THE STUDY OF THE PHOTORESPONSE OF THE MAPD MATRIX FOR SCINTILLATION RADIATION

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This paper presents the performance of the detection efficiency of gamma radiation with a detector based on LYSO, YSO (Ce), BGO scintillators and a nine-channel array of micropixel avalanche photodiodes (MAPD) with high pixel density (PD) and photon detection efficiency (PDE). The sensitive area of the detector, consisting of single MAPDs with an active area of 3.7×3.7 mm^2 and has a common output for signal output, is 11.5×11.5 mm^2. Breakdown voltages were measured for each channel, as a result of which the optimal operating voltage for the entire array was revealed. The linearity range and energy resolution for each crystal were determined by the energy range from 30 to 1770 keV. The high pixel density of the array made it possible to achieve good linearity in the studied energy range, which makes it possible to use the matrix in gamma-ray spectroscopy detectors.

Keywords: MAPD; mikropixel avalanche photodiode; SiPM; photodetection efficiency.
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INTRODUCTION

Traditional vacuum photomultiplier tubes (PMTs) have long been successfully used as a photodetector. However, modern technologies have led to the development of new types of photodetectors -silicon photomultipliers (SiPM), which have such advantages as high detection efficiency, low operating voltage, compactness, insensitivity to magnetic fields, low cost, etc. [1-3]. Despite the advantages, they have some disadvantages, such as limited pixel density (PD), and active region. Due to the limited pixel density, the SiPM response is nonlinear with an increase in the number of photons [4]. Therefore, it is necessary to develop SiPM with a high pixel density while maintaining photon detection efficiency (PDE). Significant improvement in SiPM dynamic range is provided by Zecotek Photonics Inc.'s innovative MAPD design. [3, 5-7]. For scintillation detectors, the detection efficiency increases with increasing area of the photosensor and crystals. To increase the efficiency of photon collection from large scintillators, it becomes necessary to use several SiPMs due to their small core sizes. This paper presents a study of a nine-element MAPD-based matrix with a high PD/PDE ratio and three scintillators with different light output and decay time as a detector in gamma spectrometry.

USED SAMPLES

An array of 9 single-element MAPD-3NK photodiodes from Zecotek Photonics Inc. It was assembled on a specially designed printed circuit board, the contact pads of which were located on the back side. Each MAPD-3NK element had an area of 3.7×3.7 mm^2 with a pixel density of 10 000 mm^{-2} and a high PDE - 40%. The matrix had a total capacitance of ~1.8 nF. The geometric fill factor (GFF) of the MAPD array was 76%.

To test the MAPD matrix, three types of scintillators LYSO, YSO, and BGO were selected [8], the properties of which are presented in Table 1.

Table 1

Properties of scintillators

	LYSO (Ce)	YSO	BGO
Density (g/cm^3)	7,25	4,50	7,13
Emission wavelength max (nm)	420	420	480
Light output (Photons/MeV)	28000-34000	21000-24000	8000-10000
Decay time (ns)	42	50-70	300
Refractive index	1,82	1,8	2,15
Hygroscopic	no	no	no
Size (mm^2)	10×10×10	10×10×10	10×10×10

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EXPERIMENTAL SETUP

The experimental setup is shown in fig. 1. During the measurements, the detector and preamplifier were placed in a shielded and light isolated black box. The signal was amplified by a preamplifier (gain 40) and recorded by the CAEN DT5720B analog-to-digital converter (ADC). The ADC input impedance was 50 ohms. All data analysis was performed using an algorithm written in the ROOT data analysis environment developed by CERN. The measurements were carried out at a temperature of 22° C. In the experiments, Co-57, Cs-137, Eu-152, and Bi-207 were used as gamma radiation sources, the gamma-ray energy of which is in the range 30–1770 keV. All measurements were carried out under the same conditions and in the same time interval of 300 nanoseconds.

