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Detector development for a novel Positron Emission Mammography scanner based on YAP:Ce crystals

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Abstract

A prototype for positron emission mammography is under development within a collaboration of the Departments of Physics of Pisa and Ferrara. The device will be composed of two opposing detectors (parallel plane geometry). The active part of the detector head is constituted by a matrix of scintillators with a small pixel size ($2 \times 2\,\mathrm{mm}^2$). We have evaluated the possibility to use an array of Position Sensitive PhotoMultiplier Tube (PSPMT mod R8520-C12 from Hamamatsu) for the readout of the scintillation matrix. Two different crystal-PMT coupling techniques have been explored: the results for each method are reported in this work. The overall performance, in terms of efficiency and pixel identification of the final prototype of the detector head are also presented. For future applications the new H8500 (also called the 'flat panel' PMT) has been studied and compared to the R8520 in terms of the imaging performance and other considerations such as cost and geometry. The imaging performance of these tubes is characterized in terms of the pixel image resolution and the peak-to-valley ratio.

Keywords: Positron emission mammography; Scintillators; Photodetectors

1. Introduction

Positron Emission Tomography (PET) using ^{18}F-FDG could be a valid solution for the staging of breast cancer [1]. Whole body PETs are often used but their performances do not fulfill the requirements for the detection of small tumors (less than 1 cm in diameter) and dedicated devices for Positron Emission Mammography (PEM) with high sensitivity and high spatial resolution are under development [1–6].

A matrix of scintillating crystals coupled to a position sensitive photodetector is the most widely used solution for the construction of a detector head to be employed in this application. In order to fulfill the spatial resolution requirements a small pixel size (down to $2 \times 2\,\mathrm{mm}^2$) is required. Consistently a high spatial resolution photodetector has to be used for the matrix readout and pixel identification. In addition, when large area matrices are employed, tiling of various PSPMT represents a valid solution. When used in arrays these PS-PMT are affected by a non-negligible dead space between adjacent tubes. A quartz

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window can be placed between the tube array and the scintillation matrix for the recovery of pixels facing the dead area The quartz window spreads the light emitted from the pixels facing the non-active area between detectors, so that some is detected by each. This permits recovery of the pixel position. In particular, the aim of the study is the optimization of the detection efficiency (in terms of fraction of the matrix successfully read-out), while keeping the spatial resolution good enough so as to allow an almost perfect coding (bi-unique pixel identification).

The aim of this paper is the evaluation of the performance, in terms of pixel identification resolution and effective active area (that is linked to the efficiency in the recovery of pixels facing the non-active area between adjacent PMTs) of various solution based on an array of Position Sensitive Photomultiplier Tube (PSPMT) R8520-C12 from Hamamatsu. This tube has been also compared with the novel multi anode H8500 (also called the 'flat panel' PMT) from Hamamatsu that could represent an effective alternative for future applications especially when larger active area are required.

2. YAP-PEM prototype design

A prototype for PEM is under development within a collaboration of the Departments of Physics of the Universities of Pisa and Ferrara. This device should be able to detect tumours of 5 mm diameter when there is a tumour/background specific activity ratio of 10:1 [7].

The device will be composed of two opposing detectors (parallel plane geometry). The dimensions of the scintillator are 3 cm thick with a detection area of $6 \times 6\,\mathrm{cm}^2$; each of these crystals is composed of 30×30 pixel elements of $2 \times 2 \times 30\,\mathrm{mm}^3$ each. To this aim we have evaluated the possibility to use an array of PSPMT for the readout of the scintillator matrix. Recently, novel Multi Anode Photo-Multiplier Tubes (MA-PMTs) have been introduced by Hamamatsu. These tubes offer, in a small package, performances similar to or even better than larger PSPMTs. They can also be easily arranged in matrices so as to cover the whole area of larger scintillator matrices with a relatively low dead area. One of these tubes, the R8520-00-C12, is a compact metal channel dynode tube from Hamamatsu: the active area is $22 \times 22\,\mathrm{mm}^2$, with respect an overall size of $25.7 \times 25.7\,\mathrm{mm}^2$, corresponding to a packing fraction of about 73%. The position sensitive detection is performed with a special anode made of 6 (X) and 6 (Y) crossed plates. We have demonstrated that R8520-C12 is well suited for this application [8] and now we have tested a configuration based on an array of nine of these tubes for the readout of the YAP:Ce matrix described above. Each photodetector has been read-out by a specific resistive chain and a preamplifier board which contains four channels for the anode signals and an additional channel for fast timing of the last dynode. The data from each tube are independently acquired with two 32-channel peak-sensing VME-based ADCs. The OR signal of the nine tubes is put in fast coincidence with its analogue from the other detector head. Dedicated software performs the center of gravity calculation of the light for pixel identification.

