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BILATERALLY SENSITIVE PHOTODIODE STRUCTURES IN THE SYSTEM GALLIUM ARSENIDE–CADMIUM SULFIDE

K. Vakhobov,[a] A. V. Karimov,[a]
A. G. Gaibov,[a] D. M. Edgorova,[a] and
Kh. T. Igamberdiev[b]

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It has been shown experimentally that in a double-barrier photodiode structure with a common modulated base region, the spectral characteristics for the cases of cutoff p-n-hetero- (pGaAs–nCdS) and metal-semiconductor (m–pGaAs) junctions can have the identical form where the mechanism of formation is determined by the processes occurring in the regions of space charge which are located predominantly in the common (pGaAs) region.

Photosensitive structures of visible and infrared (IR) ranges are widely used in television, communications, night viewers, IR-guidance systems, and consumer equipment [1, 2]. For creation of structures efficiently operating in the spectral range of 1.0–1.6 μm gallium arsenide and its compounds are more promising materials than silicon and germanium. This is due to the fact that silicon and germanium photodetectors do not have entirely satisfactory characteristics in the indicated range [3]. Silicon, being a semiconductor with indirect (nonvertical) internal transitions, has an absorption coefficient of only 10^{-1} cm for photons with an energy of 1.16 eV. The capacitance and the leakage currents are high even in avalanche photodiodes based on silicon, and it is inexpedient to decrease these quantities by reducing the operating temperature. For ensuring low dark currents and increasing photosensitivity, semiconductor A_3B_5 compounds are of interest. For example, in gallium arsenide, the absorption coefficient reaches a value of 10^4 cm^{-1} for a photon energy of 1.45 eV, while in the range $\lambda > 1.0$ μm one can obtain strong absorption by introducing substituting elements (In, Al, or others) into it which optimize the band width [4]. Furthermore, the characteristics of diode structures can be controlled more smoothly due to the creation of two or more barrier structures.

Procedure of Obtaining Samples. The two-barrier structure is manufactured based on a *p–p–n* junction in which a region of the *p* type is a bulk GaAs crystal with $N_A = (5–7)\cdot10^{15}$ cm^{-3} on whose surface an isotype epitaxial intermediate layer 4 to 6 μm thick has been grown. The concentration of carriers in it was $\sim6\cdot10^{15}$ cm^{-3}. A region of the *n* type was created by deposition of a cadmium-sulfide film (according to the procedure described in [5]) in a vacuum unit. The thickness of the film with a concentration of carriers of $\sim3\cdot10^{16}$ cm^{-3} was equal to 0.2–0.3 μm. A rectifying semitransparent (~100 Å) metal contact of silver was formed on the opposite side of the *p*-type region. The Ag layer deposited on the cadmium-sulfide surface was ohmic. Thus, we created an m–*p*GaAs–*n*CdS structure with an area of ~80 mm^2 which was subsequently scribed to discrete elements with an area of 16 to 20 mm^2.

Experimental Results. The volt-ampere characteristic of the m–*p*GaAs–*n*CdS two-barrier photodiode structure under study is given in Fig. 1. It consists of two reverse branches: 1) when forward voltage is applied to the *p–n* junction, the metal–*p*GaAs junction is biased in the cutoff direction; 2) when the *p–n* junction is in the cutoff regime, the m–*p*GaAs junction tends to rectification. In any of the directions, one junction acts as a current limiter. The behavior of the curve can be described by a formula that is true of two reverse junctions [6, 7]:

$$I = \frac{2I_{s1}I_{s2}\sinh\left(\frac{qV}{2kT}\right)}{I_{s1}\exp\left(\frac{qV}{2kT}\right) + I_{s2}\exp\left(\frac{qV}{2nT}\right)},$$

[a]Tashkent State Technical University, Tashkent, Republic of Uzbekistan; [b]Department of Thermal Physics, Academy of Sciences of the Republic of Uzbekistan, Tashkent, Republic of Uzbekistan. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 76, No. 1, pp. 167–169, January–February, 2003. Original article submitted December 11, 2001; revision submitted July 17, 2002.

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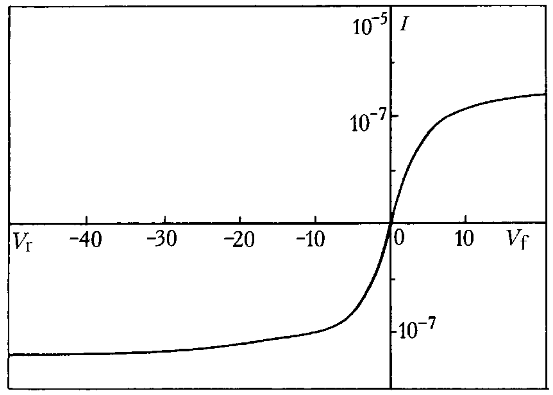
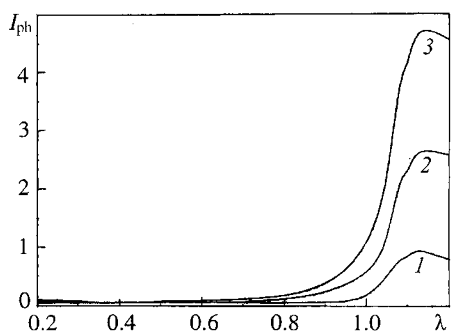


Fig. 1. Volt-ampere characteristic of the m–*p*GaAs–*n*CdS photodiode structure. *I*, A/cm^2; *V*, V.

