ALPHA-GAMMA DISCRIMINATION CAPABILITY OF ORGANIC COMPOSITE DETECTORS

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An investigation was conducted on the alpha-gamma discrimination capability ($FOM_{\alpha\gamma}$) of organic composite scintillators based on stilbene and *p*-terphenyl. The samples were excited using the combined source of gamma radiation photons and alpha particles from ^{239}Pu. Two series of composite detector samples with varying fractions of crystalline grains in the range of average grain size L_{av} from 0.2 to 1.9 mm, with a thickness of 4 mm and a diameter of 15 mm, were studied. It was shown that for composite samples based on both stilbene and *p*-terphenyl, the $FOM_{\alpha\gamma}$-values were significantly higher compared to reference samples of the corresponding single crystals. A trend towards a slight increase in the $FOM_{\alpha\gamma}$-value was observed for samples with the largest L_{av}-values.

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INTRODUCTION

Organic luminescent materials (single crystals, liquid phosphor solutions, polymers) have proven effective in many detection and spectrometry tasks for ionizing radiation, particularly in the separate detection of ionizing radiations. This primarily concerns the issue of fast neutron spectrometry in the presence of background gamma radiation [1-7]. The physical basis for such separation lies in the difference in the pulse shapes of radioluminescence generated by ionizing radiations with different specific energy loss values (*dE/dx*) [2, 6, 8, 9]. The radioluminescence pulse of an organic scintillator contains both fast and slow components. When excited by ionizing radiation with high *dE/dx*-values, the contribution of the slow component is greater than when for radiations with low *dE/dx*-values. This criterion enables the identification of radiation type in real experiments [8, 9].

Heterogeneous organic scintillators are produced from single crystalline grains. They consist of a mass of single crystalline grains that are bonded together either by sintering under pressure (polycrystals) [1, 10], or using a transparent non-scintillating matrix (composite scintillators) [1, 3, 5, 7, 10]. The main advantage of composite scintillators is the ability to create scintillation detectors of large size and arbitrary shapes.

In our previous studies [11], we investigated the light output of polycrystalline and composite scintillators based on crystalline grains of stilbene and *p*-terphenyl, depending on the average grain size L_{av} used to prepare the sample. Additionally, the neutron-gamma discrimination capability of the samples was studied when irradiated with a combined source of fast neutrons and photons of gamma radiation. This work is dedicated to the study of alpha-gamma discrimination capability of organic composite scintillators based on stilbene and *p*-terphenyl.

SAMPLE PREPARATION

We obtained two series of experimental samples of composite scintillators based on stilbene and pure *p*-terphenyl. The grains were obtained by crushing crystalline ingots of previously grown structurally perfect single crystals. The grains were sieved to produce grains of different fractions. For each series, we used the following 7 grain fractions: 0.1–0.3, 0.3–0.5, 0.5–1.0, 1.0–1.2, 1.2–1.4, 1.4–1.8, and 1.8–2.0 mm. Grains of each fraction were placed in a non-scintillating gel composition, SYLGARD-184. The samples were then left to polymerize for 24 hours. A more detailed description of the technology for producing organic composite scintillation detectors can be found in our previous works [1, 3, 5, 7, 10]. The samples had a thickness of 4 mm and a diameter of 15 mm. We determine the average size L_{av} of grain of the specific fraction as the mean between the smaller and the larger mesh sizes of our sieves, which were used to select grain fraction [12]. The reference detectors used were corresponding single crystals of stilbene and pure *p*-terphenyl, grown by the Bridgman-Stokbarger method [13]. The single crystals had a diameter of 25 mm and a height of 5 mm.

EXPERIMENTAL TECHNIQUE

A measurement system for studying the discrimination capability of organic scintillation crystals and calculating the *FOM*-value was developed and assembled. The system includes the following components: a photomultiplier (PMT) with power supply units; a pulse signal amplifier-shaper; a signal control block for the time-to-amplitude converter (TAC) (Fig. 1); a time-to-amplitude converter (TAC); a multichannel pulse amplitude analyzer (MPAA); and a computer (PC).

