PHOTOELECTRICAL PROPERTIES OF STRUCTURES WITH A HIGH-RESISTANCE LAYER ON THE RECRISTALLIZED Si BASE

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Abstract

The paper considers the functional potentiality of structures with a high-resistance thin layer between two opposite directed potential barriers and the photo-electric and electro-physical processes in them. The linear character of the dependence of the space charge territory (SCT) width of both barriers on the external bias voltage is revealed. Layers of polycrystalline silicon, recrystallized by a laser beam, were used as initial material for the receiver structures. In similar structures the inversion of the spectral photocurrent sign with the section of the linear dependence of the inversion point on the external voltage was observed. The results of the research are very promising for creating selective sensitive solid-state photoreceivers with spectrophotometrical properties.

1. INTRODUCTION

At present one of urgent tasks of photoelectronics is the creation of selective filterless photoreceivers with the spectral sensitivity controlled by the external voltage [1-4]. The use of the semiconductor structures with the high-resistance base located between two potential barriers, gives an opportunity for the solution of this problem, as the prevalence of the photocurrent caused by the first or the second potential barrier, depending on the absorbed wavelength, changes the sign of the spectral photocurrent. In this case we can control the position of the inversion point of the photocurrent by the external voltage [5,6].

2. SAMPLE PREPARATION

The Si-based diodes were made by recrystalizing, with a laser beam, a 1 micron thick n - Si (n $\geq$1,5*1015 cm^{-3}) polycrystalline film set upon a titan film. In the course of the recrystallization $TiSi_2$ (temperature of formation 600°C) and a potential Schottky barrier ~0,6 eV high were simultaneously formed. The second Schottky barrier was a translucent Ni layer, put on a silicone film, which, too, forms with silicon, NiSi (temperature of formation 400°C), with a 0,5 eV high potential barrier. The structure

of the obtained samples is shown in figure 1 [3]. The illumination was carried out through the translucent Ni contact.

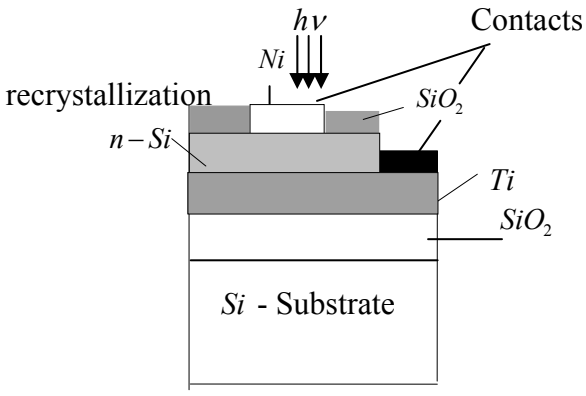

Figure 1. Structure $NiSi - n - Si - TiSi_2$

3. EXPERIMENTAL RESULTS AND DISCUSSION

The spectral characteristics of the photocurrent of silicon-based diode structures had certain peculiarities. First, the change of the sign of the photocurrent (figure 2) was observed. Secondly, the position of the inversion point did not depend on the power of the falling radiation, but it depended on the external voltage (figure 2). When

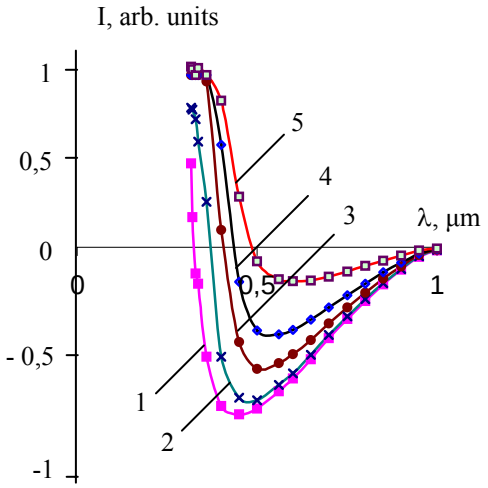

Figure 2 Spectral dependence of the photocurrent of the structures at different values of the bias voltage, V : 0,36 (curve 1); 0,34 (curve 2); 0,27 (curve 3); 0,18 (curve 4); -0,01 (curve 5).

increasing the external bias voltage ("+" on Ni contact, the figure 1), reduction of the positive and increase of the negative branches of the spectral characteristics occurred

both on the amplitude and the width (figure 2). With the change of the polarity of the bias voltage the inverse picture was observed. The longwave photosensitivity did not reach the area of the own absorption, and the structure had mainly shortwave photosensitivity.

