AMERICAN JOURNALS
Open Access, Peer Reviewed Journals
American Journal of Pedagogical and Educational Research
ISSN (E): 2832-9791| Volume 24, | May - 2024

STUDY OF PHOTODIODE STRUCTURES IN THE GALLIUM ARSENIDE-CADMIUM SULFIDE SYSTEM

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ABSTRACT	KEYWORDS
It is shown in this work that in a two barrier photodiode structure with a common modulated base region, the spectral characteristics for the cases of blockable p-n-hetero- (pGaAs-nCdS) and metal-semiconductor (m-pGaAs) junctions can have an identical form, where the formation mechanism is determined by the processes, occurring in the space charge regions located mainly in the common (pGaAs) region.	Photosensitiveity, gallium arsenide, double-barrier structure, saturation currents, current-voltage characteristic.

Introduction

Photosensitive structures of the visible and infrared (IR) ranges are widely used in television, communications, night vision devices, IR guidance systems and household devices [1,2]. Gallium arsenide and its compounds are the most promising materials in comparison with silicon and germanium to create structures efficiently operating in the spectral range of 1.0 - 1.6 μm. This is due to the fact, that, in the indicated range, silicon and germanium photodetectors have not quite satisfactory characteristics [3]. Silicon, being a semiconductor with indirect band transitions for photons with an energy of 1.16 eV, has an absorption coefficient of only 10 cm^{-1}. Even in avalanche photodiodes based on it, the capacitance and leakage currents are high, and their reduction by cooling the operating temperature is not advisable. To provide low dark currents and increase photosensitivity, A_3B_5 semiconductor compounds are of interest. For example, in gallium arsenide, the absorption coefficient at a photon energy of 1.45 eV reaches 10^4 cm^{-1}, and in the λ>1.0 μm range, strong absorption can be obtained by introducing substitute elements (In, A1, etc.) into it, which optimize the band gap. In addition, a smoother control of the characteristics of diode structures can be achieved by creating two or more barrier structures.

The double-barrier structure is made on the basis of a p-n-junction, in which the p-type region is a bulk GaAs crystal with N_A = (5-7) 1015 cm^{-3}, on the surface of which an isotopic epitaxial intermediate layer with a thickness of 4-6 microns. The concentration of carriers in it is ~6 · 10^{15} cm^{-3}. The n-type region was created by sputtering a cadmium sulfide film in a vacuum installation according to the technique described in [4]. The thickness of the film with a carrier concentration of ~3·10^{16} cm^{-3} was 0.2-0.3 μm. On the reverse side of the p-type region, a rectifying semitransparent

(~100 Å) silver (Ag) metal contact is formed. The Ag layer deposited on the surface of cadmium sulfide is ohmic. Thus, an m-pGaAs-nCdS-structure with an area of ~80 mm^2 was created, which was further scribed into discrete elements with an area of 16-20 mm^2.

The current-voltage characteristic of the investigated double-barrier photodiode m-pGaAs-nCdS structure is shown in Fig. 1. It consists of two reverse branches: when a forward voltage is applied to the pn junction, the metal - pGaAs junction is displaced in the blocking direction; when the pn junction is in the blocking mode, the metal - pGaAs junction tends to straighten. In any direction, one of the transitions acts as a current limiter. The course of the curve can be described by a formula that is valid for two reverse-switched transitions [5].