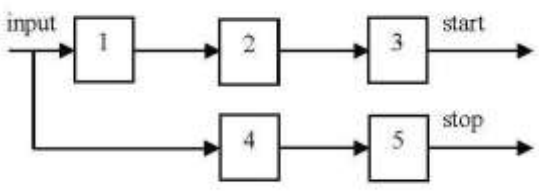

Fig. 1. The measurement setup for studying the discrimination capability (the FOM-value) of organic scintillation materials: 1 is a level discriminator, 2 is a delay circuit, 3 is a pulse shaper "start", 4 is a zero-crossing detector, and 5 is a pulse shaper "stop"

EXPERIMENTAL RESULTS

The $FOM_{\alpha\gamma}$-value (the parameter that determines the discrimination capability of a detector) was investigated for samples with different fractions of crystalline grain in the range of the average grain size L_{av} from 0.2 to 1.9 mm. The values of L_{av} were: 0.2, 0.4, 0.75, 1.1, 1.3, 1.6, and 1.9 mm.

Fig. 2 shows typical spectra obtained using the "zero crossing" technique for the stilbene single crystal and composite stilbene scintillators when excited by an alpha-particles (5 MeV) and photons of gamma radiation (60 keV) from ^{239}Pu. Fig. 3 presents similar results for *p*-terphenyl detectors. For demonstration, three samples from grains of different fractions were arbitrarily selected.

The $FOM_{\alpha\gamma}$-value was calculated using the formula [11]:

$$FOM_{\alpha\gamma} = \frac{D_{\alpha\gamma}}{FWHM_{\alpha} + FWHM_{\gamma}} \quad (1)$$

where $FWHM_{\gamma}$ – full width at half maximum of the gamma peak (in channels), $FWHM_{\alpha}$ – full width at half maximum of the alpha peak (in channels), $D_{\alpha\gamma}$ – arithmetic difference between the position of the alpha peak and the gamma peak (in channels).

Table 1 presents the values of $FWHM_{\gamma}$, $FWHM_{\alpha}$, $D_{\alpha\gamma}$, as well as the calculated value of $FOM_{\alpha\gamma}$ (1) for the reference single crystal of stilbene and for the entire series of composite scintillator samples based on stilbene, obtained from 7 grain fractions with different L_{av}-values. Table 2 presents similar parameters for detectors based on pure *p*-terphenyl. It should be noted that for the samples with the lowest L_{av}-value of 0.2 mm, the values of $FWHM_{\alpha}$, $D_{\alpha\gamma}$ и $FOM_{\alpha\gamma}$ are not provided due to the extremely low efficiency of alpha particle detection from the smallest grain size for a detector with a thickness of 4 mm.

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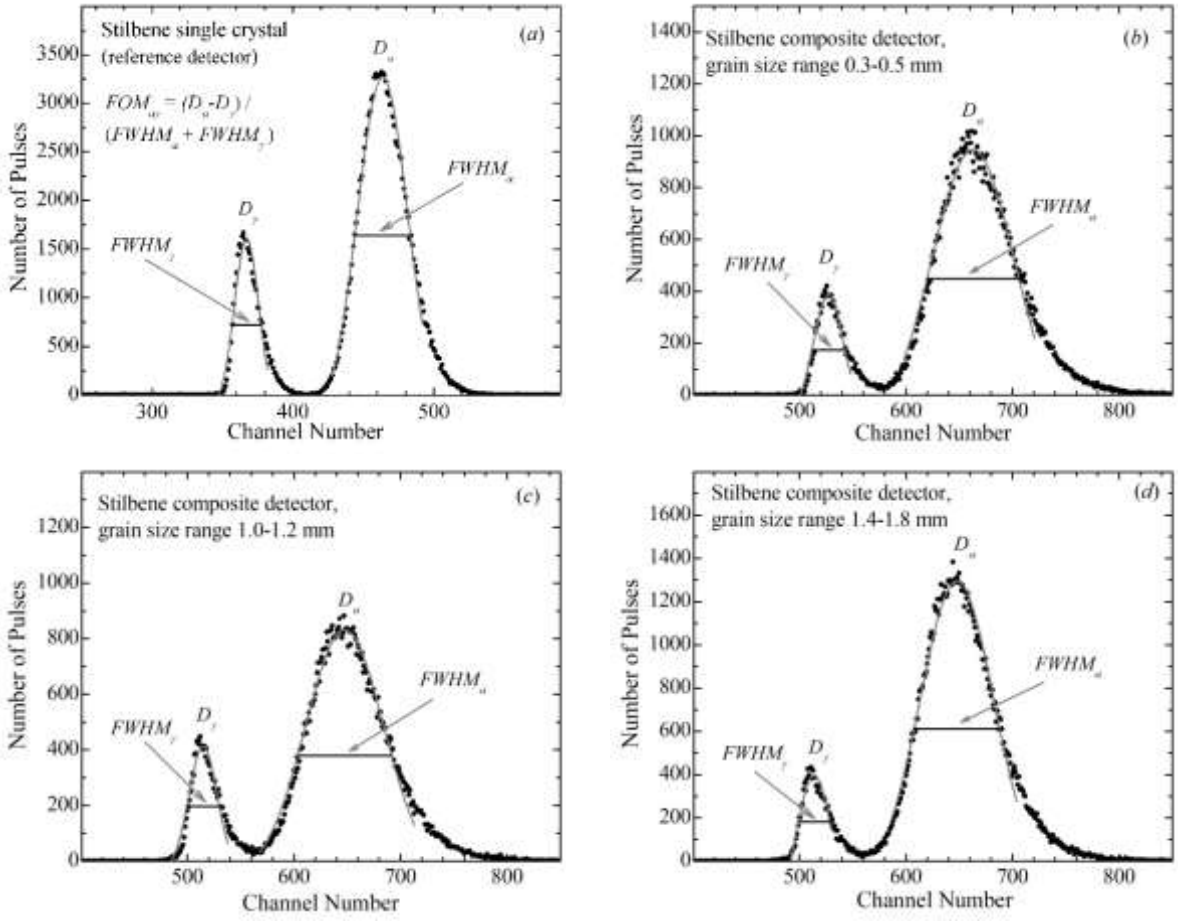

