COMBINED DETECTORS OF CHARGED PARTICLES BASED ON ZINC SELENIDE SCINTILLATORS AND SILICON PHOTODIODES

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Combined detectors of charged particles are described based on zinc selenide (ZnSe(Te)) crystals, silicon photodiodes and charge-sensitive amplifiers. ZnSe(Te) scintillators are characterized by high alpha to beta ratio (~1.0), good scintillation efficiency (up to 22%), and high radiation stability (up to 100 Mrad), together with good spectral matching with silicon PIN photodiodes. The signals coming from the photodiode in the two modes (photoreceiver and semiconductor detector) differ in the amplitude values and pulse duration, which opens new possibilities for development and application of such combined detectors.

PACS number: 29.27.Fa

1 INTRODUCTION

Among the most efficient methods used for detection and identification of charged particles and products of nuclear reactions occurring on target nuclei in mixed fields in reactors and accelerators, very promising is the use of combined detectors (CD) based on inorganic scintillators and silicon photodiodes (PD). Such solid-state combined detectors have acquired a trademark SELDI (ScintiELectronic Detectors of Ionizing radiation), which is commonly used in CIS countries. Their Western analogs are generally known as Siswich [1]. In this paper, a number of variants of such detectors are described, which are used for separate detection of neutrons and gamma-radiation in mixed fields, detection of low- and high-energy gamma-radiation, as well as internal conversion electrons together with the accompanying gamma-radiation. In this paper, we present for the first time a new SELDI type CD for separate detection of light and heavy charged particles in the mixed fields.

2 EXPERIMENTAL PROCEDURES

For the use as part of CD, we have chosen ZnSe(Te) crystals grown as described earlier [2]. From the single crystals, plates were cut, of dimensions 10x10 mm and thickness 0.8-1.0 mm. The output windows of the plates (facing the photosensitive surface of PD) were made opaque, and the input ones (facing the charged particle flux) were polished. The plates were packed in containers made of Teflon with collimator windows on the input windows for transmission of the incoming charged particles. In measurements with internal conversion electrons (ICE), the distance between the radiation source and the collimator was not less than 20 mm, while for detection of alpha-particles the sources were located just upon the collimator. The measurements were carried out at room temperature using an immersion contact, using Vaseline oil as an immersion substance. To protect Si-PIN-PD from the low-energy gamma- and X-ray radiation, light transducers made of inorganic crystals were occasionally used.

Comparative characteristics of ZnSe(Te) and CsI(Tl) are given in Table 1.

Table 1. Characteristics of scintillators produced by Concern "Institute for Single Crystals"

Cristal	λ_{max}, nm	τ, μs	α, cm^{-1}	$Z_{eff.}$	S, rel.un.	T_{max}, K
ZnSe(Te)	600-620 630-640	2-20 >20	0,05-0,15	33	100 170	400-450
CsI(Tl)	550	0,63-1	> 0.05	54	100	350-400

Designations: λ_{max} – maximum position in the radioluminesce spectra, τ - decay time, α - scintillation light absorption coefficient, Z_{eff} – effective atomic number, S – relative light output, T_{max} – maximum operation temperature.

Measurements of CD spectrometric characteristics were carried out using ICE sources ^{109}Cd, ^{137}Cs and ^{207}Bi, as well as alpha-sources ^{239}Pu, ^{241}Am and ^{226}Ra and X-ray and gamma-quanta sources ^{55}Fe, ^{241}Am, ^{57}Co, ^{137}Cs, ^{22}Na at working temperature of 294 K. As photoreceivers, we used PD obtained from Hamamatsu (S3590-01) and "Porog" type PD from NCB Ritm, Chernovtsy, Ukraine. Comparative characteristics of the PD used are presented in Table 2.

