УДК 621.383

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RADIATION SENSITIVE INTEGRATED DETECTORS BASED ON COMPOUNDS $A^{II}B^{VI}$

1. Introduction

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

From the other side, it is known [4,5] that certain complex structures based on broad-gap $A^{II}B^{VI}$ compounds display high photosensitivity in the visible range, corresponding to the luminescence maximum of ZnSe(Te) crystals (λ_{max}=600-640nm). 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 types ZnSe(Te)–ZnTe and ZnSe(Te)/ZnTe–CdSe.

2. 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)x5x5 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. Heterostructures *n*ZnSe(Te)–*p*ZnTe and ZnSe(Te)/*p*ZnTe–*n*CdSe 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 move to the mixture zone due to concentration gradient. Then they were transported in the form of atomic flux to the deposition zone. The schematic diagrams of the combined detectors, which were obtained as above described, are presented in Fig.1. It can be seen that with these detectors of "scintillator-heterostructure" type, reflection losses are minimal.

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, $(3\text{-}5)\times10^{17}$ and $(1\text{-}3)\times10^{17}$ cm^{-3}, while hole concentration in ZnTe layers was about 4×10^{17} cm^{-3}. Au and In were deposited by vacuum evaporation to make ohmic contacts for ZnTe, CdSe and ZnSe(Te).

3. Results and discussion

Among the detectors studied, the most easy to produce was the system *n*ZnSe(Te)–*p*ZnTe. Spectral distribution of the short-circuit photocurrent Isc under illumination from the scintillator side is presented in Fig.1, curve 1. Quantum yield Q of the structure *n*ZnSe(Te)–*p*ZnTe at T=300 K

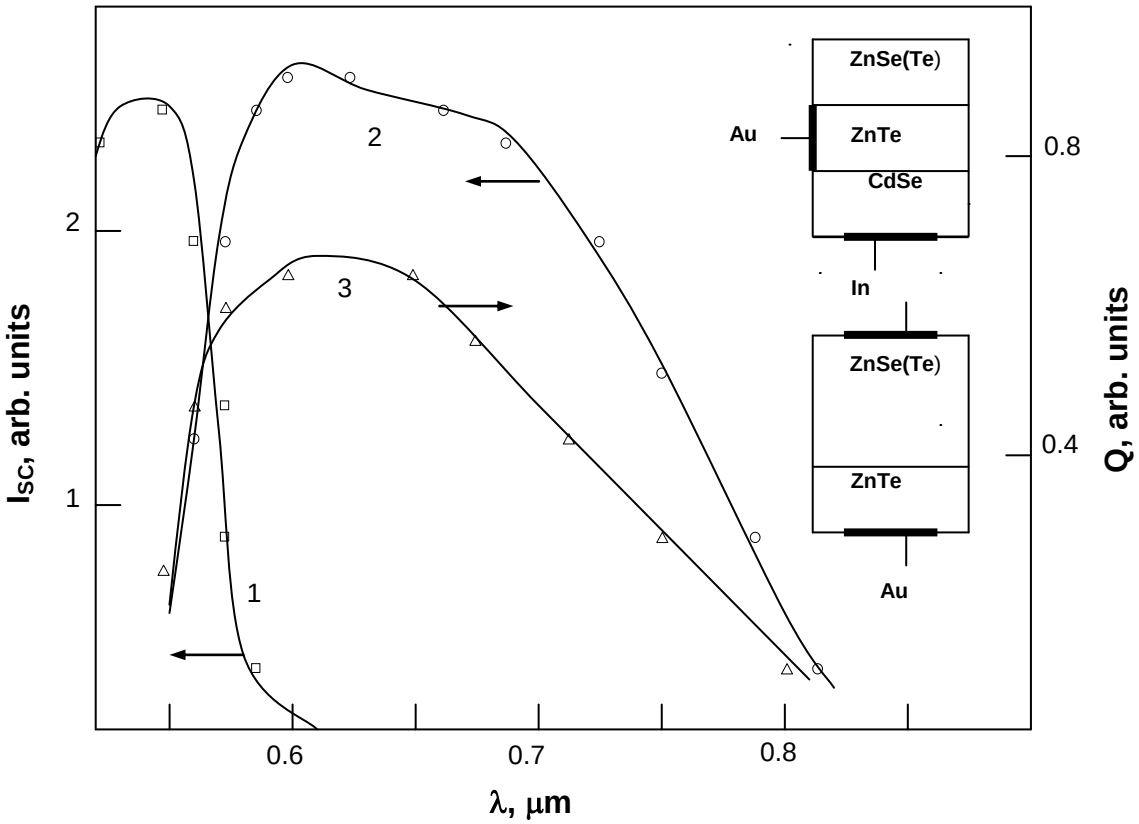

Fig.1. Spectral dependences of short circuit current I_{sc} (1,2) and quantum efficiency Q (3) for structures *n*ZnSe(Te) – *p*ZnTe (1) and *n*ZnSe(Te)/*p*ZnTe – *n*CdSe (2,3). Insert shows their schematic diagrams.

was 0.72-0.78, and e.m.f. value reaches 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 structure nZnSe(Te)–*p*ZnTe. Luminescence spectra of the scintillator (Fig.2, 3) and photosensitivity of the structure *n*ZnSe(Te)–*p*ZnTe (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]. Detectors ZnSe(Te)–ZnTe preserve linearity of the output signal in a broad dose rate range of X-ray radiation of energies E_x=8-150 keV (Fig.3, 1). The residue signal level after stopping of X-ray irradiation does not exceed 0.05 % after 20 ms.

