THE INFLUENCES OF THE SURFACE EFFECTS ON THE MECHANISMS OF THE CURRENT PASSAGE IN THE SILLICON PHOTOELEMENTS WITH OPTICAL COVERINGS

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The influence of two-layer superface coverings of $ZnS+Nd_2O_3$ on the volt-ampere characteristic (VAC) of sillicon photoelements is investigated. It is established that in a result of the penetration of zinc atoms in the near-surface region of the silicon the compensation degree of recombination centres increases. It leads to the bending of the band edges on the semiconductor surface. It, in turn, promotes the creation of the fitted electric field of the directed *p-n* transition. It is supposed that the increase of photocurrent is caused by the decrease of the velocity of the surface recombination in the result of the passivation of the surface levels.

The number of works [1-4] of the investigation of the influence of the surface coverings on the collection coefficient and efficiency of the sun elements is considered in the ref (1-4). The results of these works allow to make some preliminary conclusions on the effectivity of the application of the optical coverings with the different indexes of reflaction. However, the choice of the materials for the optical layers is so limited that it is possible to solve the given problem so that to obtain the minimum value of the reflection coefficient. Among perspective materials for using by the way of the antireflection coverings in the silicon sun elements are SiO_2, Ti_2O_5, ZnS and e.t.c., which have the high transparency in the operating region of the spectrum. Indisputably that the optimal optical characteristics should go with the light resistance and ability to save unchangeable the initial characteristics of the sun element. But, analogous way of the decrease of the reflection coefficient has the some disadvantages: the textured surface, obtained after the treatment, is the absorbing for the absorption edge, in the result of that the non-photoactive part of the sun light increases; the presence of the high-speed surface states, which are the recombination centers [4]. The given disadvantages lead to the worsening of the volt-ampere and spectral characteristic forms of the sun elements. In this regard the investigation of the influence of the optical coverings on the ascilation-recombination, and the surface channels also in the sillicon *p-n* transitions can give the information on the nature of the mechanisms of current passage. In this paper the influences of the surface covering on the volt-ampere characteristics of the sillicon sun elements with the optical coverings $ZnS+Nd_2O_3$, relieved at the different temperatures are studied.

The experiment methodology

The p-n transition have been prepared by the diffusion of the phosphor in the *p*- type sillicon with the specific resistance 2Om·cm. The depth of the deposition of *p-n* transition, the thickness of the sample and surface concentration are 0.2mkm, 350mk and $10^{20}cm^{-3}$ correspondingly. The obtained elements have the short circuit current is 0,52V and efficiency is 11%.

The antireflection coverings of ZnS and Nd_2O_3 were heated up after the purification by the plasma etching of the top layer of the doped area of the element. The first layer of the covering was the film of ZnS with thickness 70Å, heated up by the thermal way in the vacuum, the second layer is film of Nd_2O_3, obtained by the ion-plasma evaporation with the following thermal relieving at 400-450°C. The surface layer resistance of the obtained films for the double-layer covering (120Å) was from 70 to 100Om/m^2.

The results and discussion

The spectral curves of the reflection from the element surfaces with double-layer covering $ZnS+Nd_2O_3$ after the stickness of the protective glass plate are presented on the fig1.

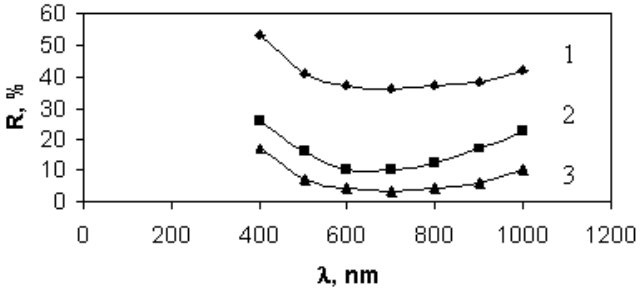

Fig.1. Spectral dependences of light reflection coefficient from the surface of silicon photoelements with coverings: 1. SiO_2 (1); 2. Nd_2O_3 (2); 3. $ZnS+Nd_2O_3$.

The reflection curves from pure silicon (1) and the sillicon with single-layer covering Nd_2O_3, SiO_2 for comparison of the experimental curves shows that the more wide area of low reflection can be obtained with the help of double-layer covering of $ZnS+Nd_2O_3$ in the visible region of spectrum. This result well agrees with experiment dates on the measured values of the short circuit photocurrent. As it is shown from fig.2 the photocurrent increase for the elements with the covering $ZnS+Nd_2O_3$ (curve2) is the 60% approximately. The output power of 1cm^2 of the sun element and the filling factor VAC for the double-layer covering are 1.62mVt and 0.62, and for SiO_2 10.1mVt and 0.65. The values I(0), A andRn calculated from load VAC by the

method (5), are 10^{-9}A/cm^2, 1.2 and 0.2 correspondingly for the covering of ZnS+Nd_2O_3 and 10^{-7}A/cm^2, 1.7 and 0.5 for SiO_2.