Table 2. Parameters of Si-PIN-photodiodes

Parameters	S3590-01	«Porog»	NPO «BIT»
Light sensetive area, mm^2	10x10	10x10	∅25
Dark current, nA	1,5	1,6	
Bias voltage, V	30	30	50
Capacitance, pF	70	67	220

Sensitivity for λ =540 nm, A/W	0,31	0,26	0,32

The spectral sensitivity maximum of Si-PIN-PD is in the region of 800-900 nm, ensuring 70 % matching with the spectral characteristics of ZnSe(Te) crystal radioluminescence. Very high requirements were put to all links of the spectrometric circuit chain, especially to the charge-sensitive pre-amplifier (CSPA) comprising a charge-sensitive section with a field transistor at the input and elements of the detector power supply. Our experiments have shown that the lowest noise level can be obtained with KP341A field transistor (the calculated intrinsic noise level is < 400 electrons at Si-PIN-PD capacitance of 70 pF. Signal ratio at the PD output was about 1:10, both in the photoreceiver mode and in the semiconductor detector mode.

After the pre-amplifier, additional amplification and signal shaping was ensured by an active filter-amplifier of 1101 type, with input shaping times up to 40 μs. Scintillation characteristics of ZnSe(Te) single crystals were studied at shaping time τ_1 = 15 μs, and this value was put as τ_2 = 0.1 μs for Si-PIN-PD used as a spectrometric detector.

Spectrometric studies were carried out using a multichannel analyzer based on a Notebook Pentium PC in combination with an original ADC (developed at STC RI in the PCMCIA standard). The energy consumption was low, with a power supply of +5 V effectuated from the PC cable. This complex of developments allowed the spectrometer to be small-sized.

3 RESULTS AND DISCUSSION

Pulse amplitude spectra recorded by scintielectronic detectors using the studied crystals and Si-PIN-PD were measured in the amplitude scale of gamma-quanta. The noise level of the semiconductor Si-PIN-PD detector (SCD) allowed to clearly detect KX-quanta of ^{55}Fe (see Fig. 1). Analysis of these spectra and calculations of the noise level for PD-CSPA system show that the intrinsic noise level of the system is 420 electrons.

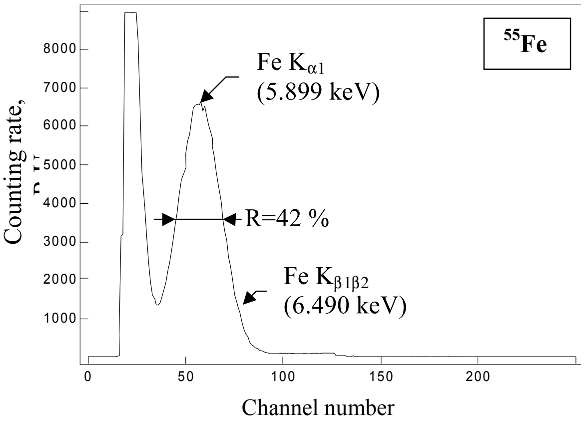

Fig. 1. Spectrum of ^{55}Fe KX-quanta obtained using a semiconductor detector based on S3590 type Si-PIN-PD.

Fig. 2 shows the amplitude spectrum of ^{226}Ra alpha-particles obtained using Si-PIN SCD with the input window of 25 mm diameter. The resolution at alpha-line with E_α = 7.687 MeV was R_α = 1.7%.

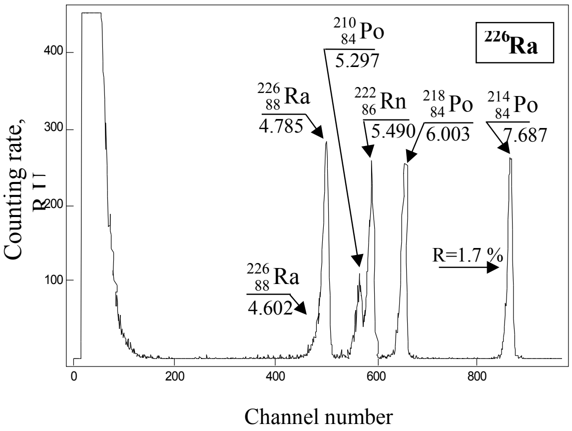

Fig. 2. Spectrum of ^{226}Ra alpha-particles obtained using a NPO «BIT» semiconductor detector of Si-PIN-PD type. Figures at the total absorption peacs denote the energy of alpha particles in MeV.

Spectra due to ^{109}Cd, ^{137}Cs and ^{207}Bi ICE obtained using a ZnSe(Te) based detector of 9x9x1 mm^3 size together with an S3590 Si-PIN-PD are shown in Fig. 3.

