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 (≈0.1), 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.

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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 source and the collimator was not less than 20 mm) 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”

<table>
<thead>
<tr>
<th>Cristal</th>
<th>$\lambda_{\text{max}}$, nm</th>
<th>$\tau$, $\mu$s</th>
<th>$\alpha$, cm$^{-1}$</th>
<th>$Z_{\text{eff}}$</th>
<th>S, rel.un.</th>
<th>$T_{\text{max}}$, K</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZnSe(Te)</td>
<td>600-620</td>
<td>2-20</td>
<td>0,05-0,15</td>
<td>33</td>
<td>100</td>
<td>400-450</td>
</tr>
<tr>
<td></td>
<td>630-640</td>
<td>&gt;20</td>
<td>&gt;0.05</td>
<td>54</td>
<td>170</td>
<td>400-450</td>
</tr>
<tr>
<td>CsI(Tl)</td>
<td>550</td>
<td>0,63-1</td>
<td>&gt;0.05</td>
<td>54</td>
<td>100</td>
<td>350-400</td>
</tr>
</tbody>
</table>

Designations: $\lambda_{\text{max}}$ – maximum position in the radioluminesce spectra, $\tau$ – decay time, $\alpha$ - scintillation light absorption coefficient, $Z_{\text{eff}}$ – effective atomic number, S – relative light output, $T_{\text{max}}$ – maximum operation temperature.

Measurements of CD spectrometric characteristics were carried out using ICE sources $^{109}$Cd, $^{137}$Cs and $^{203}$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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>S3590-01</th>
<th>«Porog»</th>
<th>NPO «B1T»</th>
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</thead>
<tbody>
<tr>
<td>Light sensitive area, mm$^2$</td>
<td>10x10</td>
<td>10x10</td>
<td>$\varnothing$25</td>
</tr>
<tr>
<td>Dark current, nA</td>
<td>1.5</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>Bias voltage, V</td>
<td>30</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Capacitance, pF</td>
<td>70</td>
<td>67</td>
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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 = 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 multi-channel 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 55Fe (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.

| Sensitivity for $\lambda$ =540 nm, A/W | 0.31 | 0.26 | 0.32 |

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 $E_{\alpha} = 7.687$ MeV was $R_\alpha = 1.7\%$.

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. Spectrum of $^{109}$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.
S3590 Si-PIN-PD are shown in Fig. 3, spectra of \(^{109}\)Cd (\(E_\gamma=85.03\) keV), \(^{137}\)Cs (\(E_\gamma=662\) keV), \(^{207}\)Bi (\(E_\gamma=569.7\) keV and \(E_\gamma=1063\) keV) internal conversion electrons obtained using a ZnSe(Te)-based detector of 9x9x1 mm\(^3\) size in combination with S3590 Si-PIN-PD.

In Fig. 3, one can distinctly discern the \(^{109}\)Cd ICE L-line (\(E_L=84.23\) 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 \(E_\gamma=59.6\) 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 \(E_L\) 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.

![Spectra](image)

Alongside the \(^{239}\)Pu alpha-line with \(E_\alpha=5150\) keV, the \(^{241}\)Am alpha-line with \(E_\alpha=5486\) keV was observed. \(^{239}\)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 \(R_\alpha=3\%\) (Fig. 4). The intrinsic resolution value \(R_i\) for the ZnSe(Te) crystal was determined according to the expression

\[
R_i = \sqrt{R_\alpha^2 - R_p^2},
\]

where \(R_\alpha\) is the resolution of the detector-CSKA 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 \(R_\alpha=141.6\) keV, or \(R_p=2.75\%\), 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 \((R_\alpha=3.7\%\) is essentially better than with plastic scintillators combined with PMT \((5-7\%)\). The \(\alpha/\beta\) 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 \(R_i\) for detectors of “ZnSe(Te) – avalanche photodiode” for gamma-radiation with \(E_\gamma=662\) keV was ~5.4 %, with intrinsic value of \(R_i\) 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 \(\alpha/\beta\) ratio, as well as resolution values \(R_\alpha, R_p, R_i\), 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.

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