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Study of the characteristics of a scintillation array and single pixels for nuclear medicine imaging applications*

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Abstract By using a pixelized Nal(Tl) crystal array coupled to a R2486 PSPMT, the characteristics of the array and of a single pixel, such as the light output, energy resolution, peak-to-valley ratio (P/V) and imaging performance of the detector were studied. The pixel size of the NaI(TI) scintillation pixel array is 2 mm×2 mm×5 mm. There are in total 484 pixels in a 22×22 matrix. In the pixel spectrum an average peak-to-valley ratio (P/V) of 16 was obtained. In the image of all the pixels, good values for the Peak-to-Valley ratios could be achieved, namely a mean of 17, a maximum of 45 and the average peak FWHM (the average value of intrinsic spatial resolution) of 2.3 mm. However, the PSPMT non-uniform response and the scintillation pixels array inhomogeneities degrade the imaging performance of the detector.

Key words characteristics, scintillation pixels array, light output, peak-to-valley ratio

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1 Introduction

In the last few years, many studies have been carried out on compact position sensitive gamma-ray detectors in order to optimize a gamma camera for nuclear medicine imaging[1—6]. Much of the work dealing with the subject, was mainly oriented towards reaching the best intrinsic detector spatial and energy resolution by using the last generation position sensitive photo multiplier tube[7] (PSPMT), on innovative collimator technique[8], a novel multi-anode readout and an optimized data acquisition system. A scintillation array coupled to a high-resolution PSPMT is a widely used solution for the construction of a compact position sensitive gamma-ray detector with good spatial resolution. When performing a study of a compact gamma-ray detector suitable for nuclear medicine application it is important to take into account the performances of the scintillation array. The knowledge on the scintillation array and single pixel, such as the light output, energy resolution allows the optimization of the imaging performances. To reach this goal a careful study of the used scintillation array is necessary. In an attempt to address this issue we have built up a compact gamma-ray detector consisting of a Nal(Tl) scintillation pixel array coupled with a Hamamastu R2486 PSPMT[9]. In this paper the characteristics of this scintillation array and a single pixel as well as the imaging performance of the detector were investigated by using a ^{241}Am collimated source.

2 Materials and methods

The NaI(TI) crystal is an appealing material for imaging because of the relatively good stopping power for medium-energy photons, the robust signal produced and the relatively low costs. Its emission spectrum (415 nm wavelength) matches well with the spectral response of the PSPMT photocathode. The NaI(TI) crystal pixels array[10], on which we are reporting here, is composed of 2 mm×2 mm elements separated by a 0.2 mm thick white reflecting powder which also covers the five blind surfaces of the

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array. The square area of the Nal(Tl) scintillating array is 48.2 mm×48.2 mm. There are in total 484 pixels in a 22×22 matrix. The crystal thickness is 5 mm. There is a 1 mm reflector and a low-density sponge gap between the aluminum entrance window and the array. A quartz window is stuck to the exit face of the crystal. Fig. 1 shows a photograph of the NaI(Tl) scintillation array. The bottom of the crystal couples to the glass window of the PSPMT with silicon grease. The PSPMT coupled with the NaI(Tl) scintillation array is light tight.

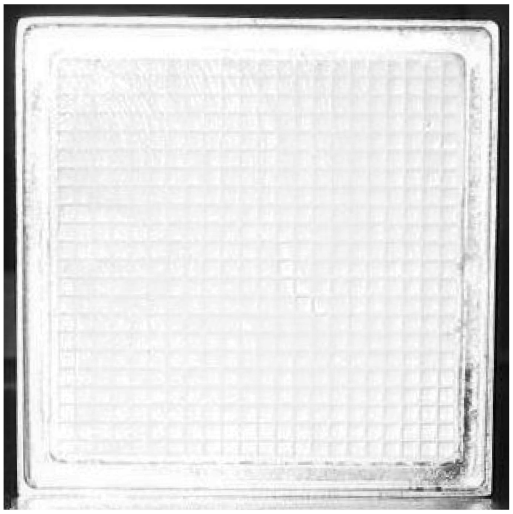

Fig. 1. Photograph of the NaI(Tl) scintillation array.

The investigation of the array presented here occurred in two steps: firstly, the performance of the individual pixels, – to study the light output and the energy resolution and secondly, the imaging performance of the array.

The measurement device consists of a ϕ1 mm copper collimator, a step motor, the detector based on the Nal(Tl) scintillation pixel array coupled to the R2486 PSPMT, a resistive chain readout electronics and a data acquisition system. The ^{241}Am source was collimated with the collimator. The position of the collimator with respect to the radiation source can be changed by using a step motor in the x and y directions. Thus we could scan over the full surface of the NaI(Tl) pixels array. The whole system including the beam scan, data acquistion and real time analysis was controlled by a PC with LabVIEW software.

