

SENSITIVITY STUDIES OF BETA-RADIATION DETECTOR BASED ON SMALL-CRYSTALLINE SCINTILLATOR ZnSe(Te)

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A new large area β - detector has been designed and studied. The design includes wedge-shaped light transducers. A composite material based on a small crystalline ZnSe(Te) was applied onto the wide surface of light transducer. This design ensures optimum light collection from the large sensitive surface onto the output window of a much smaller size. An experimental specimen has been prepared, which showed a β -sensitivity $C_{\beta}=5.5 \text{ cm}^2$. The spectrograms of a $^{90}\text{Sr}+^{90}\text{Y}$ β -source obtained with the specimen under study make it possible to evaluate the age of the source by the ratio of low- and high-energy regions of the spectrum. Other designs are proposed for application of large-area detectors possessing wedge-shaped light transducers as elements of assembled constructions for high efficiency detectors operating under flow conditions.

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1 INTRODUCTION

Solid-state scintillation detectors (SD) comprising scintillation crystals (S) and silicon PIN photodiodes (Si-PIN-PD) are widely used in dosimeters, radiometers, spectrometers, in technological equipment for medical diagnostics, environment monitoring, customs and security control, etc [1].

Detectors comprising PD have many advantages as compared with those based on PMT. PMT have the narrower dynamic range of the measured radiation levels, their amplification rate is not stable, and the output signal is rather sensibly temperature-dependent ($\sim 1\% / \text{K}$). Besides this, low voltage power supply of PD ensures its functioning in extreme conditions (including dangers of explosions, fire, etc.), and small size of PD-based detectors allows their use in portable instruments.

One of factors limiting the broad use of "scintillator-photodiode" detectors is a small area of the photosensitive surface of the photodiode ($S \sim 1 \text{ cm}^2$). This disadvantage can be partially removed by the use of crystals with a large sensitive volume. However, this leads to "hanging over" of the scintillator above the PD input window, which leads to noticeable deterioration of the signal at the detector output.

Up to date, for detection of beta-radiation the most widely used scintillators were p-terphenyl, CsI(Tl), NaI(Tl). However, alkali halide crystals are hygroscopic, that requires their additional protection against moisture. Operation under conditions of high humidity leads to deterioration of the crystal surface, a "dead layer" is formed, and detector characteristics are subsequently changed. Crystals of p-terphenyl have bad spectral matching with the Si-photodiode, and they can be used only in combination with PMT.

A promising scintillator for beta-radiation detection is ZnSe(Te), which has a high conversion efficiency ($\eta = 18\%$) [2], high spectral matching coefficient with Si-photodiode ($F = 91\%$) [3], and is not hygroscopic. However, the existing technological processes do not

allow obtaining ZnSe(Te) single crystals larger than 3 cm in diameter. Detector sensitivity can be increased with larger area of the output window and creation of optimum light collection conditions in the scintillator. One of the ways to increase the sensitive detector area is creation of a detecting layer as a conglomerate of scintillating ZnSe(Te) grains in a transparent dispersion medium located on the light transducer surface. Optimization of light collection conditions in such a detector is related to the choice of the optimum grain shape, the use of additional reflective coatings, and transparence of the dispersion medium surrounding the detector, as well as to the optimum shape and size of the light transducer.

In this paper, we studied a possibility to increase the sensitivity of beta-radiation detectors by means of a scintillation monolayer formed by small-crystalline particles of ZnSe(Te) on light transducers of large area.

2 RESULTS AND DISCUSSION

In [4], a new design was proposed for a solid-state scintillation detector, in which a conglomerate of small-crystalline particles of ZnSe(Te) was used as a scintillator. The particles were dispersed in the polymer matrix transparent to the intrinsic radiation of the scintillator. Using computer modeling, we have carried out theoretical determination of the optimum shape of the scintillator crystal grains ensuring the best light collection. The influence of the dispersion medium (optical adhesive) on the light output value was also analyzed. It has been shown that such a detector design leads to a higher detection efficiency of beta- and low-energy gamma-radiation as compared with solid single crystalline plates of the same material. The area of the scintillation layer in these detectors is technologically unlimited and can be chosen according to specific application conditions. However, as a rule, the light-sensitive area of the photodiode is small and does not exceed $1 \times 1 \text{ cm}^2$. At the same time, obtaining higher sensitivity requires larger areas of the scintillation layer. It becomes neces-

sary to use a light transducer for transmission of the scintillation light from the large area to the photoreceiver.