Fig. 2. Typical spectra obtained using the "zero-crossing" method for the stilbene single crystal and stilbene composite scintillators when excited by an alpha-particles and photons of gamma radiation from ^{239}Pu source: $FWHM_{\gamma}$ – full width at half maximum of the gamma peak (in channels), $FWHM_{\alpha}$ – full width at half maximum of the alpha peak (in channels), $D_{\alpha\gamma}$ – arithmetic difference between the position of the alpha peak and the gamma peak (in channels), $FOM_{\alpha\gamma}$ – alhpa-gamma discrimination capability. The grain sizes of the composite scintillators are shown in the figure

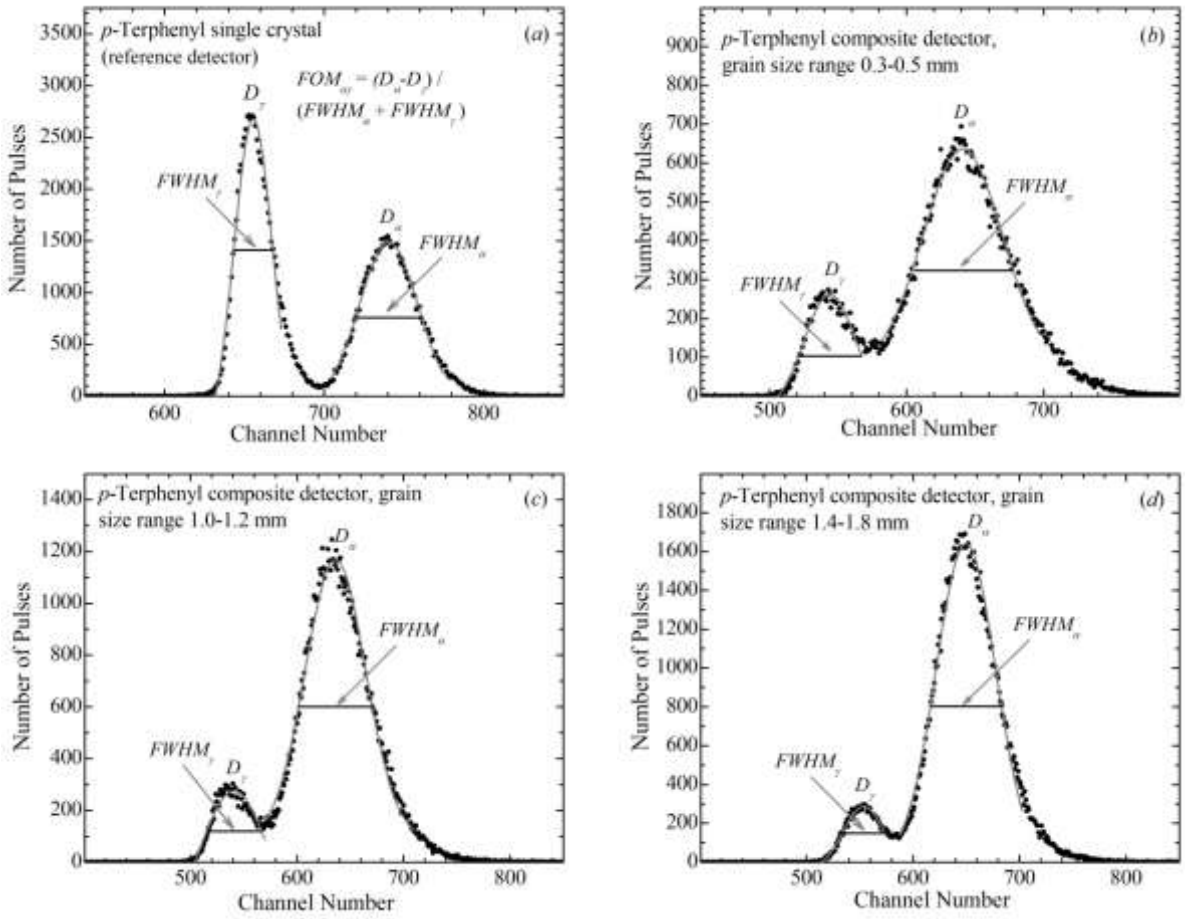

Fig. 3. Typical spectra obtained using the "zero-crossing" method for the p-terphenyl single crystal and p-terphenyl composite scintillators when excited by an alpha-particles and photons of gamma radiation from ^{239}Pu source. Other symbols are the same as in Fig. 2

Table 1

Values of $FWHM_\gamma$, $FWHM_\alpha$, $D_{\alpha\gamma}$, and $FOM_{\alpha\gamma}$ for stilbene composite detectors and the reference single crystal

	$FWHM_\gamma$, ch	$FWHM_\alpha$, ch	$D_{\alpha\gamma}$, ch	$FOM_{\alpha\gamma}$
Single crystal	20	39	98	1.66
Composite detectors				
L_{av}, mm				
0.2	32	–	–	–
0.4	29	78	136	1.27
0.75	31	83	125	1.09
1.1	29	79	135	1.25
1.3	26	79	129	1.23
1.6	28	74	133	1.31
1.9	28	72	130	1.30

Table 2

Values of $FWHM_\gamma$, $FWHM_\alpha$, $D_{\alpha\gamma}$, and $FOM_{\alpha\gamma}$ for pure *p*-terphenyl composite detectors and the reference single crystal

	$FWHM_\gamma$, ch	$FWHM_\alpha$, ch	$D_{\alpha\gamma}$, ch	$FOM_{\alpha\gamma}$
Single crystal	28	43	85	1.35