TABLE 1. Calculated Values of the Forward and Reverse Currents

V, V	3.0	6.0	9.0	10	11
$I_f \cdot 10^{-8}$, A/cm^2	1.0	1.3	1.69	9.0	13.6
$I_r \cdot 10^{-9}$, A/cm^2	8.4	8.56	8.6	8.75	8.79



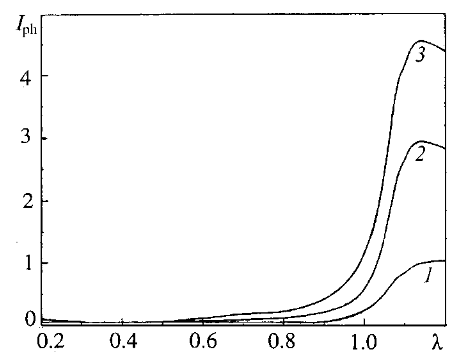


Fig. 2. Spectral characteristic of the photodiode structure for the case with a forward-biased *p–n* heterojunction at different V_f: 1) 2; 2) 6; 3) 10 V. I_{ph}, rel. units; λ, μm.

Fig. 3. Spectral characteristic of the photodiode structure for the cutoff voltages on the *p–n* heterojunction at different V_r: 1) 2; 2) 6; 3) 10 V.

where I_{s1} and I_{s2} are the saturation currents for the two branches.

A comparison of the results obtained has shown that for the characteristic parameter $n = 2$ the values of the dark currents measured experimentally are in satisfactory agreement with the calculated values (see Table 1).

On the experimental curve (Fig. 1), the forward current is $9 \cdot 10^{-8}$ A/cm^2 at 10 V, which is twice as high as the calculated value ($4 \cdot 10^{-8}$ A/cm^2). The saturation currents I_{s1} and I_{s2} are equal to $4.78 \cdot 10^{-8}$ A/cm^2 and $2.2 \cdot 10^{-9}$ A/cm^2 respectively. The differences in the calculated and experimental data are attributed to the error of determination of the inflection point on the plot.

In the regime corresponding to the forward bias of the *p–n* junction (see Fig. 2), when the voltages are low (2 V), the photocurrent appears in the region of 0.2 μm at a level of 0.3 relative unit (rel. unit) and decreases to a certain value of I_{ph} in the interval from 0.4 to 0.6 μm; next, beginning with 1.0 μm it grows to 1.0 rel. unit at λ = 1.1–1.2 μm. As the voltage increases to 10 V, the photocurrent, appearing in the vicinity of 0.2 μm, increases five times at 1.08–1.12 μm.

In the regime corresponding to the reverse bias of the *p–n* junction (Fig. 3), the photocurrent is first insignificant at low voltages (2 V) and it grows to a maximum at 1.12 μm. As the voltage applied increases to 10 V, we observe a tendency toward an increase in the photocurrent at $\lambda > 0.5$ μm with a sharper rise at 1.05 μm. The maximum photocurrent is attained at 1.12 μm. Photosensitivity increases four to six times.

A comparison of spectral characteristics upon changing the polarity of the voltage applied shows that the maximum photosensitivity is attained in both directions at the same wavelength (1.12 μm) of the driving signal. In the region of short waves (0.2–0.4 μm), the photocurrent is lower in the regime of reverse bias of the *p–n* junction than in forward biases, i.e., separation of photocarriers occurs on the metal–semiconductor junction.

An analysis of the volt-ampere and spectral characteristics of the structure under study shows that they are formed due to the physical processes occurring in the space-charge regions. When the *p–n* heterojunction is biased in the forward direction, the reverse-biased m–*p* junction is of prime importance and the space-charge layer is in the *p* region. In the reverse-biased *p–n* heterojunction, the space-charge region is also located in the *p* region since the concentration of carriers in it ($\sim 7\cdot 10^{-5}$ cm^{-3}) is lower than in the *n* region ($3\cdot 10^{16}$ cm^{-3}). As a result, in illumination, the spectral sensitivity of the structure has the identical form irrespective of the direction of the voltage applied. In the short-wave region, the current sensitivity is higher in the case of the reverse-biased metal–semiconductor junction, i.e., it changes in proportion to the thickness of the depletion layer on the source side of the illuminated surface.

NOTATION

V_f and V_r, voltage applied to the forward and reverse biases of the *p–n* heterojunction; λ, wavelength; I_d and I_r, forward and reverse current; N_A, concentration of the carriers; n, parameter determined by the type of *p–n* junction; k, Boltzmann coefficient; T, temperature; q, carrier charge; I_{ph}, photocurrent. Subscripts: ph, photocurrent; f, forward; r, reverse; A, Avogadro; s, saturation.

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