The dependence of the inversion point of the spectral photocurrent λ_{inv} on the bias voltage is given in a figure 3. In the area of the wave lengths from 0,35 up to 0,5 microns, the dependence was near to linear, and at wave lengths less than 0,35 microns, a sharp change of the value λ_{inv} was observed even at the insignificant change of the bias voltage.

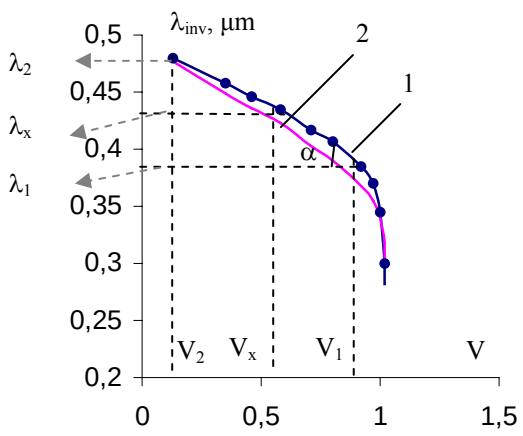

Figure 3 Dependence of the inversion point of the spectral photocurrent on the bias voltage in silicon-based samples. Curve 1 - experimental, curve 2 – calculated settlement.

For the explanation of the photo-electric properties of receiver structures we will turn to the energetic band diagrams of the structures.

The silicon-based structures have two silicide barriers on both sides of the recrystallized silicon film with N_d= 1,5*10^{15} sm^{-3} and of SCT = 1μm. At such concentration of impurity, the SCT width of each barrier, estimated by the formula $l = \sqrt{\frac{2\varepsilon\varepsilon_0\varphi_\kappa}{q^2 N_d}}$ is more than half-width (d/2) of the basis (N_d - concentration of the donor impurities, ε - relative dielectric permeability of the substance, ε_0 - dielectric permeability of the vacuum, q - charge of the electron, $-\varphi_\kappa$ contact difference of potentials). As a result of it, the SCT of the two barriers are blocked, creating a potential minimum in the point X_m of the structure (figure 4).

The energetic band diagram of the structure (figure 5) allows to explain the results of the photo-electric researches.

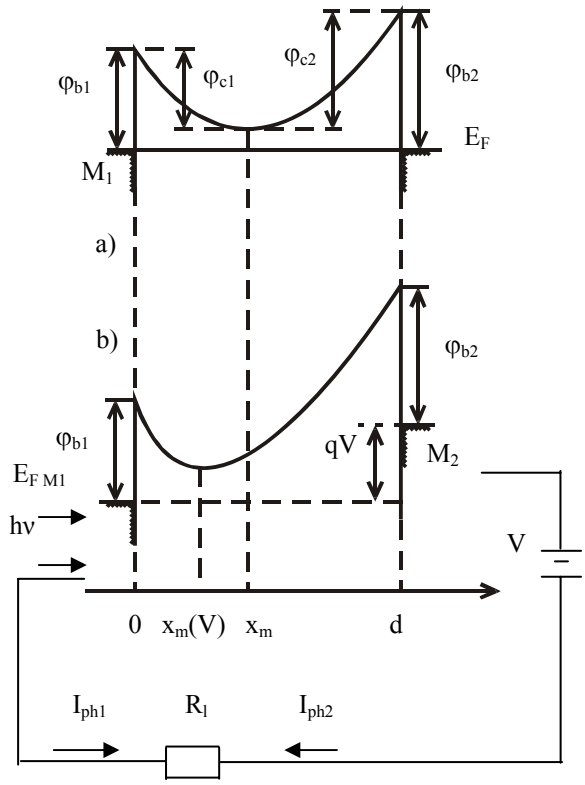

Figure 4. The energetic band diagram of the structures with two Schottky barriers; a) - at the absence of the external voltage, b) - at the presence of the external voltage.

At the "cross" illumination of the structures a photo – electromotive force occurs on the potential barriers. As the barriers "are included" towards each other, the resulting photo – electromotive force will be considerably less than the height of the barriers. The high-resistance layer will have a negative charge, and the metal contacts will be positively charged in relation to the layer. In the short circuit mode current will begin to flow in the external circuit; the direction and the quantity of it will be determined by the relation $(d - X_m)/X_m$, where $(d - X_m)$ – being the width of SCT of the rear barrier, and X_m-of the surface one, and by the efficiency of the division of the electron-hole pairs in each junction.

