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FUNCTIONAL CHARACTERISTICS OF A FIELD TRANSISTOR WITH A CONTROL p-n-JUNCTION UNDER DIFFERENT POWER-ON MODES

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ABOUT ARTICLE

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Abstract: The functional characteristics of junction field-effect transistor were researched at different bias polarities and schemes of inclusion. It was established experimentally that the maximum value of drain current when two transistors were connected varies in a quadratic law with the radiation intensity, and photosensitivity becomes more than in a discrete structure. In this case the maximum values of drain current corresponding to the light currents of discrete transistors by forward voltage vary in a quadratic law and they are a continuation of the transfer characteristics in dark, which makes possible their use as photodetectors in electronic circuits. In the series-connected field-effect transistors modulated junction, as in the two-barrier structures, controls the parameters of the second junction due to redistribution of the voltage applied from an external power source.

INTRODUCTION

Recently, field-effect transistors have been widely used in the input stages of micro and optoelectronic devices. Their use in various devices is predetermined by the high input impedance and the possibility of wide control of the operating point. Despite the fact that the first studies of phototransistors began with bipolar structures [1], significant progress has been made on the basis of field-effect transistors. For example, structures based on cadmium sulfide called a field phototriode were obtained for the first time in [2], and then, in [3], the possibility of using a field-effect transistor with a Schottky barrier based on gallium arsenide as a high-speed photodetector was shown. Field-effect transistors as photodetectors have internal amplification, although the photocurrent is created at a lockable control p-n junction. The created photocurrent, by changing the thickness of the space charge layer, modulates the channel thickness, leading to a greater change in the current flowing through the channel. In the channel cutoff mode, an n-channel transistor can be represented as two back-connected n-p-n diodes, through which a reverse current flows in the equivalent, which is a resistor. When the formed n-p-n structure (differential and dynamic) is illuminated, the resistance of the equivalent resistor will decrease in accordance with the radiation intensity.

Similarly, one can imagine a two (three) barrier photodiode p-n-m structure with the effect of amplifying the primary photocurrent [6]. In them, light radiation also leads to a decrease in the differential and dynamic resistance of the structure.

Analogues of a two-barrier photodiode are:

– field effect transistor in locking mode;

– two field-effect transistors with source and gate contacts connected through resistance, in which the drain terminal of the first transistor is connected to the gate terminal of the second transistor (equivalent to a three-barrier structure, i.e., injection of carriers into the base regions is excluded [6]);

– two field-effect transistors with source and gate contacts connected through resistance, in which the drain terminal of the first transistor is connected to the drain terminal of the second transistor (equivalent to an injection-field photodiode [7]).

It should be noted here that it is impossible to obtain analogues of two (three) barrier structures by connecting ordinary discrete photodiodes, and two-barrier diode structures can be modulated with the help of field-effect transistors.

MATERIALS AND METHODS.

Information about the first samples of a photosensitive field-effect transistor with a control p-n junction based on gallium arsenide was given in [4]. In further studies, it was found that to ensure high photosensitivity, it is necessary to choose the channel parameters so that the cutoff voltage is close to the value of the contact potential difference of the p-n junction of the gate [5]. As you know, enterprising researchers in their developments use bipolar transistors with a remote cap as phototransistors. Regarding field-effect transistors, it can also be noted that the produced silicon field-effect transistors with a remote cap and a corresponding thin channel will have a sensitivity that is not inferior to bipolar transistors, Table. 1. So, in bipolar phototransistors, as shown in Table. 1, dark currents are very large and there is a (lag) effect of charge accumulation, which also limits the possibility of their use for receiving weak optical signals. Therefore, they are used as analog and key radiation receivers, since high-frequency transistors are required to transmit digital signals.

At the same time, the systematic improvement of optical fibers and optical amplifiers requires the development of improved emitters and photodetectors, which are also suitable for use in systems for transmitting and receiving information signals. In this regard, interest has increased in low-noise photodetector structures with low dark currents, which are field-effect transistors.

Table 1

Parameters of some germanium and silicon phototransistors [6]