Composite detectors				
L_{av}, mm				
0.2	42	–	–	–
0.4	45	68	97	0.86
0.75	48	73	91	0.75
1.1	44	69	93	0.82
1.3	39	69	93	0.86
1.6	42	65	94	0.88
1.9	41	63	104	1.00

CONCLUSIONS

The analysis of the results presented in Figs. 1 and 2 and in Tables 1 and 2 allows the following conclusions regarding the alpha-gamma discrimination capability ($FOM_{\alpha\gamma}$-values) of organic composite scintillators:

1. For the stilbene composite scintillators, the $FOM_{\alpha\gamma}$-values ranged from 1.09 to 1.31, while for the *p*-terphenyl scintillators, they ranged from 0.75 to 1.0. Thus, the discrimination capability of stilbene composite scintillators is significantly higher than that of *p*-terphenyl scintillators.
2. The highest $FOM_{\alpha\gamma}$-values were obtained for samples with the largest average grain sizes (L_{av}), specifically for L_{av} = 1.6 and 1.9 mm.
3. For the corresponding reference single crystals, the $FOM_{\alpha\gamma}$-values were higher compared to the composite materials, namely 1.66 for stilbene and 1.35 for *p*-terphenyl.

The selection of optimal grain sizes for the creation of composite scintillators depends on the specific practical tasks for which the detector will be used. For example, for tasks in radioecology and the detection of short-range particles, such as alpha particles, an increase in relative light output is necessary. This can be achieved by creating single-layer composite scintillators with grain sizes smaller than 60 μm, where the most significant effect will be the reflection of triplet excitons from the grain surfaces followed by their recombination, as demonstrated by us recently [14].