Using Monte-Carlo calculations, light collection coefficient was evaluated for different types of light transducers. Light reflection from the light transducer surface on which scintillator grains were located was considered as reflection from the boundary between media with refraction indexes 1.5 and 2.57 (the light transducer and ZnSe(Te) grain, respectively). When the light beam comes into a grain, the probability of its returning back into the light transducer was taken as 0.6 (this is the value of the light collection coefficient for the case of pyramid-shaped grain with the angle of 60° between the sides and the base of the pyramid). Direction of the light beam coming into the light transducer was considered as uniform in the space (isotropic

source).

The light transducer efficiency was characterized by the relationship

$$P = S_1/S_2, \quad (1)$$

where τ is the light collection coefficient, S_1 is the area occupied by the scintillator grains, and S_2 is the area of the light transducer output window.

The value of P shows by how many times the signal from the matrix scintillator connected to the photoreceiver by the light transducer is larger than a similar signal for the case of scintillator grains applied directly onto the photoreceiver.

As a result of our calculations, we have shown that the most advantageous design of the light transducer is achieved when it is wedge-shaped (Fig. 1).

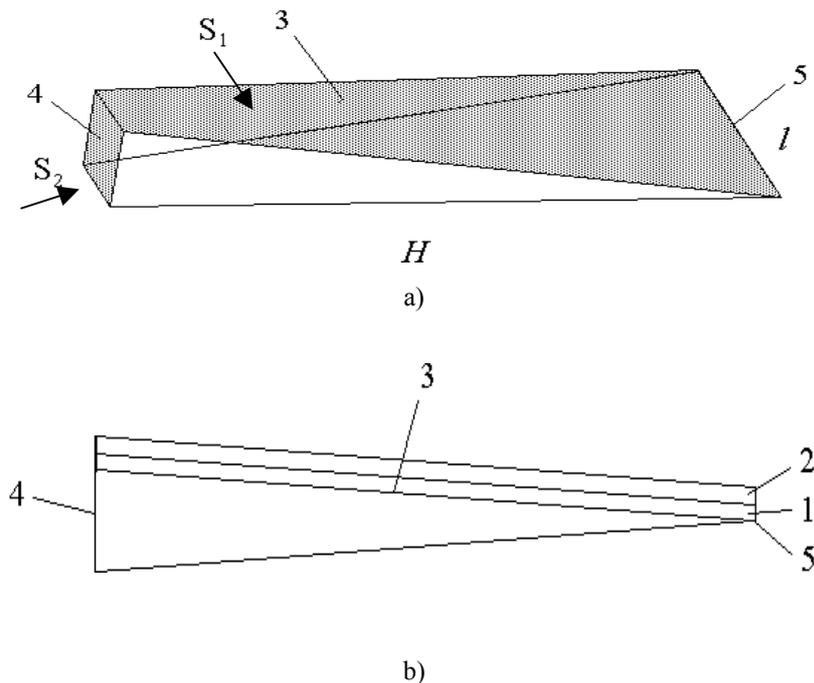


Fig. 1. Small-crystalline ionizing radiation detector of large area: a) axonometric view, b) side view. 1 – dispersion polymeric matrix, 2 – scintillation monolayer of small-crystalline ZnSe(Te), 3 – input window of the detector, 4 – output window of the detector, 5 – light transducer.

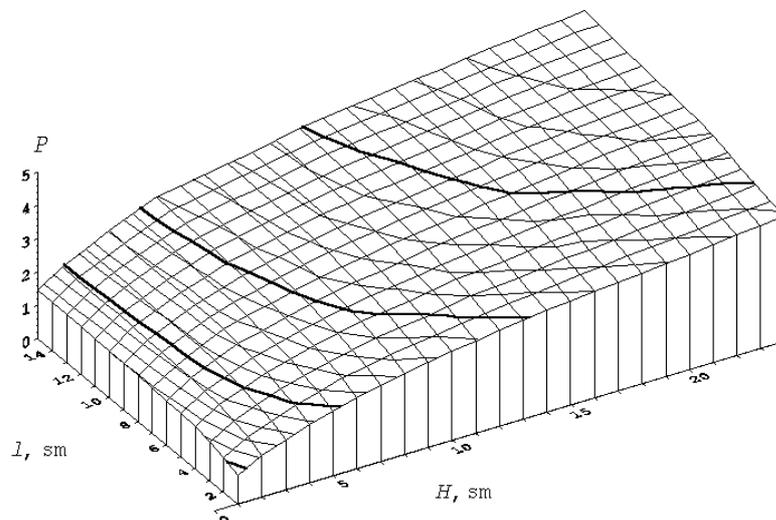


Fig. 2. Efficiency P of the wedge-shaped light transducer as a function of its dimensions – length H and width l at the side opposite to the photoreceiver. The size of the output window $S_2 = 1 \times 1 \text{ cm}^2$.

