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Preliminary study of depth of interaction measurement for a PET detector*

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Abstract: In this work we studied the feasibility of detecting the depth of interaction (DOI) with two layers of crystal arrays of LYSO and BGO scintillators coupled to a position-sensitive photomultiplier tube (PS-PMT) R8900-C12. A front-end electronics was designed, with which we got different pulse shapes for different crystals to obtain depth information. With the double integration method, we got the DOI histogram of a divided integration ratio of two crystals as the standard to determine the layer-of-interaction. The DOI accuracy, measured by scanning a ^{22}Na slit source along the side of the module, was 98% for the LYSO layer and 95% for the BGO layer. The energy resolution at 511keV was 13.1% for LYSO and 17.1% for BGO. We obtained good crystal separation in 2D position histograms of both layers. These results could be useful in the manufacture of PET scanners with high spatial resolutions.

Key words: PET, detector, DOI, spatial resolution

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1 Introduction

Using smaller scintillator crystals is an effective measure to improve the spatial resolution of a PET scanner, while a large angle gamma ray may pass through several crystals before it is stopped. These oblique crossing events which occur on the edge of field of view (FOV) lead to the incorrect location of lines-of-response (LOR), and limit resolution uniformity. PET detector modules with depth-of-interaction (DOI) capability improve spatial resolution and resolution uniformity [1–4]. A phoswich detector module comprised of different scintillators can provide DOI information by identifying the scintillators [5–9]. Here, we made a phoswich detector module with LYSO and BGO scintillators. Simultaneously, double integration, (a method that exploits differences in the light decay time of the two scintillators) is used to determine the layer of interaction. With this method the DOI accuracy of this detector was measured.

2 Materials and methods

2.1 Detector module

The detector module was comprised of 8×8 arrays of $Lu_{1.8}Y_{0.2}SiO_5$:Ce (LYSO) crystals and 8×8 arrays of $Bi_4Ge_3O_{12}$ (BGO) crystals, as shown in Fig. 1. The crystal size of two layers is 1.9 mm×1.9 mm (2.0 mm pitch), 5 mm long. The BGO crystals comprised the exit layer, which was coupled to the face of a Hamamatsu R8900-C12 position–sensitive photomultiplier

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tube (PSPMT) with silicon oil. The LYSO crystal elements were polished on all sides, while the BGO crystal elements were diffusely ground on the contact side to LYSO crystals to improve the scintillation light output [10], and polished on all other sides.

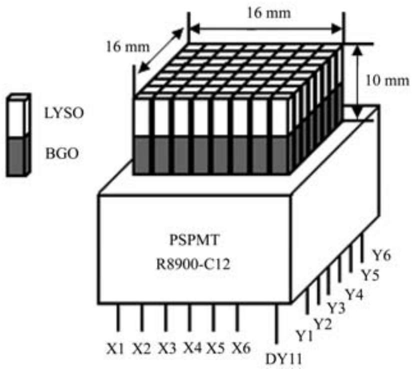

Fig. 1. The phoswich detector module.

2.2 Electronics data acquisition and processing

The R8900-C12 PSPMT contains six X anode plates and six Y anode plates that collect the amplified charge generated by each scintillation event. The six X anodes were directly connected to a simple resistive string to divide the signals in the X direction to two outputs, and the same for the six Y anodes. After being shaped, the four output signals were fed to a Continuous Sampling Module (CSM) and digitized by the charge-integrating analog-to-digital converters in it. These digital values were used to calculate the X, Y position of the event within the field-of-view of the tube, the energy deposition in the scintillator crystals and the DOI parameter of the event for layer assignment.

Since the light decay time of the two phoswich scintillators differs (LYSO=40 ns, BGO=300 ns), a shaping circuit was designed to shape the two signals as different widths (LYSO≈750 ns, BGO≈1500 ns), as shown in Fig. 2. and Fig. 3. The DOI of the event is obtained by dividing the shaped signal into two parts for charge integration, and calculating the integration ratio of the first 750 ns and full 1500 ns signal as the DOI parameter. A DOI histogram, shown in Fig. 4, was obtained by accumulating the divided integration ratio data of two layers when each layer was illuminated alone.

This DOI histogram contained two peaks of corresponding layers and nearly no overlap area. To confirm the difference in the DOI histogram of crystals, we acquired the DOI histogram of 16 BGO crystals and 16 LYSO crystals illuminated by a ^{22}Na point source. As a result, they had almost the same peak position with a difference of less than ±0.5%. The DOI standard value for the whole module was determined from the DOI histogram to identify the layer of detected events.

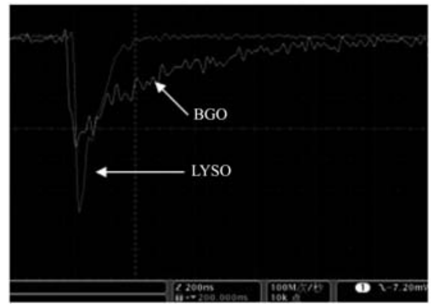

Fig. 2. The output pulse shapes before shaping.