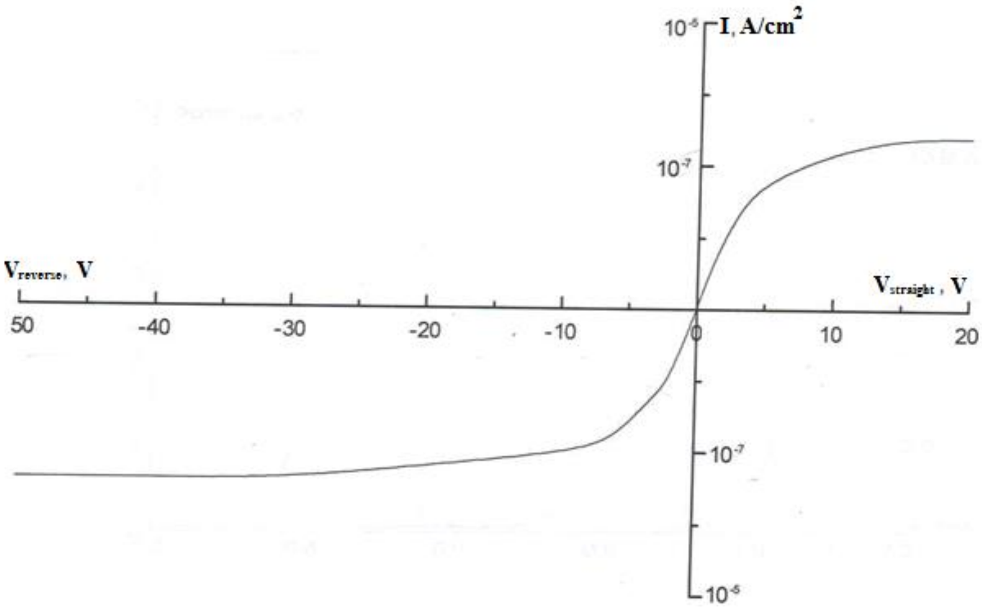

Fig. 1. Current-voltage characteristic of the photodiode m-pGaAs-nCdS-structure.

$$I = \frac{2I_{S_1} I_{S_2} Sh(qV/2kT)}{I_{S_1} \exp(qV/2kT) + I_{S_2} \exp(qV/2kT)}$$

Here, I_{S_1}, I_{S_2} - saturation currents for one and the other branches.

Comparison of the obtained results showed that, with the characteristic parameter n = 2, the experimentally measured values of the darkened currents are in satisfactory agreement with the calculated ones (table).

Calculated values of forward and reverse currents

V, W	3.0	6.0	9.0	10	11
$I_{straight}$, 10^{-8} A/ cm^2	1.0	1.3	1.69	9.0	13.6
$I_{reverse}$, 10^{-9} A/cm^2	8.4	8.56	8.6	8.75	8.79

On the experimental curve (Fig. 1) at 10 V, the forward current is $9 \cdot 10^{-8}$ A/cm^2, which is twice the calculated value ($4 \cdot 10^{-8}$ A/cm^2). The saturation currents are equal to $4.78 \cdot 10^{-8}$ A/cm^2 and $2.2 \cdot 10^{-9}$ A/cm^2, respectively. The differences between the calculated and experimental data are explained by the error in determining the inflection point from the graph.