In order to study the characteristics of the scintillation array and the single pixel, the surface of the NaI(Tl) array coupled to the PSPMT was scanned in the x and y directions from -24 mm to $+24$ mm with a step of 2.2 mm. In total 484 pixels were collected. In the experiment all information including energy, image position and count number for each irradiation spot has been stored in separate independent files.

3 Results

3.1 Pixel characteristics

Figure 2 shows the pulse height spectra measured at three typical pixels, in a boundary pixel of the scintillation array, in a center pixel of the array and in the middle pixel between the boundary and the center along one crystal axis. The dots represent the spectrum in the boundary pixel. The crosses represent the spectrum in the center pixel. The circles represent the spectrum in the middle pixel between the boundary and the center along one crystal axis.

In the boundary pixel spectrum the photoelectric peak occurs in 139 channels and an energy resolution of 21% at FWHM is obtained. In the center pixel spectrum we found the photoelectric peak in 180 channels with an energy resolution of 19% at FWHM. In the middle pixel between the boundary and the center along one crystal axis spectrum, the photoelectric peak was found in 159 channels and an energy resolution of 20% at FWHM. In the three spectra measured, the average photoelectric peak is at 1050 counts and the average Compton valley is at 65 counts, the average peak-to-valley ratio (P/V) is thus 16, which represents a good performance for a scintillation detector.

The energy resolution, measured by a Gaussian fit to the 59.5keV photopeak for the 22×22 array, ranges from 19% to 21% with an average value of 20% at FWHM.

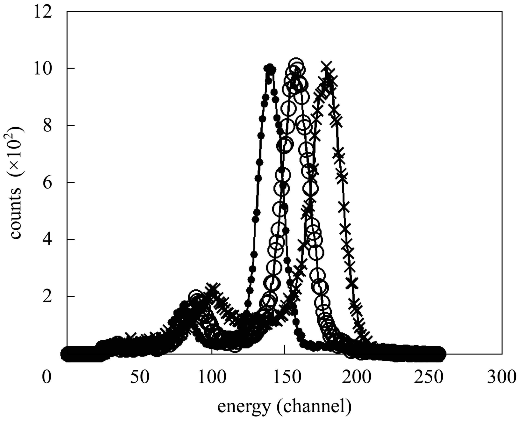

Fig. 2. The pulse height spectra measured at three typical pixels.

Figure 3 summarizes the central channel of the photoelectric peak of all the pixels of the array. The central channel of the photoelectric peak of each pixel is proportional to the light output measured of that pixel. So Fig. 3 also represents the light yield in terms of the central channel of the photoelectric peak for all the pixels of the array. It can be seen that pixels at the boundary have a significantly lower light output, which is reflected in the lower central channel of the photoelectric peak. This is due to the low number of visible photons arriving on the PSPMT edges. The light output non-uniform response observed in the scintillation array resulted mainly from the non-uniform response of the photocathode of the PSPMT and inhomogeneities of the scintillation array, and secondly from light reflection in the scintillation array and light-refractive properties of the glass interface between the crystal and the photocathode. Therefore, the energy resolution of the detector is deteriorated. In addition, different energy spectra can cause apparent differences in the sensitivity of different parts of the detector, leading to image non-uniformities and non-linearity. This problem could be corrected by using the energy calibration method.

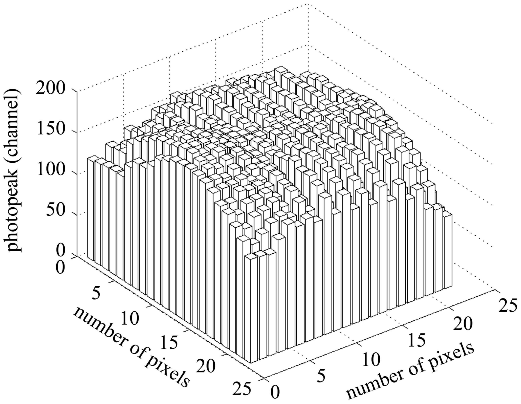

Fig. 3. The light yield in terms of the central channel of the photoelectric peak for all the pixels of the scintillation array.