For the creation of systems, such as those for the selective detection of alpha and gamma radiations, grains larger than 1.4 mm are optimal, as shown by the results presented in this work. This is due to the need for the development of bulk multilayer composite scintillators for more efficient gamma radiation detection. On the other hand, a drawback is that the large number of scintillation layers leads to light scattering at the grain boundaries, which, as a result, reduces the number of photons detected by the photodetector.

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REFERENCES

1. N. Galunov, S. Budakovsky, N. Karavaeva et al. New effective organic scintillators for fast neutron and short-range radiation detection // *IEEE Trans. Nucl. Sci*. 2007, v. 54, p. 2734-2740. https://doi.org/10.1109/TNS.2007.910423.

2. G. Hull, N.P. Zaitseva, N.J. Cherepy et al. New organic crystals for pulse shape discrimination // *IEEE Trans. Nucl. Sci*. 2009, v. 56, p. 899-903. https://doi.org/10.1109/TNS.2009.2015944.

3. J. Iwanowska, L. Swiderski, M. Moszynski et al. Neutron/gamma discrimination properties of composite scintillation detector // *J. Instrum*. 2011, v. 6, p. P07007. https://doi.org/10.1088/1748-0221/6/07/P07007.

4. N. Zaitseva, B.L. Rupert, I. Pawelczak et al. Plastic scintillators with efficient neutron/gamma pulse shape discrimination // *Nucl. Instrum. Meth. Phys. Res., Sect. A*. 2012, v. 668, p. 88-93. https://doi.org/10.1016/j.nima.2011.11.071.

5. O. Tarasenko, N. Galunov, N. Karavaeva et al. Stilbene composite scintillators as detectors of fast neutrons emitted by a ^{252}Cf source // *Rad. Meas*. 2013, v. 58, p. 61-65. https://doi.org/10.1016/j.radmeas.2013.08.005.

6. M. Joyce, S. Agar, M. Aspinall et al. Fast neutron tomography with real-time pulse-shape discrimination in organic scintillation detectors // *Nucl. Instrum. Meth. Phys. Res., Sect. A*. 2016, v. 834, p. 36-45. https://doi.org/10.1016/j.nima.2016.07.044.

7. N.Z. Galunov, I.F. Khromiuk, O.A. Tarasenko. Features of pulse shape discrimination capability of organic heterogeneous scintillators // *Nucl. Instrum. Meth. Phys. Res., Sect. A*. 2020, v. 949, p. 162870. https://doi.org/10.1016/j.nima.2019.162870.

8. J.B. Birks, *The Theory and Practice of Scintillation Counting*, London, Pergamon press, 1967, 664p.

9. N.Z. Galunov, E.V. Martynenko. Ionizing radiation energy exchange in the regions of high activation density of organic scintillators // *Rad. Meas*. 2007, v. 42, p. 715-718. https://doi.org/10.1016/j.radmeas.2007.02.060.

10. N. Galunov, D. Gryn, N. Karavaeva, I. Khromiuk et al. Delayed radioluminescence of some heterostructured organic scintillators // *J. Lumin*., 2020, v. 226, p. 117477. https://doi.org/10.1016/j.jlumin.2020.117477.

11. A.V. Krech, I.F. Khromiuk, O.A. Tarasenko. Heterostructured scintillators based on organic crystal grains for a high pulse shape discrimination. // *Problems of Atomic Science and Technology*. 2024, N 3, p. 28-33. https://doi.org/10.46813/2024-151-028.

12. N.Z. Galunov, B.V. Grinyov, N.L. Karavaeva et al. Development of new composite scintillation materials based on organic crystalline grains // *IEEE Trans. Nucl. Sci*. 2009, v. 56, p. 904-910. https://doi.org/10.1109/TNS.2009.2015761.

13. R.A. Laudise, *The Growth of Single Crystals* (Solid state physical electronics series), New York, Prentice Hall. 1970, 352p.

14. I.F. Khromiuk, A.V., Krech, E.V. Martynenko, O.A. Tarasenko. Triplet reflection at boundaries of grains and its influence on optical and scintillation characteristics of organic composite detectors // *J. Lumin*. 2025, v. 280, p. 121087. https://doi.org/10.1016/j.jlumin.2025.121087.