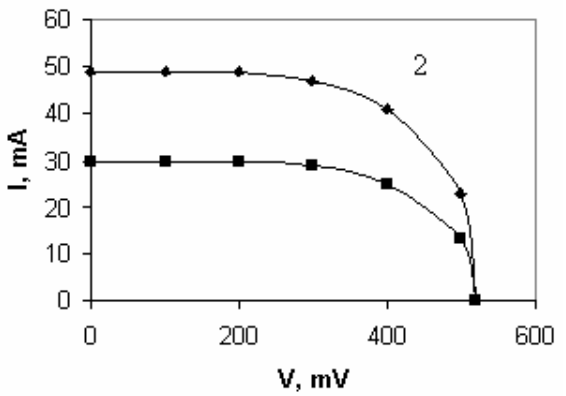

Fig.2. The load volt-ampere characteristics of silicon photoelements with coverings:1. . SiO_2; 2. ZnS+Nd_2O_3

It followes to note that the character pecularity of the obtained results is that ih them the nonload photoelectromotive force doesn't depend on the covering nature, although можно было бы ожидать the increaseof photoelectromotive force after heating up the covering of the surface by the layer ZnS+Nd_2O_3 because of photocurrent increase. However, this isn't observed. It means that in the real elements the photocurrent is defined by the mechanism of the inverse current through the p-n transition (3). The more essential contribution, besides of the warm generation and recombination, leading to the increase of the diffusion current, give the generations and recombinations in the quazineutral parts of the *p-n* transition, and the leakages trough the surface channels also.

For the calculation of the diode parameters I_0, A, R_n (where A is the recombination coefficient in the *p-n* transition region, I is the diffusion saturation current, R_n is the shunt resistance) the experimental VAC measured in the darkness in the diode mode and the nonload mode are used (fig 3). The calculation of VAC is made by the following formulae (1).

$$J = J_f - J_o(exp\frac{q(u + JR_{II})}{AKT} - 1) - \frac{u + JR_{II}}{R_{III}} \qquad (1)$$

This calculation allows to present visually the influence of the consequetive and shunt resistances on the sun elements propertie. This generation (1) is applied in the calculations in case of the big currents only ($J_d > J_0$, where J_d~10^{-7}A/cm^2, J_0=10^{-9}A/cm^2, and of the recombination mechanism of the inverse saturation current passage through the *p-n* transition also [5]. The calculation VAC of the sillicon photoelement with coverings SiO_2 (1) and ZnS+Nd_2O_3 (2) are shown in the fig. 3.

It was revealed that the plating of the surface layer resistance 75 Om/m^2 leads to the decrease R_n from 0,6Om to 0.2Om and the improvement of the form VAC of the *p-n* transition. In addition, the shunt resistance of the elements changes insignificantly.

Thus, the plating the optical covering of ZnS+Nd_2O_3 on the surface of the sillicon photoelement decreases the consequative resistance value and expresses the appreciable influence on the coefficients J_0 and A. In addition, J_0 and A are 10A/cm^2 and 1.3 correspondingly.

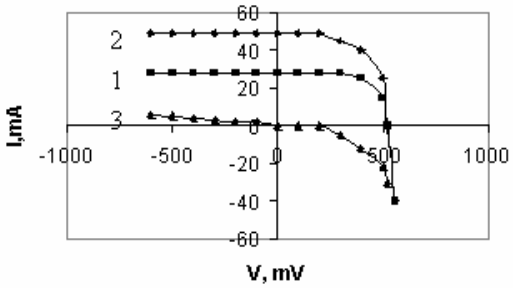

Fig.3. Calculated volt-ampere characteristics of silicon photoelements with coverings, light – 1. . SiO_2; 2. ZnS+Nd_2O_3; dark- 3.

The calculation on the light volt-ampere characteristics allows to define the values of parameters J_0 and A, for those values namelt, which are the character for the sun elements in the operating mode. The calculation is made with the linear dependence J_{sc}~$f(U_{xx})$, where $tg\alpha$~(q/AKT), and the value lgJ_0 is cutted on the axis of ordinates (fig4).

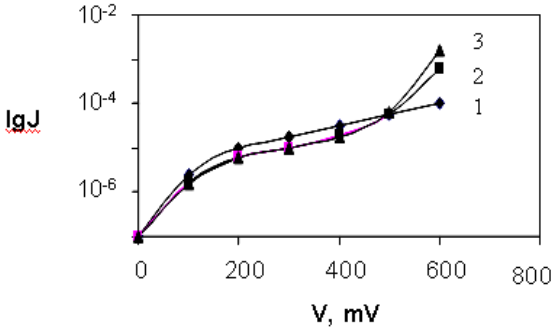

Fig.4. Dark (1) and light (2.3) Characteristics of silicon photoelements with coverings: 1. . SiO_2; 2.3. ZnS+Nd_2O_3

As it is seen from the fig 4 and dependence ?

