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Scintillators based on zinc selenide and ticor for detection of charged particles

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Abstract. Studies of charged particle detectors based on ZnSe(Te) and $Al_2O_3(Ti^{+3})$ (ticor) optically connected with photodiodes (PD) of S3590 type are reported. The charge-sensitive preamplifier connected with PD had equivalent noise level of 420 electrons with formation time of 5 μs.
The signal value from ticor on ^{207}Bi internal conversion electrons (ICE) with E_e = 976 keV is equivalent to the signal value from E_γ = 14 keV when PD operates in the semiconductor detector mode (without a scintillator); from a-particles with E_α = 5150 keV it corresponds to 20 keV. From these results, α/β-ratio is ~ 0.28. Energy resolution of ticor on α-particles R_α with E_e = 5150 keV is 11.6 %, on ICE with E_e = 976 keV $R_{e1/2}$ = 15%. Under the same conditions R_α = 3% and R_e = 3.7% for single crystal ZnSe(Te). A possibility to create combined detectors of electrons and α-particles on the basis of these two scintillators is discussed.

Keywords: zinc selenide, ticor, spectrometry, charged particle.

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1. Introduction

Scintillation crystals ZnSe(Te) are widely used in detectors for radiometric and dosimetric instruments, in radiation introscopes and other systems of radiation monitoring [1–3]. Recently, studies have been carried out on a possibility to use ZnSe(Te) crystals for detection of light and heavy charged particles, in dispersion detectors of thermal and fast neutrons [4, 5]. Principal advantages of ZnSe(Te) crystals over oxide and alkali halide scintillators are their high thermal and radiation stability, high conversion efficiency as well as good matching of the emission spectrum and sensitivity maximum of silicon photodiodes.

Crystals $Al_2O_3(Ti^{+3})$ (ticor) are used mostly in quantum electronics. The first results on their application for dosimetry of powerful fluxes of ionizing radiation have been presented in [6, 7]. High chemical stability and thermal stability of output parameters allows to use these crystals for inspection of liquid radioactive wastes or fuel-containing masses. Relatively low effective atomic number Z_{eff} and small radiation capture cross-section of thermal neutrons $\sigma_{n,\gamma}$ allow to think of ticor crystals as promising materials for measurement of β-particle fluxes in thermal neutron fields.

The aim of the present work was to study spectrometric characteristics of ZnSe(Te) and ticor crystals in the course of α-, β-, γ-radiation detection in the broad energy range, as well as to determine α/β-ratio for detectors based on these crystals and designed for simultaneous and separate detection of charged particles and radiations of different types.

2. Experimental

For the experiments we chose single crystals grown as described in [8]. From the single crystals, plates were made with dimensions 10×10 mm^2 and 1–8 mm thickness.

The output windows of the plates (directed towards the photosensitive surface of the photodiode) were mated, and the input windows (those directed towards the charged particle flux) were polished. The plates were packed into teflon containers with collimator windows on input windows for transmission of charged particles. The output characteristics of crystals ZnSe(Te) and $Al_2O_3(Ti^{+3})$ are presented in Table 1 (λ_{max} is luminescence maximum, τ – decay time, α – absorption coefficient, Z_{eff} – atomic number, S – relative light output, T_{max} – maximum operation temperature).

Table 1. Characteristics of scintillators produced in Concern «Institute for Single Crystals»

Crystal	λ_{max}, nm	τ, μs	α, cm^{-1}	Z_{eff}	S, rel.un.	T_{max}, K
ZnSe(Te)	600-620	2-20	0.05-0.15	33	100	400-450
	630-640	>20			170	
Al_2O_3(Ti)	750	3-4	-	12	16-20	350
CsI(Tl)	550	0.63-1	> 0.05	54	100	350-400

Spectrometric parameters of crystals were studied using sources of internal conversion electrons ^{109}Cd, ^{137}Cs, ^{207}Bi, source of α-particles ^{239}Pu, as well as sources of X-ray and γ-quanta of ^{55}Fe, ^{241}Am, ^{57}Co, ^{137}Cs, ^{22}Na at T = 294 K. Photodiodes of S3590-01 type (Hamamatsu, Japan) and "Porog" type photodiodes produced by NCB "Ritm", Chernovtsy, Ukraine, were used. Their comparative characteristics are shown in Table 2.

