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Optical FET Output Characteristics Research in Light-Activated Mode

D. M. Yodgorova

Physical-Technical Institute of the Scientific Association "Physics-Sun" of the Academy of Sceinces of the Republic of Uzbekistan, Tashkent, Uzbekistan

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Abstract—This paper deals with researches of output characteristics of a field-controlled phototransistor with light excitation in a light-activated mode. Optical signal transformation mechanisms in a channel are determined, considering processes in a drain-gate junction. Criteria of base region effective modulation are specified. Obtained results can be used in design of new generation transistors.

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Photorecivers that receive optical signals of desired spectral band and sensitivity are widly used for optical electronic devices. They must provide signal transmission to following reception- transmission units. In this aspect field effect transistors (FET) with controlling *p-n*-junction in depletion mode application is of interest. An excitation of the transistor with deplection layer considers development of new optical reciver type, called light-activated transistor, that is, in fact, controled by light emission. In this case gate contact is not used as an active electrode. One of the problems of this struture application is absence of such planar structures compatibile with integrated circuit (IC). Another problem is lack of fabricating tecnology of FET with gate deplection layer channel. Schottky junction usage as a gate causes essential leakage currents [1]. So, the problem of optical FET development is urgent and it needs a solution.

The problem solution can be achieved mainly by development of optical transistor with deplection channel mode, caused by a draine-gate voltage, and optical signals are recived by drain and gate contacts [2]. This optical FET with *p-n* junction was illuminated by integrated visible light and obtained results are sufficient. Photocurrent values about 1 μA were obtained when the channel was illuminated by light with intensity up to 5000 lux [3]. For futher analysis of optical electronic devices it is of interest to consider not only cases of visible and infrared light (0.85, 1.3 and 1.5 μm illumination), but also case of low intensity light ilumination. For this purpose we research optical FET in light-activated mode to investigate its possible improvements for further development of the optical FET, with better parameters.

In this paper we present results of research of functional characteristics of gallium arsenide optic FET with controling *p-n* junction in light-activated mode.

Channel length of researched optical FET is 50 μm and its width is 0.32 μm. Channel area of *n*-GaAs, tin-doped up to concentration of $\sim 3\times10^{16}$ cm^{-3} is grown by means of liquid epitaxy on the top of intermediate epitxial *p*-GaAs layer with concentration of 3×10^{17} cm^{-3} and with thickness of 0.1 μm, which is grown on heavily p^{+}GaAs (2×10^{19} cm^{-3}) substrate. We selected such carrier concentration to provide channel effective overlap by bloking voltage, and it provides expansion of gate chanell space charge.

Reserched optical FET has typical drain volte-amper characteristics, shown in Fig. 1. If gate voltage is fixed, then drain voltage increase causes sublinear current dependence on voltage with great value of output resistance that provides high optical sensitivity of reserched optical FET [4, 5].

While blocking voltage increases from 0 to 1.6V, drain current decreases. Voltage increase causes increase of channel resistance, which means channel blocking by *p-n* junction space charge layer as it is shown in Fig. 1. This case corresponds to zero value of drain–source voltage, or to so-called process of channel blocking by means of voltage. So, channel resistance R_{ds} is a function of gate-source voltage [6]

$$R_{\text{ds}} = R_0 / (1 - \{V_{\text{gs}} / V_{\text{cut}}\}^n),$$

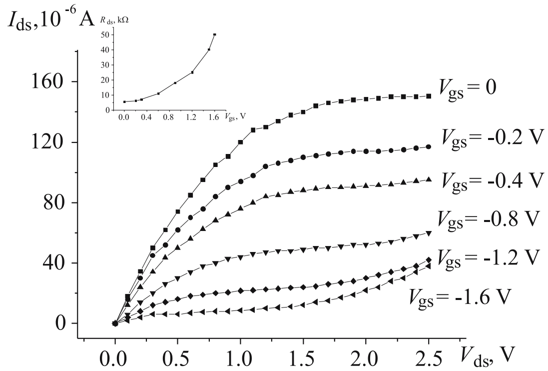

Fig. 1.

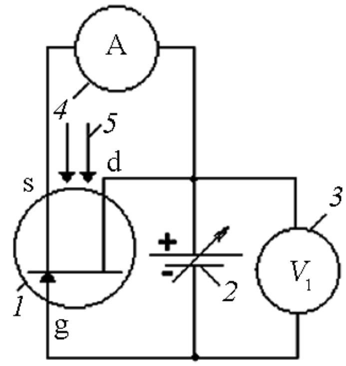

Fig. 2.

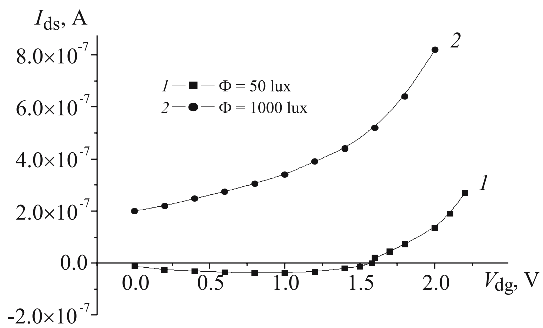

Fig. 3.

