ФІЗИЧНІ, ХІМІЧНІ ТА ІНШІ ЯВИЩА, НА ОСНОВІ ЯКИХ МОЖУТЬ БУТИ СТВОРЕНІ СЕНСОРИ

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MIS-PHOTOTRANSISTOR WITH *p-n-…-p-n*-STRUCTURE AS A GATE

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Abstract

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The physical mechanisms of the operation of the field-effect MIS-phototransistor with *p-n-…-p-n* — structure as the gate is considered. The photo-voltage, which is raised with illumination, operates by current in the channel of the transistor. The photosensitivity of such transistors better than that of the photodetector with absorption of light only in the channel. The utilization as the gate of semiconductor with greater wide band gap than material of channel is extended the spectral region of sensitivity in ultraviolet.

Key words: field-effect transistor, MIS-structure, phototransistor, *p-n*-junction

Анотація

МДН-ФОТОТРАНЗИСТОР З *p-n-...-p-n*-СТРУКТУРОЮ В ЯКОСТІ ЗАТВОРУ.

І. М. Вікулин, Ш. Д. Курмашов, В. А. Мінгалєв, Ю. Г. Туманів

Розглянуто фізичні механізми дії польового МДН фототранзистора з p-n-... — p-n — структурою в якості затвору. Виникаюча при освітленні затвора фотонапруга управляє струмом у каналі транзистора. Фоточутливість такого приладу набагато вища, ніж у фотоприймача з однорідною структурою затвора. Використання в якості затвора напівпровідникової p-n-... — p-n — структури з більшою шириною забороненої зони, ніж матеріалу каналу, розширює спектральний діапазон чутливості в УФ-області.

Ключові слова: польовий транзистор, МДН — структура, фототранзистор, p-n- перехід.

Аннотация

МДП-ФОТОТРАНЗИСТОР С *p-n-…-p-n*-СТРУКТУРОЙ В КАЧЕСТВЕ ЗАТВОРА

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Рассмотрены физические механизмы действия полевого МДП фототранзистора с *p-n-…-p-n* — структурой в качестве затвора. Возникающее при освещении затвора фотонапряжение управляет током в канале транзистора. Фоточувствительность такого прибора намного выше, чем у фотоприемника с однородной структурой затвора. Использование в качестве затвора полупроводниковой *p-n-…-p-n* — структуры с большей шириной запрещенной зоны, чем материала канала, расширяет спектральный диапазон чувствительности в УФ-области.

Ключевые слова: полевой транзистор, МДП — структура, фототранзистор, *p-n-* переход.

The saturation current of the MIS-phototransistor with the built-in channel of the *n*-type and semi-transparent metal electrode is determined by the relation [1].

$$I_н = \frac{\mu_n C}{2l^2}\left(V_{з0} \pm V_з\right)^2, \quad (1)$$

were C — capacity of a gate; $V_{зо} = qn_n abl/C$ — pinch-off voltage of a gate; n_n - equilibrium concentration of electrons in a gate; a, b, l — width, breadth and length of the channel, $V_з$ - voltage on a gate.

The concentration of the charge carriers at the irradiation of the channel is increased on the value $\Delta n = \alpha_к \beta_к \tau_к \Phi$, that gives to the corresponding increase of the current at the network source-drain. Here $\alpha_к$ — absorption coefficient of the channel material, $\beta_к$ — quantum efficiency, $\tau_к$ — life time of the electrons, Φ — light intensity.

For increase of the sensitivity and expansion of the spectral range of sensitivity it is offered to utilize instead of a metal gate and also resistively gate [2], *p-n-…-p-n*-structures from the semiconductor with greater band gap E_{g2}, than E_{g1} of the channel's material [3]. The structure of the phototransistor on the fig. 1 schematic is shown. At irradiating structure with a gate, for example, from five *p-n*-junctions the photovoltage $V_Ф$ is generated on each of them. And on junctions 1, 3, 5 from the source it is one sign, and on the junctions 2, 4 — opposite. In order to, that voltages of the evens *p-n*-junctions was not subtracted from the voltages of the odds, the evens junctions are shunted by the metal bridges. Then the general voltage on the edge of a gate near the drain $V_з = mV_Ф$, were m — quantity of the odd *p-n*-junctions.

