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Photoelectric Processes in Thin-film Solar Cells Based on CdS/CdTe with Organic Back Contact

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The features of photovoltaic processes in thin-film solar cells based on CdS / CdTe with organic back 29 contact were studied. It is shown that when applying PEDOT-PSS organic contact on the core layer of CdTe by the method of centrifugation, the efficiency of the received solar cell does not exceed 2 %. It is established that such a low efficiency is due to the operation of the instrumental structure in the mode of the «through diode», which is characterized by low values of open-circuit voltage.

Keywords: Cadmium Telluride, Organic Rear Contact, Through Diode, PEDOT-PSS.

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1. INTRODUCTION

The majority of metals with telluride of cadmium form a Schottky barrier, it influences efficiency of photo-electric processes in solar cells based on CdS/CdTe. The layer of the degenerate semiconductor is formed for minimization of the negative influence of back contact the layer of the degenerate semiconductor is formed and it leads to decrease of the sizes of area of a space charge and formation of tunnel contact. If the tunnel contact is not created, it is necessary to consider the diode properties of back contact [1]. Now there are several theoretical models in which the back contact is described as the diode which is switched on in the opposite direction rather main separating barrier [2]. According to the physical analog presented in [3] the back contact is described as the inverted diode which connected sequentially to the main photo diode (Fig. 1 a).

In this model a theoretical light current-voltage characteristic solar cell is superposition light current-voltage characteristic of the separating barrier with a basic layer without back contact and the dark current-voltage of the back diode.

There are numerous experimental data, that the technology of causing back contacts allows to form instrument structures in which there is not negative impact of back contact on open-circuit voltage [4-7]. The main negative impact is bound to decrease in a factor of filling light current-voltage characteristic. At the same time there are a number of works in which the experimentally recorded decrease in open circuit voltage in low back contact [8-12]. By authors of article [3] it is shown that the physical analog of the inverse diode stops being physically correct when the back barrier reaches defined values. In this model, there is a decrease the open-circuit voltage and the solar cell is described in terms of through diode (Fig. 1 b).

Development of physical and technological bases of creation of efficient solar cells based on CdS/CdTe involves experimental research. These studies have to be directed to ascertainment a physical model of the back contact influence on the efficiency of device structures.

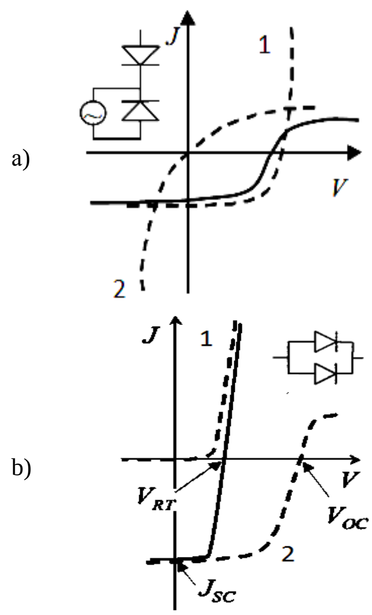

Fig. 1 – Equivalent circuit and current-voltage characteristic: a) working in the mode of the inverse diode (photodiode (1), inverse diode (2)); b) working in the mode of through diode (through diode (1), back diode (2))

Use of organic materials for creation of efficient CdTe cells is the perspective direction. The idea to use these materials is confirmed by the fact that on the surface of organic semiconductors are absent the broken covalent bindings, and they should not create the padding centers of capture and a recombination on border with a basic layer. Besides, the larger sizes of organic molecules have to limit the speed of their diffusion in a basic layer of a solar element and formation of the new impuritiest centers. It is known that CdTe represents the *p*-type semiconductor with high electron affinity (4.5 eV) and bandgap (1.5 eV). Therefore creation of good ohmic contact with CdTe, requires high-conductivity material with a high electrical conductivity [13].

2. EXPERIMENTALE

The solar glass/ITO/CdS/CdTe/PEDOT-PSS/Au elements were received by methods of a physical vapor deposition (PVD) [13]. The ITO layers (oxides of indium and tin) were created by method of not jet magnetron dispersion on a direct current. The CdS layer is grown up in the camera by high vacuum of evaporation (HVE) at a temperature of substrate 150 °C and then tempered at 450 °C for a recrystallization, then CdTe besiege at a temperature of substrate of 300 °C in the same camera, without breaking a vacuum. Typical thickness of CdS is 0.1-0.5 mm, and thickness of CdTe is from 3 to 4 microns. The CdTe/CdS connection is activated by evaporation of 400-600 nanometers of $CdCl_2$ on a surface of CdTe and the subsequent annealing of bedded structure on air at 430 °C within 30 minutes. High-conductivity layers of a polymeric compound PEDOT-PSS were used as organic contacts.

