Selective Photoreceivers with Modulated Sensibility

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***Abstract* — The paper presents new type of photoreceivers (photodiodes, photoresistor) on the basis of semiconductor heterostructures of III-V compounds. As distinct from classic devices elaborated photoreceivers possesses new functional properties: selective spectrum, photosensibility modulated by supply voltage, possibility to detect simultaneously two or more optic signals with different wavelength. Photoreceivers are elaborated for use in various optoelectronic systems.**

***Index Terms* — heterostructure, modulated sensibility, selective photoreceiver.**

I. INTRODUCTION

The III-V semiconductor compounds wide use for making various optoelectronic active elements, as laser, photodiode, light-emission diode, etc. GaAs, InP, GaP and their related solid solutions are more used. Photoreceivers on the basis of III-V homojunctions possess high efficiency, but they have wide photosensibility spectrum. Unlike the binary compounds quaternary solid solutions have possibility to vary the band-gap in a large interval and allow to form heterostructures with peculiar photoelectrical properties [1]. The semiconductor heterostructures on the basis of quaternary solid solutions InGaAsP are successfully used for preparing the photoreceivers for IR spectral range 0.9 – 1.65 μm. They ensure higher conversion efficiency, lower dark currents and a higher work frequency. Moreover, the $In_xGa_{1-x}As_yP_{1-y}$ multiplayer heterostructures can realize some devices with novel characteristics and parameters.

II. THE PHOTODIODE WITH SELECTIVE SENSIBILITY

To obtain selective photosensibility we made double heterostructures by liquid phase epitaxy on the InP substrate (Figure 1). The first at the substrate layer with band gap E_{g1} determines red boundary of sensibility and second (frontal) layer with band gap E_2 limits sensibility at short-wave side.

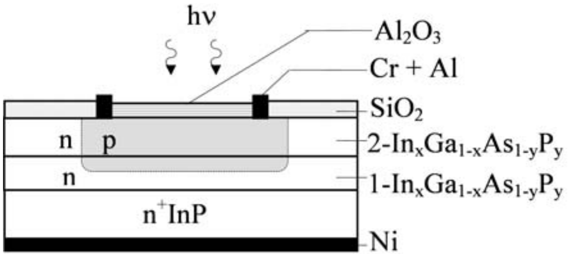


Fig. 1. The structure of selective photodiode.

High-energy radiation ($h\nu > E_{g2}$) is absorbed completely into frontal layer if its thickness d is more than $1/\alpha$, where α is light absorption coefficient, and d is more than diffusion length of minor charge carriers generated into frontal layer. Radiation with photon energy more than E_{g1} and less than E_{g2} ($E_{g1} < h\nu < E_{g2}$) is absorbed into first active layer and generates nonequilibrium charge carriers, which are separated by internal electric field of p-n junction and form photocurrent.

The photosensibility spectra of selective photodiode on the basis of double heterostructure InP - $In_{x1}Ga_{1-x1}As_{y1}P_{1-y1}$ - $In_{x2}Ga_{1-x2}As_{y2}P_{1-y2}$ with various thickness of frontal layer is presented in Figure 2. This structure have values of band gap E_{g1} = 1.12 eV for active layer, E_{g2} = 1.18 eV for frontal layer and spectra maximum for λ = 1.06 μm [2].

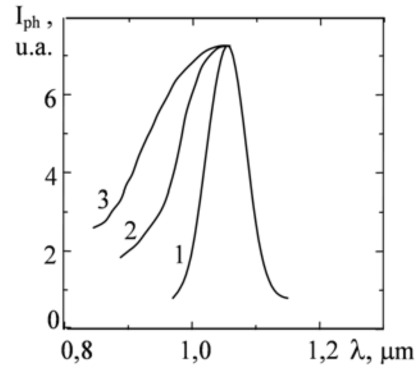
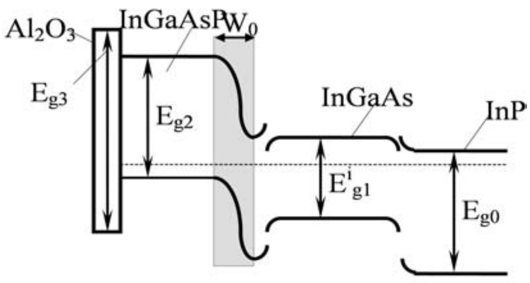