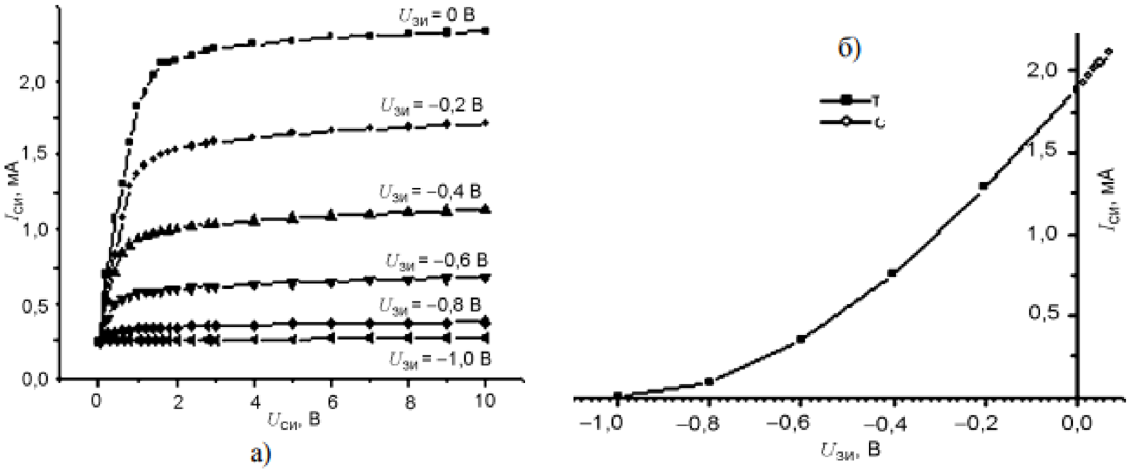
Phototransistor	Element dimensions, mm^2	Dark current, μA, no more	Operating voltage, V	Maximum spectral sensitivity, μm	Integral sensitivity, μA/lx
ФТ-1К	2,8	3	5	0,8÷0,9	0,4
ФТ-2Г	1,0	500	12÷24	1,5÷1,6	2,0
ФТ-3	3,0	60	5÷10	1,5÷1,55	1,0
ФТГ-5	3,0	50	5÷10	1,5÷1,55	1,0
КТФ109А	2,0	-	5	0,83	0,25 А/ВТ

This paper presents the results of a study of the photoelectric characteristics of a field-effect transistor with a control p-n junction on the example of a silicon transistor analog KP 303 in various switching modes. In particular, research was carried out on the light drain characteristics of a discrete field-effect transistor, as well as when they are connected in series and in parallel.

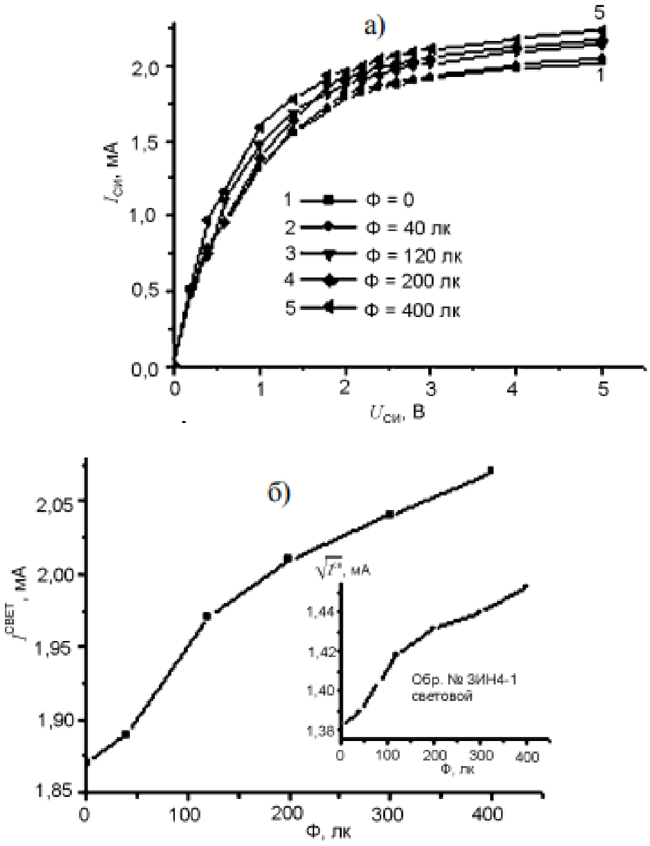
RESULTS AND DISCUSSION.

Light characteristics of series and parallel connected field transistors.

The field-effect transistors under study are silicon field-effect transistors with a control p-n junction and an n-type conductivity channel. Stock characteristics have a typical form, fig. 1. The drain current saturates at 2 V. As the blocking voltage increases, the drain current decreases. The cutoff voltage is about 1 volt, and the maximum drain current is 1.85 ÷ 2 mA. Transfer characteristics in the dark are described by a quadratic dependence [7]. That is, in coordinates, the root of the dark drain current from the blocking voltage gives a straight line. The maximum slope of the current-voltage characteristic is ΔISI/ΔUZI = 3.2 mA/V. The contact potential difference of the control p-n junction, determined from the direct current-voltage characteristic of the gate junction, is 0.64 V, that is, it meets the criterion of a photosensitive field-effect transistor. Accordingly, as shown in Fig. 2, when the channel region is illuminated with integrated radiation from a tungsten lamp with a maximum at $\lambda = 860$ μm, a photocurrent appears. With zero gate bias and operating voltage USI = 3.0 V, the photosensitivity (the ratio of the increase in drain current from illumination to radiation intensity), having a maximum at low illumination, decreases from 0.0005 mA/lux to 0.00015 mA/lux at Ф = 400 lx (Table 2). That is, this field-effect transistor is effective for receiving weak optical signals.



