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A.V. KOZYNETZ, V.A. SKRYSHEVSKY
Taras Shevchenko National University of Kyiv, Institute of High Technologies
(4g, Academician Glushkov Ave., Kyiv 03127, Ukraine; e-mail: alk@univ.kiev.ua)

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THEORETICAL ANALYSIS OF THE EFFICIENCY OF SILICON SOLAR CELLS WITH AMORPHIZED LAYERS IN THE SPACE CHARGE REGION

A possibility to enhance the efficiency of silicon solar cells by creating an amorphized barrier structure in the space charge region has been demonstrated. The positive effect can be achieved owing to the absorption of infrared photons with energies lower than the silicon band gap and a reduction of the dark current. Optimal parameters of this structure (the barrier height and position in the space charge region) are determined in the framework of the diode theory approximation.

Keywords: solar cell, silicon n^+–p junction, efficiency, amorphized layer, infrared absorption.

1. Introduction

One of the fundamental factors that restrict the efficiency of silicon photoconverters (nowadays, it amounts to 25% for laboratory test devices [1]) consists in the impossibility of using photons with energies lower than the energy gap width in silicon (1.12 eV). For instance, under irradiation conditions AM1.5, the fraction of such photons amounts to 38%, and a considerable part in the infrared spectral range remains unused. In order to achieve a higher efficiency of photoconversion, new approaches have to be developed, such as the application of the impurity absorption and $Si_{1-x}Ge_x$ alloys, the creation of conditions to enlarge the optical path, and so forth [2, 3].

Infrared light with $h\nu < 1.12$ eV is known to be absorbed in silicon layers with violations in their crystal structure: a high concentration of impurities, defects, amorphous inclusions [4–8]. Those physical processes are based on the impurity photovoltaic effect with the participation of a system of deep energy levels located in the silicon energy gap in the two-stage generation of electron-hole pairs. Such deep levels emerge owing to the implantation of certain elements (C, Ge, S, Si, Er, Yb) and a partial amorphization of single crystalline silicon [9, 10]. Note that the modern technologies of ionic implantation and molecular beam epitaxy make it possible to create structures with given modification parameters, which can be varied in a wide range.

From the analysis of literature data, two main approaches can be distinguished in the subject concerned. In the framework of one of them, the creation of "prolonged" implanted substructures in the emitter, the space charge region, or the base of silicon photoconverters is considered. Theoretical calculations predict, e.g., the efficiency growth by 1.5–2% for structures with Te impurities homogeneously distributed over the solar cell base [11, 12]. However, according to experimental data, the effect of spectral sensitivity expansion in the interval $h\nu < 1.12$ eV and an increase of the short circuit current are always accompanied by an undesirable growth of the dark current [13]. Since the concentration of local states appearing in the forbidden gap is high, there emerges the problem to find a compromise between the positive influence of additional photogeneration and the negative influence of additional recombination losses.

In the framework of the other approach [4–8], "thin" (with a width of a few tens of nanometers, which corresponds to the diffusion length in amorphized silicon) substructures created, in particular, in the space charge region are considered. In this configuration, the built-in electric field of the junction can reduce the influence of recombination processes and promote the separation of electron-hole pairs in the layer. A positive effect also includes a reduction of the dark current even for amorphized layers that are characterized by a short lifetime of minority charge carriers [7]. An important condition for those approaches to be realized is the application of optical schema or cell configurations that would provide a multiple passage of the light flux through a solar cell, e.g., using Bragg mirrors [14]. It should be noted that the formation of silicon clusters in the defect layer can stimulate the additional light scattering and increase the optical path irrespective of whether external optical systems are used or not [15, 16].

