FILM PHOTODIODE ARRAYS

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Abstract

Full Text

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Physics

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FILM PHOTODIODE ARRAYS

BASED ON nCdS–pCdTe HETEROJUNCTIONS

1. Processing a distributed light flux requires the creation of array structures based on microminiature photodetectors. Photosensitive arrays can be used as a spectral image converter, a tracking system with feedback, a vacuum-free analogue of the vidicon, etc. ([1–10]). Most array devices have been developed on the basis of planar technology, with single-crystal wafers of silicon, germanium, gallium arsenide, and other materials serving as the starting materials. The present state of thin-film technology and its capabilities apparently make it possible to solve these same problems without limiting the area of the photosensitive array.

Fig. 1. External appearance of the photodiode array

In the present communication a film photodiode array is described, fabricated on the basis of nCdS–pCdTe heterojunctions, some charac-

characteristics of which (current–voltage, lux–voltage, spectral, and frequency) are described in [11]. The prospects for using heterodiodes as light receivers are due primarily to the fact that they possess a broad band of spectral sensitivity with an almost constant value of quantum yield, which is very important in the processing of an optical signal.

2. The external appearance, electrical circuit, and structure of the microphotodiodes of the array are shown in Figs. 1 and 2. This array is an nCdS–pCdTe heterostructure with two mutually perpendicular systems of grid electrodes–strips of SnO_2, through which illumination of the structure is carried out, and copper strips serving as the upper current-collecting electrodes. Thin-film arrays with 144 photodiodes per 1 cm^2, with an active element area of 0.25 mm^2, were fabricated and studied. The element

Fig. 2. a –electrical circuit of the array; b –structure of the microphotodiodes.

Figure 2: Fig. 2. a –electrical circuit of the array; b –structure of the microphotodiodes.

Fig. 3 and Fig. 4

Figure 3: Fig. 3 and Fig. 4

packing density achieved in these laboratory samples is by no means the technological limit.

Fig. 2. *a* –electrical circuit of the array; *b* –structure of the microphotodiodes.

Table 1

K ($V = \pm 2$V)	J_{rev}, A ($V = -1$V)	$J_{\text{s.c.}}$, μA($I =$ 10^3 lx)	$V_{\text{o.c.}}$, V($I =$ 10^3 lx)	$\Delta\lambda$, μ	β, mA/lm
$10^3 \div 10^4$	$2 \cdot 10^{-7} \div 2 \cdot 10^{-8}$	1 ∓ 0.15	0.16 ∓ 0.02	$500 \div 900$	2.5 ± 0.4

3. The most important problem is to ensure the identity of the parameters of the photodiodes forming the array. For this purpose, the parameters of all microphotodiodes were measured on several arrays. These parameters were: the rectification coefficient K, the reverse dark current J_{rev}, the short-circuit photocurrent $J_{\text{s.c.}}$, the open-circuit voltage $V_{\text{o.c.}}$, the integral photosensitivity β, and the spectral photosensitivity range $\Delta\lambda$. The values of these characteristics and the limits of their scatter are given in Table 1.

For operation of the array in the diode mode, the most important parameter is the reverse dark current. As can be seen from the table, in the laboratory samples the scatter of the reverse current lies within one order of magnitude. This fact imposes a limitation on the minimum light intensity that can be converted into an electrical signal by a given array. Since at an intensity of 10^3 lx the short-circuit current is 10^{-6} A, the minimum light intensity at which the photocurrent of all elements will be identical must be $\simeq 100$ lx.

If the reverse dark current and the photocurrent are separated in the frequency range, then the minimum light intensity that can be converted is determined by the signal-to-noise ratio.

4. To clarify the question of the mechanism of current flow through the heterojunction nCdS—pCdTe, we considered the current-voltage (I-V) and temperature characteristics of the forward current* (Figs. 3 and 4). The experiment was carried out on specially prepared single samples with a heterojunction area of 6 mm^2.

Let us consider the theoretical models of a heterojunction proposed by various authors. Donnelly and Milnes ([12]) analyze four possible–

Fig. 3. Forward branch of the I-V characteristic at different temperatures: *a* –140° K; –200° K; –250° K; –293° K

Fig. 4. Dependence of the forward current on temperature at different applied voltages: *a*–0.1 V; –0.2 V; –0.3 V; –0.4 V; –0.5 V

possible mechanisms: diffusion (Anderson ([13])), emission (Perlman and Feucht ([14])), recombination (Dolega ([15])), and tunneling-recombination (Riben and Feucht ([16,17])).

The diffusion, emission, and recombination models of the heterojunction lead to similar expressions for the forward current, from which it follows that

$$\ln J + \text{const} \sim \begin{cases} V & \text{for } T = \text{const}, \\ -\dfrac{1}{T} & \text{for } V = \text{const}. \end{cases} \tag{1}$$

Riben and Feucht ([16,17]), studying the heterojunction nGe—pGaAs, obtained experimental data that did not correspond to any of the three models considered above. The dependence of $\ln J$ on V for these heterojunctions had practically the same slope at room and liquid-nitrogen temperatures. The temperature dependence of $\ln J$ also did not coincide with expression (1), but could be approximately described by the straight line BT or by two such rectilinear segments. As can be seen from Figs. 3 and 4, the experimental data obtained by us for the structure nCdS—pCdTe have a similar character.

Having modified Chynoweth' s tunneling-recombination model ([18]), proposed to explain excess currents in tunnel diodes,

* G. I. Neimark participated in this study.

Riben and Feucht obtained the following expression for the forward branch of the current-voltage characteristic of a heterojunction:

$$J = BN_t \exp[-\alpha(V_d - k_2 V)], \tag{2}$$

where $B = \text{const}$; N_t is the trap density in the space-charge region;

$$V_d = E_{g1} + \Delta E_v - kT \ln \frac{N_{v2} N_{c1}}{N_{d1} N_{a2}} \tag{3}$$

is the diffusion potential; V is the applied voltage; k_2 is a coefficient indicating the fraction of the voltage drop in the material with the wider band gap;

$$\alpha = \frac{8\pi}{3h} \left(\frac{m^* \chi}{N_{a2}} \right)^{1/3}; \tag{4}$$

m^* is the effective mass of holes in the wide-gap material; N_{v2}, N_{c1} are the densities of states in the valence band and the conduction band, N_{d1} and N_{a2} are the concentrations of the main impurity; χ is the dielectric permittivity; the indices 1 and 2 refer respectively to the narrow-gap and wide-gap materials.

Formula (2) corresponds to the tunnel-recombination mechanism, according to which current passage through the heterojunction occurs as a result of one-step or multistep recombination via local levels and a series of successive tunneling transitions from level to level through the space-charge region. It follows from formula (2) that the dependence of $\ln J$ on V should be linear, with a slope independent of temperature, while the temperature dependence of the forward current can be governed only by the temperature dependence of the diffusion potential. According to (3), this leads to a linear dependence of $\ln J$ on T.

The character of the dependence of the current on voltage and temperature established by us for nCdS–pCdTe heterojunctions does not correspond to the diffusion, emission, or recombination models and is in agreement with the theory of Riben and Feucht. This makes it possible to conclude that the forward current through the nCdS–pCdTe heterojunction is governed by a tunnel-recombination mechanism, and quantitative comparison of experiment and theory shows that the passage of carriers through the heterojunction is multistep in character.

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Note: Figure translations are in progress. See original paper for figures.