Rice. Fig. 1. Stock (a) and transfer (b) characteristics of a 3IN4-1 silicon field-effect transistor in the dark and under illumination.



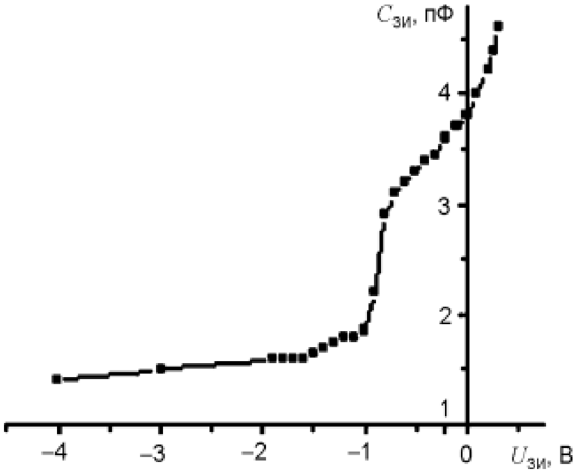
Rice. Fig. 2. Light characteristics at zero gate bias and the dependence of the maximum light current on the illumination intensity No. 3IN2-2.

Table 2

Current photosensitivity data on radiation intensity at URI = 0, USI = 3.0 V

Ф, лк	40	80	120	200	400
S, мА/лк	0,0005	0,0005	0,00034	0,0002	0,00015

Despite the fact that the dark transfer characteristics obey a quadratic law, the dependences of the light current on the illumination intensity of the discrete transistor in coordinates $\sqrt{I^{CB}} \sim f(\Phi)$ are non-linear, Fig. 2b. Characterizing the distribution of impurities in the channel, the volt-capacitance characteristic of the gate junction of the transistor under study is nonmonotonic and is divided into characteristic sections due to the uneven distribution of impurities over the channel thickness, Fig. 3.



Rice. 3. Dependence of the capacitance of the gate-source junction on voltage.

In principle, the resistance of the field-effect transistor channel increases from the blocking voltage, and decreases with light excitation. In this case, the blocking voltage reduces the thickness of the channel, and the illumination reduces the magnitude of the blocking voltage, leading to an increase in the thickness of the conductive part of the channel, that is, theoretically, the drain currents from the voltage should change according to one pattern. Indeed, when identifying the radiation intensity with a forward bias voltage, the corresponding values of the drain currents were obtained, which are determined by a quadratic dependence (Table 3).

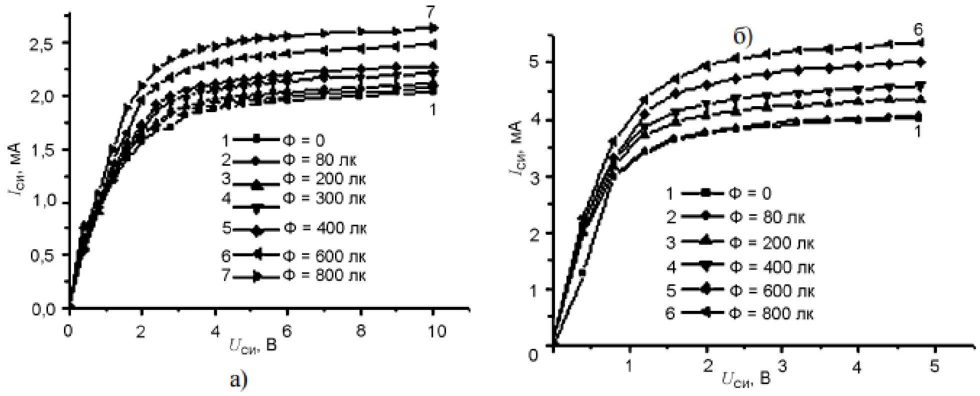
Table 3

Drain light current data under illumination and identified gate forward voltage

Iси. свет, мА	Ф, лк	Uзи. прям., В
1.91	0	0
1.93	40	0.015
1.97	80	0.025
2.01	120	0.036
2.05	200	0.05
2.11	400	0.07