Table 2. Parameters of Si photodiodes

Parameters	S3590-01	«Porog»
Light sensitive area, mm^2	10×10	10×10
Dark current, nA	30	30
Capacitance, pF	70	67
Sensitivity for λ = 540 nm, A/W	0.31	0.26

Spectral sensitivity maximum of Si-PIN-PD is in the 800–900 nm range, which matches by 70% the radioluminescence spectrum of crystals ZnSe(Te). High requirements were put to all parts of the spectrometric circuit, especially to the charge-sensitive preamplifier (CSPA). CSPA comprises a charge sensitive section with a field transistor at the input and power supply elements of the photodiode. Our studies have shown that the lowest level of intrinsic noise can be obtained with KP 341A field transistors (calculated noise level <400e at Si-PIN-PD capacitance of 70 pF). After the preamplifier, further amplification and shaping was made by an active filter-amplifier of 1101 type with additionally introduced shaping times to 40 μs. Studies of scintillation characteristics of single crystals ZnSe(Te) and ticor were carried out with shaping times τ_1 = 15 μs and τ_2 = 4 μs, respectively; studies of spectrometric characteristics of Si-PIN-PD as semiconductor detector of ionizing radiation – at τ_3 = 0.1 μs.

Spectrometric studies were carried out using multichannel analyzers based on Pentium Notebook PC and an original analog to digit converter (ADC) developed by STC RI and an original software. ADC is placed in the computer compartment intended for PCMCIA cards, has low energy consumption and power supply +5V from the computer wire. This arrangement makes the instrument small-sized.

3. Results and discussion

Pulse amplitude spectra measured by scintielectronic detectors with the studied crystals and Si-PIN-PD were measured on the amplitude scale from γ-quanta using a semiconductor Si-PIN-PD detector (SCD). The noise level of SCD and CSPA allowed to clearly detect KX-quanta of ^{55}Fe (Fig.1). Analysis of the spectrum and calculation of the PD-CSPA system noise level shows that the intrinsic noise level of the system is 420 electrons.

Spectra of ^{109}Cd, ^{137}Cs, ^{207}Bi internal conversion electrons obtained using a ZnSe(Te)-based detector (9×9×1 mm^3) and a S3590 type Si-PIN-PD are presented in Fig. 2. Spectra of ^{241}Am γ-quanta, ^{90}Sr β-particles and ^{239}Pu α-particles obtained in the same way are shown in Fig. 3.

Energy resolution of the detector over α-particles with E_α = 5150 keV is R_a = 3% (Fig. 3). The value of intrinsic resolution of crystal ZnSe(Te) R_a was determined as

$$R_\alpha = \sqrt{R_d^2 - R_p^2} ,$$

where R_d is resolution of the detector-CSPA with α-particles (155 keV), and R_p is resolution of the system detector capacitance-CSPA with pulse generator (63 keV). Hence R_α = 141.6 keV or R_α = 2.75%, which is not worse than the best CsI(Tl) crystals measured with PMT.

Energy resolution of detectors of ZnSe(Te) – Si-PIN-

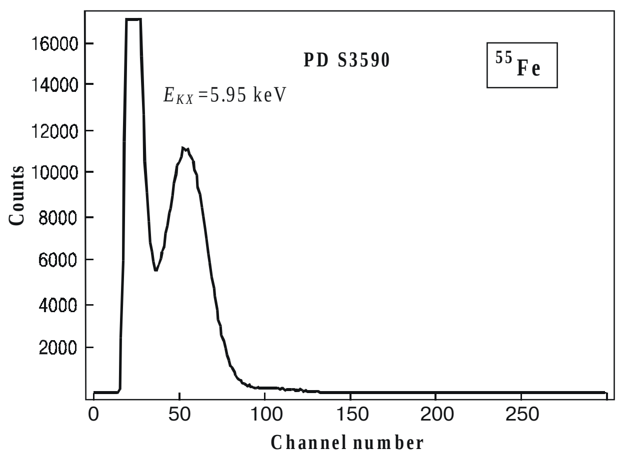

Fig. 1. Spectrum of ^{55}Fe KX-quanta obtained using a semiconductor detector based on S3590 type Si-PIN-PD.