At the illumination of the structures through the translucent metal contact, the situation changes. If the photon energy $h\nu \geq E_g$, the radiation is absorbed near to the surface, and the division of the electron-hole pairs occurs only in the field of the SCT of the first contact. The area of the second barrier remains dark. The layer in relation

to the translucent contact is charged negatively, and in the short circuit mode the current I_{ph1} (fig. 4b) will begin to flow through the resistance R_l. With the reduction of the energy of the falling photons the depth of the light penetration increases. If the thickness of the layer is small, at sufficient reduction of the energy of the photons, the electron-hole pairs are generated in the area of the second junction too, which results in the appearance of **a** photo – electromotive force and a current I_{ph2} of the opposite sign on it, and also in the reduction of the current through the resistance R_l.

Thus, when a greater number of photo-generated pairs is divided by the rear barrier, the I_{ph2}/I_{ph1} ratio may exceed 1. However illumination through the translucent metal contact, in the short circuit mode the change of the sign of the spectral photocurrent is possible with the reduction of the photon energy.

To substantiate the obtained experimental results and I-V characteristics the analysis of the dependence of the barrier width on the bias voltage was carried out. From the solution of the Poisson's equation the following expressions were obtained, according to which the thickness of each barrier changes linearly within 0 up to d [5], depending on the quantity of the external voltage:

$$x_m = \frac{d}{2} - \frac{L_s^2(\Delta\varphi_b + qV)}{kTd}, \qquad d - x_m = \frac{d}{2} + \frac{L_s^2(\Delta\varphi_b + qV)}{kTd},$$

where - $\Delta\varphi_b = \varphi_{b2} - \varphi_{b1}$ difference of the opposite directed potential barriers heights, V - external voltage, L_s - length of shielding, and kT - thermal energy.

In the diffusion approximation, by the method described in [7], the expression of I-V characteristics for the dark current j_d is obtained, too. To obtain the expression of the photocurrent j_{ph}, it was taken into account that at the longitudinal illumination of the sample, the areas of the spatial charges of the opposite directed barriers give the opposite contribution into the photoresponse of the structure.

Hence, the obtained expression for the complete photocurrent, consisting of dark current and photocurrents, is as follows:

$$j = j_d + j_{ph} = \frac{\mu_n kTN_c L_э^{-1}\sqrt{2}\, e^{\frac{1}{2}\left(\frac{x_m}{L_э}\right)^2} e^{-\frac{\varphi_{б1}}{KT}}\left(e^{\frac{qV}{KT}} - 1\right)}{\sqrt{\pi}\left(erfi\left(\frac{d - X_m}{\sqrt{2}L_э}\right) + erfi\left(\frac{X_m}{\sqrt{2}L_э}\right)\right)} + \tag{1}$$

$$+ qS\beta J_0\left(2e^{-\alpha x_m} - e^{-\alpha d} - 1\right),$$

where q-the charge of the electron, J_0 - the flow of the falling photons per area unit in the time unit is equal to $W(1-R)/S*h\nu$, where R - the reflection coefficient, α - the absorption coefficient, β - the quantum output, W - the power of the radiation, S - the area of the photosensitive platform.

The expression (1) describes the spectral characteristics of the photocurrent for the condition $\alpha d \geq 1$, at which effective absorption of own and short-wave radiations takes place. As in the silicon-based structures for the own radiation $\alpha d \prec 1$, part of the own radiation passes through the base without being absorbed. So at stricter approach, it is necessary to take into account the radiation reflection and the photoissue from the barrier contacts.

As a result for the photocurrent (I_{ph}) through the structure the following expression was obtained [5]:

$$I_ф = qS\beta J_0 \frac{1 - R_1}{1 + R_1 R_2 e^{-2\alpha d}}[(1 + e^{-\alpha d})(1 - R_2 e^{-\alpha d}) - 2e^{-\alpha x_m}(1 - R_2 e^{-2\alpha(d - x_m)})], \tag{2}$$

where R_1 and R_2 - coefficients of reflection from the first and second barriers.

The settlement spectral characteristics of the photocurrent repeats qualitatively the experimental one (figure 7).

In the samples with reflecting properties of the rear barrier contact the expansion of the spectral characteristics both for the positive and for the negative branches is observed, i.e. the longwave sensitivity increases, and the degree of the expansion depends on the bias voltage V [8]. However, the expansion of the spectral line, even at the reflection factor equal to 1, does not reach the area of the own absorption, and the structure has mainly short-wave photosensitivity.