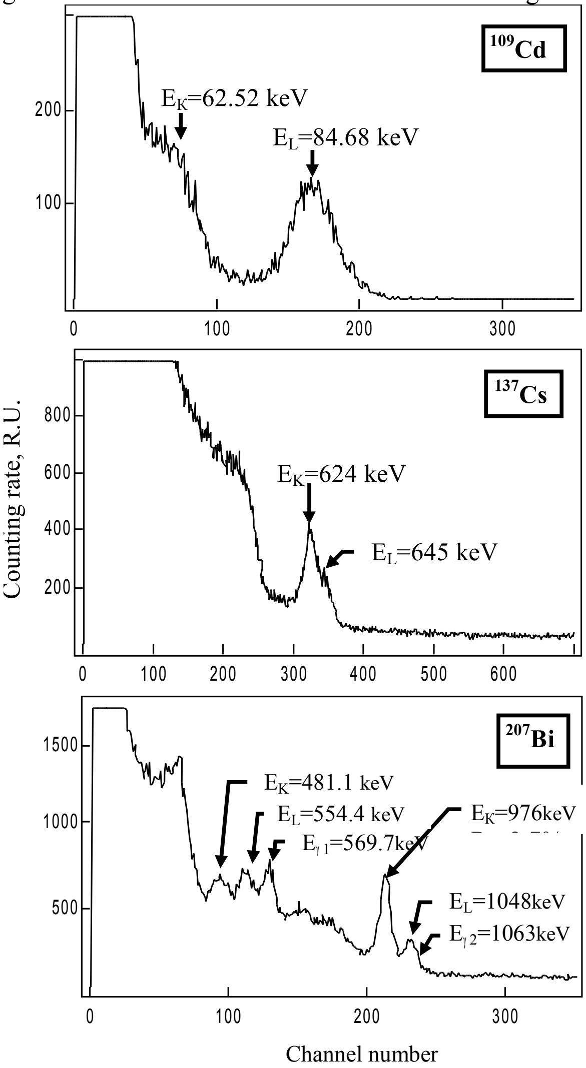

Fig. 3. Spectra of ^{109}Cd (E_γ=85,03 кэВ), ^{137}Cs (E_γ =662 keV), ^{207}Bi ($E_{\gamma 1}$=569,7 keV and $E_{\gamma 2}$=1063 keV) internal conversion electrons obtained using a ZnSe(Te)-based detector of 9x9x1 mm^3 size and an S3590 Si-PIN-PD.

In Fig. 3, one can distinctly discern the ^{109}Cd ICE L-line (E_{L1} = 84.23 keV, E_{L2} = 84.68 keV). The K-line due to ^{109}Cd ICE (E_K = 62.52 keV) is not clearly seen at the background of noises, presumably because of ICE energy losses in the "dead" surface-adjacent crystal layer. This is confirmed by the data presented in Fig. 3. The ^{241}Am gamma-line with E_γ = 59.6 keV is clearly discerned at the background of detector noises. Turning back to Fig. 2, one should note that detection of ^{137}Cs ICE allows in principle resolution of K- and L-series ICE with E_e of 624 and 645 keV. The ^{207}Bi spectrum shown in Fig. 2 gives clear resolution of ICE and gamma-lines.

Spectra of ^{241}Am gamma-quanta and of ^{239}Pu alpha-particles obtained using the above-described ZnSe(Te) based detector of 9x9x1 mm size in combination with S3590 Si-PIN-PD are shown in Fig. 3.