Before drawing organic contacts cadmium telluride etching in brome methanol on reference technology was carried out. Organic contacts of PEDOT-PSS in liquid state were applied on a surface of an etched basic layer with a centrifugation method. For applying organic contacts has been used 1.3 % aqueous solution of PEDOT-PSS was purchased from Aldrich. 5 ml of this solution was mixed with 120 ml of glycerol, 250 ml of N-metilpirrolidona (NMP), 6.25 ml of isopropanol and и 81 ml tetraethoxysilane to increase the electrical conductivity of the film PEDOT-PSS. Increased electrical conductivity films PEDOT-PSS is caused by the effect of shielding between the dash and the polymer backbone chain. Isopropanol is the solvent for fast drying, in addition it improves wettability between polymer film and base layer of cadmium telluride and improves adhesion. Tetraethoxysilane improves resistance to mechanical damage type scratches when centrifuged. After application the coating in a vacuum dried out during three hours at a temperature of 40 °C. Average thickness films PEDOT-PSS was about 150 nm. Films of silver and gold which were put with a chemical and vacuum method, respectively were applied to the top contacts.

3. RESULTS AND DISCUSSION

The high work-function electrons CdTe significantly limits the choice of materials for formation ohmic contacts to such semiconductors. Drawing metal contacts with a work function is lower, than at CdTe leads to formation of a Schottky barrier. The barrier works as the diode which is switched on in an opposite direction to the main *p-n* to transition and blocks driving of the photogenerated charge carriers. This phenomenon known as a back barrier or the back diode which interferes with efficient removal of current in solar cells on the basis of CdTe, silicon, $CuInSe_2$ etc. [14]. Formation of low-impedance contacts to base layers of CdTe is a prerequisite for creating high-efficient device structures and creates one of two approaches. The first approach involves the use of ohmic contact. To create it we need a metal with work-function value more than the electron affinity in a semiconductor. The second approach is to use tunneling contact. The high-alloyed top layer of a basic layer is for this purpose created. The widespread use of ohmic contact from pure metals to the underlying layers of CdTe-based solar cell is problematic. Only platinum has the necessary work-function value electrons (5 eV). In this work, the organic layer of conductive polymer PEDOT-PSS is seen as an alternative to traditional ohmic contacts to CdTe-based solar cell, because PEDOT-PSS has a high work-function value electrons the level 5 eV.

The analysis of a transverse section of instrument structures showed when thickness of a layer of PEDOT-PSS reaches 150 nanometers, in it there is no through pores. Existence of a through pores destroys effect of use of organic polymer because there is an immediate contact of a film of silver or gold with a cadmium telluride layer.

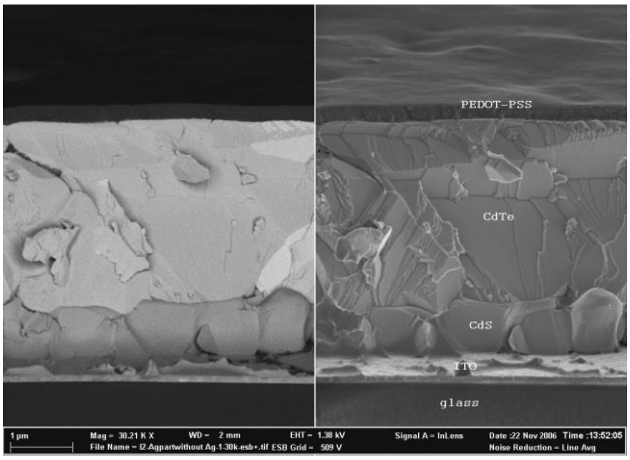

Fig. 2 – Transversal chip of instrument structure glass/ITO/CdS/CdTe/PEDOT-PSS

Light current-voltage characteristics of the solar cells ITO/CdS/CdTe/PEDOT-PSS/Au and ITO/CdS/CdTe/PEDOT-PSS/Ag were investigated for identification of the physical mechanism of oscillation of a photoelectric in solar elements with organic back contact of PEDOT-PSS.

Typical light current-voltage characteristics of instrument structures is given in the Fig. 3.

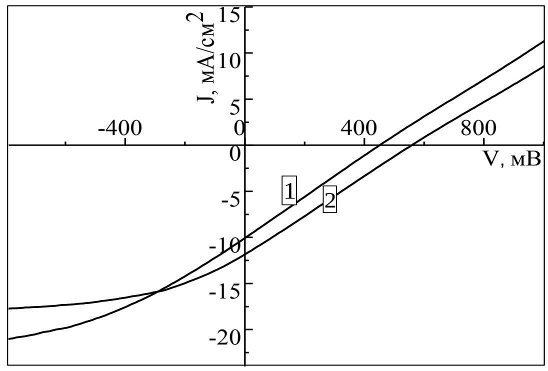

Fig. 3 – Light current-voltage characteristics of the devices ITO/CdS/CdTe/PEDOT-PSS/Au (1) ITO/CdS/CdTe/PEDOT-PSS/Ag (2)

Output parameters of the studied structures in the Table 1.