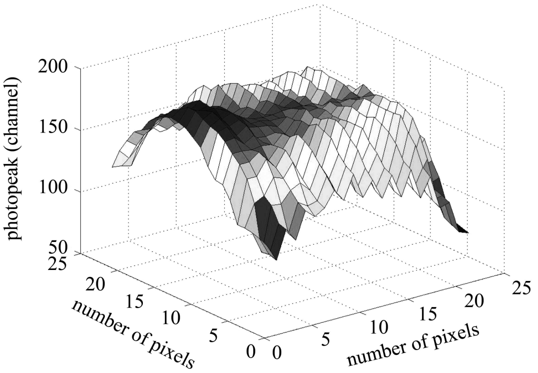

Fig. 4. All pixels' energy response obtained by irradiating the scintillating array with a ^{241}Am collimated source.

With the central channel of the photoelectric peak of all the pixels an energy spectrum table was obtained (see Fig. 4). Energy calibration was performed by using the pulse height spectrum of each of the 484 pixels to set an energy window for each region.

3.2 Scintillation array characteristics

Figure 5 shows the image of all the pixels. Fig. 6 shows the point spread functions (PSFs) of the five typical pixels along one crystal axis. By fitting a 2D Gauss curve to the PSFs of all the pixels, the average peak FWHM (the average value of the intrinsic spatial resolution) of 2.3 mm is obtained for both, the x and the y direction. From the profiles of the PSFs of all the pixel, the peak-to-valley ratios (P/V) are calculated. We obtained reasonable good peak-to-valley ratios, with a mean of 17 and a maximum of 45. Each value was calculated as the ratio between the peak value of an element and the mean of the two corresponding valleys. These values provided an indication of the pixel identification ability. It can also be seen that the number of detected photoelectrons of each pixel is slightly different, which is reflected in its variation of the counts (see Fig. 6). This is also

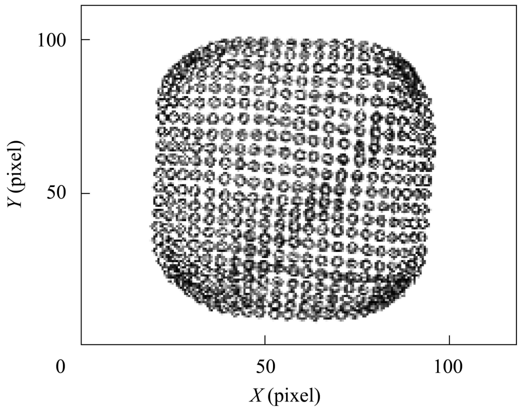

Fig. 5. The image of all the pixels.

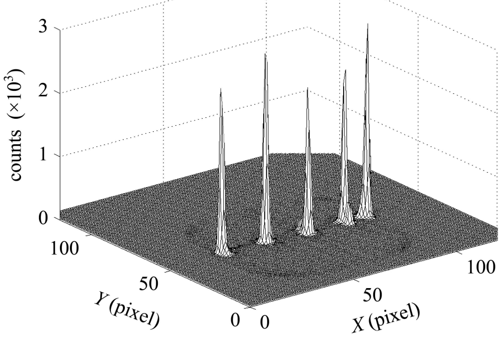

Fig. 6. Point spread functions (PSFs) of the five typical pixels along one crystal axis.

due to the non-uniform response of the photocathode of the PSPMT and inhomogeneities of the scintillation array. The results demonstrated that the compact gamma-ray detector using a pixelized NaI(Tl) array, coupled with the PSPMT has a good intrinsic spatial resolution. This good intrinsic spatial resolution response allowed one to produce a table in order to correct the small shrinkage effect near the edges of the crystal. The shrinkage effect involves a shift of the light distribution centroid toward the detector center and thus reduces the useful field of view (FOV).

4 Conclusions

The reported measurements of this work allowed us to investigate the characteristics of a scintillation array and a single pixel. In addition, the imaging performance of the detector based on the NaI(Tl) scintillation pixel array coupled with the Hamamastu R2486 PSPMT has been investigated, so that we can correct the non-uniform light output response observed in the scintillation array and the small shrinkage effect near the edges of the crystal.

In the pixel spectrum, an average peak-to-valley ratio (P/V) of 16 was obtained. The energy resolution for the 22×22 array, ranges from 19% to 21% with an average value of 20% at FWHM. In the image of all the pixels, the obtained peak-to-valley ratios are reasonably good, with a mean of 17 and a maximum of 45, the average peak FWHM (the average value of intrinsic spatial resolution) of 2.3 mm.

We have found that the PSPMT non-uniform response and the scintillation pixel array inhomogeneities reduce the useful field of view (FOV) and degrade the imaging performance of the detector. So future work will study and develop energy correction and shrinkage effect algorithms for better performance of the gamma-ray detector.

Nevertheless, these results show that is possible to construct a compact position sensitive gamma-ray detector with good spatial resolution, using a NaI(Tl) scintillation pixel array coupled with a Hamamastu R2486 PSPMT.

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