Coded-aperture imaging system characteristics based on GAGG:Ce scintillator array

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1. Introduction

Gadolinium aluminum gallium garnet ($Gd_3Al_2Ga_3O_{12}$ or GAGG) is a high-density, high absorption coefficient material [1]. Our coded-aperture based gamma ray imager development is driven by the desire to image the gamma ray flux sprung from the surrounding environment following neutron-based active interrogation, for application in stand-off environmental radiation area mapping, demanding both good energy-resolution and large active areas [2–4].

The prototype technology, called *EPSILON* (**E**nergetic **P**article **S**ensor for the **I**dentification and **L**ocalization of **O**riginating **N**uclei), is based on a 12 x 12 pixelated inorganic scintillator coupled to a position-sensitive silicon-based photonic readout, a detector module that can serve as a single element in an arrayed instrument if large intercept areas are required by the application.

In this paper, we evaluate the bright (50,000 photons/MeV) oxide scintillator, cerium-doped GAGG(Ce) that is partitioned on both the scintillator and photonic readout planes. A 12 x 12 pixel silicon photomultiplier (SiPM) array is coupled to a GAGG(Ce) scintillator array and tested for a coded-aperture based gamma ray imaging system. For the evaluation of characteristics for the GAGG(Ce) based coded-aperture imaging system for gamma camera, *EPSILON-G*, the full-width at half maximum (FWHM) energy resolutions at 511keV, 662 keV, and 1173.2 keV, will be presented. In addition, pixel-identification resolutions will also be presented.

2. Methods and Results

2.1 GAGG(Ce) Scintillator Arrays

Suitable scintillators for gamma-ray imaging possess a high light yield, a fast decay time, a high effective Z number, and high density, for both efficient radiation detection and good energy resolution [1,5,6]. GAGG(Ce) scintillators from Epic-crystal Co. Ltd. in China and Furukawa Denshi Co. Ltd. in Japan have high light yield (50,000 photons/MeV), a fast decay time of the main photonic decay component (87 ns, 90%) and excellent energy resolution (4.8-11.9%) [5,6]. The material has a relatively high density of 6.63 g/cm^3 and an effective atomic number of 54.4. The GAGG(Ce) scintillators emit a light-yellowish color light, are not hydroscopic, and have no intrinsic radioactivity.

2.2 SiPM Array and Data Acquisition System

The 12 x 12 SiPM array (ArrayC-30035-144P, On semiconductor) which has a 50.02 x 50.02 mm^2 of active area and 4.2 mm pixel pitch can be operated by applying an over bias from 1V to 5V when the breakdown voltage is 24.5V. The light pulse from the scintillator excitation and decay is converted into a current signal in the SiPM array, which is matched to have the same area and number of pixels. The photoelectric conversion gain of 10^5 to 10^7 is realized in the photo-sensor depending on the bias voltage applied to the SiPM. The bias voltage supply circuit provides a voltage of 0 V to 30 V and a maximum current of 2 mA to the SiPM through a DC-DC convertor. The bias voltage adjustment is digitally controllable to approximately 0.1 V accuracy.

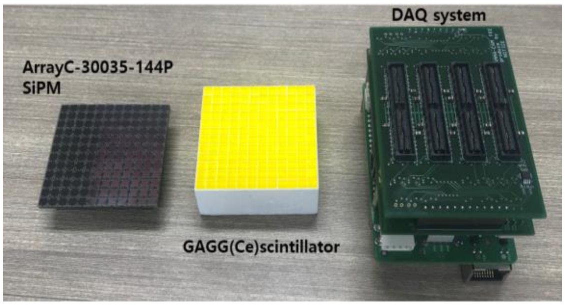

Fig. 1. System components for testing GAGG(Ce) scintillator array coupled with a large area SiPM with data acquisition system composed of front-end circuit, charge division circuits, and Raspberry Pi 4 board.

In reducing the channel multiplicity, the signals from 144 pixels are first reduced to 12 for each of orthogonal X and Y direction. The signals of the channels are tied together and added. An Anger logic circuit is used to modify the 12 signals for each of the X and Y axes by a number corresponding to their relative row (or column) position- 1 to 12 in a given direction- before they are added together. In the digital signal processing circuit, the magnitude of the detector signal and the detected position are extracted from the input waveform. The data obtained from the digital signal processing circuit is transferred to the CPU board through the USB2 protocol. The CPU board is equipped with an ARM CPU based on the Linux OS that utilizes a Raspberry PI board.