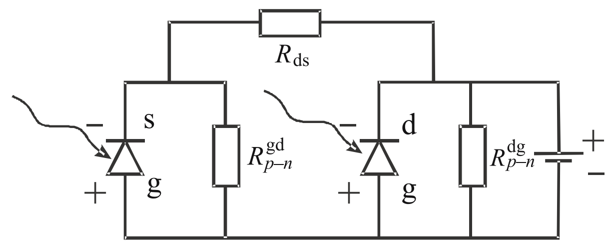

Fig. 4.

where R_0 is channel initial resistance, V_{cut} is cut-off voltage, V_{gs} is blocking voltage. Moreover researched optical FET has light sensitivity area from 0.54 to 0.96 μm. It provides its application in attention devices and in fiber-optic transmission systems. So, it is important to research optical FET in light-activated mode for analysis of its functionality.

We analyze optical FET behavior by means of circuit connection, described in [2]. In case of light-activated mode channel of the researched FET *1*, which is represented in Fig. 2, is blocked by drain-gate voltage from a source *2*. Operating voltage value is measured with a voltmeter *3*, and photocurrent is measured with an amperemeter *4*. The channel is activated by optical radiation *5*.

In observed connection, an operating voltage is applied to gate-source junction through the amperemeter. Therefore, channel resistance is a function of drain-source voltage $R_{ds} \sim f(V_{gs} = V_{ds})$ in case of light-activated mode.

Drain–source current is equal to zero in the dark for any drain-gate operating voltage values. Light-activated mode means that if channel is excited by optical radiation, then photoelectromotive force appears between gate channel even in case of zero operation voltage whose direction is opposite to operation voltage one [7]

$$V^{ph} = \frac{kT}{q} \ln\left(\frac{I^{ph}}{I_{ld}} + 1\right) \quad \text{when } I^{ph} >> I_{ld}.$$

While operation voltage increases, photo current value decreases to compensation point, where this current changes its sign and then it increases (curve *1* in Fig. 3). When radiation intensity increases, in our case, up to 1000 lux, photo current value became positive and its value four times greater, while voltage changes from 0 to 2 V (curve *2*). Photo current value depends nonlinearly on drain-gate operation voltage (curve *2* in Fig. 3) and its increase means that there is optical signal amplification. Our task is to recreate this phenomenon and to optimize optical FET parameters. During optimization we intend to receive greater values of photosensitivity and amplification factor.

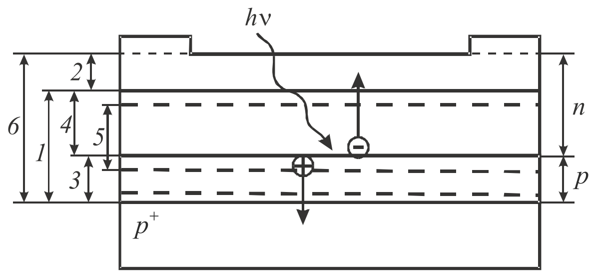

Fig. 5.

Structure current behavior in light-activated mode is defined by means of equivalent circuit, shown in Fig. 4.

If there is zero offset in drain-gate junction regardly to illuminated gate-source junction, then drain-gate junction acts as a load, and gate-source photo (photoelectric) current appears in circuit, its sign is opposite to supply source current sign. While drain-gate operating voltage increases drain-gate junction changes its photodiode state, gate-source junction becomes a load, and some photocurrent changes its sign. A value of this current increase is proportional to optical signal intensity increase.

Modulation processes in a space charge layer and in a FET channel in light-activated mode are shown in Fig. 5 (curve *1* is $W^{0}_{p-n} = W_p + W_n$; *2*—$W_{\text{ch}} = W^{\text{cut}}_{p-n} - W^{0}_{p-n}$; *5*—$W^{\text{light}}_{p\text{-}n} \sim f(\Phi, h\nu)$; *6*—$W_{p\text{-}n} \sim f(V_{\text{dg}})$). Observed behavior of photocurrent dependence on drain-gate voltage values can be explanted by following mechanism. In balance state, when there is no external operating voltages, initial thickness of *p-n* junction space charge layer is *w*, it contains partly both *n*-region $W^{0}_{p-n} = W_p + W_n$ and *p*-region W_p (Fig. 5) in compliance with carrier concentration proportion

$$\frac{N_n}{N_p} = \frac{W_p}{W_n}.$$

Thickness of space charge layer decreases on $\Delta W_{p-n} = W^{0}_{p-n} - W^{\text{light}}_{p-n}$ illumination of gate-source junction causes photo current and photo carriers amount decreases. If there is external operating voltage V_{dg}, then thickness W_{p-n} expands in both sides with increase of the photo carriers amount in space charge layer. This layer expands by means of the blocking drain-gate voltage. This process repeats with illumination intensity increase. The greater is illumination intensity, the thinner is initial space charge layer.

Thus, considering light transformation process into expansion of space charge layer in channel area W_n is limited by its thickness, and its expansion in gate region W_p is limited by the thickness of interlayer of *p*-GaAs. So, modulation of gate area is less effective with that characteristic parameter values. In future we propose to reduce carrier concentration in gate area and to make controlling *p-n* junction in form of symmetrical step. In this case we improve modulation depth and effectiveness of the optical signal conversion by the optical FET. Furthermore, using of a heterojunction with a corresponding prohibited area width instead of controlling homo *p-n* junction provides photosensitivity increase of optical FET in desired spectral area by means of AlGaInAs junction application.

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