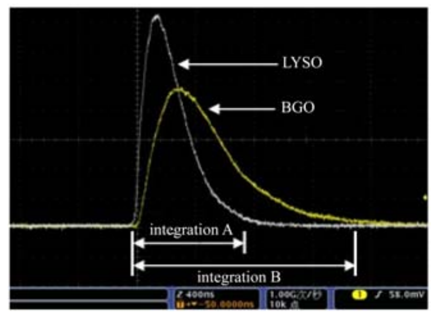

Fig. 3. The output pulse shapes after shaping.

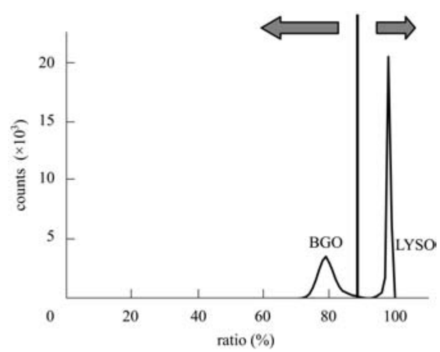

Fig. 4. The DOI histogram of divided integration ratio.

2.3 DOI accuracy

A highly collimated 1 mm-wide slit source of ^{22}Na was stepped at 1 mm increments along the side of the detector module to illuminate a slice at each point, and the layer of every event which occurred was determined by it's DOI parameter. At the same time, a BGO-detector was placed opposite in time coincidence in order to suppress the background count rate of ^{176}Lu (300 s^{-1}· cm^{-3} of LYSO), which has a big noise to coincidence rate of 511 keV photon beam (≈8 s^{-1}). The geometry of the experiment is shown in Fig. 5.

A fraction of events occurring in each layer compared with the events occurring anywhere in the module was obtained when the module was illuminated at each point. This was considered to be the DOI accuracy.

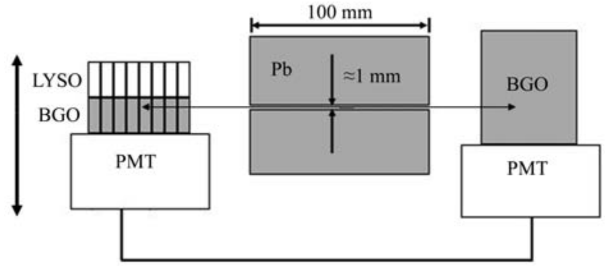

Fig. 5. Geometry of the scanning slit source experiment.

2.4 2D position histogram and energy resolution

To localize the LOR of every coincidence event, the ability of the module to identify crystals within a layer is also important for a PET scanner as well as DOI information. 2D position histograms of two layers were created by applying the DOI standard value to event acquisitions from the ^{22}Na point source. Next, we obtained crystal identification lookup tables (LUT) for each layer to get the count and energy spectrum of each crystal. The energy spectrums of each crystal revealed the energy resolution and the collection of scintillating light for two scintillator crystals.

3 Results

The counting rate plot of coincidence events with different collimating height along the side is shown in Fig. 6. It is about 7cps when the slit source is placed at a height of 2 mm to 10 mm, and less than 0.5cps when the slit source is away from the module. The phoswich detector module was illuminated for 3600s at each point.

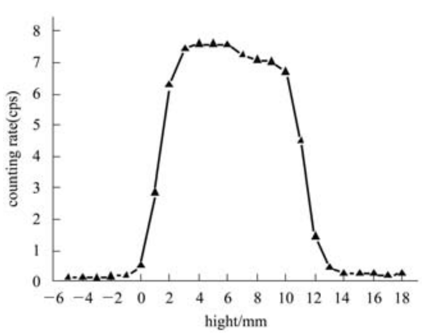

Fig. 6. The counting rate of coincidence events with different collimating height along the side.

The fraction of events occurring in the illuminated layer is plotted in Fig. 7 as the DOI accuracy. It is about 98% for the LYSO layer and 95% for the BGO layer.

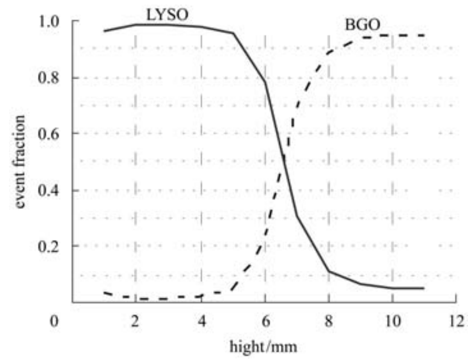

Fig. 7. Fraction of events assigned to each layer with different collimating height along the side.