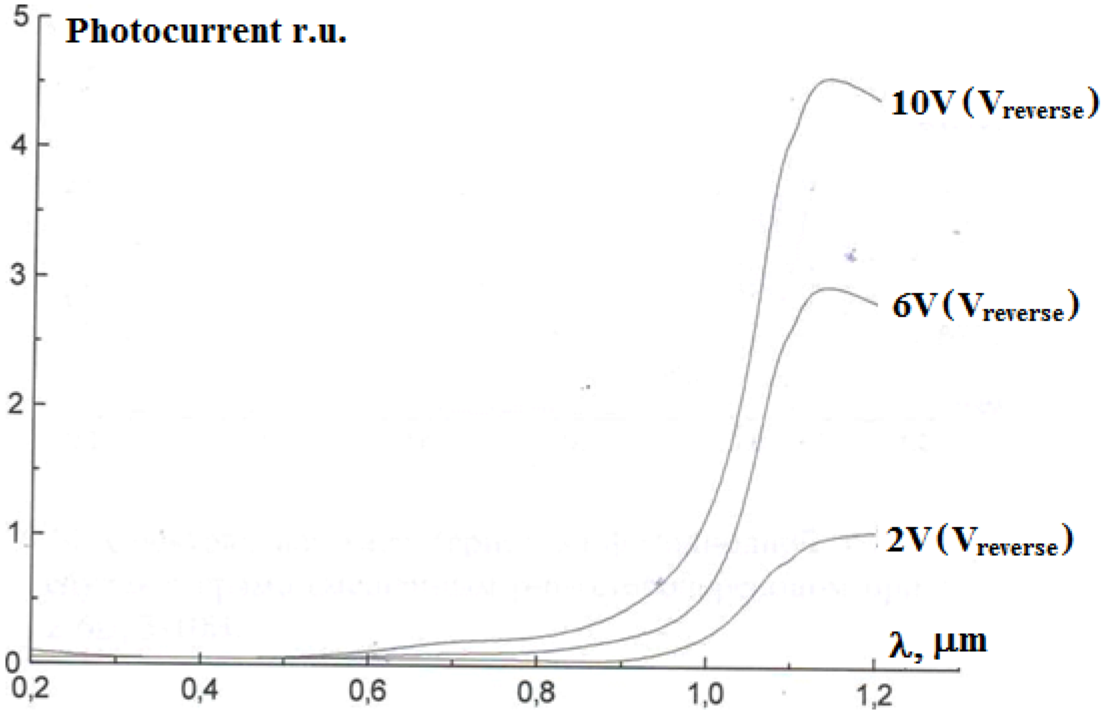

Fig. 2. Spectral characteristic of the photodiode structure at blocking voltages at the pn-heterojunction at $V_{reverse}$ 1-2 V, 2-6 V, 3-10 V.

In the mode corresponding to the forward bias of the p-n junction in Fig. 2., at low voltages (2 V), the photocurrent appears in the region of 0.2 µm at a level of 0.3 relative units (r.u.) and decreases to a certain value in the range from 0.4 to 0.6 µm, then, starting from 1.0 µm, it grows to 1.0 r.u. at λ = 1.1 - 1.2 µm. With an increase in voltage to 10 V, the photocurrent appearing in the vicinity of 0.2 µm increases fivefold at 1.08–1.12 µm.

In the mode corresponding to the reverse bias of the p-n junction (Fig. 2) at low voltages (2 V), the photocurrent is initially insignificant and grows to a maximum at 1.12 µm. With an increase in the applied voltage to 10 V, there is a tendency to an increase in the photocurrent at λ> 0.5 µm with a sharper rise at 1.05 µm. The maximum photocurrent is reached at 1.12 µm. Photosensitivity increases 4.6 times.

Comparison of the spectral characteristics with a change in the polarity of the applied voltage shows that the maximum photosensitivity is achieved in both directions at the same wavelength of 1.12 µm of the exciting signal. In the region of short wavelengths (0.2-0.4 µm) in the mode of reverse bias of the p-n junction, the photocurrent is lower than in the case of forward bias, i.e. the separation of photocarriers occurs at the metal-semiconductor transition.

An analysis of the current-voltage and spectral characteristics of the structure under study shows that they are formed due to physical processes occurring in the space-charge regions. When the p-n heterojunction is forward biased, the decisive role is played by the reverse biased m-p junction and the space charge layer is in the p region. In a reverse biased p-n heterojunction, the space charge region is also located in the p-region, since the carrier concentration in it (7×10^{15} cm^{-3}) is lower than in the n-region (3×10^{16} cm^{-3}). As a result, under illumination, regardless of the direction of the applied voltage, the spectral sensitivity of the structure has an almost identical form. In the short-wavelength region, the current sensitivity is higher in the case of an inversely mixed metal-semiconductor junction, i.e. changes proportionally to the thickness of the depletion layer from the side of the illuminated surface.

It has been shown experimentally that in a two-barrier photodiode structure with a common modulated base region, the spectral characteristics for the cases of blockable p-n-hetero- (pGaAs-nCdS) and metal-semiconductor (m-pGaAs) transitions can have an identical form, where the formation mechanism is determined by the processes occurring in areas of space charge located mainly in the general (pGaAs) area.

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