Fig. 2. Photosensibility spectra of selective photodiode with thickness of frontal layer d:
1 - 7 μm; 2 - 4 μm; 3 – 2.5 μm.

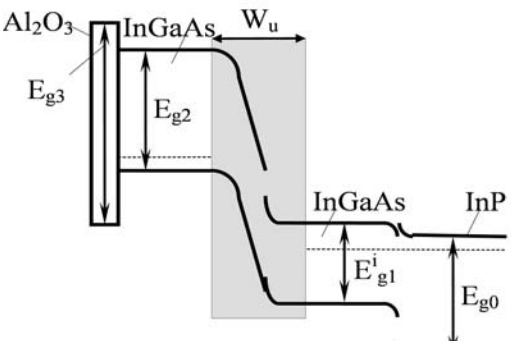
The spectra semi-width depends on thickness of frontal layer and for structure with 7 μm thickness of frontal layer is 75 nm. The $In_xGa_{1-x}As_yP_{1-y}$ multiplayer heterostructures can be optimised and accommodated, varying the coefficients “x” and “y”, to receive radiation with spectra maximum in interval 0.9 μm < λ < 1.65 μm and the spectra semi-width can be reduced to 20 –30 nm.

III. THE PHOTODIODE WITH MODULATED SENSIBILITY

One of important characteristics of photodiode for optic communication is possibility to have control over photodiode sensibility easy and quickly. Heterostructures on the basis InP – InGaAs – InGaAsP allow to make photodiode with modulated photosensibility and new functional properties. Liquid phase epitaxy was utilized to obtain the semiconductor heterostructures. The photodiode consists of n^+-InP substrate, InGaAs layer with band gap E_{g1} = 0.75 eV, InGaAsP layer with E_{g2} = 1.12 eV, Al_2O_3 antireflection layer with wide band gap E_{g3} and ohmic contacts. The p-n junction is realized by Zn diffusion through the opened in SiO_2 windows and is placed in frontal layer near the heterojunction. Figure 3 shows the energetic diagrams of photodiode without any polarization voltage (Fig. 3,a) and for reverse polarization voltage more than any "threshold" one U_{thr} (Fig. 3,b). In the case "a" charge carriers generated in active layer with E_{g1} cannot be separated due to a potential barrier in the valency zone between InGaAs layer and InGaAsP one. Only for $U_{rev} > U_{thr}$ the space charge region W extends also into the InGaAs photoactive layer, the potential barrier decreases to disappearance.



a)



b)

Fig. 3. The energetic diagrams of photodiode:
a) without any polarization voltage;
b) for reverse polarization voltage.

Thus, the photocurrent generated in active layer by optic communication signal with λ = 1.3 μm or λ = 1.55 μm (regions "II" and "III") increases quickly from the zero to its maxim value at exceeding $U_{rev} \geq U_{thr}$ (Fig. 4). Dotted lines show characteristics for classic photoreceiver (with illumination "I", without illumination "0"). For first time, it was realized a photodiode whose photosensibility can be modulated by a polarization voltage with modulation degree of 100 % [3]. The new photodiode can be successfully utilized in optoelectronic systems to receive, to code and to processe the optic information.

