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New phoswich detector based on LFS and *p*-terphenyl scintillators coupled to micro pixel avalanche photodiode

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This paper presents the results of phoswich detector which developed on the basis of micro pixel avalanche photodiode and LFS+*p*-terphenyl scintillators. The beta particles and gamma rays detection performance of the phoswich detector (LFS+*p*-terphenyl) was investigated. The energy resolution of monochromatic electron was 23 % (625 keV). The detected count ratio of beta particle and gamma ray was about 37 %. It was obtained that this type of phoswich detector discriminates between gamma rays and beta particles due to the differences in the light decay time of scintillators.
Keywords: phoswich detector, LFS+*p*-terphenyl scintillators, beta particle, gamma ray.

Представлены результаты исследования фосвич-детектора, который разработан на основе микропиксельных лавинных фотодиодов и LFS+*p*-терфенил сцинтилляторов. Исследована эффективность обнаружения бета-частиц и гамма-лучей фосвич детектором (LFS+*p*-терфенил). Энергетическое разрешение монохроматического электрона составило 23 % (625 кэВ). Обнаруженное соотношение количества бета-частицы и гамма-излучения составило около 37 %. Выявлено, что этот тип фосвич-детектора отличает гамма-лучи от бета-частиц по различию во времени распада света в сцинтилляторах.

Новий фосвіч-детектор на основі LFSs, *p*-терфеніл сцинтиляторів і мікропіксельного лавинного фотодіода. *Ф.Ахмедов, Ф.Абдуллаєв, Г.Ахмедов, А.Садигов, З.Садигов, Р.Мадатов, С.Сулейманов, Р.Акберов, Н.Гейдаров, М.Назаров.*

Представлено результати дослідження фосвіч-детектора, розробленого на основі мікропіксельних лавинних фотодіодів і LFS+*p*-терфеніл сцинтиляторів. Вивчено ефективність виявлення бета-частинок і гамма-променів фосвіч детектором (LFS+*p*-терфеніл). Енергетичний дозвіл монохроматического електрона склав 23 % (625 кеВ). Знайдене співвідношення кількості бета-частинки і гамма-випромінювання становить близько 37 %. Виявлено, що цей тип фосвіч-детектора відрізняє гамма-промені від бета-частинок за відмінностю у часі розпаду світла у сцинтиляторах.

1. Introduction

The phoswich detectors which were developed on the basis of photomultiplier tubes (PMT) are widely used in medicine, nuclear equipments, space application and environmental monitoring [1–6]. Basically, phoswich detectors consist of two or more different scintillators that have various decay time and detection efficiency for radiation. These types of phoswich detectors allow to detect ionizing particles (alpha, beta, neutron) in the mixed radiation fields by decay time of scintillators [3]. Organic scintillator with the low Z has a very low detection efficiency for gamma ray (compton scattering will dominate) but has high detection efficiency for ionizing particles. The inorganic scintillators, which used for gamma rays detection have very high Z which allow to find out the energy of gamma rays (by photo peak). Sometimes the phoswich detectors could not separate two gamma rays or beta particles which energies are very close to each other. This disadvantage related to the detection efficiency of PMT. It is known that the detection efficiency of PMT is 20 %. That is why the development of a new photo detector with high detection efficiency is very actual. The progress in development of micropixel avalanche photodiodes made them capable for serving as photo sensors in the phoswich detectors.

The micropixel avalanche photodiodes are produced by different Companies during the last years [9–11]. A new type of MAPD with deeply buried pixels developed by Zecotek Photonics. This type of photodiodes allowed to improve their main parameters such as photon detection efficiency (>30 %), pixels density (>10000 pixel/mm^2) and radiation hardness [12].

In this work the phoswich detector is designed on the basis of LFS & *p*-terphenyl scintillator and a single MAPD photodiode for measuring beta particles and gamma rays. The isotope of cesium, $_{55}Cs^{137}$ is used as gamma ray and beta particle source.

2. Experiment procedures and results

New designed phoswich detector was rectangular in shape with dimensions of 3×3×33 mm^3 and consisting of LFS & *p*-terphenyl with a 3×3 mm^2 sensitive area coupled to a MAPD-1P. The thickness of scintillators was 3 mm for Lutetium Fine Silicate (LFS) and 30 mm for *p*-terphenyl ($C_{18}H_{14}$). The *p*-terphenil scintillator sample from Institute for Scintillation Materials (Ukraine) was used as a target for ionizing radiation [7]. Its decay time is 3.7 ns. The *p*-terphenyl scintillator gives the light yield of 27000 photons per MeV of deposited energy. The maximum wavelength of light emission is 440 nm. The LFS-8 scintillator sample was used as target for gamma rays. The dimensions of the LFS-8 scintillator fully matching the sensitive area of the MAPD-1P was 3×3×3 mm^3. LFS-8 has a light output of 30,000 photons/MeV and decay time of 35 ns. The wavelength of maximum light emission is 422 nm. The sides of the LFS-8 crystals were wrapped into two layers of 0.1 mm thick white Teflon tape excepting one face, which was coupled to MAPD-1P with silicone optical grease. The LFS-8 scintillator was developed by Zecotek Photonics Pte. Ltd [8]. The used MAPD-1P contains a silicon substrate of *n*-type conductivity on which two silicon epitaxial layers of *p*-type conductivity were grown. The device also contains a dense matrix of independent *n*+-type pixels buried deep within the epitaxial layers mentioned above. Such design of the device provides super-wide linearity range of photo response due to high pixel density within the sensitive area. Detailed descriptions of the design and the operation principle of this device can be found in [9, 10]. The MAPD-1P photodiode has the following working parameters: operating voltage — 93.8 V, gain — $6 \cdot 10^4$, device capacitance — 120 pF, dark current at the operating voltage — 70 nA, PDE at 450–525 nm light wavelengths — 25–30 % [11].