It is evident that the local amorphization of single-crystalline silicon resulting from variations of the doping level and fluctuations of the energy gap width gives rise to the appearance of additional potential barriers. Therefore, the conditions of charge carrier transport in such structures are substantially changed. Even in the case of highly efficient infra-red generation of carriers in a "thin" substructure, the preservation of the characteristics of a basic element at the maximally possible level remains to be a key issue. In this work, the case where a thin amorphized layer is located at various points in the space charge region of a silicon junction will be analyzed, and the features of the formation of the short circuit current and the open-circuit voltage in this system will be considered. The work aims at finding the parameters of the modified layer (the height of the barrier and its position in the space charge region) that provide the growth of the junction efficiency. The results obtained can be used in experimental researches of such silicon-based photoconverters.

2. Model

Consider the energy diagram of an asymmetric silicon n^+–p junction with a modified layer in its space charge region (Fig. 1). For this junction, the latter is almost completely located in the base p-region. The dependence of the space charge region thickness L on the applied voltage V can be written as

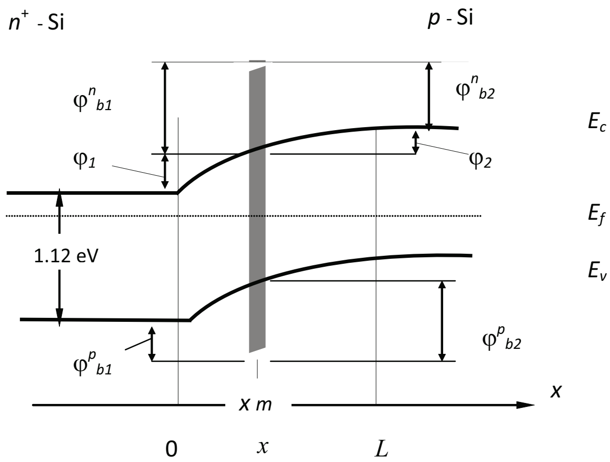

Fig. 1. Energy diagram of a p–n junction with a modified layer in its space charge region in the equilibrium state

$$L(V) = L\sqrt{(\varphi_0 - eV)/\varphi_0}, \tag{1}$$

where L is the equilibrium region thickness, and φ_0 is the potential barrier height. The dependence of the potential on the coordinate x and the voltage in the space charge region is described by the relation

$$\varphi_(x, V) = (\varphi_0 - eV)\left(1 - \frac{x}{L(V)}\right)^2. \tag{2}$$

In what follows, the amorphous component of the modified layer is considered to be a semiconductor with a certain distribution of localized states in the energy gap, the width of which amounts to 1.8–2.4 eV. Suppose that such a modified layer is created at some point x_m, and its thickness d is small in comparison with L. Neglecting the voltage drop across the layer, the voltage drops to the left, V_1, and to the right, V_2, from the point x_m can be written as follows:

$$eV_2 = \varphi(x_m, 0) - \varphi(x_m, V), \quad V_1 = V - V_2. \tag{3}$$

In the framework of the diode theory approximations, charge carriers are supposed to pass through the space charge region without collisions with crystal lattice atoms [17, 18]. Therefore, the influence of this layer can be taken into account as a change in the overbarrier fluxes from the emitter and base regions. At the same time, overbarrier fluxes are determined by the number of charge carriers moving toward the potential barrier and having a sufficient energy to overcome it. In order to analyze the processes of charge transfer, it is expedient to use known solutions obtained for the continuity equations in quasineutral regions with modified boundary conditions [19]. This approach allows the results of the Shockley theory to be applied directly to our system.

