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High radiation resistant crystals for X-ray and γ-radiation detectors

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ABSTRACT. $Hg_2MnInTe_6$ (MMIT) single crystals are of interest for the manufacturing of radiation sensors based as radiation-resistant materials. They were grown by a modified method of zone melting. Samples were prepared with a thickness of 0.7 mm. Single crystals have n-type conductivity and resistivity of $\rho \approx 5 \cdot 10^6$ Ohm·cm (at 293 K). Photosensitive sensors with a Schottky rectifier barrier were fabricated and studied. Gold and chromium were used for the rectifying contact and indium for the ohmic contact. Two types of structures were obtained - Au/MMIT/In and Cr/MMIT/In. The contact areas were 4 mm². Both structures (Au/MMIT/In and Cr/MMIT/In) had a diode-like I-V behavior. The initial part of I–V curves could be described by the Sah-Noyce-Shockley model. The current monochromatic sensitivity S_λ for the Au/$Hg_2MnInTe_6$/In and Cr/$Hg_2MnInTe_6$/In structures reached a maximum at the wavelength λ≈1.15μm and were equal to $S_\lambda \approx 1.2$-1.3 A/W. Importantly, Cr/MMIT/In photo-sensors had a significantly higher rectification factor and significantly lower dark currents. At a voltage U=1 V, the dark current for Au/MMIT/In was I=29 nA, and for Cr/MMIT/In the dark current was 2 nA. At a voltage U=10 V, respectively, the dark currents were 150 nA and 7 nA. The rectification coefficient for Au/MMIT/In at a voltage U = 10 V was equal to K≈7, and for Cr/MMIT/In - K≈40. The band-gap E_g of single crystals was equal to 1.15 eV, which is close to the band-gap of silicon, but $Hg_2MnInTe_6$ single crystals have much higher radiation resistance.

Keywords: radiation-resistant single crystals, AFM-topographs, ohmic contact, rectifying contact, CLSC, surface nanostructure, manufacturing.

