Functional Materials 17, No.4 (2010)

Combined composite scintillation detector for separate measurements of fast and thermal neutrons

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Received August 11, 2010

Studied has been a combined detector for fast neutron spectrometry and simultaneous detection of thermal neutrons in the presence of gamma background radiation. The detector consists of a composite scintillator containing stilbene crystal grains and another scintillator with inorganic Gd-containing crystal grains. The separation of different scintillation material signals corresponding to different ranges of scintillation amplitudes has been used instead of the standard separation method using the decay times of different scintillation materials.

Рассмотрен комбинированный детектор для спектрометрии быстрых нейтронов и одновременной регистрации тепловых нейтронов в присутствии гамма-полей, состоящий из композиционного сцинтиллятора из гранул органического монокристалла стильбена и сцинтиллятора из гранул неорганических кристаллов, которые содержат Gd. Применен не стандартный метод разделения по временам высвечивания различных сцинтилляционных материалов, а использовано разделение сигналов от разных сцинтилляционных материалов, лежащих в различных диапазонах амплитуд сцинтилляций.

1. Introduction

The simultaneous detection of fast and thermal neutrons fluxes of low intensity in the presence of background gamma radiation is a very important and complicated problem. We have proposed the production technology of a new type of organic scintillation materials which are effective detectors of fast neutrons and have no technological limitation in the area and configuration of the input window. These are the organic composite scintillators containing stilbene ($C_{14}H_{12}$) or *p*-terphenyl ($C_{18}H_{14}$) crystal grains i.e. hydrogen bearing materials [1]. Using the same approach, we have obtained new composite detectors of thermal neutrons based on grains of Ce-doped gadolinium silicate (Ce:GSO) or gadolinium pyrosilicate (Ce:GPS) crystals [2]. In this work, we describe a new combined composite scintillation detector for separate detection of fast and thermal neutrons in the presence of gamma background.

2. Preparation of composite scintillators

We have prepared a combined detector (Fig. 1) consisting of a composite detector containing stilbene crystal grains (1, a detector of fast neutrons) [3] and a thin composite detector with inorganic Gd-containing crystal grains (2, a detector of thermal

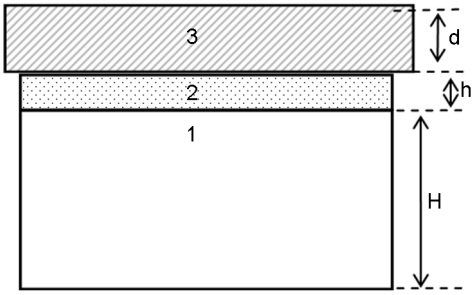

Fig. 1. Schematic diagram of the combined heterogeneous detector: *1*, fast neutron detector containing stilbene grains; *2*, detector of thermal neutrons with Ce:GPS grains; *3*, passive protection material.

neutrons) [4]. It is known that Ce:GPS detectors have higher light yield than Ce:GSO ones [5]. The scintillation photons generated in the inorganic substance and detected by a photomultiplier tube are adsorbed in part when passing through the organic detector acting as a light guide. So, to obtain the maximum signal detecting thermal neutrons by a combined detector, the composite detector containing Ce:GPS crystal grains was preferred. We have manufactured three combined detectors using organic glass containers (∅30 mm×20 mm). The detector (Fig. 1) consists of an organic composite scintillator detecting fast neutrons and a single-layer inorganic composite scintillator detecting thermal neutrons. To detect thermal neutrons, we used the composite scintillators containing a selected fraction of Ce:GPS grains. Three fractions with grain size L_{GPS} 0.06 to 0.1, 0.1 to 0.3 and 0.3 to 0.5 mm were chosen. The organic scintillator was about 15 mm thick. It contained stilbene crystal grains of size L 2.5 to 3.0 mm. Silicone matrix (Silgard-527) was used for the both organic and inorganic composite scintillators. The scintillators were separated by an additional 2 mm thick organic glass plate (the same material as the container).