2.3 Energy Resolution Measurements

Fig. 2a shows the best energy resolution of a single pixel, at 5.49 %, noting that the low-energy shoulder on the peak corresponds to the Gd K_α (44.5 keV) escape peak. If a simple single-point (662 keV channel number) calibration is utilized, then the mean resolution increases to 8.3 % at 662 keV, as shown in Fig. 2b. Furthermore, the relatively high density of the material results in an excellent PCR and PVR, compared to the equivalent CsI(Tl), $LaCl_3$(Ce) and LYSO(Ce) scintillators characterized in Ref [3].

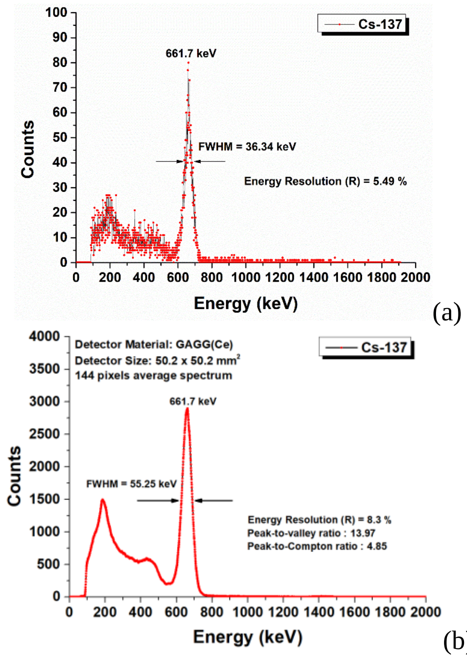

Fig. 2. ^{137}Cs gamma ray spectra of (a) single pixel and (b) average of 144 pixels of 4 x 4 x 20 mm^3 GAGG(Ce) scintillators for 5 minutes of detection time when the source is positioned at 10 cm from the face of the detector module.

2.4 Flood Histogram Quality

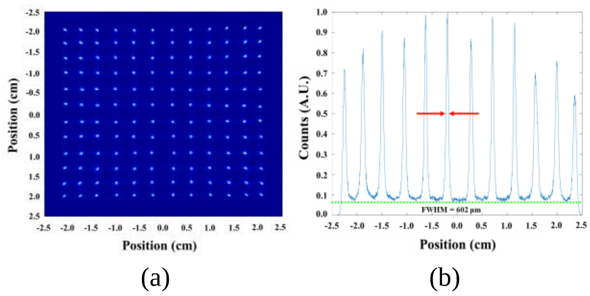

Fig. 3. Two-dimensional flood histogram (a) and 1D row-sum profile (b) of (a) of GAGG(Ce) scintillator array coupled with for 5 minutes of detection time when the 3.3 MBq ^{137}Cs is positioned at 10 cm from the face of the detector module.

Spatial flood maps reflect the intensity with which a given position is sampled during a measurement were obtained using GAGG(Ce) scintillator array with a 3.3 MBq ^{137}Cs gamma ray source positioned in the face of detector module, as shown at Fig. 3. They demonstrate that fine intrinsic pixel identification, in both x- and y-directions for all positions was carried out. After the charge division circuit separates the charge, the two-dimensional (2D) flood histograms demonstrated that each pixel can be identified and the uncertainty (FWHM) in that identification has 602 μm spatial resolution in on-dimensional (1D) row-sum profile.

3. Conclusions

A large dimension SiPM array was coupled to a pixelated GAGG(Ce) scintillator array in order to evaluate the spectral and position-sensitivity performance when considering it in coded-aperture based gamma ray imaging system. In order to simplify the readout for the 144 pixel array, a symmetric charge division circuitry is applied, which successfully provides a significant reduction in the multiplicity of analog outputs and reduces the size of the accumulated data. The system shows 8 %, 8.3 %, and 9.1 % energy resolutions at 1.173 keV, 662 keV, and 511 keV, respectively, for a 4 x 4 x 20 mm^3 finely pixelated GAGG(Ce) scintillator array. Sub-millimeter FWHM pixel-center identification resolutions were acquired from all measured data.

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