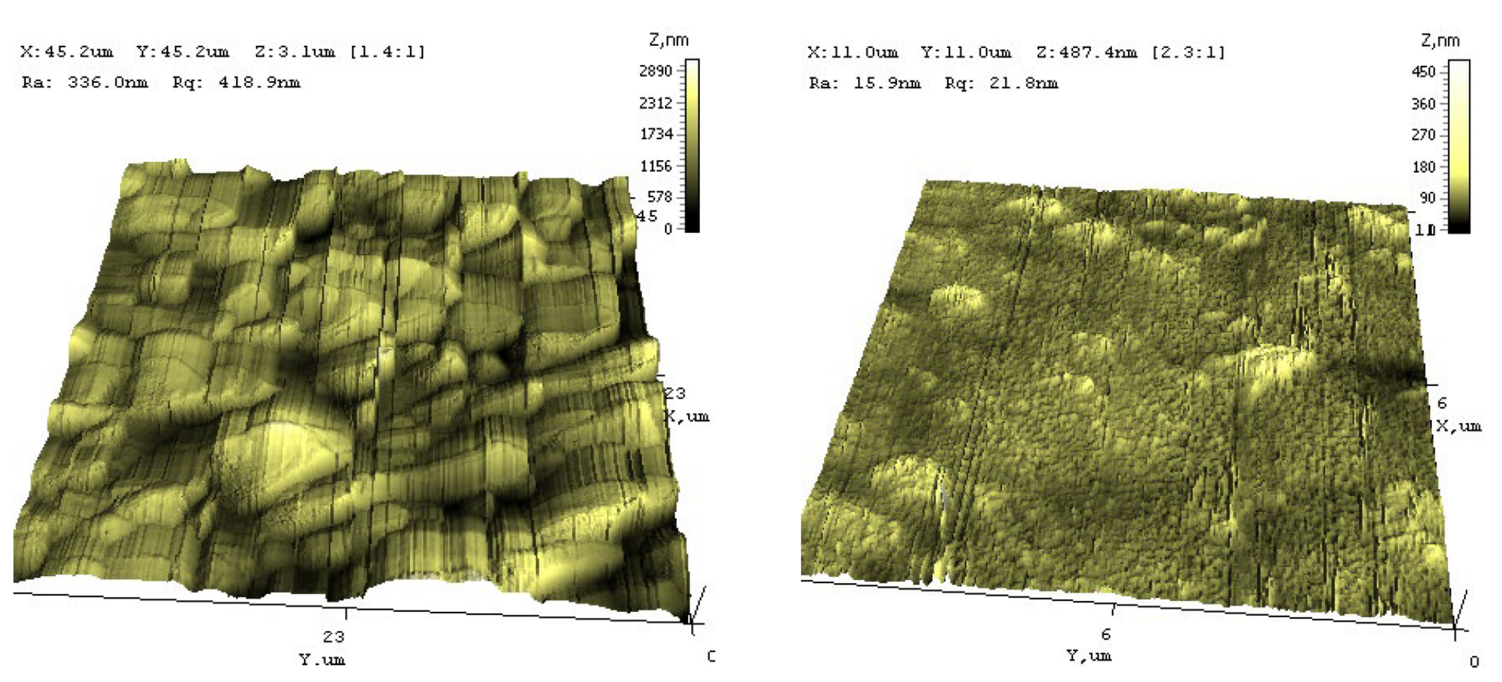


Fig. 1. AFM surface topographs of the Au/$Hg_2MnInTe_6$/In structure (left) and Cr/$Hg_2MnInTe_6$/In structure (right).

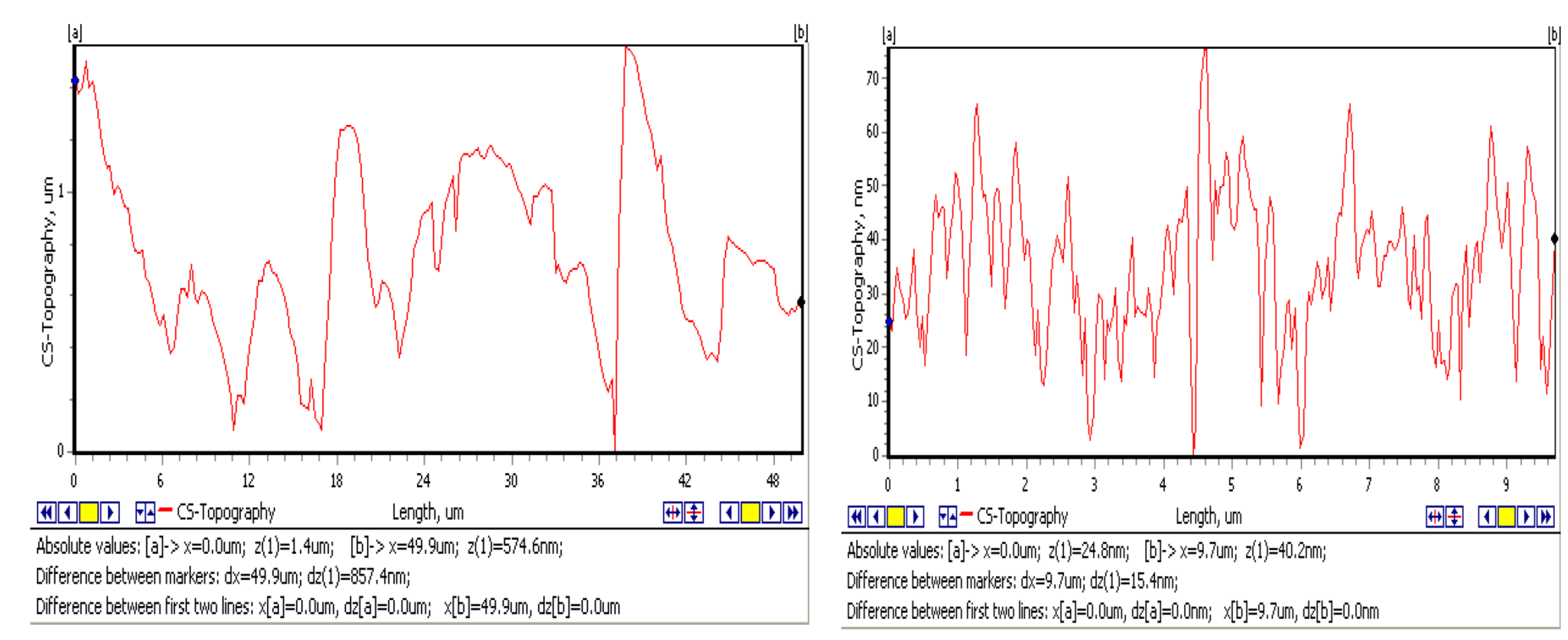


Fig. 2. The surface profilogram of the Au/$Hg_2MnInTe_6$/In structure (left) and the Cr/$Hg_2MnInTe_6$/In structure (right).