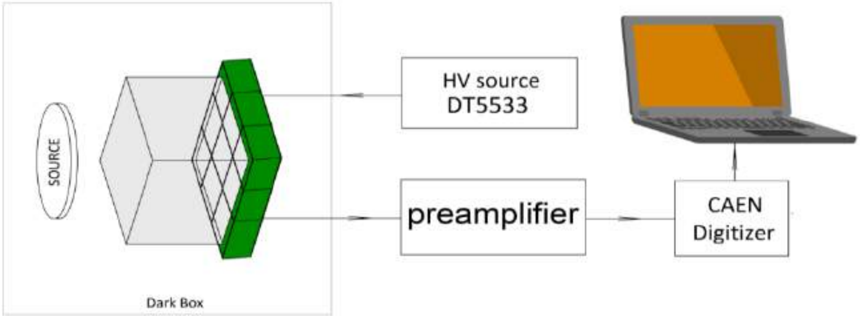

Fig. 1. The block diagram of the experimental setup.

EXPERIMENTAL RESULTS

The breakdown voltage for each SiPM is individual and also depends on production processes. Therefore, it was necessary to determine the breakdown voltage for each MAPD. Measurements of the current-voltage characteristics (I-V) were performed for all MAPDs.

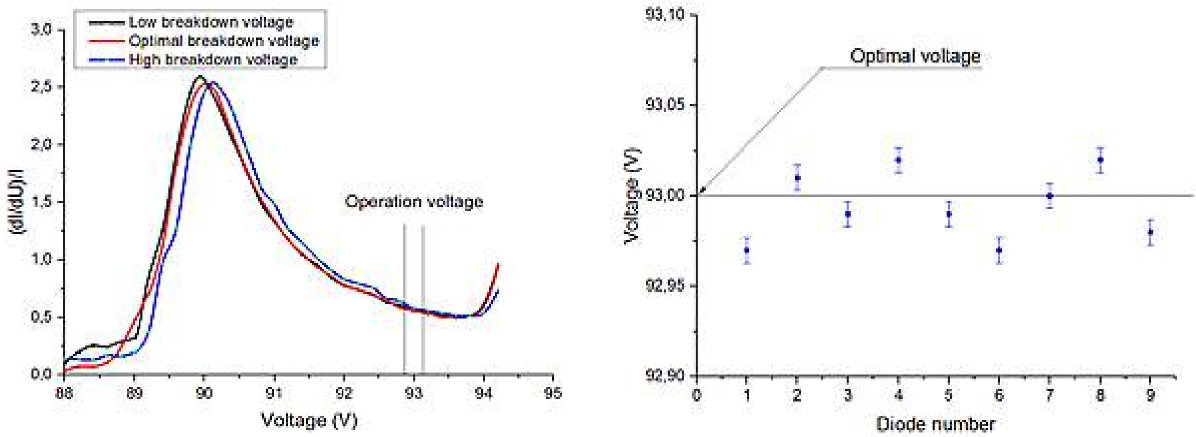

Fig. 2. Current-voltage characteristics (left) and operating voltages (right) for all MAPDs in the matrix.

Fig. 2 (left) shows the I–V characteristics for MAPDs with lower, normal, and higher operating voltages in the array. As shown on diagram, the breakdown voltage is at the point 90±0.05 V. Also, fig. 2 (right) shows the scatter of the operating voltage of photodiodes. The average value of the operating voltage was chosen of 93 V for all elements of the matrix.

For detecting the efficiency of gamma radiation with assembled matrix of MAPDs and scintillators, we used point sources Co-57, Cs-137, Eu-152 and Bi-207. The signal integration time was chosen corresponding to the decay time of the scintillator. For LYSO and YSO crystals, the signal integration time was 400 ns, and for BGO, it was 750 ns. The characteristic energy spectra for the LYSO and YSO scintillators are shown in fig. 3 (a) and (b), respectively. Fig. 3 (c) shows the energy spectra for the BGO scintillator. The diagrams clearly show the main lines of gamma radiation of the used sources. The pulse height and energy resolution were determined from the peaks using a Gaussian function.

