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Performance comparison of finely pixelated LYSO- and GAGG-based Si-PM gamma cameras for high resolution SPECT

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ABSTRACT

Although Lu-based scintillators, including Ce-doped $Lu_{1.8}Y_{0.2}SiO_5$ (LYSO) scintillators, are often used for positron emission tomography (PET) detectors, they are not commonly used in gamma cameras for single-photon emission computed tomography (SPECT) because background counts due to contamination of the natural radioisotope in Lu are detected. However, several studies report that deterioration in image contrast due to background counts of the natural radioisotope is not critical and thus LYSO is promising for use in SPECT detectors. Meanwhile, a new scintillator, the Ce-doped $Gd_3Al_2Ga_3O_{12}$ (GAGG) with a high light yield and no natural radioisotope, has been developed and is also thought to be a promising scintillator. Thus, we compared the performance of LYSO with that of GAGG to determine which is more appropriate for a silicon photomultiplier (Si-PM)-based high-resolution small field-of-view (FOV) gamma camera for SPECT. We used finely pixelated LYSO and GAGG plates that were optically coupled to Si-PM arrays to form gamma cameras and measured the basic performance for 122-keV gamma photons. The energy resolutions of the LYSO- and GAGG-based Si-PM gamma cameras were 30% and 23% full width at half maximum (FWHM), respectively. The intrinsic spatial resolution of the GAGG (~0.5 mm FWHM) based gamma camera was better than that of the LYSO (~0.6 mm FWHM). The background counts of the LYSO-based gamma camera were 28 times larger than that of the GAGG. Based on these results, we conclude that GAGG is more appropriate than LYSO for the development of a Si-PM based gamma camera for high resolution SPECT.

1. Introduction

After Anger developed the first gamma camera in 1952 [1], various scintillators have been created for radiation detection. Since each scintillator has its own unique properties, it is important to select an appropriate scintillator in accordance with its intended use. Gamma cameras intended for single-photon emission computed tomography (SPECT) use NaI(Tl) because of the large light yield and relatively low cost. Most scintillators intended for photon emission tomography (PET) detectors use lutetium (Lu)-based scintillators such as Lu_2SiO_5 (LSO) or Ce-doped $Lu_{1.8}Y_{0.2}SiO_5$ (LYSO) because of their high stopping power, large light yield, and short decay time [2]. Recently, a new type of photodetector, the silicon photomultiplier (Si-PM), has been developed and is now being used in PET detectors because Si-PM-based scintillation detectors have good timing properties when combined with suitable scintillators [3,4]. Si-PM is also promising for small field-of-view (FOV) gamma cameras for single photon emission radionuclides [5].

Lu-based scintillators, including LYSO scintillators, have high density and high light yields, and thus may be suitable for SPECT Si-PM-based gamma cameras. However they contain approximately 2.6% of Lu's natural radioisotope [6,7]. A Lu-based scintillator produces background counts from the natural radioisotope that emit gamma photons and beta particles [6,7]. Because the coincidence method is used and a relatively high energy threshold level is applied when Lu-based scintillators are used for PET detectors, the background counts of the Lu-based scintillator are not a serious problem if the lower energy window levels are set higher than ~350 keV [6], except in low-activity imaging applications [8]. However, in a SPECT gamma camera, it is usually impossible to set such a high energy threshold level. Furthermore, the coincidence method cannot be used for SPECT gamma cameras; thus, the background counts from Lu are a much more serious problem. Nevertheless, there are several papers on simulating or developing gamma cameras for SPECT using LYSO [9–12]. These papers

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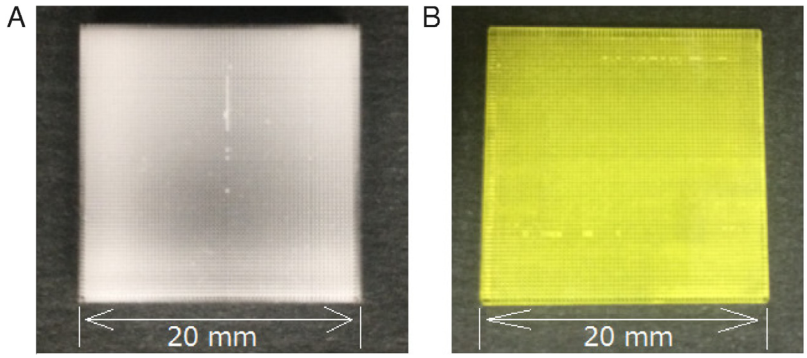

Fig. 1. Photos of finely pixelated LYSO (A) and GAGG plates (B).

Table 1
Major property of LYSO and GAGG [16].

Scintillator	LYSO	GAGG
Density [g/cm^3]	7.10	6.63
Light yield [ph/MeV]	25 000	42 000

report that image contrast degradation due to LYSO's background counts is not critical for gamma cameras used in SPECT.