I-V curves for Au/$Hg_2MnInTe_6$/In and Cr/$Hg_2MnInTe_6$/In

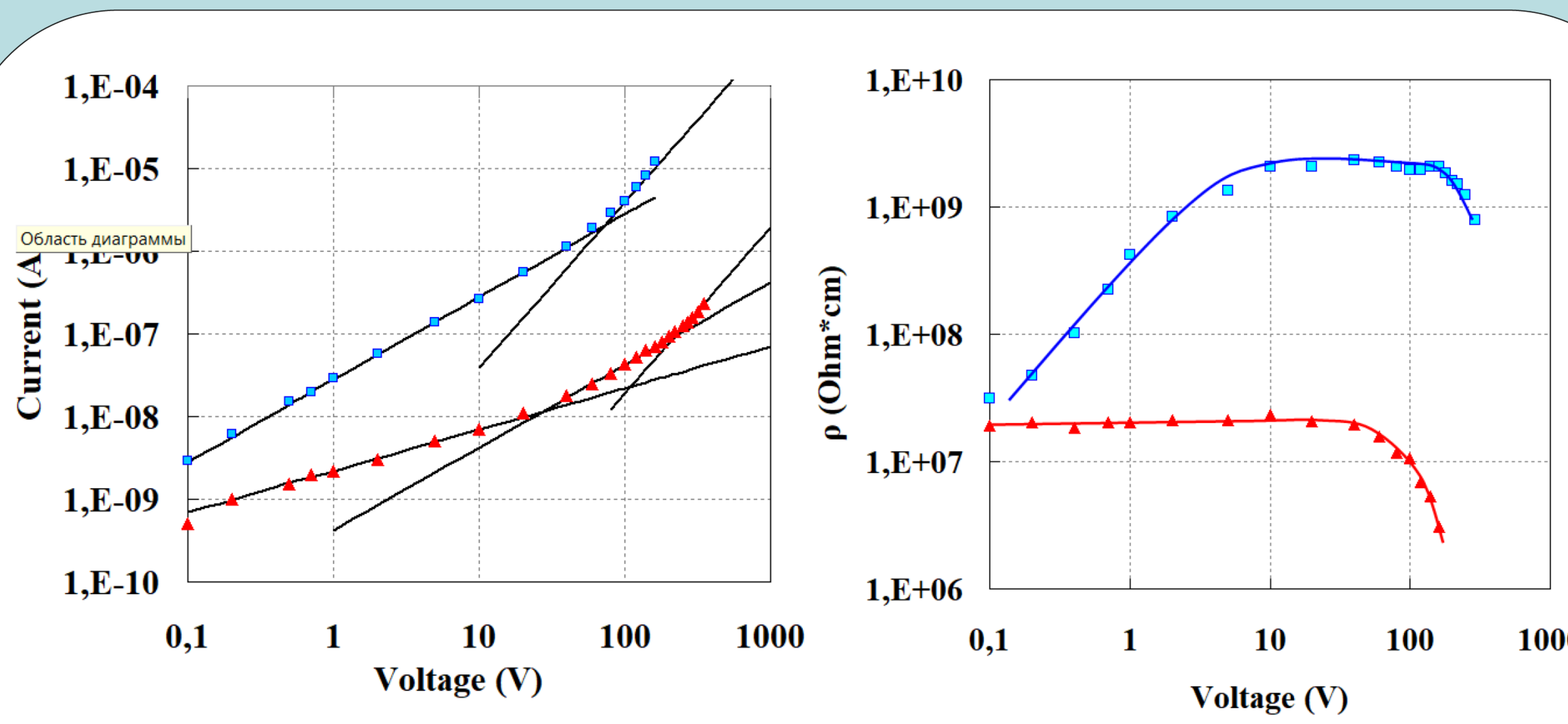


Fig. 3. I-V curve and dependence of differential resistance on voltage for Cr/$Hg_2MnInTe_6$/In structure. Direct bias – squares, reverse – triangles. Solid lines are the theoretical relations $I \sim U^{1/2}$, $I \sim U$, and $I \sim U^2$ respectively (293 K).