The field flood image of the module illuminated by a ^{22}Na point source from the top is shown in Fig. 8 (upper). It is a sum 2D position histogram of all events occurring anywhere in the module without DOI information. When the DOI parameters are implied, this histogram separates into two 2D position histograms, one for each layer (middle in Fig. 8). The 2D position histograms of two layers are not exactly the same because of the gap of reflector material in

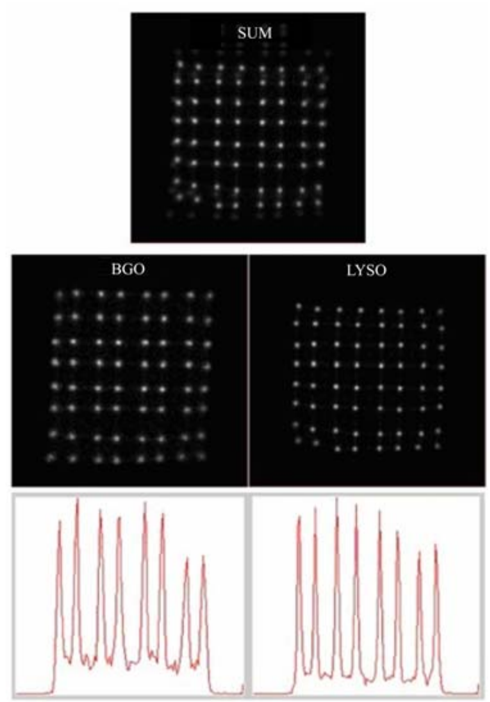

Fig. 8. DOI decomposition of the sum field flood image into two images, and the count profiles along the central row.

the crystal arrays. From the count profiles along the central row of the two histograms shown in Fig. 8, the LYSO layer has a higher peak-to-valley ratio, which is due to LYSO having more scintillation light output. The crystal identification LUT of each layer was created from the 2D position histograms.

An energy spectrum of all events occurring in the phoswich module appears as "SUM" line in Fig. 9. When the DOI parameters are implied, the layer information of each event is acquired to plot the BGO energy spectrum and LYSO energy spectrum of the

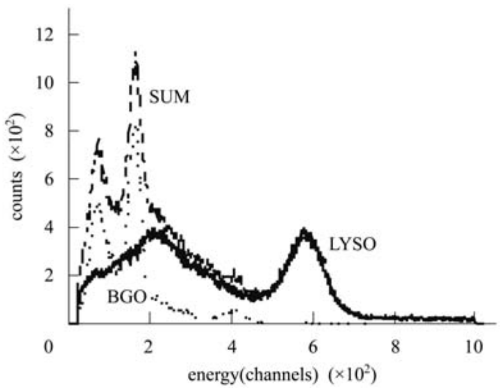

Fig. 9. The sum energy spectrum and energy spectrum of each layer by applying the DOI parameters.

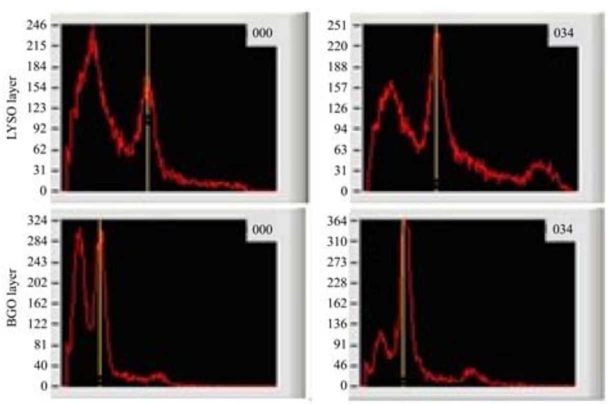

Fig. 10. Typical energy spectrum of signal LYSO and BGO crystal in the center or corner of the module.

^{22}Na source. After looking up the crystal identification LUT of the corresponding layer, we get the energy spectrum of each crystal. The energy spectra of two individual elements (element numbers 0 in the corner and 34 in the middle of the array) are shown in Fig. 10. For element 0, the energy resolution at 511 keV is 16.3% for LYSO and 25.1% for BGO. For element 34, the energy resolution is 13.1% for LYSO and 17.1% for BGO.

4 Discussion

The results obtained in the scanning slit source experiment (see Fig. 7.) suggest that it is feasible for the double integration method to identify the layer-of-interaction of the phoswich detector module. The ratio of wrong layer assignment is less than 5%. However, this layer-of-interaction identification isn't exact enough for accidental events which are multiple interactions, such as absorption and scattering events in each layer at almost the same time. The scintillation light of these events has two component parts with a different decay time. As a result, their DOI parameters appear between the two peaks of the DOI histogram (see Fig. 2.), and the calculating energy of 511 keV is between the two peaks of the energy spectrum (see Fig. 9.). At the same time, the calculating X, Y position is the weighted center of the scattering crystal and absorption crystal, which leads to an incorrect line of response. In the following work, we will determine the intrinsic DOI parameter region of two scintillator crystals to get rid of these harmful events.

Crystal separation was good between crystals in both layers with the phoswich crystal arrays coupled to the effective area of PSPMT directly. The dead area of PSPMT will become a big problem when we assemble these phoswich detector modules to a detector ring. The coupling method of the module will be studied in the near future.

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