Let us determine the short circuit current (the photocurrent at $V = 0$), when the structure is illuminated with light characterized by the wavelength λ and the spectral density $F(\lambda)$. Unlike the ordinary n^+–p junction, the additional barrier structure brings about a situation where the concentration of photogenerated electrons in the cross-section $x = L$ and holes in the cross-section $x = 0$ cannot be taken equal to zero. We take into account that, in the base region, the photocurrent is formed only by those electrons that move toward the potential barrier φ_{b2}^n and possess the corresponding energy. Using the known solution of the continuity equation that makes allowance for photogeneration, we find the electron concentration distribution $n(x)$ and the short circuit current $j_b(\lambda)$. The required boundary condition is obtained by equating the fluxes $\frac{1}{4}v_n\left[n(L) - n_p\right]\exp\left(-\varphi_{b2}^n/kT\right)$ and $D_n\frac{dn}{dx}$, where $n(L)$ is the electron concentration in the cross-section $x = L$, n_p is the equilibrium electron concentration in the base, D_n is the diffusion coefficient of electrons, v_n is their thermal velocity, k is the Boltzmann constant, and T is the temperature. This boundary condition is equivalent to the introduction of the final recombination rate. Ultimately, we obtain that, in the cross-section $x = L$,

$$j_b(\lambda) = \frac{j_b^0(\lambda)}{1 + \frac{j_{sn}}{f_n}}, \tag{4}$$

where $j_b^0(\lambda)$ is the short circuit current, j_{sn} is the saturation current for the base region in the n^+–p junction,

$$f_n = \frac{1}{4}ev_n n_n \exp\left(-\left(\varphi_1 + \varphi_{b1}^n\right)/kT\right),$$

n_n is the equilibrium concentration of electrons in the emitter, and e is the electron charge.

In a similar way, by considering the motion of photogenerated holes toward the barrier φ_{b1}^p, we can find the distribution of their concentration $p(x)$ and the expression for the short circuit current in the emitter region $j_e(\lambda)$ in the cross-section $x = 0$. The corresponding boundary condition is obtained by equating the fluxes

$$\frac{1}{4}v_p(p(0) - p_n)\exp\left(-\varphi_{b1}^p/kT\right)$$

and $-D_p\frac{dp}{dx}$, where p_n is the equilibrium concentration of holes in the emitter, D_p is the diffusion coefficient of holes, and v_p is their thermal velocity. As a result, we find that, in the cross-section $x = 0$,

$$j_e(\lambda) = \frac{j_e^o(\lambda)}{1 + \frac{j_{sp}}{f_p}}, \tag{5}$$

where $j_n^0(\lambda)$ is the short circuit current, j_{sp} the saturation current in the emitter region of the n^+–p junction,

$$f_p = \frac{1}{4}ev_p p_p \exp\left(-\left(\varphi_2 + \varphi_{b2}^p\right)/kT\right),$$

and p_p is the equilibrium concentration of holes in the base.

The processes of light absorption and charge carrier generation directly in the space charge region form a drift component of the short circuit current for the n^+–p junction. If comparing with its initial value, the drift component can evidently decrease. This is a result of the accumulation of photogenerated charge carriers in potential wells to the left ($x < x_m$) and to the right ($x > x_m$) from the amorphized layer and, as a consequence, the growth of recombination losses. The results of researches concerning α-Si:H/c-Si heterostructural silicon photoconverters with superthin α-Si:H layers [20–22] allow us to suppose that, for the barriers φ_{b2}^p and φ_{b1}^n less than 0.45 eV, such recombination losses can be insignificant. The numerical simulation with regard for the influence of local states at the interface demonstrates that the photocurrent practically is not changed if the magnitude of electric field near the interface is enough to maintain a certain threshold concentration of photogenerated charge carriers [22]. In the case of higher barriers, the undesirable accumulation of charge carriers in the potential wells and the band flattening in a vicinity of x_m are possible. It is probable that the drift component undergoes minimal changes if the major part of carriers "overcomes" additional barriers in the amorphized layer owing to the thermionic emission or with the participation of local states. We write down the maximum possible photocurrent in this region in the form

$$j_{\mathrm{scr}}(\lambda) = eF(\lambda)(1 - R(\lambda)) \times$$

$$\times \exp(-\alpha(\lambda)W_n)\,[1 - \exp(-\alpha(\lambda)L)], \tag{6}$$

where $\alpha(\lambda)$ is the absorption coefficient in silicon, $R(\lambda)$ is the coefficient of reflection from the front surface, and W_n is the emitter region thickness. The additional current associated with the absorption of infrared radiation is determined by the formula

$$j_m = eF(\lambda)(1 - R(\lambda))\alpha_m(\lambda)d, \tag{7}$$

where $\alpha_m(\lambda)$ is the coefficient of absorption in the modified layer. In expression (3), we took into account that, for the selected d, all charge carriers that were photogenerated in the modified layer become separated by the field in the space charge region. The density of short circuit current is a sum of four components defined by formulas (4)–(7).