With such a design, scintillator grains are applied onto the largest area surface of the wedge. Light collection onto the photoreceiver is made from the backside of the wedge. Optimization of the design consists in choosing such values of the wedge length H and its width l at the farthest end from the window that would ensure the highest efficiency P as determined according to (1). Fig. 2 shows the calculated two-dimensional dependence of P on the mentioned geometric factors.

It follows from our calculations that a wedge-shaped light transducer is 2-3 times more efficient than an ordinary concentrating light transducer. It is important that the area is practically not limited and should be related only to the specific uses of a detector.

We have prepared experimental samples of the large-area detector with a wedge-shaped light transducer with scintillation layer in the form of crystalline particles of ZnSe(Te). The light transducer dimensions were: output window area – $S_2 = 1 \times 1 \text{ cm}^2$; the area of the input surface of the light transducer on which the crystalline particles were placed – $S_1 = 40 \text{ cm}^2$. This surface was trapezium-shaped with bases 1 cm and 7 cm and height 10 cm. The light transducer was made of transparent material – polystyrene. The light absorption coefficient did not exceed 0.01 cm^{-1} .

Measurements of the detector sensitivity in the counting mode by measuring the output signal were carried out by the pulse method using a set-up with a charge-sensitive preamplifier. An S3590 Hamamatsu Si-PIN-PD was connected to the input of the preamplifier. From the output, the signal came to the input of a standard amplifier-shaper, and after that – to a frequency meter. As a radiation source, we used a reference $^{90}\text{Sr}+^{90}\text{Y}$ beta-source with the active surface area of 160 cm^2 . The detector sensitivity to beta-radiation was determined from the number of flashes (events) per second under irradiation by the beta-source located directly

on the input surface of the detector.

The following expression was used for calculations:

$$C_\beta = S_{det} \cdot N_c / N_f, \quad (2)$$

where C_β is the detector sensitivity, cm^2 ; S_{det} is the area of the input window of the detector, cm^2 ; N_c is the number of recorded events per second; N_f is the number of beta-particles falling onto the input window effective surface, which can be presented as

$$N_f = S_{det} K_{fil} \cdot (1 - K_{bs}) \cdot A_0 \cdot e^{-0.693t/T} / S_{sour}, \quad (3)$$

where A_0 is the external radiation from the active layer inside 2π angle, beta-particles per second; t is the age of the source, years; T is the half-decay time, years; S_{sour} is the active surface area of the source, cm^2 ; $K_{fil} \approx 0.8$ is the filling coefficient of the detector working surface by the scintillation material; $K_{bs} \approx 0.4$ is the coefficient of back scattering by scintillator material.

As a result of calculations, we obtained the sensitivity value $C_\beta = 5.5 \text{ cm}^2$.

As material for wedge-shaped light transducer, a polished single crystal CsI(Tl) was also used, which showed good sensitivity to gamma-radiation of a ^{137}Cs source. This allows application of such detectors as “phoswich” detectors for separate detection of gamma- and beta-radiation.

In Fig. 3, the beta-spectrogram of a $^{90}\text{Sr}+^{90}\text{Y}$ source is presented, which was obtained using a scintillation spectrometer with the detector developed on the basis of ZnSe(Te) and plastic scintillator (PS) of $\text{Ø } 6.3 \times 6.3 \text{ cm}^3$ size. The spectrograms were recorded without passive protection.

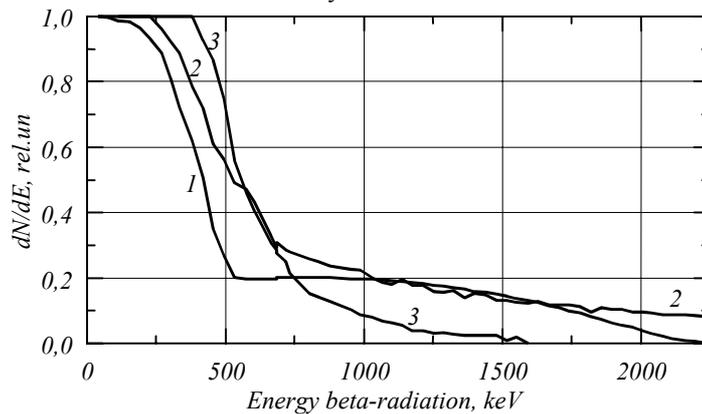


Fig. 3. Beta-spectrograms of a $^{90}\text{Sr}+^{90}\text{Y}$ source: 1 – calculated; 2 – obtained using plastic scintillator; 3 – obtained using ZnSe(Te).