As is known, for one *p-n*-junction the photovoltage $V_ф = (kT/q)\ln(j_ф/j_н + 1)$, where $j_ф = q\alpha_з\beta_з W\Phi$; $j_н = qD_p p_n W/L_p^2$, $\alpha_з$ and $\beta_з$ — absorption coefficient and quantum efficiency of a gate, accordingly; W — breadth of each *n*-layer in a gate (remaining labels conventional). Therefore it is possible to note

$$V_ф \approx \frac{kT}{q}\ln\left(\frac{\alpha_з\beta_з L_p^2}{D_p p_n}\Phi\right), \quad (2)$$

Substituting relations for Δn, $V_з$ and $V_Ф$ in (1) we shall receive for the current of saturation

$$I_н = \frac{\mu_n C}{2l^2}\left[\frac{qabl}{C}\left(n_n + \alpha_к\beta_к\tau_n\Phi\right) \pm \right.$$

$$\left. \pm m\frac{kT}{q}\ln\left(\frac{\alpha_з\beta_з L_p^2}{D_p p_n}\Phi\right)\right]^2. \quad (3)$$

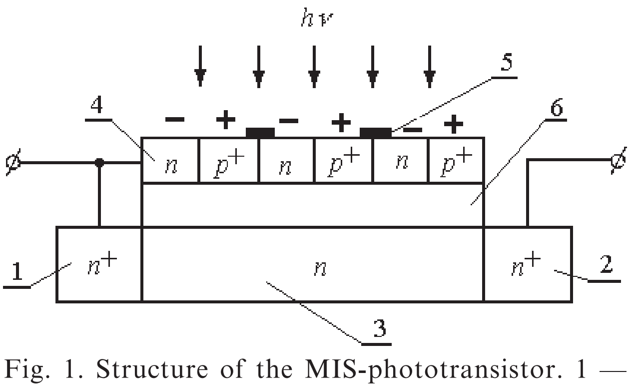

Fig. 1. Structure of the MIS-phototransistor. 1 — source, 2 — drain, 3 — channel of conductance, 4 — gate, 5 — shunting bridge, 6 — dielectric.

We shall collector (drain current — source voltage) volt-ampere characteristics (VAC) of the MIS-phototransistor. Practically all radiation is adsorbed in the channel under the illumination of the structure by a stream of the light with photon's energy $E_{g1} < h\nu < E_{g2}$. The second item in (3) is equal to zero ($б_з$=0), the drain's current (and the pinch-off current accordingly) increases proportionally Φ^2.

Practically all the radiation is adsorbed in the material of the gate at photon's energy $h\nu = E_{g2}$. The value (3) $\Phi = 0$ is equally to zero at the first item and the phototransistor's current increases proportionally to $mln\Phi^2$. The second item in this case takes with the symbol "+" since the voltage direction V_Φ of the gate corresponds to enhancement of the channel by charge carriers.

If the *p-n-…-p-n*-structure of the gate to upturn (*p*-layer to the source, *n*-layer to drain), the polarity of the gate's voltage V_Φ becomes negative and the channel is depleted by the charge carriers. In equality (3) the second item takes with the symbol "-", the current of the drain (and the saturation current) at irradiation decreases in relation to the current at $\Phi = 0$.

The first variant of an arrangement of the gate's structure is expedient to utilization for measuring integrated intensity in all range of the energies of the photons falling light, when the both items in (3) securing the grown of the current with the increase of the intensity Φ. The second variant of the hook up of the *p-n-…-p-n*-structure is convenient for definition of the spectrums portion, into which the radiation falls. The current is increase with the growth Φ when $h\nu < E_з$, when $h\nu > E_з$ — the current of the drain is decreased with the grown Φ.

The experimental structures made on the basis of the epitaxial layers of the *n*-type silicon by width 4…5 with the resistively 10…15 Om·sm. The SiO_2 layer was a dielectric. The gate's electrode by the area 100×180 μm^2 created by drawing on SiO_2 of the hydroqenized amorphous *n*-Si by width up to 5 μm. The layers of the *p*-type created by the ion implantation. The bridging layers created by deposition of Al. The spectral characteristic of such structure corresponds to the silicon MIS-phototransistor's characteristics. Simultaneously for comparison there were making the test field MIS-structures with the gate of amorphous silicon without *p-n*-junctions.