From the speculations given above, it follows that the photocurrent in the regime $V \neq 0$ depends on the applied voltage. Really, in order to form the diffusion components of the photocurrent, electrons in the base region and holes in the emitter one have to overcome the potential barriers $\varphi_{b2}^n \pm eV_2$ and $\varphi_{b1}^p \pm eV_1$, respectively, and the distribution of electric field in the space charge region affects the formation of the drift component.

Below, while determining the open-circuit voltage, we will use the dependence of the dark current density on the applied voltage, $j(V)$. Its detailed calculation in the case where the amorphized layer remains within the space charge region, $x_m < L(V)$, was carried out in work [19]. Here, we present the main factors that are responsible for the emergence of a dark current in the forward bias regime. For instance, let us consider the features inherent to the formation of the electron injection current in the p-region. If the charge transfer does not violate the distribution function of charge carriers over their energies, the electron flux in the cross-section $x = L$ is equal to the difference between the number of electrons moving from the emitter region,

$$\frac{1}{4}v_n n_n \exp\left(-\left(\varphi_1 + \varphi_{b1}^n - eV_1\right)/kT\right),$$

and the number of electrons moving from the base region,

$$\frac{1}{4}v_n n(L) \exp\left(-\left(\varphi_{b2}^n + eV_2\right)/kT\right).$$

On the other hand, the gradient of the concentration of minority charge carriers times the diffusion coefficient, $D_n\frac{dn}{dx}$, determines the diffusion flux of electrons through the same cross-section $x = L$. Hence, making use of the known solution for the continuity equation, we determine the concentration distribution for injected electrons and the current in the base region.

The injection current of holes into the emitter region can be found following the similar method of "flux matching". For this purpose, the fluxes $(\frac{1}{4}v_p p_p \exp(-(\varphi_2 + \varphi_{b2}^p - eV_2)/kT) - \frac{1}{4}v_p p(0) \times \exp(-(\varphi_{b1}^n + eV_1)/kT))$ and $-D_p\frac{dp}{dx}$ have to be equated to each other at the cross-section $x = 0$. As a result, the density of dark current $j(V)$ calculated as a sum of the density of electron injection current into the base at $x = L$ and the density of electron injection current into the emitter at $x = 0$ amounts to

$$\begin{aligned} j\,(V) &= j_o\left(\exp\left(\frac{eV}{kT}\right) - 1\right), \\ j_o &= \frac{j_{sn}}{1 + j_{sn}/f_n} + \frac{j_{sp}}{1 + j_{sp}/f_p}, \end{aligned} \tag{8}$$

where $f_n = \frac{1}{4}ev_n n_n \exp\left(-\left(\varphi_1 + \varphi_{b1}^n + eV_2\right)/kT\right)$, $f_p = \frac{1}{4}ev_p p_p \exp\left(-\left(\varphi_2 + \varphi_{b2}^p + eV_1\right)/kT\right)$.

In the case of charge carrier tunneling through the amorphized layer ($d < 10$ nm), the quantities f_n and f_p in formulas (4), (5), and (8) should be substituted by

$$f_n = \frac{1}{4}ev_n n_n P_n\,(V) \exp\left(-\varphi_0/kT\right),$$

$$f_p = \frac{1}{4}ev_p p_p P_p \exp\left(-\varphi_0/kT\right),$$

respectively, where $P_n(V)$ and $P_p(V)$ are the coefficients of tunnel transparency [19].