3. Experimental measurements

3.1. Detector head development

Two different crystal-PMT coupling techniques have been explored: the first standard solution is the direct coupling of the array with a silicone-based optical grease. Fig. 1 shows the flood field image obtained with the uniform irradiation (flood field) of the YAP:Ce matrix with 511 keV photons from a ^{22}Na source. Annihilation events are selected by the coincidence detection of the second photon using a BGO scintillator coupled to a PMT. In this way only the crystals that are facing the active area of a tube can be identified (676 out of 900 crystals), corresponding to a fraction of about 75% of the whole matrix. The measured mean Peak-to-Valley ratio (P/V) is 8.0 and the mean FWHM of the pixel image is 0.9 mm.

For an evaluation of the imaging performance of the detector head with respect to the thickness

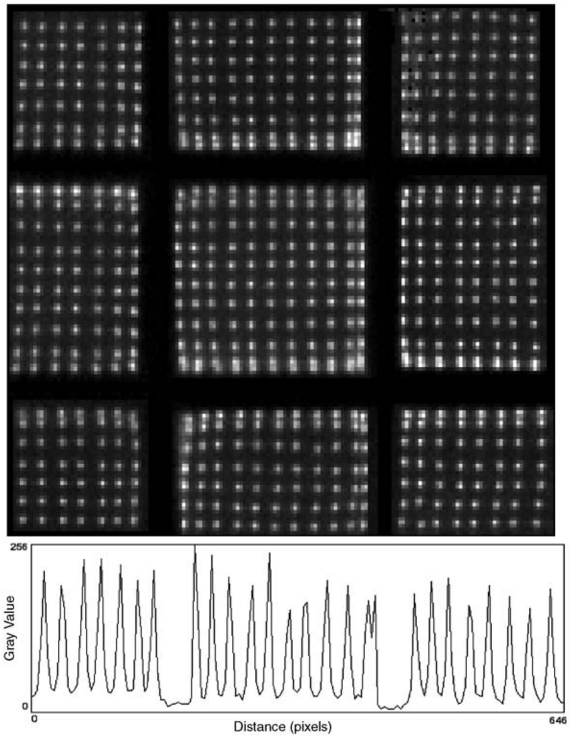

Fig. 1. Flood field image (511 keV) of the $6\times 6\,\mathrm{cm}^2$ YAP:Ce matrix obtained with the direct coupling with the array of nine R8520. The plot below represents the profile of a single row.

of the quartz window, various quartz thickness, ranging between 1 and 3 mm, have been tested. The resulting P/V in the active area and the efficiency in recovering the events that occurred in pixels facing the non-active area are represented in Fig. 2. As one might expect, as the quartz thickness increases, the P/V is reduced, due to the broader light spot on the photocathode, which ultimately reduces the spatial resolution on the reconstructed pixel position. On the other hand, thicker quartz gives a better efficiency in the recovery of the dead area. An image of the YAP:Ce crystal array has been produced using the quartz window scheme, too. For this test we have chosen the 3 mm thick quartz, which represents the reverse condition (improved efficiency, degradation of pixel identification) with respect to the direct coupling technique. The resulting flood field image is shown in Fig. 3. In this case we have measured a mean P/V of 2.2 and a pixel FWHM of 1.4 mm.

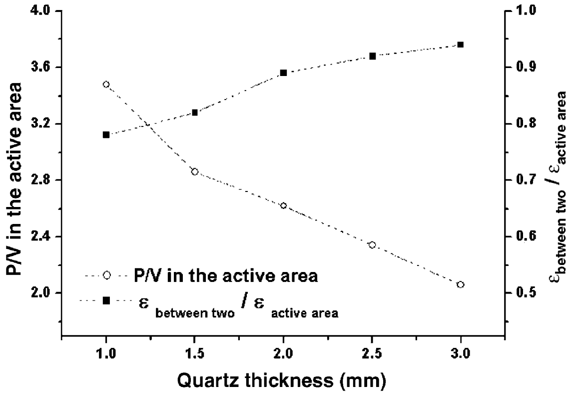

Fig. 2. Evaluation of the effect of the quartz thickness on the recovery efficiency $\varepsilon_{\text{between two}}/\varepsilon_{\text{active area}}$ and on the P/V ratio of pixels in the active area.

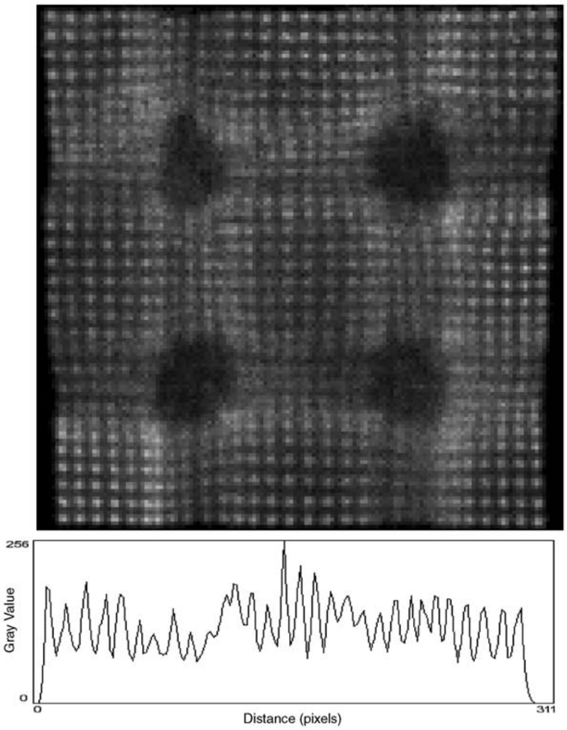

Fig. 3. Flood field image (511 keV) of the $6\times 6\,\mathrm{cm}^2$ YAP:Ce matrix obtained with the 3 mm thick quartz window coupled to nine R8520. The plot represents the profile of a single row.