The special checking of the kind of the Al-ohmic contacts to amorphous silicon both n-type and p-type (the material of the gate) were executed on the preliminary samples. The volt-ampere characteristics were linear at these cases. The resistors which we calculated were corresponded to resistors just of the silicon's (the *n*-type and *p*-type of the conductivity) volume. The causes of such behavior of the metal (Al) which is contacted with the amorphous silicon may be a few. We incline to think the cause of it is the formation of the intermediate combinations and the extraordinary thin transitional regions. The tunneling of the charge carriers through of them most probably. Just of this case it is not to be possible to reduce the band structure of the real *n*-Si – Al – *p*-Si contact because the "ideal" version of it don't corresponds to real.

The output characteristics of the MIS-phototransistor with the continuos homogeneous gate (curves 1, 2) and the gate as *p-n-…-p-n*-structure (curves 3, 4) in the fig. 2 are shown. The specific power of the radiation for the diagrams 1 and 3 $P_{sp} = 0$ and $P_{sp} = 4\cdot10^{-5}$ W/sm² for diagrams 2 and 4. The sizes of the each *p-n*-region of the gate is 15…18 μm. The photosensitivity of the field MIS-phototransistors with the *p-n-…-p-n*-structure as the gate in the wavelength interval $\lambda = 0.5 \ldots 1.0$ μm in 5…50 times are higher, than for transistors with homogeneous structure of the gate, depending on number *p-n*-junctions of the gate *m*. The photo-charge carriers, which are near Al-contact, may recombined. But the concentration of such non-equilibrium electrons and holes is no impotence, because the charge carriers are separated by the potential barriers of the p-n-junctions which are lighted.

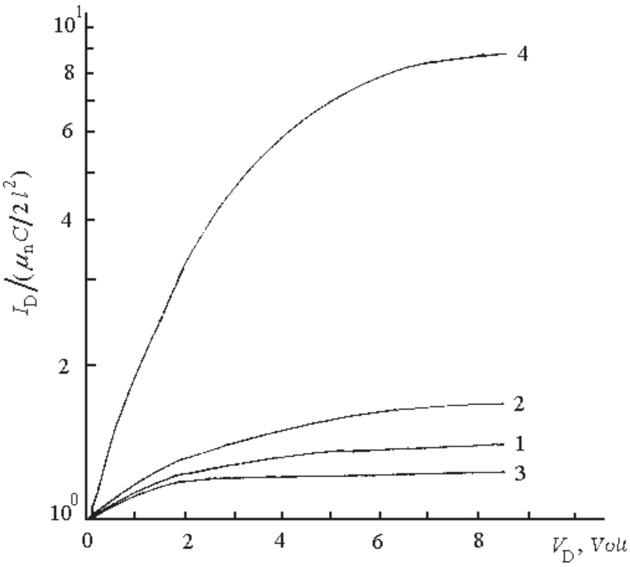

Fig. 2. Collector characteristics of the MIS-phototransistor. 1, 2 — gate from amorphous silicon; 3, 4 — gate as system *p-n-…-p-n*-junctions. The specific power,W/sm²: 1, 3 — 0; 2, 4 — $4\cdot10^{-5}$. λ = 0. 6 μm, $V_з = 5$ V.

We conducted the experiments on the manufacture of the gate of the MIS-transistor from the material with greater, than for silicon of the breadth of the band gap. For example, the thermal evaporation of CdTe films allows to get *p-n-… -p-n*-layers in which the high photovoltage is generated anomalously [4]. The special technology (for example, thermal deposition on the oblique substrate) allow to get *p-n-…-p-n*-junctions, in which the *p-n*-regions are illuminated and the *p-n*-regions are blacked out. Such MIS-phototransistors except an increase of the photosensitivity, have more broad, in relation to silicon, spectral range of the sensitivity, in particular, in short-wave ($\lambda = 0.\ 4…0.\ 6\ \mu$m) region.

The interest represents also making of the gate from the silicon carbide, the technology of making of which films is well enough completed [5]. The films it have a high photosensitivity in a ultra-violet portion of the spectrum ($\lambda = 0.\ 2…0.\ 4\ \mu$m). The phototransistor with such gate (see fig. 1) will allow to expand the region of the radiation registration to 0. 2…1 μm. If to replace a voltage direction of a gate $V_з$ (to translocate making bridges on odd *p-n*-junctions), in a visual portion of the spectrum ($\lambda > 0.\ 4\ \mu$m) the current $I_н$ will be increased with grown Φ, and in ultra-violet region ($\lambda < 0.\ 4\ \mu$m) — to decrease. Accordingly, on a sign of change of a current it is possible to spot to what region of the spectrum the radiation falls.

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