Hence, the formation of an additional barrier structure confines the injection of charge carriers into quasi-neutral regions and gives rise to a more complicated dependence of the dark current in the junction on the applied voltage. The obtained analytic expressions make it possible to estimate the photoconversion efficiency of the structure at various parameters of the amorphized layer and find their optimum values.

3. Results and Their Discussion

Consider an n^+–p photoconverter on the basis of a silicon junction with the following typical parameters: the doping level of the emitter is 10^{19} cm^{-3} and that of the base 10^{16} cm^{-3}, the diffusion length of electrons in the base is 200 μm and that of holes in the emitter 0.5 μm, the emitter thickness is 0.3 μm, the base thickness is 200 μm, and the width of the space charge region $L = 0.6$ μm. The calculations carried out with the help of the PC1D software program testify that, under conditions AM1.5, 0.1 W/cm^2, the open-circuit voltage $V_{\rm oc} = 0.57$ V ($\varphi_0 = 0.87$ eV) and the total density of short circuit current $j_{sc} = 33$ mA/cm^2 for this structure. The j_{sc} magnitude consists of three components: 6 mA/cm^2 are collected as a result of the light absorption in the n^+-emitter, 22 mA/cm^2 are collected as a result of the light absorption in the p-base, and 5 mA/cm^2 are given by the absorption in the space charge region. Now, let us analyze how the photoconversion parameters of this junction vary after the introduction of an amorphized layer into the space charge region.

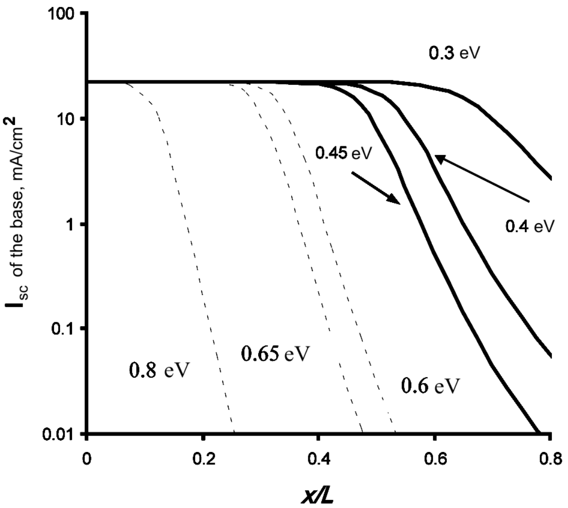

Fig. 2. Dependences of the photocurrent density collected from the base on the modified layer position for various φ^n_{b1} values

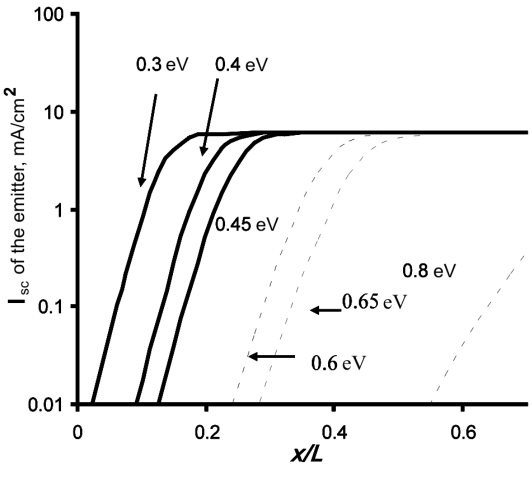

Fig. 3. Dependences of the photocurrent density collected from the emitter on the modified layer position for various φ^p_{b2} values

The calculation of the additional photocurrent using formula (6) testifies that the magnitude of j_m for one passage of the light flux amounts to 0.12 mA/ cm^2 if the thickness of amorphized layer is $d = 45$ nm (in the interval 0.5 eV $< h\nu <$ 1.12 eV, the absorption coefficient $\alpha_m(\lambda) = 10^2$ cm^{-1}). For 100 passages, which can be provided either using an external optical system or a resonance structure for infrared radiation, j_m can be raised to 1.2 mA/ cm^2. In the course of calculations, the approximation of sunlight spectral power distribution was taken from the PC1D program.