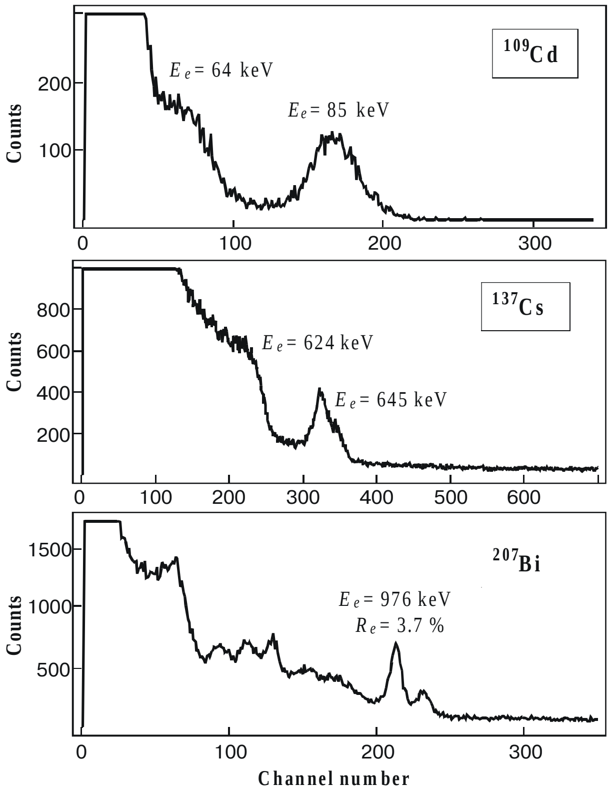

Fig. 2. Spectra of internal conversion electrons of ^{109}Cd, ^{137}Cs, ^{207}Bi obtained using detector based on 9×9×1 mm^3 ZnSe(Te) crystal and S3590 type Si-PIN-PD.

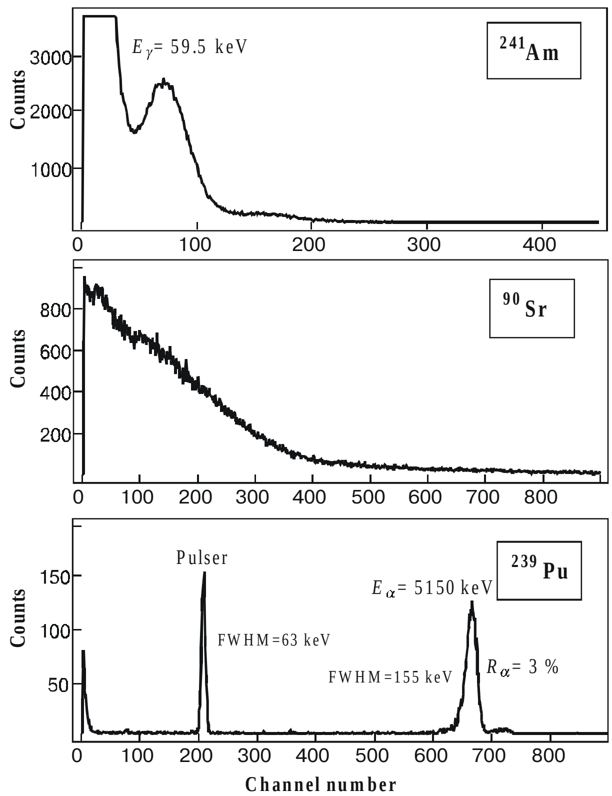

Fig. 3. Spectra of ^{241}Am γ-quanta, ^{90}Sr β-particles and ^{239}Pu α-particles obtained using detector based on 9×9×1 mm^3 ZnSe(Te) crystal and S3590 type Si-PIN-PD.

