

INFLUENCE OF GAMMA, ELECTRON, PROTON AND GAMMA NEUTRON IRRADIATION ON PHOTODIODES BASED ON InSe WITH IMPROVED PARAMETERS

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Abstract: *The influence of simulating factors of a nuclear explosion and proton irradiation on the photoelectric properties of photodiodes based on indium selenide was studied. It was established that neutron pulses lead to an improvement in the photoelectric properties of the photodiodes under study. It has been shown that high fluences of neutron irradiation facilitate the process of breaking off complexes in the interlayer space of layered indium selenide, as a result of which the photoelectric parameters of photodiodes somewhat deteriorate.*

Keywords: *Nuclear explosion, neutron irradiation, photodiode, single-crystal samples of indium selenide, photosensitivity.*

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Introduction

At present, the development of technologies and the manufacture of radiation resistance of photoreceivers based on layered connections for the near-IR region of the spectrum are of great practical and scientific interest. Such photodiodes can be used in receivers of visible and near-IR radiation, which work in conditions of increased radiation [1-7].

In the article, the effects of gamma rays in doses of 10^7 P and 10^8 P, electron radiation with an energy of 6 MeV with fluences of 1.2×10^{12} cm⁻² and 1.31×10^{14} cm⁻² and proton radiation with a fluence of 1.0×10^{13} cm⁻² and 5.0×10^{13} cm⁻² are considered. Spectral characteristics of photodiodes based on pulsed gamma-neutron irradiation of indium selenide with fluences of

10^{12} cm⁻² and 5.0×10^{14} cm⁻² and 3.5×10^{12} cm⁻² and 1.2×10^{14} cm⁻². Monochromatic, integral and volt-watt sensitivity of photodiodes at 300 K before and after irradiation were studied.

Monocrystalline samples of indium selenide with initial parameters at 300 K were used for the production of photodiodes: concentration and mobility of the main charge carriers, respectively, 10^{14} – 10^{15} cm⁻³ and 800–1200 cm²/V·s, resistivity 10–100 Ω·cm.

Photodiode structures were obtained with the help of vacuum sputtering of gold on hot monocrystalline layers of indium selenium with subsequent annealing for two hours at a temperature of 250 °C [8-10].

Experiments and Results

Fig. 1 shows the spectral distribution of photosensitivity of the investigated photodiodes at room temperature before and after electron irradiation. Photodiodes exposed to ionizing radiation had photosensitivity in the spectral region of 0.45–1.1 mkm with a maximum at $\lambda_{\text{max}} = 0.95$ mkm.

From Fig. 1 also follows that the

photosensitivity at an electron fluence of 1.2×10^{12} cm⁻² in the short-wave region of the spectrum increases slightly, and the next electron fluence leads to its decrease and a shift of the main maximum towards longer waves. The following values were calculated from the spectral characteristics: monochromatic sensitivity - 0.95–4.0 A/W, volt-watt sensitivity

(1.3–7.1) 10^4 V/W and integral sensitivity to source “A” - (10–20) mA/lm. (Source “A” is a source included in the device for measuring sensitivity after irradiation). Practical changes were also observed with other types of irradiation used. In the case of gamma-neutron irradiation at a fluence of 1.2×10^{14} cm^{-2} , a decrease in photosensitivity occurred over the entire spectral region (Fig. 2).

A similar picture is also observed when photodiodes based on indium selenide are irradiated with protons with fluences of 1×10^{13} cm^{-2} and 5.0×10^{13} cm^{-2} , as in the case of irradiation with electrons with an energy of 6

MeV and pulsed gamma neutrons. In Fig. 3 (curves a and b) presents the results of the influence of proton irradiation on the spectral characteristics of photodiodes based on indium selenide. As can be seen from the figure, at a fluence of 1.0×10^{12} cm^{-2} throughout the spectral characteristic board, the photosensitivity of the photodiodes increases. And their next fluence of 5.0×10^{12} cm^{-2} leads to a decrease in photosensitivity in the short-wave region of the spectrum and, increasing, tends to increase the additional maximum. In this case, the main maximum shifts slightly to the longer wavelength side of the spectrum.