The dependences of the photocurrent densities "collected" from the emitter and base regions on the position of modified layer (formulas (4) and (5)) calculated for various barrier heights are depicted in Figs. 2 and 3, respectively. A quicker reduction of the photocurrent in the emitter region in comparison with that in the base one can be explained by a substantial difference between the magnitudes of saturation currents in those regions in the asymmetric n^+–p junction ($j_{sn} \gg j_{sp}$).

If φ^n_{b1} is fixed, the approach of the modified layer to the base region induces a reduction of the base photocurrent. Analogously, if φ^p_{b2} is fixed, the approach of the modified layer to the emitter region induces a reduction of the emitter photocurrent. From the exhibited plots, it also follows that, for small φ^p_{b2} and φ^n_{b1} barriers (0.3–0.4 eV), photocurrents practically do not change if x_m varies within a certain interval, or their reduction can be compensated by the additional photogeneration in the modified layer. For instance, in the case of constant photocurrent in the space charge region, the optimum interval is $0.2L < x_m < 0.6L$ for $\varphi^n_{b2} = \varphi^p_{b1} = 0.3$ eV and $0.3L < x_m < 0.4L$ for $\varphi^n_{b2} = \varphi^p_{b1} = 0.4$ eV. In the "limiting" case $\varphi^n_{b2} = \varphi^p_{b1} = 0.45$ eV, the optimum position of the modified layer is close to the point

$x = 0.4L$ (Fig. 4). Note that larger barrier heights φ^n_{b2} and φ^p_{b1} result in a substantial degradation of photoconversion parameters in the initial n^+–p structure. Therefore, there is no sense to consider the contribution made by the additional generation in the modified layer. Hence, the increase of the short circuit current amounts to 1–2%. Provided the other conditions are identical, the choice of a modified layer with a larger $\alpha_m(\lambda)$ allows the interval of permitted x_m values, in which the density of short circuit current increases, to be expanded.

Suppose that the short circuit current in a photoconverter is kept constant at least at the initial level. Let us estimate the possibility to increase $V_{\rm oc}$ owing to the influence of the modified layer on dark currents. For an asymmetric n^+–p junction, the open-circuit voltage is determined by the saturation current in the lower doped p-region. Therefore, it is important to analyze the influence of a modified layer on its dark current. In the general case, in order to find $V_{\rm oc}$, we must solve a transcendental equation. However, avoiding a considerable error, we may use the simplified expression

$$V_{\rm oc} = \frac{nkT}{e} \ln\left(\frac{j_{sc}}{j_0} + 1\right),$$

where j_0 is given by formula (8).

Figure 5 demonstrates the curves for the relative increase of the open-circuit voltage in the case where the additional potential barrier affects the saturation current in the base. In this case, $V_{\rm oc}$ can be made larger by 10% without allowing the modified layer to go beyond the limits of the space charge region. The plateau on the curves in Fig. 5 results from the constant saturation current of the emitter. Although the open-circuit voltage for high barriers also grows owing to an increase of the nonideality factor n [19], the deterioration of the shapes of light current-voltage characteristics ultimately leads to a reduction of the photoconversion efficiency [19, 23]. In this case, the dependence of the photocurrent on the voltage is an additional factor that negatively affects the shapes of light current-voltage characteristics.

As follows from our model consideration, it is problematic to simultaneously increase the short circuit current and the open-circuit voltage of the junction, because the physical origin of the influences of the barrier layer on the light and dark currents is the same. However, in principle, the short circuit current can be increased without changing the open-circuit voltage (and *vice versa*) if the choice of the modified layer parameters is optimal.

