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# "PHOTOSENSITIVE HETEROSTRUCTURE – CHALCOGENIDE SCINTILLATOR" DETECTORS OF IONIZING RADIATION BASED ON $A^{II}B^{VI}$ COMPOUNDS

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Methods for preparation of photosensitive structures *n*ZnSe(Te)–*p*ZnTe and ZnSe(Te)/*p*ZnTe–*n*CdSe are considered. The methods use solid-phase substitution reactions and subsequent epitaxial growth on ZnSe(Te) crystals. It has been shown that maximum e.m.f. value for integrated detectors is 1.2-1.4 V, and their X-ray sensitivity reaches values up to 150-200 nA·min/R·cm$^2$. Dynamic linearity range of output characteristics of the detectors was not less than $10^5$, afterglow level after 20 ms – less than 0.05 %, allowing to use them in X-ray tomographs.

## Introduction

Development of scintillators based on $A^{II}B^{VI}$ compounds has efficiently filled the empty gap in the "scintillator-photodiode" detector family for modern radiation introscopes. In fact, scintillators based on isovalently doped ZnSe crystals show conversion efficiency 4-7 % higher, and radiation stability – more than $10^3$-$10^4$ times higher than CsI(Tl) [1-3].

It is also known [4, 5] that certain complex structures based on $A^{II}B^{VI}$ compounds with properties of wide band gap semiconductors display high photosensitivity in the visible range, corresponding to the luminescence maximum of ZnSe(Te) crystals ($\lambda_{max}$=600-640 nm). Accounting for unique combination of properties – ZnSe(Te) crystals are both semiconductor materials and highly efficient scintillators – it seemed possible to obtain photosensitive structures based on $A^{II}B^{VI}$ compounds directly on the surface of the semiconductor scintillator.

In this paper, preparation methods and properties are described of combined detectors of ionizing radiation of ZnSe(Te)–ZnTe and ZnSe(Te)/ZnTe–CdSe types.

## Experimental

ZnSe(Te) crystals were grown by vertical Bridgman method in graphite crucibles in argon atmosphere. Content of activator Te in ZnSe crystals was 0.5 mass %. To obtain scintillation properties, ZnSe(Te) samples of (2-5)×5×5 mm$^3$ size were annealed in Zn vapor at T=1300 K for 24 hours. Before application of ZnTe and CdSe layers, ZnSe(Te) samples were mechanically polished and etched in bromine/methanol. The *n*ZnSe(Te)–*p*ZnTe and ZnSe(Te)/*p*ZnTe–*n*CdSe heterostructures were obtained by the vapor phase epitaxy [2,4]. To increase sensitivity of the heterostructures, during epitaxial growth ZnTe layers were doped with As, and CdSe layers – with indium. The impurity atoms moved to the mixture zone due to concentration gradient. Then they were transported in the form

of atomic flux to the deposition zone. Schematic diagrams of the combined detectors, which were obtained as above described, are presented in Fig.1. It can be seen that these detectors of "scintillator-heterostructure" type ensured minimal reflection losses.

Metallographic and X-ray studies of the ZnTe and CdSe layer growth processes show that the optimum conditions are the following: ZnTe source temperature – 1110 K, ZnSe(Te) substrate temperature – 850 K; for CdSe, these values are 1040 K and 910 K, respectively. For detectors of ZnSe(Te)–ZnTe type, optimum thickness of ZnTe layer was 80–100 μm; for ZnSe(Te)/ZnTe–CdSe detectors, thicknesses of ZnTe and CdSe layers were 6-8 μm and 18-20 μm, respectively. Measurements of electrical parameters of the detector components by the van der Pauw method have shown that free electron concentration $n_e$ in ZnSe(Te) crystals and CdSe layers were, respectively, $(3\text{-}5)\times10^{17}$ cm$^{-3}$ and $(1\text{-}3)\times10^{17}$ cm$^{-3}$, while hole concentration in ZnTe layers was about $4\times10^{17}$ cm$^{-3}$. Au and In were deposited by vacuum evaporation to make ohmic contacts for ZnTe, CdSe and ZnSe(Te).

## Results and discussion

Among the detectors studied, the *n*ZnSe(Te)–*p*ZnTe system was the most easy to produce. Spectral distribution of the short-circuit photocurrent $I_{SC}$ under illumination from the scintillator side is presented in Fig.1, curve 1. Quantum yield $Q$ of the *n*ZnSe(Te)–*p*ZnTe structure at T=300 K was 0.72-0.78, and the e.m.f. values reached 1.2-1.4 V. This suggests rather efficient separation of the light-generated electron-hole pairs under the built-in electric field formed in the transition layer of the *n*ZnSe(Te)–*p*ZnTe structure. Luminescence spectra of the scintillator (Fig.2, 3) and photosensitivity of the *n*ZnSe(Te)–*p*ZnTe structure (Fig.2, 1) are only weakly overlapping, and the spectral concordance factor does not exceed 0.3. However, due to high level of light collection in ZnSe(Te)–ZnTe detectors, their X-ray sensitivity reaches 50 nA·min/R·cm$^2$, which is comparable to parameters of "scintillator – Si-photodiode" detectors [2]. The ZnSe(Te)–ZnTe detectors preserved linearity of the output signal in a broad dose rate range of X-ray radiation with energies $E_x$=8-150 keV (Fig.3, 1). The residue signal level did not exceed 0.05 % in 20 ms after X-ray irradiation.