For structure ZnSe(Te)/*p*ZnTe–*n*CdSe, 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 3×10^{-4}–2×10^{-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 3.6×10^{15} cm^{-3} to 2.4×10^{17} cm^{-3}, the spectral concordance factor rises from 0.62 to 0.98. Dosimetric characteristics of detectors ZnSe(Te)/ZnTe–CdSe 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 ZnSe(Te)–ZnTe and ZnSe(Te)/ZnTe–CdSe can be successfully used instead of

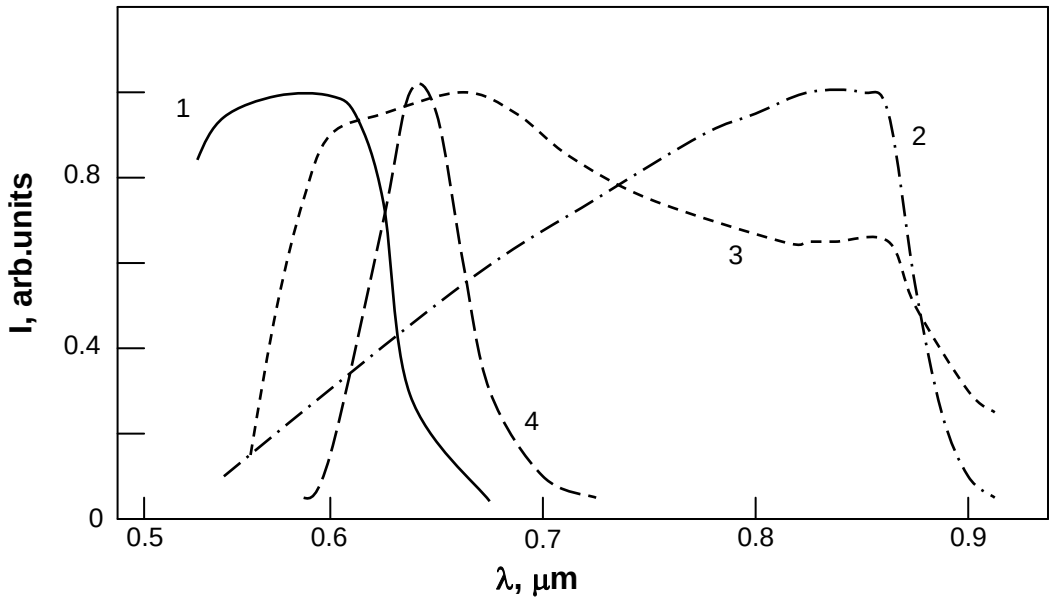

Fig.2. Spectral distributions for structures *n*ZnSe(Te) – *p*ZnTe (1) and ZnSe(Te)/*p*ZnTe – *n*CdSe (for different concentrations n_e in CdS layers: 2 – for $n_e=3.6\times10^{15}$ cm^{-3}, 3 – $n=2.4\times10^{17}$ cm^{-3}), and luminescence spectrum of scintillator ZnSe(Te) (4).

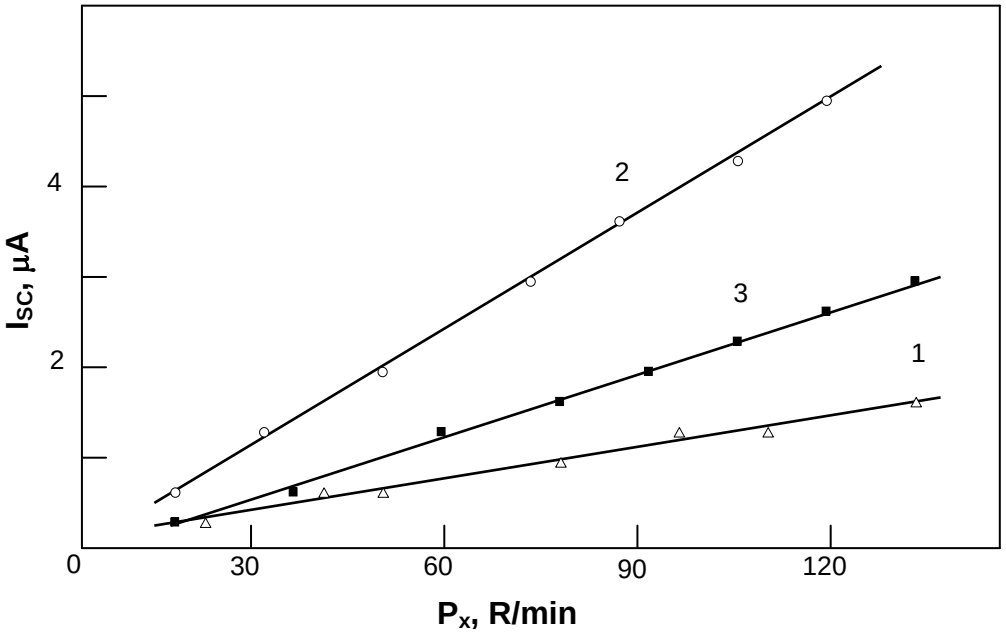

Fig.3. Output signal I_{SC} as function of X-ray ($E_x \approx 60$ keV) dose rate P_x for detectors ZnSe(Te)–ZnTe (1), ZnSe(Te)/ZnTe–CdSe (2) and "scintillator CsI(Tl) – Si-photodiode" (3).

conventional "scintillator – Si-photodiode" detectors in X-ray tomographs and dosimetric equipment.

This work is supported by the INTAS 05-104-7519 and STCU №4115 Grands.

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