As can be seen from Table 1, the use of organic-layer conducting polymer PEDOT-PSS has resulted in low efficiency values not exceeding 2 %. The analysis of Table 1 allows to establish that the value of low efficiency is caused by low V_{oc} value. As is well-known from [15] during the work of instrument structure in the mode of the through diode low values of tension of a no-load operation are observed. It is caused by existence of through microdiodes. The back barrier can have infrequent microscopic «defects» of a low transparence. It can be bound from inhomogeneity of a doping. Such «defects» represent through diodes which are connected in parallel to «standard» microdiodes and for which the value open-circuit voltage does not depend from height of a back barrier.

Table 1 – Output parameters of solar cells ITO/CdS/CdTe/PEDOT-PSS/Au and ITO/CdS/CdTe/PEDOT-PSS/Ag

Parameters	PEDOT-PSS/Au	PEDOT-PSS/Ag	Cu/Au
J_{sc} (mA/cm^2)	10	12	21.2
V_{oc} (mV)	461	560	731
FF	0.25	0.26	0.66
η (%)	1.12	1.74	10.23

For a solar cell with through microdiodes open-circuit voltage is limited to value V_{ocRT}:

$$V_{ocRT} = 2V_{m0}\left(1-\sqrt{\frac{V_B}{V_{m0}}}\right) \quad (1)$$

where V_B – height of a back barrier, V_{m0} – height of the separating barrier if the back barrier is absent.

Thus, decrease of height of the separating barrier or increase in height of a back barrier leads to decrease open-circuit voltage in the mode of the through diode. Estimates showed that the mode of the through diode is implemented if height of a potential barrier of back contact is more than 0,4-0,5 eV [16]. The quantity of the charge carriers which passed through a barrier as a result of thermal oscillation (N) is defined by expression:

$$N \sim n\upsilon \exp(V_B / kT) \quad (2)$$

where υ – the speed of charge carriers, n – the semi-permanent density of electrons depending on intensity of light. If the number of the charged particles (N) corresponds to recombination level, then in the mode of the through diode:

$$N \sim l\gamma n^2 \quad (3)$$

where γ – a coefficient of recombination, l – thickness of a basic layer.

Comparison of expressions 2 and 3 allows to estimate V_B value:

$$V_B = \frac{kT}{2} In\left(\frac{\upsilon^2}{I\gamma l}\right), \quad (4)$$

Low values of open-circuit voltage demonstrate that instrument structures work in the mode of the through diode. Thus, use of high-conductivity layers of PEDOT-PSS with a work-function 5 eV, do not allow to create ohmic or high-quality tunnel contacts to basic layers of telluride cadmium. The near-surface CdTe/PEDOT-PSS areas which visualized by method of induced currents in which there is no recombination, represent the microdiodes which are switched on in an opposite direction to the main diode.

Besides at realization of the mode of the through diode there is no dependence of open-circuit voltage on intensity of irradiating and an exit of a direct branch light current-voltage characteristics on saturation is not observed. Such behavior light current-voltage characteristics is observed for solar cells with organic back contact PEDOT-PSS and is shown in the Figure 1.

4. CONCLUSIONS

It was shown that the developed approach which is characterized by use of high-conductivity organic PEDOT-PSS polymer for formation of back contact to basic layers of thin film solar cells ITO/CdS/CdTe allows to receive solar cells with low value of effectiveness less than 2 %.

Restriction of efficient of the received solar cells glass/ITO/CdS/CdTe/PEDOT-PSS at the level of 2 % is caused by low value of open-circuit voltage

Low values open-circuit voltage, being absent dependences of open-circuit voltage on intensity of irradiating and an exit of a direct branch light current-voltage characteristics on saturation indicates work of instrument structure in the mode of the through diode.

Thus, application of high-conductivity layers of PEDOT-PSS to the surface of telluride cadmium put with method of a centrifugation does not allow to create efficient ohmic contacts.

Фотоелектричні процеси в тонкоплівкових сонячних елементах на основі CdS/CdTe з органічним тильним контактом

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Изучены особенности фотоэлектрических процессов в тонкопленочных солнечных элементах на основе CdS / CdTe с органическим тыльным контактом. Показано, что при нанесении органического контакта PEDOT-PSS на основной слой CdTe методом центрефугирования эффективность полученного солнечного элемента не превышает 2 %. Установлено, что такое низкое значение эффективности обусловлено работой приборной структуры в режиме «сквозного диода», который характеризуется низкими значениями напряжения холостого хода.

Ключевые слова: Теллурид кадмия, Органический тыльный контакт, Сквозной диод, PEDOT-PSS.

Фотоелектричні процеси в тонкоплівкових сонячних елементах на основі CdS / CdTe з органічним тильним контактом

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Вивчено особливості фотоелектричних процесів в тонкоплівкових сонячних елементах на основі CdS/CdTe з органічним тильним контактом. Показано, що при нанесенні органічного контакту PEDOT-PSS на основний шар CdTe методом центрефугіровання ефективність отриманого сонячного елемента не перевищує 2 %. Встановлено, що таке низьке значення ефективності обумовлено роботою приладової структури в режимі «наскрізного діода», який характеризується низькими значеннями напруги холостого ходу.

Ключові слова: Теллурид кадмію, Органічний тильний контакт, Наскрізний діод, PEDOT-PSS.

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