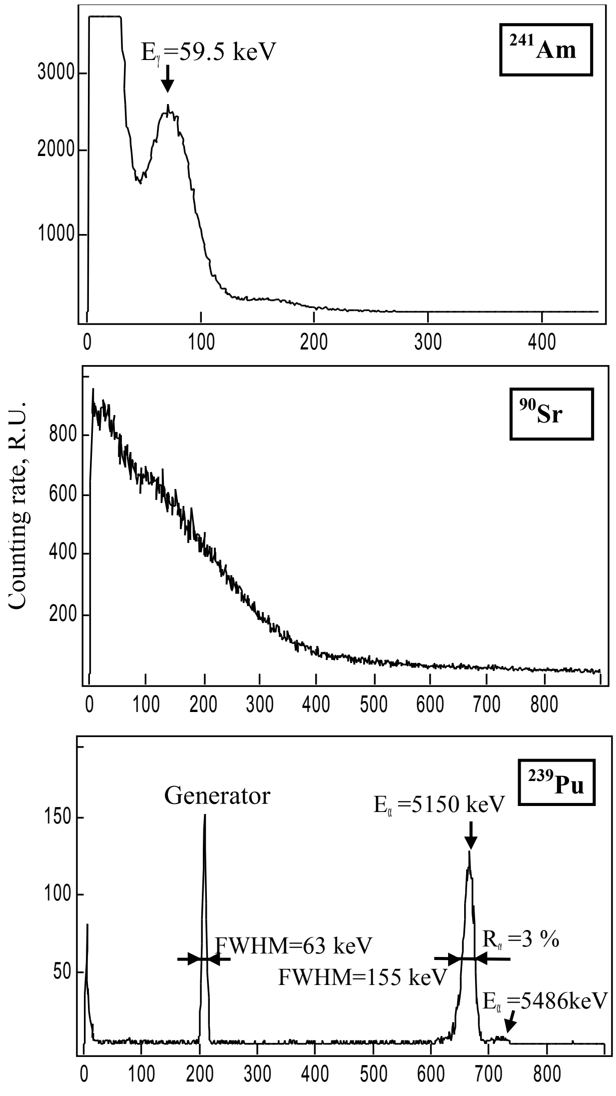

Fig. 4. Spectra of ^{241}Am gamma-quanta, ^{90}Sr beta-particles and ^{239}Pu alpha-particles obtained using a ZnSe(Te) based detector of 9x9x1 mm size and an S3590 Si-PIN-PD.

Alongside the ^{239}Pu alpha-line with E_α = 5150 keV, the ^{241}Am alpha-line with E_α = 5486 keV was observed. ^{231}Am is formed as a result of ^{241}Pu beta-decay, which is present in the alpha-source as an admixture. The energy resolution of the detector for 5150 keV alpha particles is R_α = 3% (Fig. 4). The intrinsic resolution value R_α for the ZnSe(Te) crystal was determined according to the expression

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

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

The energy resolution of the ZnSe(Te) – Si-PIN-PD detector for ^{207}Bi ICE (R_e = 3.7%) is essentially better than with plastic scintillators combined with PMT (5-7%). The α/β ratio for ZnSe(Te) crystals is ~1, which is substantially higher as compared with alkali halide and oxide scintillators.

Our further studies of "fast" ZnSe(Te) scintillator crystals (which had been also produced at STC RI) showed that the energy resolution R_γ for detectors of "ZnSe(Te) – avalanche photodiode" for gamma-radiation with E_γ = 662 keV was ~5.4 %, with intrinsic value of R_γ being about 3.3 % [3].

4 CONCLUSIONS

Studies of spectrometric characteristics, which were carried out for combined detectors based on Si-PIN-PD and ZnSe(Te) crystals, show that such detectors can be promising for applications in spectrometry of charged particles.

Our results for α/β ratio, as well as resolution values R_α, R_β, R_γ, show that these detectors, taking into account their high thermal and radiation stability, are very promising, especially for detection and identification of fission products of various radioactive materials in extreme conditions.

This work is supported by the INTAS Grant No 99-01348.

REFERENCES

1.J.Friese et al. The SISWICH, a Detector Telescope with Intrinsic Calibration // *IEEE Trans. Nucl. Sci.* 1993, v. NS-40, N. 4, p. 443-446.

2.L.V.Atroschenko, S.F.Burachas, L.P.Gal'chinetskii, B.V.Grinev, B.D.Ryzhikov, N.G.Starginskii. *Crystals of scintillators and detectors of ionizing radiation on their base.* Kiev: Naukova dumka, 1998, 310 p.

3.M.Balcerzyk, W.Klarma, M.Moszynski et al. Nonproportionality and temporal response of ZnSe(Te) scintillators studied by large area avalaunche photodiodes and photomultipliers // *Scientific Program and Abstracts of the Fifth International Conference on Inorganic Scintillators and Their Applications "SCINT 99"*, P1-5, Moscow State University, Russia. 1999, p. 125.