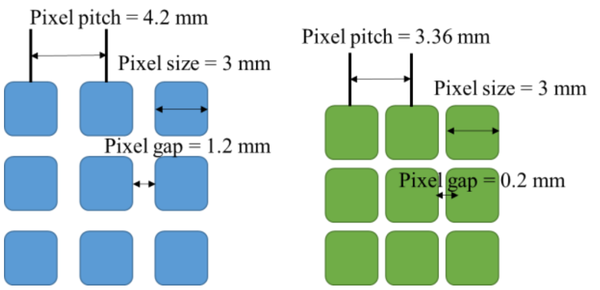

Fig. 1. Example of pixel structure of ArrayC-30035-144P (left) and ArrayJ-30035-16P (right).

In this paper, we examined how different physical properties of SiPMs coupled with GAGG(Ce) scintillator arrays affect the performance of code-aperture imaging (CAI) systems. For this reason, a comparison of spectral characteristics with a pixelated GAGG(Ce) array using both one ArrayC-30035-144P and nine ArrayJ-30035-16P was evaluated for energy resolution, peak-to-Compton ratio, and peak-to-valley ratio. 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 acquired by the CAI system. The physical characteristics of ArrayC-30035-144P and ArrayJ-30035-16P used in this paper are shown in Table I. The biggest physical differences between the two types of sensors are PDE at 420 nm, after-pulsing probability, and dark count rate (DCR).

2. Methods and Results

TABLE I:
SUMMARY OF THE MAIN PARAMETERS FOR ARRAYC-30035-144P (C-TYPE) AND ARRAYJ-30035-16P (J-TYPE).

Series	C-type	J-type
Key feature (Cells)	• 64% Fill factor • Lowest noise (4774)	• 75% Fill factor • Best timing performance (4774)
Sensors & Microcell Size	3 mm, 35 μm	3 mm, 35 μm
PDE @420nm	31%	38%
V_{br}	24.5 V	24.5 V
Gain	3 x 10^6	3 x 10^6
After-pulsing	2%	0.75%
Crosstalk	7%	8%
Dark Count Rate	30 kHz/mm^2	60 kHz/mm^2

Figs. 2 and 3 show components for the coded-aperture imaging system based on 12 x 12 SiPM array (ArrayC-30035-144P and ArrayJ-30035-16P, On semiconductor) coupled with 12 x 12 pixels GAGG(Ce) scintillator arrays partitioned 4 x 4 x 20 mm^3 pixel for C-type and 3.16 x 3.16 x 20 mm^3 pixel for J-type and MURA mask for each type of SiPM. Each mask pixel size is 4.105mm and 3.299mm for C-type and J-type. And Fig. 5 shows the comparison of spectral performance for the C-type SiPM coupled with 5.02 x 5.02 cm^2 plane of GAGG(Ce) scintillator and J-type SiPM coupled with 9 of 4 x 4 pixels GAGG(Ce) scintillator array partitioned 3.16 x 3.16 mm^2.

Fig. 6 shows when the 1m distant ^{137}Cs point source is located at the center of field of view using different type of SiPM. The result of this study, an average energy resolution, a peak-to-valley ratio, and a peak-to-Compton ratio was 7.97%, 19.10, and 7.89 when the system uses ArrayC-30035-144P. And when use ArrayJ-30035-16P, an average energy resolution, a peak-to-valley ratio, and a peak-to-Compton ratio was 7.11%, 15.54 and 5.4. Peak signal-to-noise ratio(PSNR), normalized mean-square error (NMSE),and structure similarity (SSIM) were evaluated 26.4368, 9.14 x 10^{-4}, 0.8512 when use ArrayC-30035-144P, and 27.7356, 9.13 x 10^{-4},and 0.8616 when use ArrayJ-30035-16P.

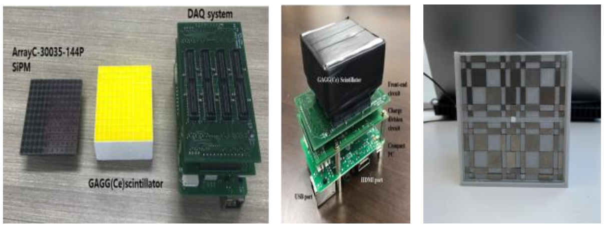

Fig. 2. Components for the coded-aperture imaging system based on 12 x 12 SiPM array (ArrayC-30035-144P, On semiconductor) coupled with 12 x 12 pixels GAGG(Ce) scintillator array partitioned 4 x 4 x 20 mm^3 pixel and MURA mask (right).

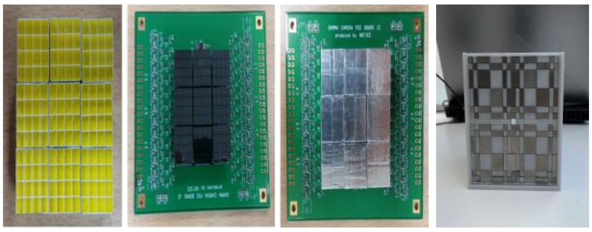

Fig. 3. Components for the coded-aperture imaging system based on 9 of 4 x 4 SiPM array (ArrayJ-30035-16P, On semiconductor) coupled with 9 of 4 x 4 pixels GAGG(Ce) scintillator array partitioned 3.16 x 3.16 x 20 mm^3 pixel and MURA mask (right).

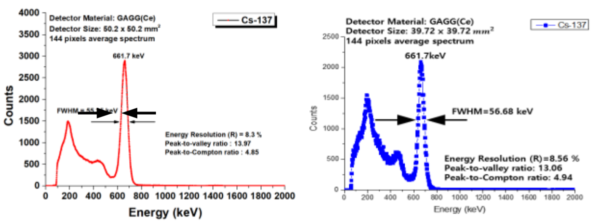

Fig. 5. (Left) ^{137}Cs gamma-ray spectra of average of 144 pixels GAGG(Ce) scintillators coupled with ArrayC-30035-144P. (Right) Photopeak mean height (ADC number) as a function of gamma energy for the same SiPM array.

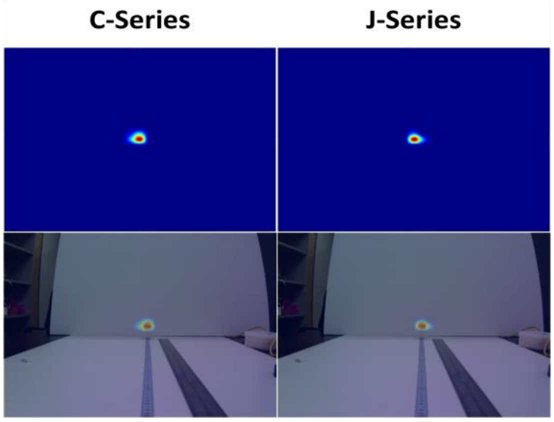

Fig. 6. Image formation of ^{137}Cs point source located at 1m from the detector. The top row shows the MLEM image and the bottom row displays the overlay between the radiographic image and optical image.

3. Conclusions

In the coded-aperture imaging system, we will suggest a new readout method for removing Compton scatting events that can cause blurring and mislocation in reconstructed images. The new readout method effectively identified the Compton scatting event, which resulted in improved quality and good positioning. This method will be used to detect the accurate location of radiation sources in real-time and to develop equipment for nuclide analysis in the field of medical, nuclear industry, and homeland security.

In this Summary, the J series has a higher PDE than the C series and similar in Gain, but as you can see in Figure 4, the J series is about twice as high as the C series. It has been confirmed that these characteristics also make the spectrum more ideal, and that better image quality can be obtained during image reconstruction.

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