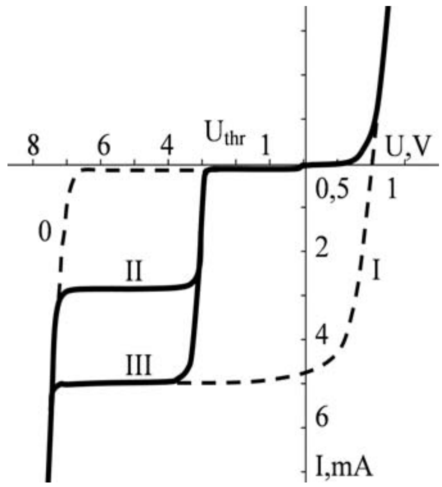


Fig. 4. Volt-current characteristics of photodiodes with modulated sensibility (II, III) and classic (I).

IV. THE PHOTODIODE WITH MODULATED SENSIBILITY FOR RECEIVE TWO WAVELENGTH

On the basis of photodiode with modulated sensibility can make selective photodiode with possibility to receive simultaneously two optic signals with different wavelength and to modulate photosensibility for each of them by supply voltage. The design of this photodiode (Fig. 5) is similar to described above structure only in addition contains on the back side the active layer with band gap $E_{g4} < E_{g1}$ and thickness less than diffusion length of minor carriers and back layer with E_{g1} where was formed second p-n junction with space charge region W_2. The space charge region of first p-n junction into layer with E_{g2} is W_1.

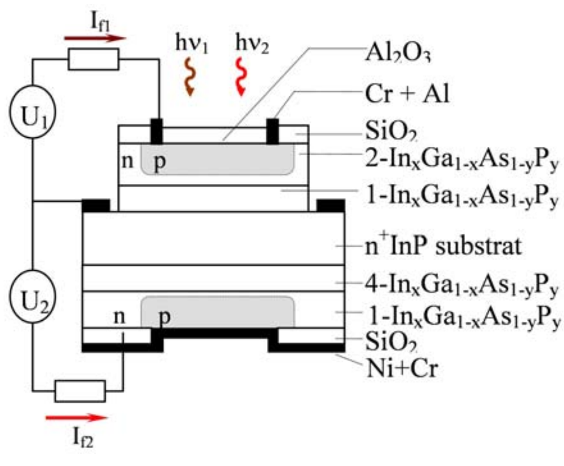


Fig. 5. The photodiode with modulated sensibility for receive two wavelength.

The energetic diagrams of this structure are presented in Figure 6: a) without any polarization voltage; b) for reverse voltage more than threshold voltage.

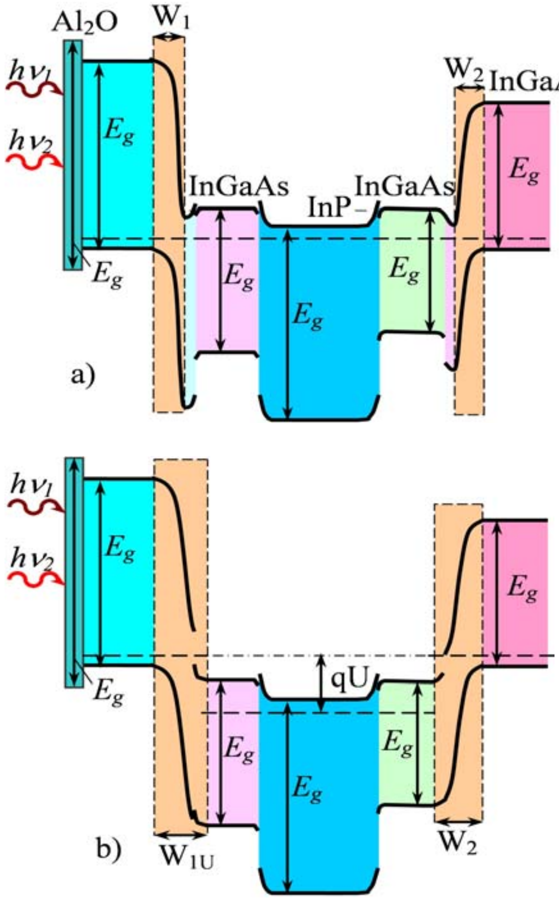


Fig. 6. The energetic diagrams of selective photodiode with modulated sensibility to receive two optic signals with different wavelength.
a) without any polarization voltage;
b) for reverse voltage more than threshold voltage.