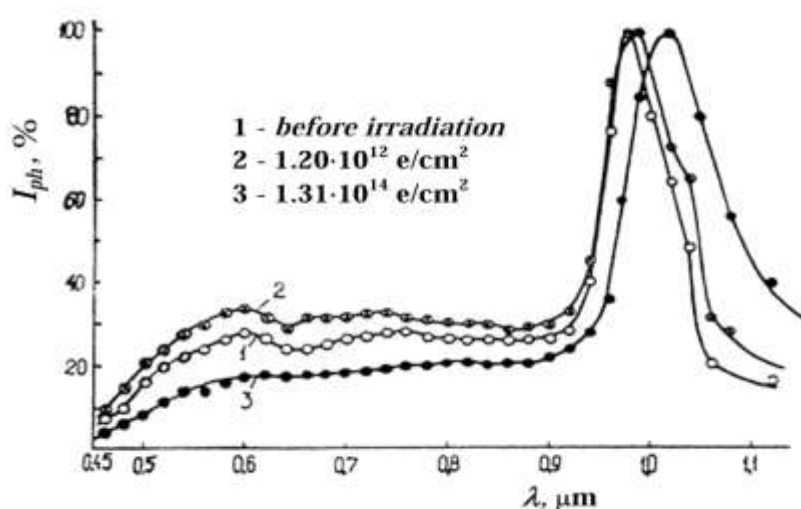


Fig. 1. Spectral distribution of photosensitivity photodiodes based on InSe before and after irradiation electrons with energy 6 MeV at 300 K

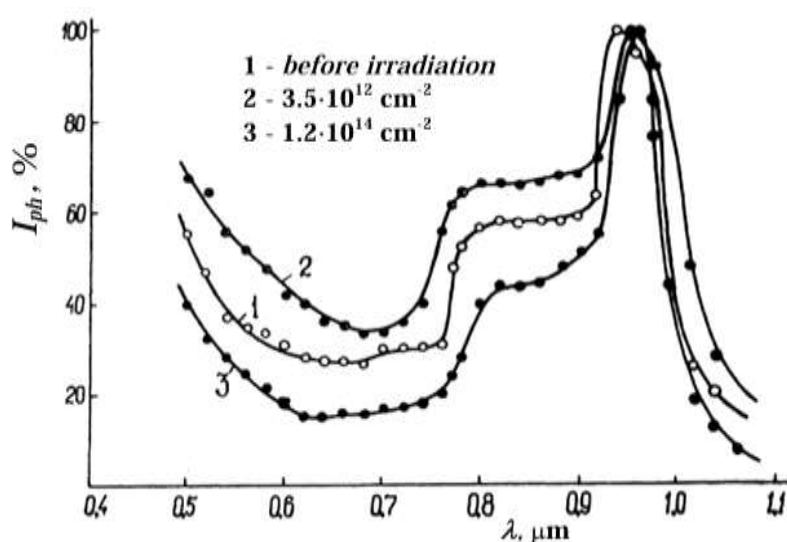


Fig. 2. Spectral distribution of photosensitivity photodiodes based on InSe before and after irradiation pulsed gamma neutrons at 300 K