Recently a new scintillator, the Ce-doped $Gd_3Al_2Ga_3O_{12}$ (GAGG), has been developed [13–15]. GAGG has a large light yield. Table 1 compares the basic properties of LYSO with GAGG [16]. Although GAGG is thought to be a promising scintillator for SPECT gamma cameras, it is unclear whether GAGG is better than LYSO for this purpose, especially when combined with Si-PMs. Thus, we developed Si-PM-based LYSO and GAGG gamma cameras and compared their performance in terms of energy resolution, spatial resolution, background counts, and sensitivity to determine which is appropriate for a high-resolution Si-PM-based gamma camera.

2. Materials and methods

2.1. Configuration of the Si-PM-based gamma cameras

To improve the spatial resolution of the gamma camera detectors, finely pixelated scintillator plates for both LYSO and GAGG were used for the performance comparison of the Si-PM based gamma cameras. Photographs of the finely pixelated LYSO and GAGG plates are shown in Fig. 1 (A) and (B), respectively. The pixel sizes of both plates were 0.2×0.2 mm with 0.1-mm-wide slits between pixels. The slits were made using a dicing technique [17]. The size of the LYSO plate was $20 \times 20 \times 2$ mm^3 and that of the GAGG plate was $20 \times 20 \times 1$ mm^3. The LYSO plate was originally intended for use in a gamma imaging detector for high energy gamma photons; thus, it was thicker than the GAGG plate.

Each scintillator plate was optically coupled to a Si-PM array with 1.5-mm-thick light guides using silicon rubber (Shin-Etsu Silicones KE-420). We show a photo of the Si-PM array used for the gamma cameras in Fig. 2. The Si-PM arrays used for the Si-PM gamma cameras had 8×8 channels made of 3 mm $\times$ 3 mm channel sizes that are made up of four sets of Si-PM arrays (Hamamatsu MPPC S11064-050P) arranged in a 2×2 matrix.

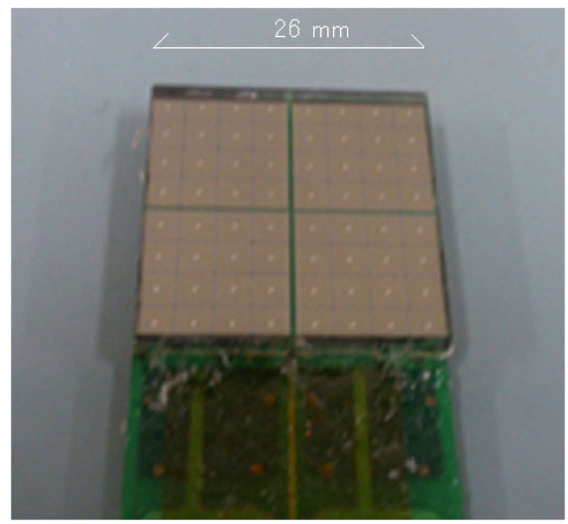

Fig. 2. Photo of 8×8 Si-PM array used for gamma cameras.

Fig. 3 shows the block diagram of the data acquisition system used for the gamma cameras. The signals from the Si-PM array were fed to a weight summing circuit made of high-speed feedback operational amplifiers that summed for rows and columns and then weight summed with position-dependent linear gains to produce the weighted sum signals. These weight-summed signals were fed to analog-to-digital (A-D) converters to digitize the signals and digitally integrate for 320 ns. The two-dimensional distribution was derived by calculating the center of gravity for the X and Y positions and the energy distribution was also calculated for each pixel. These calculations were performed digitally by a field programmable gate array (FPGA) and the calculated results were fed to a personal computer (PC).

2.2. Performance evaluation

2.2.1. Energy resolution

We acquired the energy spectrum by uniformly irradiating ^{57}Co gamma photons (122 keV) to the surface of each Si-PM-based gamma camera. We set regions of interest (ROIs) on the image and evaluated the energy spectrum. We plotted the energy spectra and measured the energy resolution in full width at half maximum (FWHM).

2.2.2. Intrinsic spatial resolution

We estimated the intrinsic spatial resolution using a bar pattern phantom made of tungsten, shown in Fig. 4, which has 0.3-mm to 0.6-mm slit areas in it. After the phantom was set on each Si-PM gamma camera, gamma photons from ^{57}Co gamma photons (122 keV) were irradiated and the images were acquired. The intrinsic spatial resolution can be estimated at a slightly smaller value than double of the width of the smallest slit of the bar pattern phantom [18].

2.2.3. Background counts and sensitivity

We measured the background counts and the system sensitivity for the ^{57}Co point source with a 1-mm diameter pinhole collimator attached to each gamma camera. We show a schematic drawing of the