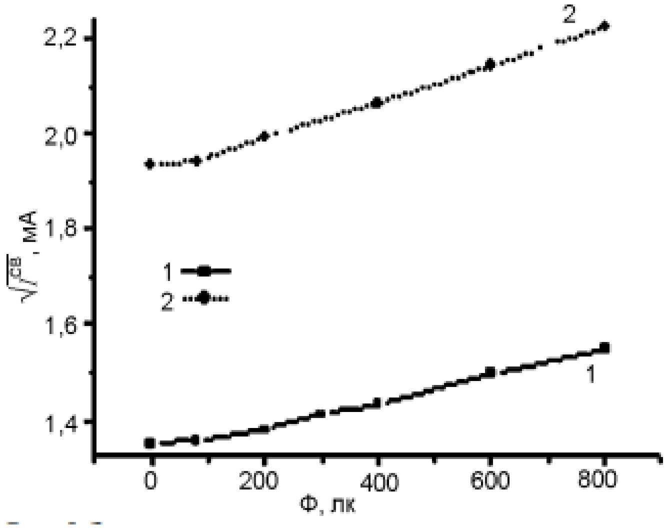
When constructing the transfer characteristic using the data corresponding to the light maximum currents in the forward bias mode, the light component becomes a continuation of the dark component, fig. 1b.

When two transistors are connected in series, in which the maximum currents and cutoff voltages are close, the allowable operating voltages increase, and when connected in parallel, both dark and light currents increase (Fig. 4).



Rice. 4. Stock characteristics in series (3IN2-2 + 3IN4-1) (a) and (b) parallel-connected transistors 3IN4-4 = 3IN4-1.

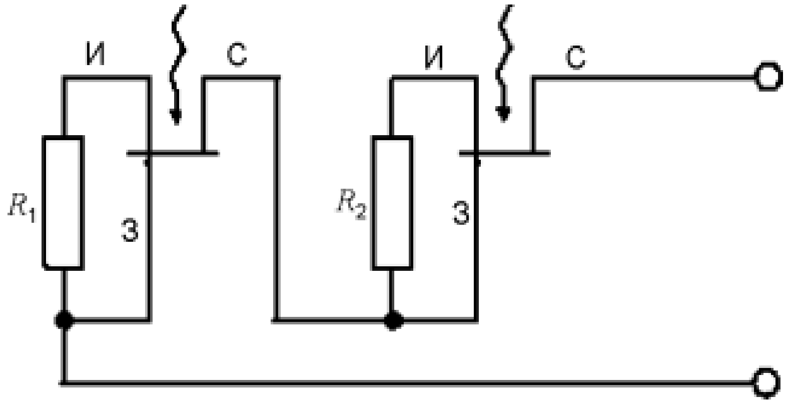
The dependences of their light currents on the illumination intensity obey the same quadratic law (Fig. 5).



Rice. Fig. 5. Dependences of light currents on illumination intensity for series and parallel connected field-effect transistors.

This behavior of the light characteristics in series and parallel connection can be explained by the stabilization of the generation processes and the operating mode. In this case, an important role is played by the fact that in a transistor with a large drain current, due to the heat released, the mobility of charge carriers in the channel decreases, leading to a decrease in the drain current, while in a colder transistor, the drain current increases.

As shown in fig. 6 in the proposed serial connection of two transistors, the source terminals are connected to the gate terminal through a resistance, and the gate of the first transistor is connected to the source terminal.



Rice. 6. Two-terminal field-effect transistors connected in series.

With respect to the operating voltage, the control p-n junctions are in blocking mode. As a result, each transistor turns into a two-terminal diode, and the current of one transistor becomes equal to the current of the second transistor, as in two-barrier diode structures [8]. The modulated transition controls the parameters of the second transition by redistributing the voltage applied from an external power source. Since the maximum drain currents for both transistors have the same values, the family of dark drain characteristics in the saturation region remains unchanged, but the saturation voltage increases and the saturation mechanism changes [9, 10]. In particular, the operating voltage simultaneously compresses the channel from the source and drain sides, which leads to an increase in the output dynamic resistance and gain [11]:in the output dynamic resistance and gain [11]:

$$K_H = \frac{(SR_i + 1)R_H}{(SR_{i+1})R_{\text{источ}} + R_i + R_H},$$

where R_{SOURCE} is the internal resistance of the input signal generator; R_i is the dynamic resistance of the field effect transistor; $R_i = dU_{SI}/dISI$, U_{ZI} = const.

CONCLUSION

FETs connected in series can be considered as analogs of multibarrier structures. Accordingly, changing the physics in one gate junction results in changing the physics in the other gate junction, improving the modulation efficiency of the active channel. It has been experimentally established that the maximum values of the drain currents when two transistors are connected depend on the radiation intensity according to a quadratic law. In this case, the maximum values of the drain currents corresponding to the light currents of discrete transistors from the forward-bias voltage also change according to a quadratic law and are a continuation of the dark transfer characteristic, which makes it possible to use them as photodetectors in electronic circuits.

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