3.2. PSPMT comparison

For the future development of PEM systems with improved field-of-view size, we are considering the possibility to use the novel H8500 multi-anode tubes by Hamamatsu. This is a large area square detector of 52 × 52 mm^2 with 64 independent anodes (6.08 pixel pitch) corresponding to an active area of 49 × 49 mm^2. The readout of the Flat Panel has been made by using a resistive chain [9]. In order to compare the imaging performance of the H8500 with respect to the R8520-C12 tube, we have performed a study of the photocathode uniformity and the position linearity. Both studies have been performed by scanning the photocathode of the tube, across the center, with a blue led, coupled to a clear fiber, 2 mm diameter. The resulting plots are reported in Fig. 4.

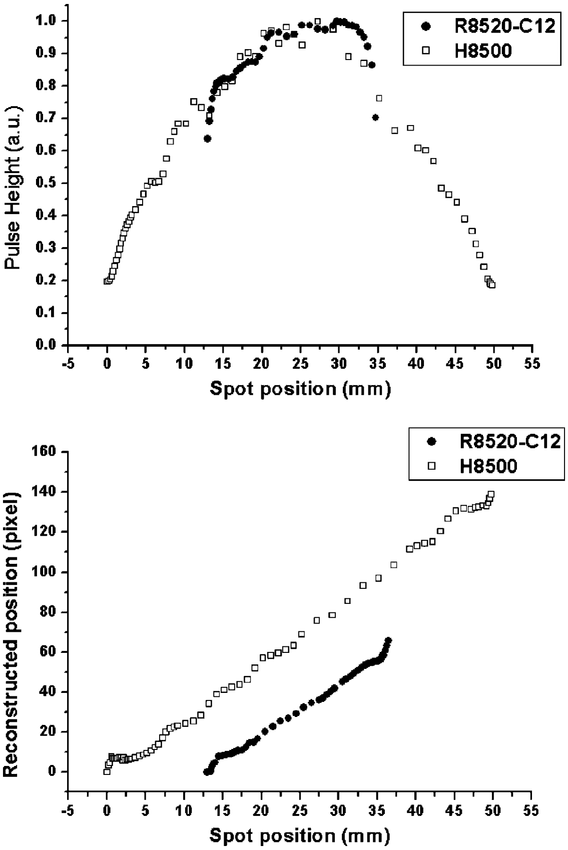

Fig. 4. Plots of the photocathode uniformity (top) and the position linearity (bottom) for both R8520-C12 and H8500 PMTs.

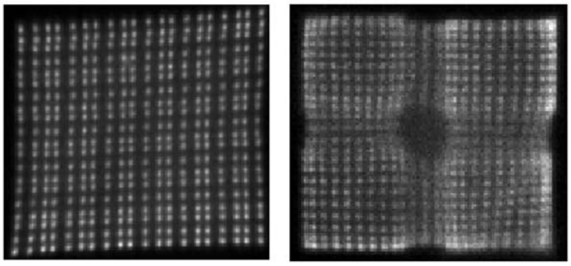

Fig. 5. Flood field images (511 keV) of the 4 × 4 × 2.5 cm^3 YAP:Ce matrix obtained with the H8500 (left) and R8520-C12 (with a 3 mm thick quartz window) (right).

We have measured the ratio between the lowest and the highest value in the uniformity plot, obtaining 1:1.6 and 1:5.4 for the R8520-C12 and the H8500, respectively. However, the local non-uniformity is very similar. We have measured just one profile rather than the whole area so the overall figure will likely be much larger. The R8520-C12 shows a good linearity while the H8500 suffers position non-linearities when used with relatively narrow light distribution. The comparative study of the imaging performance of these tubes has been performed on the readout of an high quality 4 × 4 cm^2 YAP:Ce matrix, with 2 × 2 × 25 mm^3 pixel size. Fig. 5 shows the flood field images (511 keV) obtained with the H8500 and with the R8520-C12, the latter using a 3 mm thick quartz window.

4. Conclusions

We have successfully constructed a detector head to be used in a novel PEM prototype. The use of a quartz window allows an array of nine R8520 to read out the whole 6 × 6 cm^2 YAP:Ce matrix with a pixel P/V ranging between 2.06 and 3.48 and pixel recovery efficiency ranging between 78% and 94% with respect to the ideal readout. However, a final choice for the quartz thickness cannot be made at this stage. The optimal compromise between spatial resolution and efficiency can only be obtained from a Signal-to-

Noise ratio measurement of the entire PEM system with hot phantoms. We have tested the new H8500 multi anode PMT that shows very interesting performance that will make this tube the reference photodetector for future PEM applications.

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