PD system with internal conversion electrons of ^{207}Bi R =3.7%. This is better than results obtained with best plastic scintillators with PMT (5–7%). α/β-Ratio for ZnSe(Te) crystals is ~1, which is substantially higher than with alkali halide and oxide scintillators.

Studies of "fast" ZnSe(Te) crystals, which were also prepared at STC RI, have shown that energy resolution R_γ of detectors of "ZnSe(Te) – avalanche photodiode" for γ-radiation with E_γ = 662 keV is about 5.4%; intrinsic resolution is R_γ^* = 3.3% [8].

Spectra of ^{207}Bi internal conversion electrons, ^{60}Co γ-quanta and ^{239}Pu α-particles, obtained using detectors based on $Al_2O_3(Ti^{+3})$ and Si-PIN-PD (of S3590 type) are shown in Fig. 4. The value of energy resolution R_α = 11.6% with α-particles (E_α = 5150 keV), with internal conversion electrons (E_e = 976 keV) $R_{e1/2}$ = 15% ($R_{e1/2}$ value is measured over the right-hand side of the pulse amplitude distribution). Comparison with the signal from Si-PIN-SCD shows that the pulse amplitude from E_e = 976 keV with ticor is equivalent to the signal value with E_g = 14keV with Si-PIN-SCD, and from α-particles of E_a = 5150 keV on ticor – 20 keV, respectively. α/β-Ratio determined from these data was 0.28, which corresponds to the values found with most oxide scintillators [9].

Conclusions

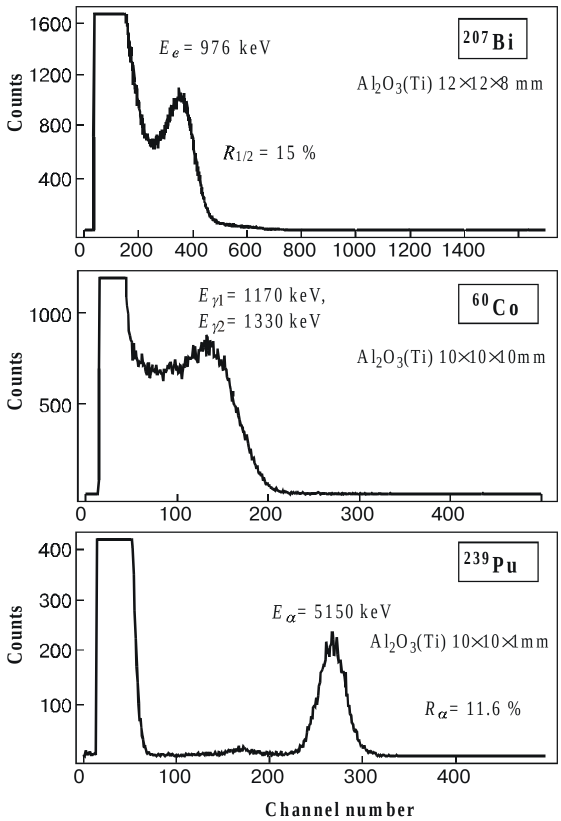

Fig. 4. Spectra of ^{207}Bi internal conversion electrons, ^{60}Co γ-quanta and ^{239}Pu α-particles obtained using detector based on $Al_2O_3(Ti^{3+})$ and S3590 type Si-PIN-PD.

Our studies of spectrometric characteristics of detectors based on Si-PIN-PD and crystals ZnSe(Te), as well as ticor, show that they are very promising for spectrometry of charged particles.

Basing on the results obtained on *a*/*b*-ratio, values of R_α, R_e, R_γ, high thermal and radiation stability, we consider these crystals to be promising for applications in extreme conditions for detection and identification of decay products of radioactive materials of various origin.

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