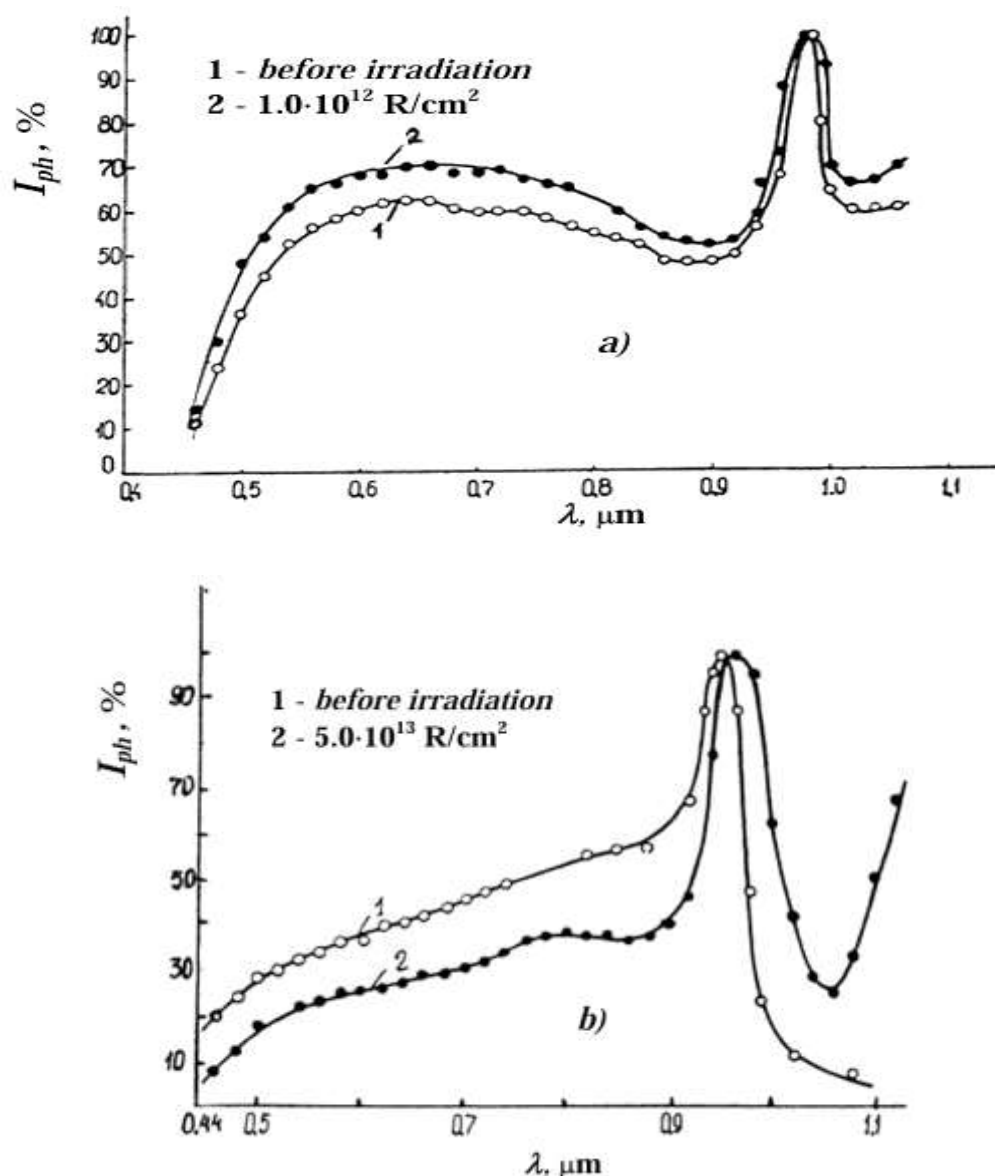


Fig. 3. Spectral distribution of photosensitivity of photodiodes based on indium selenide before and after proton irradiation at 300K

The observed changes as a result of exposure to ionizing radiation may be associated with the formation of radiation defects created in the layered structures of indium selenide.