PS-based scintillators in the high-energy region have a “tail” from high-energy radiation of uranium-radium and thorium series of the environment. As is seen from Fig. 3, the closest, as for shape, to the calculated spectrogram is that obtained using a plastic scintillator. The source chosen for measurements had equal quantities per time unit of the forming and decaying daughter nuclei, i.e., an equilibrium is established between the number of “mother” and “daughter” nuclei. For

ZnSe(Te)-based detectors, the daughter nucleus contribution into the counting rate is not significant, which is probably related to stronger (as compared with PS) reflection of the particles from an inorganic scintillator with higher atomic number than that of PS. The other reason could be non-optimum thickness of ZnSe(Te) for this spectral range. This difference in the spectrum shape can presumably be used to evaluate the age of the source, using PS as light transducer.

Detectors with wedge-shaped light transducers can be used as construction elements of flow combined detector for radioactive liquids and gases. At least three types of the design can be proposed:

1. With the shape of “flower with petals” (Fig. 4(a)) – two-dimensional detector.
2. Shaped as a flow construction where each construction element is a blade of a fan-like system,

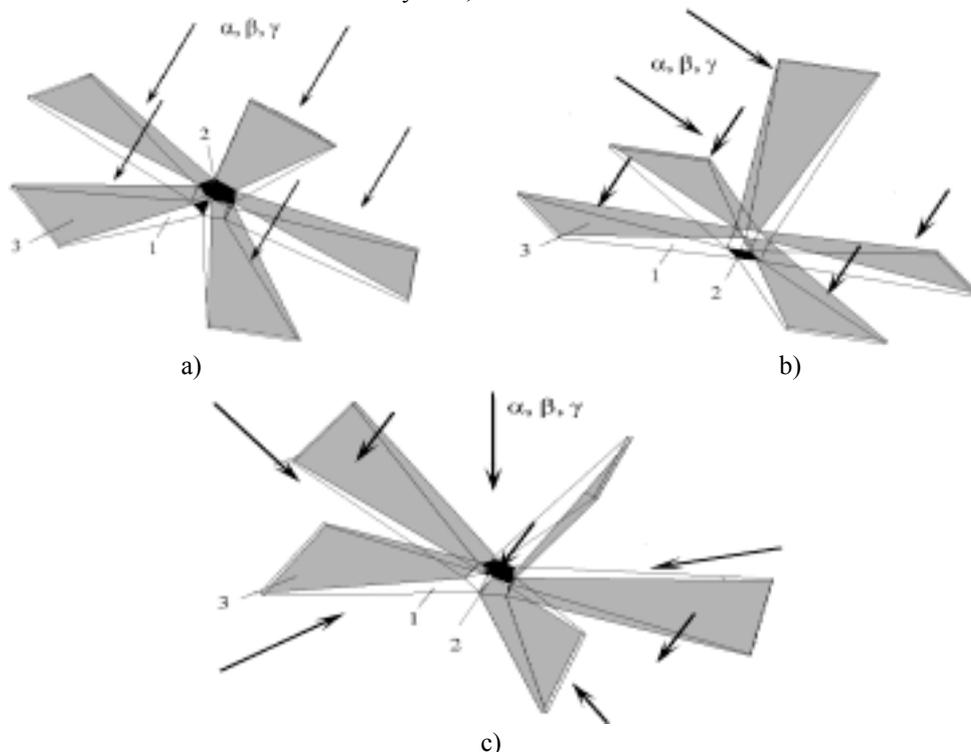


Fig. 4. Possible design variants of combined flow detectors: 1 – construction element of the detector as a small-crystalline detector of large size; 2 – photodiode; 3 – scintillation layer of the detector element.

3 CONCLUSIONS

As a result of our work, a new combined detector has been designed and studied, which had a large area and used wedge-shaped light transducers. Onto the wide light transducer surface, a composite material was applied based on small crystalline ZnSe(Te). Such design ensures optimum light collection from the large sensitive surface of the input window onto the output window of much smaller size. An experimental specimen was made, for which sensitivity to $^{90}\text{Sr}+^{90}\text{Y}$ beta-source was determined – a source with sensitivity of 5.5 cm^2 . Replacing the light transducer material with PS or CsI(Tl), it is possible to obtain “phoswich” detectors for separate registration of charged particles and the background gamma-radiation. The spectrograms of a $^{90}\text{Sr}+^{90}\text{Y}$ beta-source obtained with the detector specimen under study make it possible to evaluate the age of the source by the ratio of low- and high-energy regions of the spectrum. Variants are proposed for application of large-area detectors with wedge-shaped light transducers as elements of assembled constructions for high-efficiency detectors operating under flow conditions.

with a minimum number of petals – 4-5 (Fig. 4(b)).

3. Fan-like system, the number of petals not limited (Fig. 4(c)).

Light collection for all the design variants is made using a $1 \times 1 \times 1 \text{ cm}^3$ light transducer, or a polyhedron of the same volume upon the silicon photodiode with $1 \times 1 \text{ cm}^2$ input window area.

4 ACKNOWLEDGMENTS

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