

Scintillation panels based on zinc selenide for detection of alpha radiation

V.Litichevskyi, V.Tarasov, S.Galkin, O.Lalaiants, E.Voronkin

Institute for Scintillation Materials, STC "Institute for Single Crystals", National Academy of Sciences of Ukraine, 60 Lenin Ave., 61001 Kharkiv, Ukraine

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The possibility of obtaining dispersed scintillation panels based on zinc selenide for alpha radiation registration has been demonstrated. Thanks to the good energy resolution R_α ~ 30 % of the panel it can be used for the registration of alpha radiation in radiometric and spectrometric modes. In this work the optimal particle size and the effective thickness of the composite layer of powder scintillator have been determined that provides high quantum yield of the panels. Experimental data of the dependence of light output from the panels on the size of the scintillator's particles at the influence of X-ray and alpha radiation have been presented.

Показана возможность получения дисперсных сцинтилляционных панелей на основе селенида цинка для регистрации альфа излучения. Благодаря хорошему энергетическому разрешению R_α ~ 30 % панель может быть использована для регистрации альфа излучения как в радиометрическом, так и в спектрометрическом режимах. В работе определены оптимальные размеры частиц и эффективная толщина композитного слоя порошка сцинтиллятора, обеспечивающие высокий квантовый выход панелей. Приведены экспериментальные данные о зависимости светового выхода панелей от размера частиц порошка сцинтиллятора при воздействии рентгеновского и альфа излучений.

1. Introduction

In the field of nuclear fuel production, as well as in its reprocessing after use it is necessary to monitor the content of alpha-active radionuclides in the air [1].

Currently, the detection of alpha radiation most widely performed by semiconductor detectors and scintillation detectors based on ZnS(Ag) [2]. Semiconductor detectors demonstrate good results in well-ventilated rooms and laboratories. However, in some areas of the processing industry such detectors should be in fairly harsh conditions (high level of temperature and humidity, the presence of nitric acid vapors in the atmosphere), which reduce their effectiveness after a few months of their exploitation. Scintillation detectors based on ZnS(Ag) show greater stability, but they also have several drawbacks. Due to its physical characteristics scintillation material ZnS(Ag) has a low energy resolution (R_α ~ 70 %), which does not allow efficient identification of the source of alpha particles. In addition, the phosphor of ZnS(Ag) is not suitable for selective registration of α and γ radiation from ^{241}Am. Also scintillation layer of ZnS(Ag) has a significant self-absorption and scattering of light, which leads to a reduction of the scintillation signal. The maximum of the emission spectrum for ZnS(Ag) is 450 nm, which limits its use in conjunction with silicon photodiodes and matrices of photodiodes, since their maximum sensitivity is in the red spectrum region. The improvement of the scintillation detectors for alpha particles may be obtained due to use of other scintillation materials, in particular zinc selenide (ZnSe).

ZnSe(Al) scintillator relates to the semiconductor materials class of $A^{II}B^{VI}$ group. It is widely used in scintillator-silicon photodiode systems for X-ray detectors of modern multichannel low energy means of visualization of hidden image (systems of non-destructive control, medical tomography, radiography) [3]. Crystals of zinc selenide possess a high luminescent efficiency (60 thousands gamma photons/MeV) and short afterglow duration, which allows registration of the shadow image of biological objects in real time. Also the emission colour of this phosphor is orange-red, which makes it perfectly suited to detection by silicon semiconductor devices [4].

The geometrical detection efficiency of alpha radiation increases with increasing the detector active surface. The possibility of obtaining large crystalline samples of scintillator ZnSe is technologically limited, because with increasing the crystal size the inhomogeneity of the luminescence is also increasing due to segregation of alloying elements in the crystal in the process of growth. Use of the fine-crystalline powder of zinc selenide eliminates these drawbacks and allows obtaining large area scintillators with a high homogeneity of the luminescence (luminescence inhomogeneity is less than 2 %).

This paper presents the results of parameters determination of the experimental samples of scintillation panels based on ZnSe(Al) fine-crystalline powder. The work was conducted for investigation of the possibility of manufacturing a scintillator for the registration of alpha particles, which will provide selective registration of alpha- and X-ray (soft gamma) radiation of the radionuclide ^{241}Am, and which will have an energy resolution sufficient to work not only in the radiometric, but also in the spectrometric mode. The scintillator should also has a large geometric size.

In this work we have studied the dependences of the light output intensity of panels on the particle size of ZnSe scintillator powder under X-ray radiation and alpha radiation. The optimum effective thickness and the energy resolution for alpha radiation from ^{241}Am have been determined.