Using the data from the spectra, energy curves were constructed for the photodiode array. A linear dependence of the energies and the experimentally measured pulse heights was found fig. 4.

The calibration curve has a linear function. The results showed that the MAPD-based matrix showed good linearity over a wide energy range (30–1770 keV). This linearity can be explained by the high pixel density of the MAPD. Fig. 4 also allows determining the relative light output of the used scintillators, respectively to the relative light outputs given in Table 1.

Fig. 5 shows the function of the dependence of the energy resolution as a function of the energy of gamma radiation for all three scintillators. For gamma radiation with energy of 661.7 keV Cs-137, the energy resolution was 9.25% (LYSO), 9.28% (YSO) and 14.33% (BGO). The BGO crystal showed low energy resolution due to its low light output.

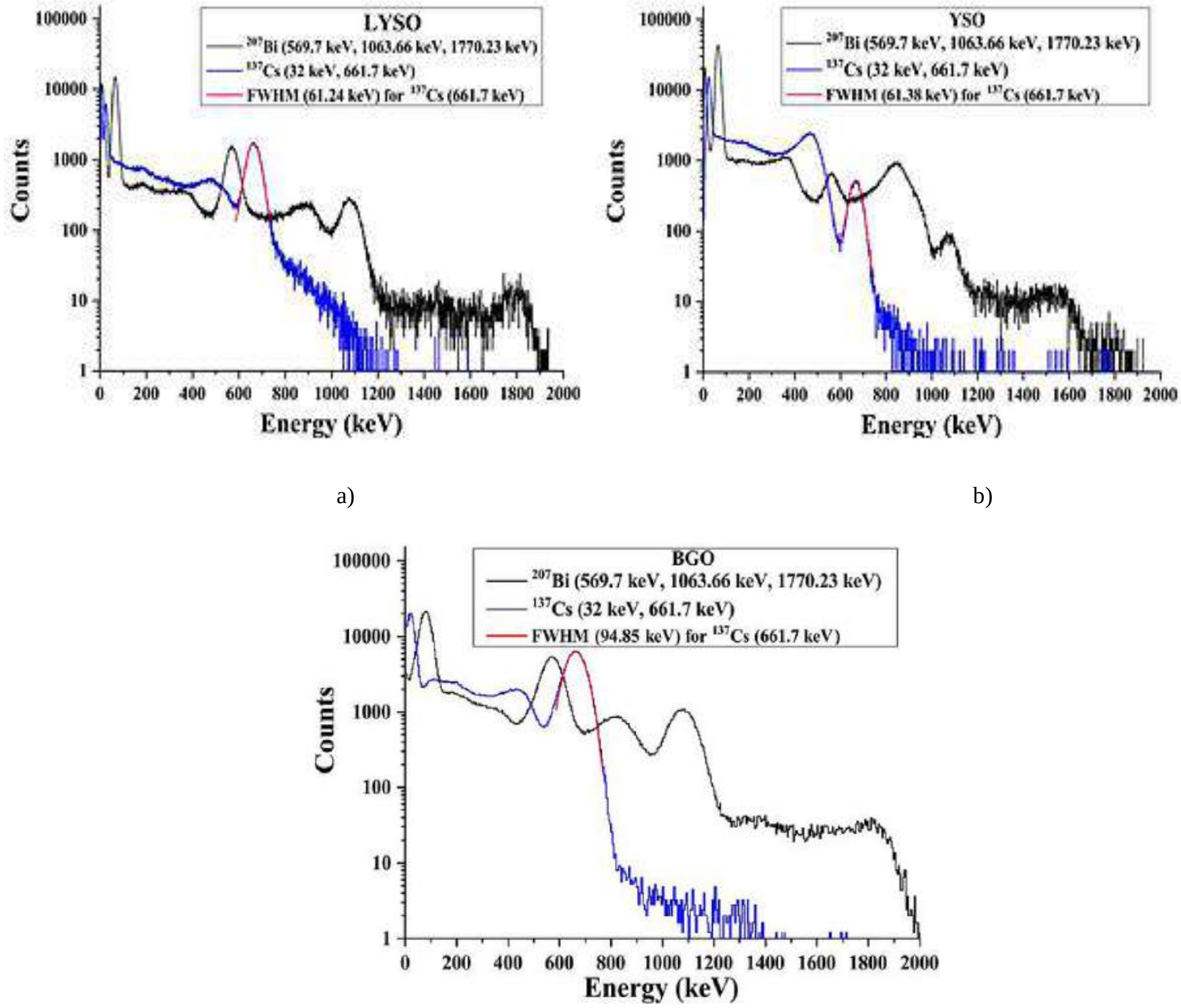

Fig. 3. Energy spectra of gamma radiation from Cs-137 and Bi-207 sources, measured by MAPD detectors and the scintillator LYSO (a) and YSO (b) and BGO (c).

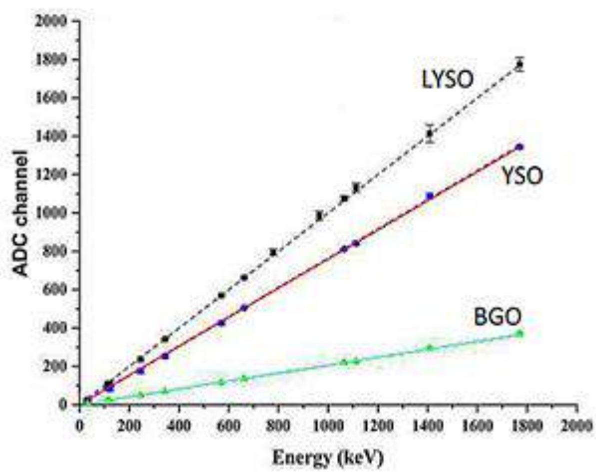

Fig. 4. The dependence of the ADC channel on the energy of gamma radiation.

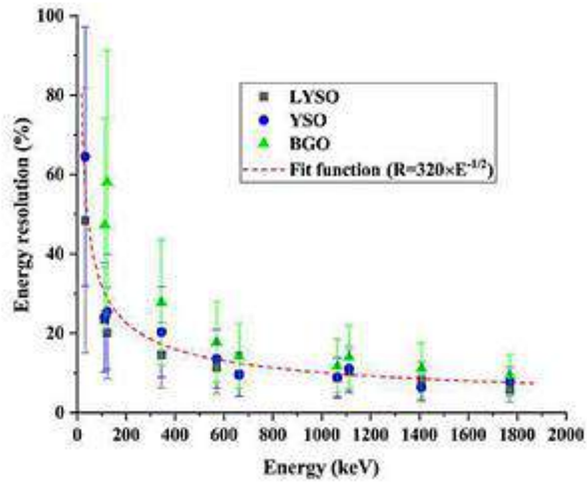

Fig. 5. The dependence of the energy resolutions on the energies of Cs-137 gamma rays with an energy of 661.7 keV.

CONCLUSION

A matrix of 9 elements based on MAPD photodiodes was assembled, the total active region of which was 11,5×11,5 mm^2, and the gap between the individual elements was up to 200 µm. For the matrix test, LYSO, YSO, and BGO scintillators with a size of 10×10×10 mm^3 were used. For Cs-137 gamma rays with energy of 662 keV, the energy resolution was 9.25% (LYSO), 9.28% (YSO), and 14.33% (BGO). The detector showed a good linearity between the ADC channels and the gamma radiation in the range up to 1770 keV. The energy resolution characteristics for LYSO, YSO and BGO showed the same curve shape. The relative luminous efficiencies obtained by the LYSO, YSO, and BGO scintillators were in good agreement with the data of [8].

The results showed that a matrix of 9 MAPD photodiodes can be used as a light sensitive element in scintillation detectors in field of medicine, space industry and public safety. In addition, the high pixel density (10 000 pixels/mm^2) of sensitive elements can be considered the most important advantage, which provides a fairly good linear response while maintaining PDE (40%).

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