The calculated values J and A for the samples at the low voltages are 10^{-6}A/cm^2 and 2.5, 10^{-5}A/cm^2 and 2.5; and at the high voltages are 10^{-9}A/cm^2 (and 1.2, 10^{-6}A/cm^2 and 2 correspondingly. The comparison of the values J_0, A and Rn shows that plating the optical double-layer covering of ZnS+Nd_2O_3 leads to the decrease of J_0, R_n and A, which mainlydepend on properties of the interface metal-semiconductor [1]. It is need to take into consideration that volt-ampere characteristics of the photoelement with the wide transition is true only for the definite voltage value (i.e. near the operating point of the photoelement). However, the influences of the surface recombination on the photoelements' characteristics don't take into consideration in it. The comparison of the values J_0, A and R_n for the photoelements with the optical coverings SiO_2 and ZnS+Nd_2O_3 shows that the dark VAC differ insignificantly at the low voltages, (J_{in}...J_0), but light characteristics differ strongly at the high levels of lightening. The such significant change of VAC structure at the plating of the layer ZnS+Nd_2O3 can show that atoms of the zinc, ionized by the lightening action diffuse intensively into the sillicon near lighted surface.

Aaaaathe combination of the obtained dates on the base of the electric, photoelectric and optical measurements bear on that in the sillicon photoelements with the optical

coverings $ZnS+Nd_2O_3$ the creation of the electro-compensated layer in the surface area of the sillicon is the one of the possible reason of the observed changes of the recombination parameters of *p-n* transition. At the lightening the balance brakes and the photostimulated diffusion of the zinc occures, in the result of which the compensation degree of the recombination centres increases that in turn leads to the bend of the edges of the band on the semiconductor surface. In addition, the surface recombination velocity increases from 10^5 to 10^3cm/c [6].

Judging by the investigations of VAC and effect of the field also, carried out in [4], the increase of the efficiency with the covering $ZnS+Nd_2O_3$ is caused by the decrease of J_0 and A in the area of the average voltages, where the sun element works. Thus, at the plating of $ZnS+Nd_2O_3$ on the sillicon sun element surface in distinction of SiO_2 the thin isolating layer occures with the polarized states on the Si surface accordingly. This layer, in turn, can promote to the acceleration of the zinc ions migration in the Si volune and the creation of the fitted electric field of the directed *p-n* transition.

In the result of the made investigation it can make the following conclusions:

1) The efficiency can be increased from 10 to 15% because of the decrease of the reflection in the spectrum region 0.4-0.8mkm at the plating of the double-layer covering $ZnS+Nd_2O_3$ on the surface of the sillicon photoelements.
2) The experimental photoelements have the low consequent resistance and the well volt-ampere characteristics in comparison with the photoelements with SiO_2 coverings, having the same depth of the deposition of p-n transition.

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OPTİK ÖRTÜKLÜ SİLİSİUM GÜNƏŞ ELEMENTLƏRİNDƏ CƏRƏYANKEÇMƏ MEXANİZMİNƏ SƏTH EFFEKTLƏRİNİN TƏSİRİ

Silisium fotoelementi üzərinə çəkilmiş $ZnS + Nd_2O_3$ səth örtüyünün VAX-na təsiri öyrənilmişdir. Müəyyən edilmişdir ki, sink atomlarının silisiumun səthinə diffuziyası nəticəsində rekombinasiya mərkəzlərinin kompensasiya dərəcəsi artır. Bu isə, yarımkeçiricinin səthində zonanın əyilməsinə və keçidə doğru yönəlmiş elektrik sahəsinin yaranmasına səbəb olur. Fərz edilir ki, fotocərəyanın artmasına səbəb, səth səviyyələrinin passivləşməsi nəticəsində rekombinasiya sürətinin azalmasıdır.

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ВЛИЯНИЯ ПОВЕРХНОСТНЫХ ЭФФЕКТОВ НА МЕХАНИЗМЫ ТОКОПРОХОЖДЕНИЯ В КРЕМНИЕВЫХ ФОТОЭЛЕМЕНТАХ С ОПТИЧЕСКИМИ ПОКРЫТИЯМИ

Исследовано влияние двухслойных поверхностных покрытий из $ZnS+Nd_2O_3$ на вольт-амперную характеристику (ВАХ) кремниевых фотоэлементов. Установлено, что в результате проникновения атомов цинка в приповерхностную область кремния возрастает степень компенсации рекомбинационных центров, что приводит к изгибу краев зоны на поверхности полупроводника. Это, в свою очередь способствует созданию встроенного электрического поля направленного p-n перехода. Предполагается, что рост фототока обусловлена уменьшением скорости поверхностной рекомбинации в результате пассивизации поверхностных уровней.

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