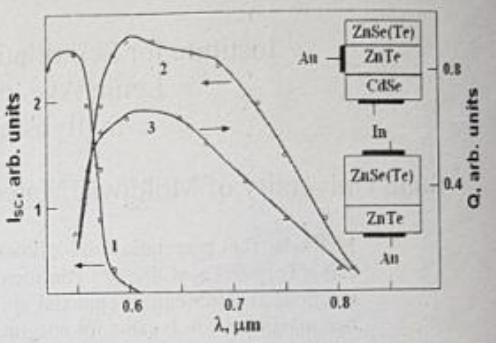


Fig.1. Spectral dependences of short circuit current $I_{SC}$ (1,2) and quantum efficiency $Q$ (3) for *n*ZnSe(Te)–*p*ZnTe (1) and *n*ZnSe(Te)/*p*ZnTe–*n*CdSe (2, 3) structures. The insert shows their schematic diagrams.

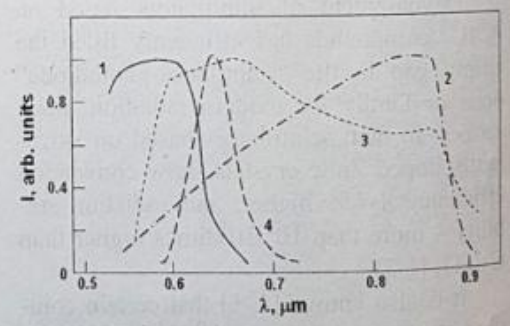


Fig.2. Spectral distributions for *n*ZnSe(Te) – *p*ZnTe (1) and ZnSe(Te)/*p*ZnTe–*n*CdSe structures (for different concentrations $n_e$ in CdSe layers: $n_e=3.6\times10^{15}$ cm$^{-3}$ (2) and $n_e=2.4\times10^{17}$ cm$^{-3}$ (3)), and luminescence spectrum of ZnSe(Te) scintillator (4).

For the ZnSe(Te)/*p*ZnTe–*n*CdSe structure, maxima of $I_{SC}(\lambda)$ and $Q(\lambda)$ plots are located in the 0.58-0.67 μm region (Fig.1; 2, 3), and the value of $Q$ can reach 0.61-0.68. The absolute monochromatic sensitivity at

0.63 μm is 0.32-0.35 A/W. The time constant of this structure is $3\times10^{-4}$-$2\times10^{-5}$ s. The shape of the spectral characteristic depends upon concentration $n_e$ in the CdSe layer (Fig.2; 2, 3). When $n_e$ is increased from $3.6\times10^{15}$ cm$^{-3}$ to $2.4\times10^{17}$ cm$^{-3}$, the spectral concordance factor rises from 0.62 to 0.98. Dosimetric characteristics of ZnSe(Te)/ZnTe–CdSe detectors were found to be linear within 5-6 orders of magnitude. As can be seen from (Fig.3, 2), their X-ray sensitivity is noticeably higher as compared with conventional detectors "scintillator CsI(Tl) – Si-photodiode" (Fig.3, 3) and can reach values up to 180-200 nA·min/R·cm$^2$.

Thus, it can be concluded that, as for the full set of their output and functional characteristics, integrated detectors based on ZnSe(Te)–ZnTe and ZnSe(Te)/ZnTe–CdSe structures can be successfully used instead of conventional "scintillator – Si-photodiode" detectors in X-ray tomographs and dosimetric equipment.

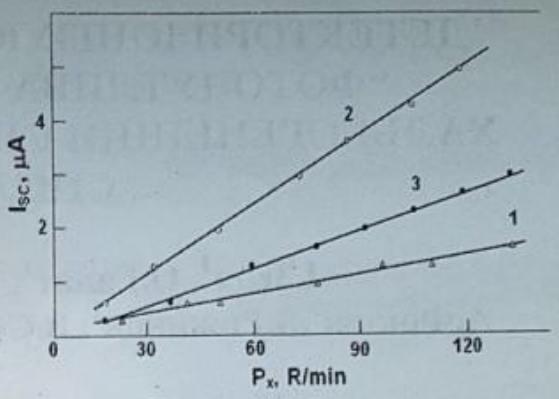


Fig.3. Output signal $I_{SC}$ as function of X-ray ($E_x$≈60 keV) dose rate $P_x$ for ZnSe(Te)–ZnTe (1), ZnSe(Te)/ZnTe–CdSe (2) and "scintillator CsI(Tl) – Si-photodiode" (3) detectors.

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