3. Experimental results

The spatial structure investigations of composite materials by an Axioskopp Zeiss optical microscope have shown that the grains are quite evenly dispersed in the single-layer composite scintillators (Fig. 2). Measurements of radioluminescence kinetics evidenced that the decay time of scintillation pulse fast component in the organic crystal or in composite scintillator based on its grains is about nanoseconds (3 to 4 ns).

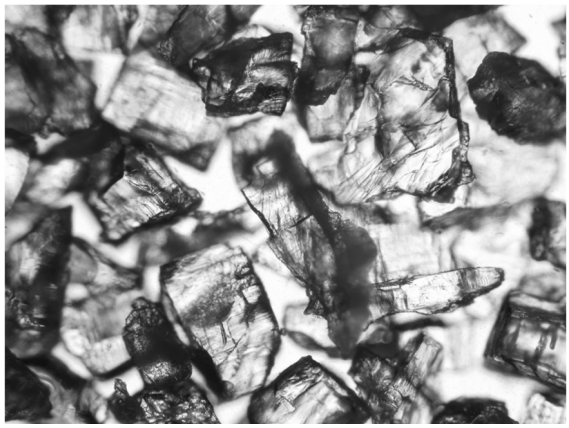

Fig. 2. Optical photography of the composite material spatial structure obtained using an Axioskopp Zeiss optical microscope (×50).

The onset of the scintillation pulse slow component can be described coarsely by exponential function with characteristic decay time about hundreds of nanoseconds (about 300 ns). This agrees with known literature data [6]. The decay time of detectors based on gadolinium silicate or gadolinium pyrosilicate is about several tens nanoseconds (Table). This time is longer than decay time of scintillation pulse fast component and shorter than characteristic decay time of scintillation pulse slow component in organic crystals of stilbene and *p*-terphenyl. For this reason, the standard approach where the "short" time signal and "long" time signal are used as the separation criterion for signals of the two scintillators is unsuitable in this case. A different solution is required.

If we limit the measurements to the detection of scintillation signals generated by secondary radiations of 33 keV (conversion

Table. Value of decay time parameter τ for Ce:GSO and Ce:GPS detectors

No.	Detector	τ, ns
1	Inorganic single crystal Ce:GSO, thickness 0.39 mm	33.0
2	Single-layer composite detector, Ce:GSO grains 0.06 to 0.1 mm	44.5
3	Single-layer composite detector, Ce:GSO grains 0.3 to 0.5 mm	44.5
4	Inorganic single crystal Ce:GPS, thickness 0.35 mm	45.2
5	Single-layer composite detector Ce:GPS, grains 0.06 to 0.1 mm	42.1
6	Single-layer composite detector, Ce:GPS grains 0.3 to 0.5 mm	42.1

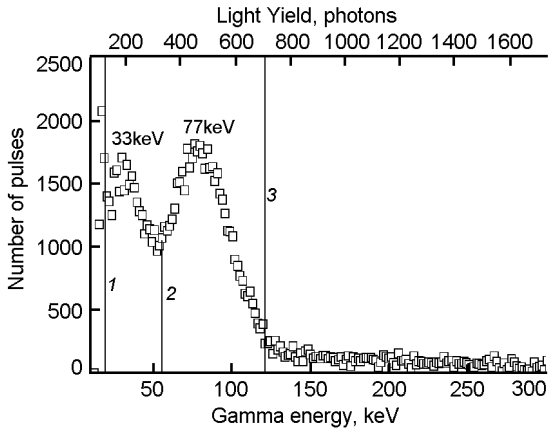

Fig. 3. Scintillation amplitude spectrum of the combined detector (stilbene composite scintillator with L_S 2.5 to 3.0 mm and Ce:GPS single-layer composite scintillator with L_{GPS} 0.06 to 0.1 mm) excited with thermal neutrons.