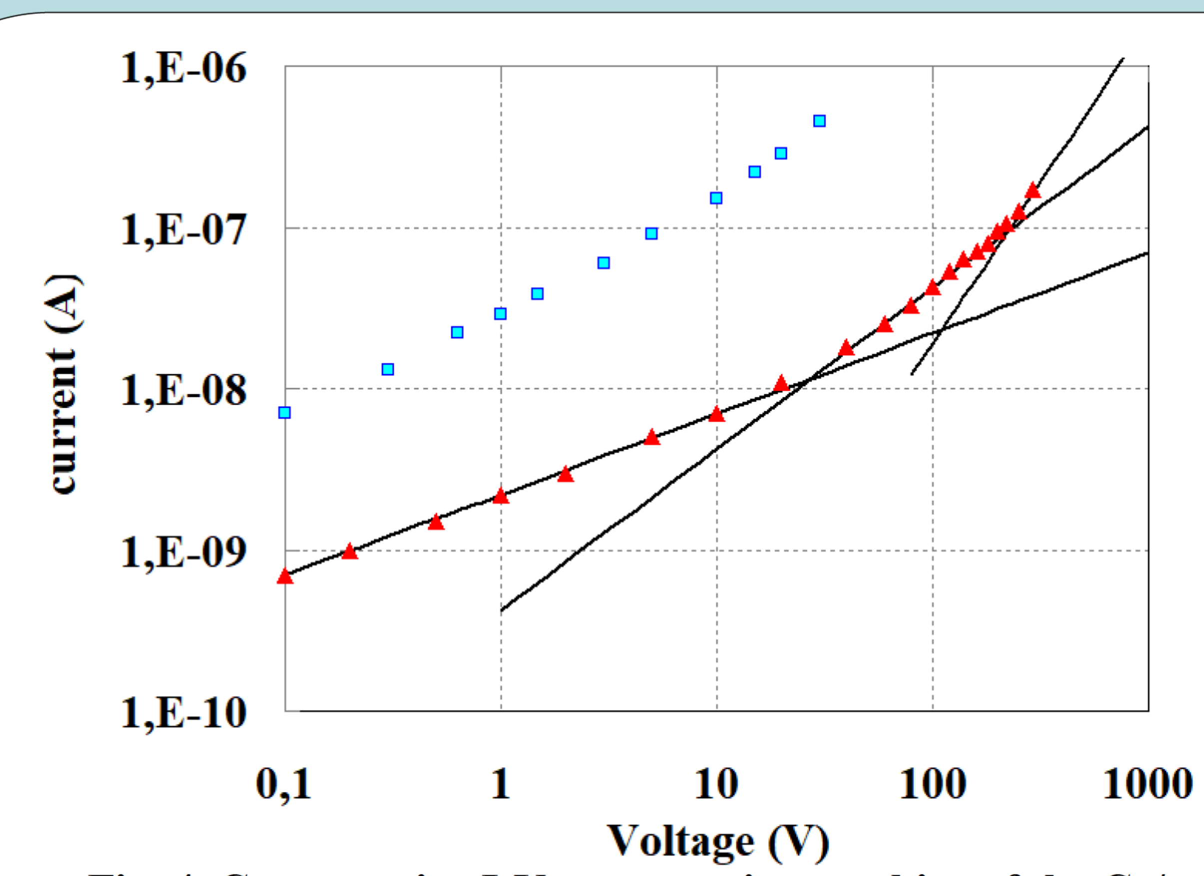
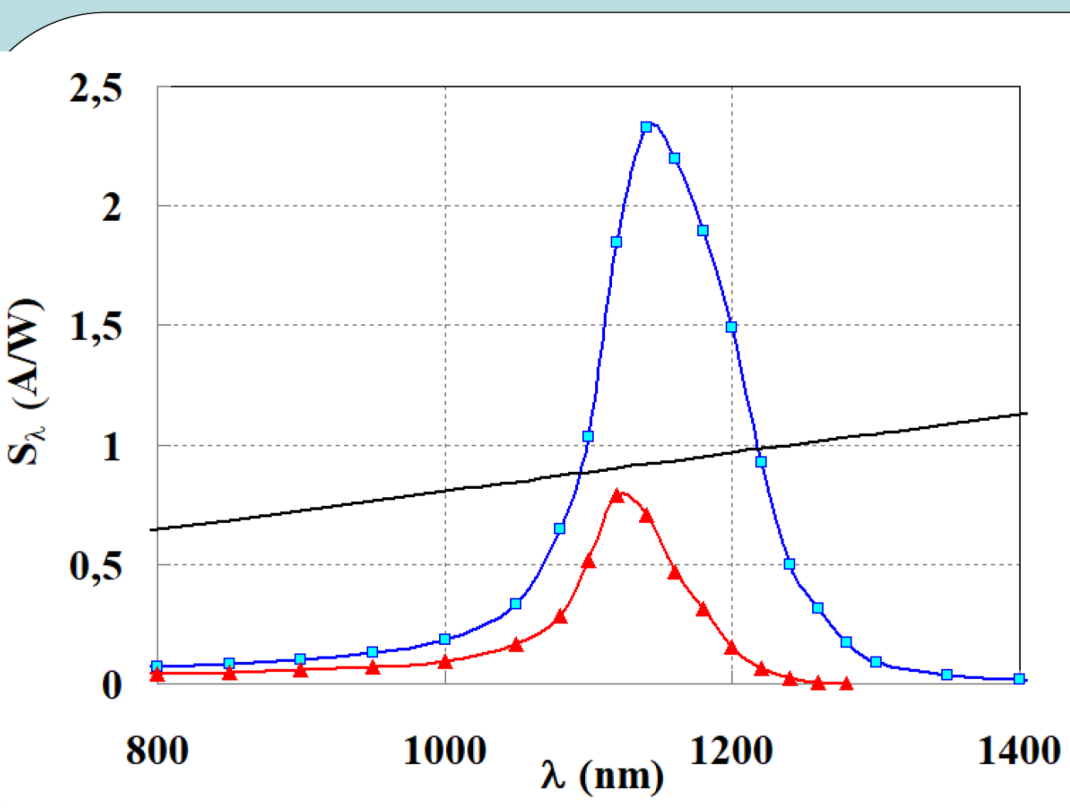