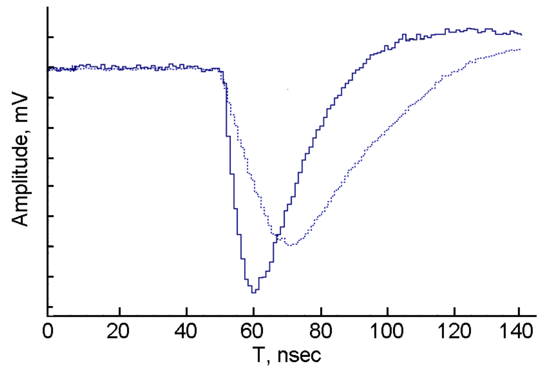

Fig. 1. The pulse waveforms for LFS and *p*-terphenyl.

The MAPD signal was sent to an amplifier. The amplifier is designed on the basis of two LMH-6657 [12]. In our measurements, the signal from MAPD-1P was fed to amplifier with signal gain 36 and was recorded by CAEN DT5720B digitizer module with 12-bit resolution and 250 MS/s sampling rate. All measurements were carried out at room temperature without any shielding material against to external background. The isotope of cesium, $_{55}Cs^{137}$ was used as gamma ray (662 keV) and beta particle (557 keV, 605 keV, the internally con-

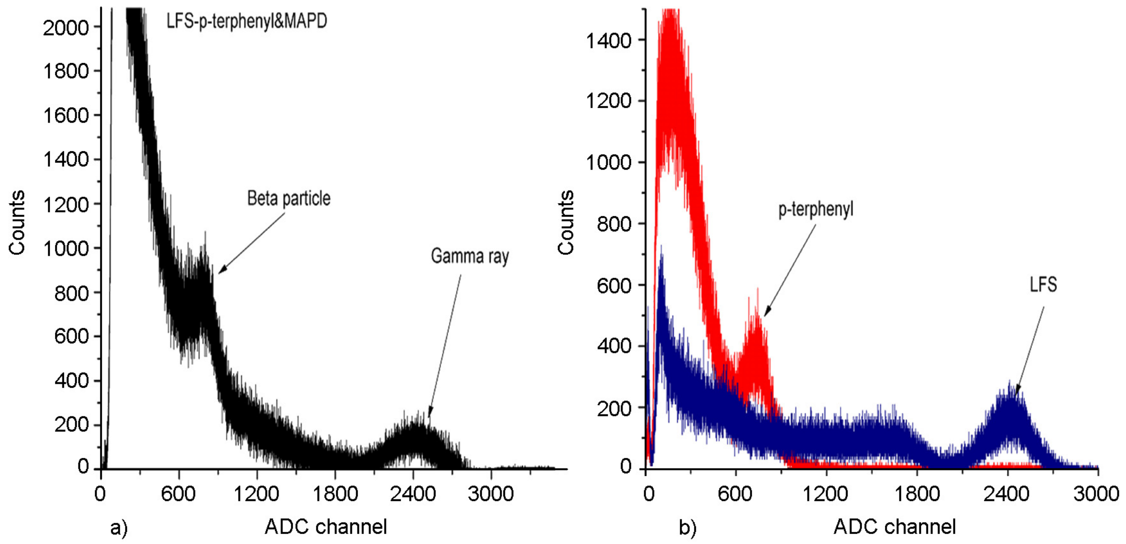

Fig. 2. Beta particle and gamma ray detection performance of MAPD with phoswich detector: a — the signals of phoswich detector; b — the separated signals produced by LFS and *p*-terphenyl scintillators.

verted electrons (625 keV and 656) and 1.174 MeV) source [12].

The pulse waveforms for LFS and *p*-terphenyl are shown in Fig. 1. The pulse durations and rising time for LFS and *p*-terphenyl were 21 nsec, 14 nsec and 9 nsec, 5 nsec.

The beta particles and gamma rays detection performance of MAPD-1P is tested with the new phoswich detector. The spectra obtained from the $_{137}$Cs source are shown in Fig. 2a. The full absorption peaks of gamma ray and monochromatic electrons which correspond to LFS and *p*-terphenyl are observed in spectrum. Special algorithm is used to discriminate events by events due to pulse waveform.

In Fig. 2b is presented the separated signals which produced by LFS and *p*-terphenyl scintillators. This type of phoswich detector can discriminate between gamma ray and beta particle using the differences in the light decay time of scintillators. Obtained results for both scintillators gave the same results with single scintillator. Energy resolution of 662 keV gamma ray become worse due to interaction of beta particle (557 keV, 605 keV, the internally converted electrons (624 keV, 656 keV) and 1.174 MeV) to LFS. Cu foils (1mm) was inserted between source and detector to stop all beta particles during the record of spectrum with LFS. The energy resolution of the 662 keV gamma ray was 11.2 %.

The energy resolution of monochromatic electron which is detected by *p*-terphnyl was 23 % (625 keV). The detected count ratio of beta particle and gamma ray was about 37 %.

3. Conculusion

The detection performance of phoswich detector which consists of *p*-terphenyl and LFS scintillators was studied. The full absorption peaks of gamma ray and monochromatic electrons which correspond to LFS and *p*-terphenyl were observed in spectrum. The energy resolution of monochromatic electron was 23 % (625 keV). The detected count ratio of beta particle and gamma ray was about 37 %. The energy resolution of the 662 keV gamma ray was 11.2 %. It was obtained that this type of phoswich detector discriminates between gamma ray and beta particle due to the differences in the light decay time of scintillators. This type detector can be used to develop compact phoswich detector.

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