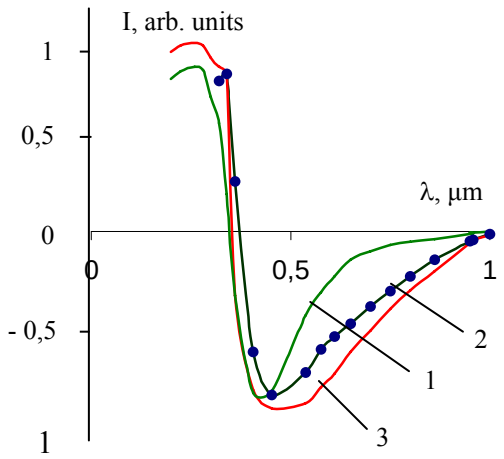

Figure 7 Spectral characteristics of silicon-based structures at the bias voltage of 0,9V and the constant power of falling radiations. Curve 2 - experimental; curve 1 - settlement, without taking into account the reflection from contacts (1) ($R_1 = 0$); curve 3 – settlement taking into account the reflection ($R_2 = 1$).

Figure 7 shows the settlement spectral characteristics in the presence (curve 3) and in the absence (curve 1) of reflection from contacts, and also the experimental spectral dependence (curve 2). The comparison of the dependences shows, that in the structure, in all probability, reflection from the contacts took place. Figure 7 shows also, that in two-barrier structures, with a thin base, there is a real possibility of cutting off the visible and the infra-red areas of the spectrum, which, at appropriate technical decisions, can prove promising for the creation of filterless selective short-wave photodetectors.

The position of the inversion point λ_{inv} of both experimental (figure 3, curve 1) and settlement (figure 3, curve 2) spectral photocurrents depends on the bias voltage, and it moves towards the long waves with the increase of the return bias of the first barrier, and towards the short wave lengths – with the increase of the return bias of the second barrier. As the calculations show, the dependence of the inversion point λ_{inv} on the bias voltage has a linear section. The voltage range ΔV, at which the dependence has a linear section, corresponds approximately to the interval of the wave lengths from 0,35 microns to 0,5 microns. Considering the structure as zero – frequencymeter, the settlement and experimental sensitivity of the zero point have approximately identical values and are equal to ~ 5,3 V / micron. It should be noted, that the zero – frequencymeter, proposed in the paper [6], had sensitivity of 0,387V/micron in the near infra-red area of the spectrum. We can see from figure 3, that with the increase of

the voltage in the area of shorter wave lengths the inclination of the curves increases sharply, and in this area the sensitivity of the zero point is insignificant.

It is important to note, that the inversion point of the photocurrent does not depend on the power of the registered radiation.

You can see from figure 4 that the presence of the inversion point permits to obtain two areas of photosensitivity (positive and negative), the width of which can be controlled, to a certain extent, by the external bias voltage. It allows to make devices with the selective sensitivity of the photocurrent.

It is quite obvious, that the unknown wave length of the absorbed radiation can be determined from the value $tg\alpha$ in the linear area of the dependence of the inversion point on the bias voltage of (fig. 3) by the expression

$$\lambda_x = \frac{V_x(\lambda_2 - \lambda_1) + \lambda_1 V_2 - \lambda_2 V_1}{V_2 - V_1}$$

where V_x – the bias voltage to be measured, at which the photocurrent is equal to zero, V_1 and V_2 the limiting meanings of the voltage of the interval, where the position of the inversion point depends linearly on the voltage, λ_1 and λ_2 the values of the wave lengths corresponding to the voltages V_1 and V_2.

4. CONCLUSION

1. At the illumination of the sample, the absorption in the field of the spatial charges of the opposite directed barriers gives the opposite contribution into the photoresponse of the structure, which results in the change of the spectral photocurrent sign. The photoresponse depends on the balance between the absorption coefficient $\alpha(\lambda)$, . x_m and (d -. x_m). The change of the external voltage for ΔV changes this balance, changing the position of the inversion point. The presence of the inversion point allows to obtain devices with the selective sensitivity of the photocurrent.

2. Due to the presence of the linear dependence of the inversion point λ_{inv} of the spectral photocurrent on the bias voltage, the investigated structures can be used as photometric device ("0" - frequencymeter).

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