Fig. 4. Comparative I-V curves at inverse bias of the Cr/n-$Hg_2MnInTe_6$/In structure - triangles, Au/ $Hg_2MnInTe_6$/In - squares. Solid lines are the theoretical dependences of $I \sim U^{1/2}$, $I \sim U$, and $I \sim U^2$, respectively (300 K).

Spectral dependence of current monochromatic sensitivity of Au/$Hg_2MnInTe_6$/In and Cr/Hg_2MnTe_6/In photosensors



$$S_\lambda = 0{,}806\eta\lambda T_\lambda \qquad (1)$$

where η is the internal quantum yield, and T_λ is the transmittance of the material of the front electrode.

Fig. 5. Spectral dependence of the current monochromatic sensitivity at reverse bias U=3 V for Au/$Hg_2MnInTe_6$/In (mirror surface) – triangles, for Cr/$Hg_2MnInTe_6$/In (matte surface with PNS) – squares. The solid line shows the theoretical dependence according to (1).

Studies with an atomic force microscope showed that the surface of Cr/$Hg_2MnInTe_6$/In structures, which was visually perceived as matte, consisted of small (10-50 nm) nanograins in the shape of pyramids, which can combine into larger ones (100-300 nm). Nanograins of small sizes are responsible for the formation of a high-energy radiation spectrum with $h\nu > E_g$. The band gap is equal to E_g=1.21 eV. Nanograins of large sizes participate in the processes of multiple reflection of the radiation falling on the surface, thus causing an increase in the probability of absorption of photons, especially of the low-energy ones, $h\nu < E_g$. This leads to an increase in the current monochromatic sensitivity in the region of the maximum sensitivity. Our measurements of the photosensitivity spectrum generally support this assumption.

CONCLUSION

N-type single crystals of $Hg_2MnInTe_6$ were grown by the modified zone melting. Cr/$Hg_2MnInTe_6$/In photodiodes with a surface nanostructure, which are sensitive to optical radiation in the range of 0.8-1.8 µm, have been produced. Atomic force microscoppy measurements confirmed the presence of small (10-50 nm) pyramid-shaped nanograins in the surface layer of the semiconductor, which can combine into larger ones (100-300 nm). Comparative studies of two types of photodiodes Cr/$Hg_2MnInTe_6$/In with (matte surface) and Au/$Hg_2MnInTe_6$/In (mirror surface) showed a significant advantage of photodiodes with such surface nanostructure. The photodiodes had significantly smaller dark currents, a higher rectification coefficient and a higher current monochromatic sensitivity at the maximum value. The band gap of single crystals, which was determined from optical measurements, was found to be E_g=1.21 eV, which is close to the band gap of silicon, but $Hg_2MnInTe_6$ single crystals have much higher radiation resistance, so photosensitive sensors and other devices based on this material can be of great practical importance.