For the effective structures of this type to be realized in practice, it is important to provide the number of light passages through the cell active region as large as possible, to look for technological capabilities aimed at raising the absorption coefficient for infrared quanta [24, 25], and to monitor the recombi-

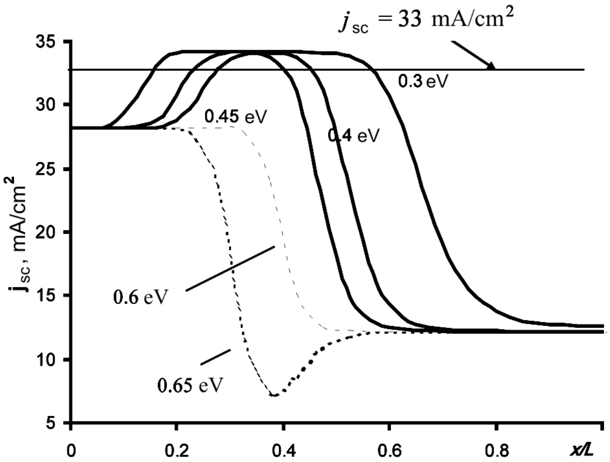

Fig. 4. Dependences of the short circuit current density on the position of the modified layer for various potential barrier heights φ^p_{b2} and φ^n_{b1}

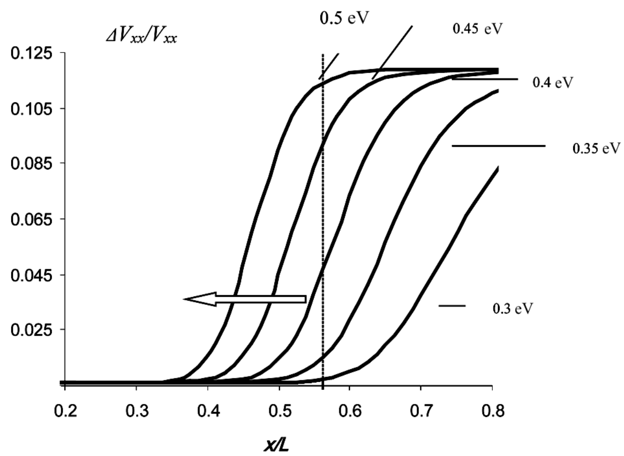

Fig. 5. Dependences of the relative variation of the open-circuit voltage on the amorphized layer position for various barrier heights φ^n_{b1}. The arrow marks the region of permitted x_m values

nation characteristics at the interfaces of the modified layer, e.g., making use of the field passivation effects [21, 26, 27].

4. Conclusions

In the framework of the diode theory approximations, the features of the current flow have been analyzed, and the optimal parameters of the modified layer in the space charge region of asymmetric silicon n^+–p junction are determined. A possibility to enhance, in principle, the photocurrent owing to the absorption of quanta with energies $h\nu < 1.12$ eV in the modified layer is demonstrated, as well as a possibility to reduce dark currents owing to the influence of additional potential barriers of this layer. The maximum increase of the short circuit current density can be equal to 1–2%, and the open-circuit voltage to 10–12%.