Based on the experimental data obtained, it can be assumed that a number of changes in the photoelectric parameters of photodiodes when irradiated with high-energy particles are apparently associated with a specific feature of the crystal structure of layered materials, i.e. interaction of radiation defects arising in crystalline layers and interlayer spaces. The low energy barriers that exist in the interlayer spaces compared to the layer favor the migration of radiation defects. This, in turn, facilitates the

process of formation of complexes from radiation and initial defects in the interlayer gap, which leads to a change in the relaxation time of the photocurrent and, consequently, a change in photosensitivity [2-5]. At low irradiation fluences, in all likelihood, there is mainly a redistribution of gold impurities, which is a compensating element in the production of a p-n junction, as a result of which a more perfect and stable p-n junction is obtained and the photosensitivity of photodiodes increases [4-6].

To find out the reason for the degradation of the main parameters of photodiodes as a result of exposure to ionizing radiation, in the experiment, photosensitive elements and photodiodes created on their basis were

simultaneously irradiated. Changes in the main parameters in them were practically the same, which indicates an insignificant effect of irradiation on the structural elements of the photodiode.

Before and after irradiation, the effect of isochronous annealing lasting 30 minutes on the photoelectric properties of irradiated photodiodes was also considered. It turned out

that after isochronous annealing in the range of 70-130 °C (in increments of 20 degrees), the photoelectric parameters of the photodiodes under study are almost completely restored. It has been established that defects introduced by irradiation are unstable; they disappear in one stage of isochronous annealing, i.e. gradual recombination of radiation defects occurs.

Table 1. The effect of electron and proton irradiation on the parameters of a diode based on indium selenide

Photo-Electrical parameters	Electron radiation with energy 6 MeV				Proton irradiation			
	Before exposure	After irradiation			Before exposure	After irradiation		
		$5,0 \times 10^{11}$ e/sm ²	$1,2 \times 10^{12}$ e/sm ²	$1,3 \times 10^{14}$ e/sm ²		1×10^{12} r/sm ²	5×10^{13} r/sm ²	$1,0 \times 10^{14}$ r/sm ²
monochrome maternal sensitivity, S, A/Bt	1, 6	1,8	2,1	1,20	2,1	2,85	1,95	1,3
Volt-watt sensor, J, B/Bt	$2,5 \times 10^4$	$2,8 \times 10^4$	$3,1 \times 10^4$	$2,2 \times 10^4$	$4,5 \times 10^4$	$5,2 \times 10^4$	$4,0 \times 10^4$	$2,5 \times 10^4$
Integral sensitivity, Ji, mA/lm	11,0	12,5	16,2	1,0	15,3	18,2	14,5	12,5

Table 2. The effect of pulsed gamma-neutron and gamma radiation on the parameters of a diode based on indium selenide

Photo-Electrical parameters	Electron radiation with energy 6 MeV				Proton irradiation			
	Before exposure	After irradiation			Before exposure	After irradiation		
		$5,0 \times 10^{11}$ n/sm ²	$3,5 \times 10^{12}$ n/sm ²	$1,2 \times 10^{14}$ n/sm ²		10^6 R	10^7 R	10^8 R
monochrome maternal sensitivity, S, A/Bt	1,35	1,25	1,45	0,95	1,5	1,6	1,8	1,15
Volt-watt sensor, J, B/Bt	$3,2 \times 10^4$	$3,1 \times 10^4$	$3,8 \times 10^4$	$2,9 \times 10^4$	$1,9 \times 10^4$	$1,95 \times 10^4$	2×10^4	$1,7 \times 10^4$
Integral sensitivity, Ji, mA/lm	8,5	8,7	9,3	6,2	7,5	7,3	6,5	7,5

Defects created in photodiodes as a result of electron and proton irradiation are practically restored after a single annealing at a temperature of -100 + 300 °C. After irradiation with pulsed gamma neutrons followed by annealing at the

specified temperature, the defects are not completely restored, but only by 80%.

The results obtained suggest that photodiodes based on indium selenide are

radiation-resistant and, therefore, can be used in conditions of high radiation [3-6].

The obtained calculation results are shown in Tables 1 and 2.

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