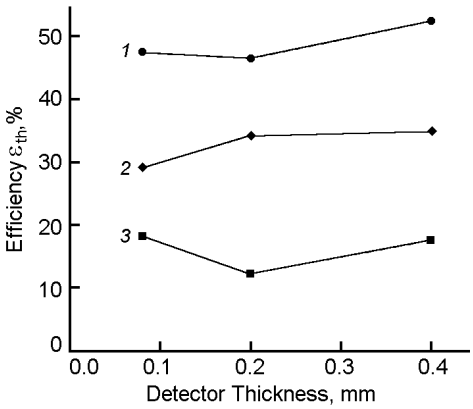

Fig. 4. The ε_{th}-values for the combined detectors containing stilbene grains with L 2.5 to 3.0 mm and single-layer composite scintillator with Ce:GPS-grains of different fractions: L_{GPS} 0.06 to 0.1, 0.1 to 0.3 and 0.3 to 0.5 mm. *1* – 20-120 keV; *2* – 56-120 keV; *3* – 20-55 keV.

electrons) and 77 keV (total signal of conversion electrons and 44 keV of X-rays) appearing in gadolinium under the influence of thermal neutrons, and compare the results with scintillation amplitude spectra of recoil protons for stilbene or *p*-terphenyl, then it follows from our measurement results [3, 4] that they are spaced enough at the scintillation amplitude scale. Thus, it is possible to use scintillation amplitude separation and to measure in two different energy windows to develop a combined detector.

The scintillation spectra of thermal neutrons for combined detector were obtained by cadmium difference method for three above-named fractions of Ce:GPS grains. Fig. 3 demonstrates the scintillation spectrum of thermal neutrons for combined detector that contains organic composite scintillator containing stilbene grains of size L 2.5 to 3.0 mm and single-layer composite scintillator with Ce:GPS-grains of size L_{GPS} 0.06 to 0.1 mm. The vertical lines *1–3* show the energy ranges where the efficiency of thermal neutron detection was studied. Using the results of thermal neutron spectrum measurements, the thermal neutron detection efficiency ε_{th} was calculated for energy ranges (see Fig. 4): 20 to 55 keV (the range of the scintillation peak generated by 33 keV conversion electrons), 56 to 120 keV (the range of total 77 keV peak), and 20 to 120 keV. The thermal neutron detection efficiency was estimated as follows:

$$\varepsilon_{th} = \frac{N_{\Sigma}}{t \cdot F_{fast} \cdot \eta_{th} \cdot S/4\pi R^2} \times 100\%, \quad (1)$$

where N_{Σ} is the number of thermal neutron detection events; t, the accumulation time of the events (spectrum); F_{fast}, the number of fast neutrons emitted by the source per second; $\eta_{th} = 0.09$ is the number of neutrons moderated in the paraffin sphere to thermal energy per one fast neutron; S, the thermal neutron detector area; R is the distance between the source and the detector.

Fig. 4 presents the calculation results of the thermal neutron detection efficiency ε_{th} for combined detectors with different grain size at the chosen fraction L_{GPS}. The thickness of the single-layer composite scintillator was characterized by the average grain size of chosen fraction. The calculations were made for three above mentioned energy ranges.

The curves *1* and *2* (Fig. 5) show the scintillation spectra obtained using the pulse shape discrimination (a recoil proton spectrum), and without pulse shape discrimination (a total spectrum), respectively. Fig. 6 shows the neutron spectrum of the ^{239}Pu–Be source reconstructed from the recoil proton spectrum (see Fig. 5, the curve *1*). Peaks numbering from 1 to 9 in the reconstructed neutron spectrum corresponds to the neutron energy values 3.1; 4.2; 4.9; 6.4; 6.7; 7.3; 7.9; 8.6; and 9.7 MeV [1].