1. M.A. Green, Progr. Photovolt. Res. Appl. **17**, 320 (2009).
2. M.A. Green, *Third Generation Photovoltaics: Advanced Solar Energy Conversion* (Springer, New York, 2003).
3. A. Luque, J. Appl. Phys. **110**, 031301 (2011).
4. Z.T. Kuznicki and M. Ley, Solar Energy Mater. Solar Cells **72**, 613 (2002).
5. Z.T. Kuznicki, Appl. Phys. Lett. **81**, 4853 (2003).
6. M. Hossatt, M. Basta, A. Sieradski, and Z.T. Kuznicki, Proc. SPIE **8065**, 806508 (2011).
7. Z.T Kuznicki, J.C. Muller, and M.A. Lipinski, in *Proceeding of the 23rd IEEE Photovoltaic Specialists Conference (Louisville, USA, 1993)*, p. 327.
8. D. Macdonald, K. McLean, J. Mitchel *et al.*, in *Proceeding of the 19th European Photovoltaic Solar Energy Conference (Paris, France, 2004)*, p. 88.
9. M.J. Keevers, F.W. Saris, and M.A. Green, in *Proceeding of the 13th European Photovoltaic Solar Energy Conference (Nice, France, 1999)*, p. 1215.
10. M.J. Keevers and M.A. Green, J. Appl. Phys. **75**, 4022 (1994).
11. P. Harder and P. Wurfel, in *Proceeding of the 19th European Photovoltaic Solar Energy Conference (Paris, France, 2004)*, p. 84.
12. H. Kasai, T. Sato, and H. Matsumura, in *Proceedings of the 26th Photovoltaic Specialists Conference* (Anaheim, USA, 1997), p. 215.
13. J. Yuan, H. Shen *et al.*, J. Optoelectr. Adv. Mater. **5**, 866 (2011).
14. I.I. Ivanov, V.A. Skryshevsky *et al.*, Renew. Ener. **55**, 79 (2013).
15. V.A. Skryshevsky and A. Laugier, Thin Solid Films **346**, 261 (1999).
16. J. Bruns, W. Seitfer, P. Wawer, and H. Winnicke, Appl. Phys. Lett. **64**, 20 (1994).
17. V.I. Strikha, *Contact Phenomena in Semiconductors* (Vyshcha Shkola, Kyiv, 1982) (in Russian).
18. S.M. Sze, *Physics of Semiconductor Devices* (Wiley, New York, 1981).
19. O.V. Kozynets, V.I. Strikha, Z.T. Kuznicki, and V.A. Skryshevsky, Ukr. Fiz. Zh. **44**, 1003 (1999).
20. M. Rahmouini, A.P. Datta *et al.*, J. Appl. Phys. **107**, 054521 (2010).
21. S. Zhong, X. Hua, and W. Shen, Trans. Electr. Devic. **60**, 2104 (2013).
22. V.A. Dao, Y. Lee, S. Kim, J. Cho, Sh. Ahn, and Y. Kim, J. Electrochem. Soc. **158**, H11292 (2011).
23. O.V. Kozynets, in *Abstracts of the 3rd International Scientific and Practical Conference on Semiconductor Materials, Information Technologies, and Photovoltaics (Kremenchuk, Ukraine, 2014)*, p. 55 (in Ukrainian).
24. O. El Daif, E. Drouard, G. Gomard, A. Kaminski *et al.*, Opt. Expr. **18**, 293 (2010).
25. Y. Park, E. Drouard, O. El Daif *et al.*, Opt. Expr. **17**, 14312 (2009).
26. O V. Kozynets and S.V. Litvinenko, Ukr. J. Phys. **57**, 1234 (2012).
27. A.I. Manilov, A.M. Veremenko, I.I. Ivanov, and V.A. Skryshevsky, Physica E **41**, 36 (2008).

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О.В. Козинець, В.А. Скришевський

ТЕОРЕТИЧНИЙ АНАЛІЗ
ЕФЕКТИВНОСТІ КРЕМНІЄВИХ СОНЯЧНИХ
ЕЛЕМЕНТІВ З АМОРФІЗОВАНИМИ ШАРАМИ
В ОБЛАСТІ ПРОСТОРОВОГО ЗАРЯДУ

Р е з ю м е

В роботі показано можливість підвищення ефективності монокристалічних кремнієвих сонячних елементів внаслідок створення аморфізованої бар'єрної структури в області просторового заряду. Позитивний ефект можна досягти за рахунок додаткового поглинання інфрачервоних квантів з енергією меншою, ніж ширина забороненої зони та зменшення темнового струму. В наближеннях діодної теорії визначено оптимальні параметри такої структури (висота бар'єра і його положення в області просторового заряду).