2. Experimental

The objects of our study were samples of scintillation panels with different dispersion of ZnSe(Al) powder particles. Experimental samples were made in form of a polycrystalline particles layer of irregular shape of inorganic scintillator ZnSe(Al) (Fig. 1) in the optical immersion medium — silicone rubber. Samples preparation included mixing of scintillator's powder with an immersion medium and subsequent uniform coating on transparent substrate, followed by polymerization of the immersion medium. The particles size of ZnSe(Al) was in range from 1 to 315 μm.

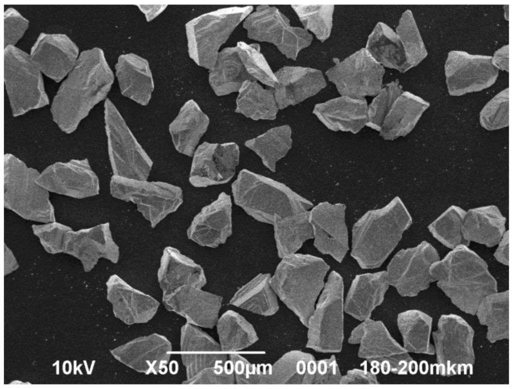

Fig. 1. Image of the crystalline powder of zinc selenide obtained by using the scanning electron microscope JSM-6390LV.

For measurements of scintillation and optical parameters of the scintillation panel samples they were optically connected with photo-electron multiplier by immersion medium — vaseline oil.

Measurements of spectrometric parameters of the samples were carried out by installation, which includes: photo-electron multiplier PEM-125, preamplifier BUS-2-94, amplifier BUI-3K and impulse analyzer AMA-03F. As a source of ionizing radiation ^{241}Am with alpha particles energies about 5.5 MeV was used.

Image of ZnSe(Al) powder was obtained by using the scanning electron microscope JSM-6390LV. Measurements of X-ray light output value of the samples were carried out at 140 kV, 30 mkA and 20 cm distance from anode by using the installation for measurement of light yield and afterglow — "Smiths Heimann AMS-1".

3. Results and discussion

The efficiency of the scintillation panel depends on several factors: size of the powder particles of the scintillator, effective thickness of the scintillation layer, surface quality of the panel etc.

For optimization of the scintillation panel parameters the dependence of the

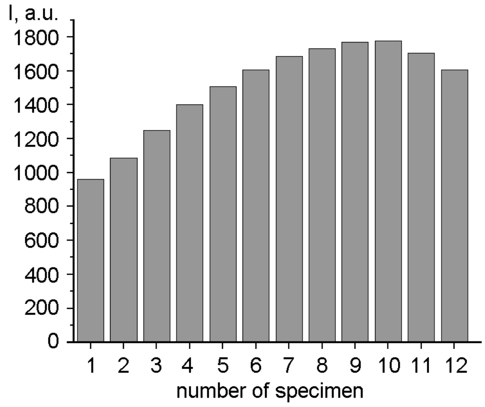

Fig. 2. Dependences of the luminescence intensity of scintillation panels based on zinc selenide on the particle size of polycrystalline powder under the effect of alpha radiation. There was considered twelve ranges of dispersion of the particles: 1–40, 40–63, 63–80, 80–100, 100–125, 125–140, 140–160, 160–180, 180– 200, 200–250, 250–280, 280–315 μm. A sample No.1 was made of the smallest fraction of the powder, the rest — of the following fractions in order of increasing particle size.

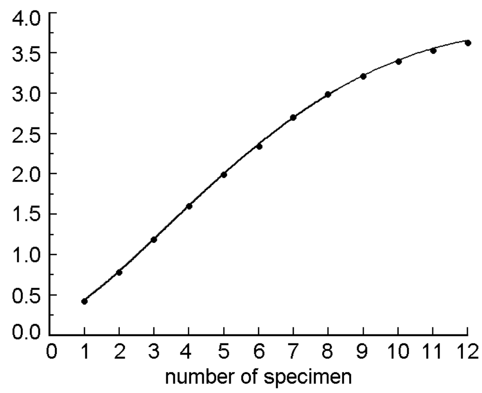

Fig. 3. Dependence of the relative light yield of scintillation panels based on zinc selenide on the particle size of polycrystalline powder under the effect of X-ray radiation. There was considered twelve ranges of dispersion of the particles: 1–40, 40–63, 63–80, 80–100, 100–125, 125–140, 140–160, 160–180, 180–200, 200–250, 250–280, 280–315 μm. A sample No.1 was made of the smallest fraction of the powder, the rest — of the following fractions in order of increasing particle size.

relative light output on the size of zinc selenide particles under the influence of alpha- and X-ray radiation was determined (Fig. 2 and Fig. 3).

Under effect of alpha radiation on the panel samples the maximum intensity of luminescence was observed when the size of the scintillator's particles was in the range from 200 to 250 μm (Fig. 2). The use of the scintillator's particles size less than 200 μm leads to decrease of the panel's light output parameters according to reduction of the panel's effective thickness. For particle size greater than 250 μm the decreasing of light output due to increasing of the panel's effective thickness was observed.