Optic signals with photon energy $h\nu_1 = E_{g1}$ and $h\nu_2 = E_{g4}$ are introduced into photodiode structure through the antireflection layer with band gap E_{g3}, which ensures minim optic loses. Selectivity of photodiode is ensured by absorption of photons with energy $h\nu > E_{g2}$ at the surface of frontal layer, which don't participate in formation photocurrents of p-n junctions, as since thickness of frontal layer with E_{g2} is more than diffusion length of minor charge carriers, and photons with energy $h\nu < E_{g4}$ go through the semiconductor structure without absorption. The optic signal with photon energy $h\nu_1 < E_{g2} < E_{g3}$ is absorbed into first active layer with E_{g1} and other optic signal with photon energy $h\nu_2 < E_{g1} < E_{g2} < E_{g3}$ propagates through structure and is absorbed into second active layer with E_{g4}. Generated nonequilibrium charge carriers cannot be separated due to potential barriers φ_b into valence band and in this case, photocurrents through both p-n junctions are equalled zero. At the reverse polarization of p-n junction $U_{rev} > U_{thr} = q\varphi_b$ the potential barrier disappears (Fig. 6, b) and generated charge carriers is separated by electric field of p-n junction forming current proportional intensity of incident signal. Thus, we modulate output signals (currents through the p-n junctions) with modulation degree of 100 % by change reverse polarization on the p-n junctions in very small interval about values $U_{rev} = U_{thr}$ (Fig. 7).

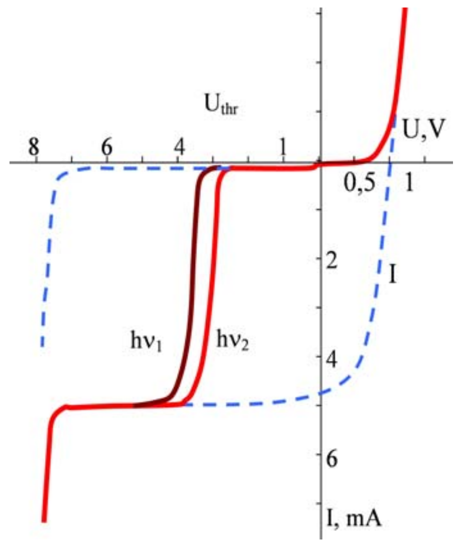


Fig. 7. Volt-current characteristics of selective photodiode with modulated sensibility, which receives simultaneously two optic signals with wavelength. ($h\nu_1$, $h\nu_2$) and classic (I)

V. CONCLUSION

The scientific investigations demonstrate that III-V compound heterostructures permit manufacturing of photodiodes with unique functional properties:

- exclusion of optic background influence and detecting of signals with certain wavelength only;
- photosensibility modulation on 100 % by polarization voltage;
- detecting simultaneously two or more optic signals with different wavelength.

REFERENCES

[1] V.Dorogan, N.Syrbu, T.Vieru, etc. Variable composition layers in the optoelectronic devices structure based on A^3B^5 compounds.// Romanian Journal of Optoelectronics.- V.6, Issue 1, 1998, Bucharest, Romania, P.20-23.

[2] V.Dorogan, N.Bejan, T.Vieru, V.Coseac, V.Secrieru. Selective reception of optic signals transfered through atmosphere.// Ist Internation. Conf. on Information Tecnologies. 11-13 April, 2001, Chisinau, Moldova, V.2001, N.1, P.95.

[3] V.Dorogan, T.Vieru, S.Vieru, A.Dorogan. Fotodiodă selectivă cu sensibilitate modulată.// Brevet de invenție MD 2413 G2 - Buletin Oficial de Proprietate Industrială, Nr.3, 2004, P.22.