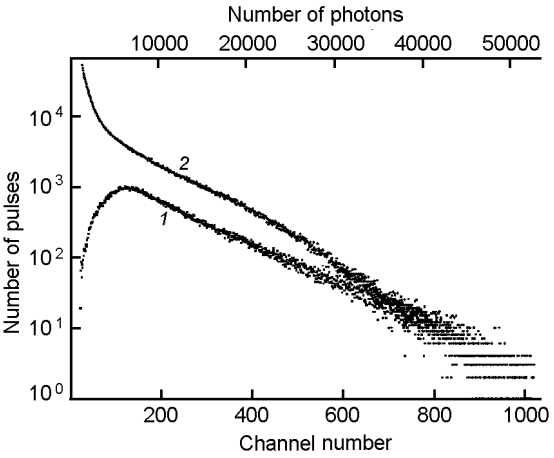

Fig. 5. Scintillation amplitude spectra of the same combined detector as in Fig. 3 irradiated with fast neutrons and gamma photons from the ^{239}Pu–Be source. Curves *1* and *2* show the scintillation spectra obtained with and without pulse shape discrimination, respectively.

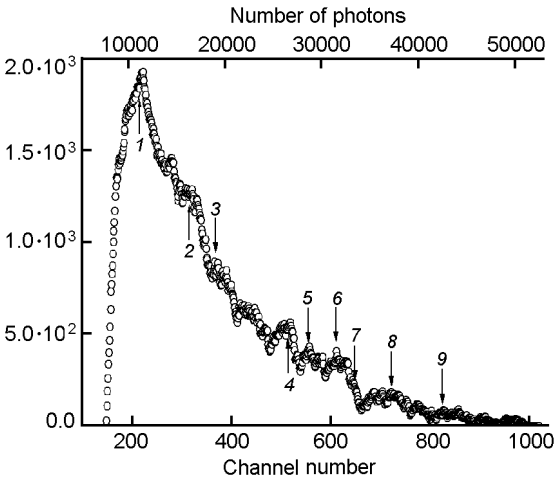

Fig. 6. The reconstructed neutron spectrum of the ^{239}Pu–Be source.

The comparison of the results presented in Fig. 3 and spectra in Fig. 6 evidences that the scintillation amplitudes obtained under thermal and fast neutron excitation correspond to different dynamic ranges of scintillation amplitudes.

4. Conclusions

Thus, the combined detector for fast neutron spectrometry and simultaneous detection of thermal neutrons in the presence of gamma background radiation has been studied. Taking it as an example, the main opportunities to vary composite scintillation material characteristics were studied (due to selection of grain size and thickness of scintillation material). The separation of different scintillation material signals corresponding to different ranges of scintillation amplitudes has been used instead of the standard method of separation by decay time of different scintillation materials. The new scintillation materials prepared as described in [3, 4] used in the combined detector allow to reconstruct the fast neutron spectrum. This has been shown taking a radionuclide ^{239}Pu–Be source as an example. This is in a good agreement with the results presented in [3]. In other words, the composite scintillation material does not change its characteristics when being a component part of the combined detector that is irradiated with mixed radiations. The calculation results of the thermal neutron detection efficiency ε_{th} of material of the proposed combined detector agree well with the results of similar investigations described in [4] obtained for single-layer composite detectors containingn Ce:GPS crystal grains.

Authors acknowledge Dr.S.V.Budakovsky and Dr.O.Ts.Sidlecky working at Institute for Scintillation Materials, National Academy of Sciences of Ukraine, for providing with samples of organic and inorganic single crystals.

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Комбіновані композиційні сцинтилятори для реєстрації швидких та теплових нейтронів

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Розглянуто комбінований детектор для спектрометрії швидких нейтронів в присутності гамма-полів, що складається з композиційного сцинтилятора з гранул органічного монокристалу стильбену та сцинтилятора з гранул неорганічних кристалів, що містять Gd. Використано не стандартний метод розділення за часом висвітлювання різних сцинтиляційних матеріалів, а розділення сигналів від різних сцинтиляційних матеріалів, що знаходяться у різних діапазонах амплітуд сцинтиляцій.