The effective thickness of the panel is about 100 μm, which allows the registration of alpha particles with an average energy ~ 5.5 MeV and higher. With decrease of the scintillator's powder effective thickness the scintillation signal also decreases, because there is no complete absorption of alpha radiation in the panel and, accordingly, the maximum level of luminescence is not achieved. The increase of the element's effective thickness is pointless, since this scintillation signal also decreases due to deterioration of the optical transparency of the element, which reduces the part of light detected by a photodiode.

If we will increase the effective thickness of the element by positioning in several layers the scintillator's particles less than 200 μm in size in order to compact the scintillation layer, the scintillation signal will also become low due to the deterioration of the optical properties of the medium. Thus, since the alpha particles have low penetration length (the free length path of alpha particles from ^{241}Am in zinc selenide is ~ 50 μm) the optimal configuration of the scintillation layer of the panel matches to a single-layer dense packing of the particles of 200–250 μm in size.

Under effect of X-rays on the panel samples the linear dependence of increase of the relative light output with increase of scintillator's particles size was determined (Fig. 3). With reaching the size in 200 μm the deviation from the linear dependence of light output increases and approaches to the maximum level of scintillation signal. Thus, the scintillator's particle size in the range from 200 to 250 μm provides an effective registration not only alpha particles but also the X-ray radiation.

The use of powder particles of 200–250 μm in size and homogenic distribution of compact-packed scintillation layer on the surface of the substrate provides the magnitude of the energy resolution R_α ~ 30 % for alpha particles from ^{241}Am.

Table. Scintillation and physical characteristics of the powder scintillators ZnSe(Al) and ZnS(Ag)

Parameter	Powder scintillator	
	ZnS(Ag)	ZnSe(Al)
Density ρ, g/cm^3	4.09	5.42
Emission maximum λ_{max}, nm	450	610
Conversion efficiency, %	20–23	22
Energy resolution (alpha particles from ^{241}Am), %	~70	~30
Refractive index, n	2.36	2.6
Hygroscopicity	no	no
Chemical stability	unlimited	unlimited
Mechanical and thermal resistance	good	good
Radiation resistance	good	good

The quality of the panel surface also determines the scintillation detection efficiency of alpha radiation. The presence of contaminants or a thick layer of immersion medium on the surface significantly decreases the light output of the panel. It was established experimentally that the thickness of the protective layer of immersion medium on the surface of the panel based on ZnSe(Al) scintillator must be in range from 5 to 10 μm. With such a thickness of protective layer the panel's surface protected from external influences with minimal energy loss of alpha radiation in a layer of immersion medium.

The use of zinc selenide in a dispersed form allows manufacturing the scintillation elements with vast space dimensions.

Scintillation powder concentration in immersion medium does matter very much for alpha sensitivity. It was in the range from 80 to 90 vol.%. This ratio of components provides minimal absorption of alpha radiation in the gaps between the scintillator's particles and the same time maintains the mechanical characteristics of the panel. Synthetic rubber is selected as the immersion medium due to its high chemical stability and high refractive index, which is close to refractive index of ZnSe(Al).

4. Conclusions

In this work the optimal particle size and the effective thickness of the composite layers of powder scintillator have been determined. The effective thickness provides a high quantum yield and high energy resolution (for disperse medium), which allows the use of the panels for registration of alpha radiation in radiometric and spectrometric modes. For example, a widely used scintillator ZnS(Ag) is applied only in the radiometric mode, since it has the low energy resolution R_{α} ~ 70 % (Table).

The larger particle size in the panels based on ZnSe(Al) in comparison with the alpha particle detectors based on ZnS(Ag) provides less scattering, reflection and reabsorption of radiation in the scintillation elements and it provides higher scintillation signal of panels [2].

The use of scintillator ZnSe(Al) in a dispersed form allows the manufacturing of the scintillation panels for registration of alpha radiation with a high homogeneity of the luminescence and without limitation of the linear dimensions of the panels.

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Сцинтиляційні панелі на основі селеніду цинку для детектування альфа випромінювання

В.О.Літічевський, В.О.Тарасов, С.М.Галкін, О.І.Лалаянц, Є.Ф.Воронкін

Показано можливість отримання дисперсних сцинтиляційних панелей на основі селеніду цинку для реєстрації альфа випромінювання. Завдяки достатньо високому значенню енергетичної роздільної здатності $R_{\alpha} \sim 30$ % панель може бути використана для реєстрації альфа випромінювання як у радіометричному, так і у спектрометричному режимах. В роботі визначено оптимальні розміри частинок і ефективну товщину композитного шару порошку сцинтилятора, що забезпечують високий квантовий вихід панелей. Наведено експериментальні дані про залежність світлового виходу панелей від розміру частинок порошку сцинтилятора при впливі рентгенівського та альфа випромінювань.