THIN LAYER PHOTOVOLTAIC MODULES BASED ON CdS-CdTe HETEROJUNCTIONS

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Abstract

A technology of thin layer photovoltaic modules with dimensions of 65 x 80 mm^2 based on CdS-CdTe heterojunctions prepared via the quasi-closed volume technique was developed. The modules were made on a single glass plate; each element was positioned along the given plate so that the resulting module contains nine solar cells with an area of 3 cm^2. The design of the module made it possible to study the energy parameters of each solar cell as well as the entire module. The study of the photovoltaic module based on CdS-CdTe heterojunctions showed the following parameters: short circuit current I_{sc} = 270 mA; open circuit voltage U_{cd} = 0.786 V; FF = 0.46, power discharged in the load $P_{max} \approx$ 100 mW, and efficiency $\eta \approx$ 8.2% at the radiation power of 53 mW/cm^2.

1. Introduction

The prospects for the development of solar cells (SCs) based on II-VI compounds are determined by using hetrojunctions, because these materials are characterized by high values of surface recombination rate. The large band gap semiconductor plays the role of a „window" and also protects the colar cell photoactive region from the influence of the surface states. For the formation of cadmium telluride based heterojunctions, cadmium sulfide was used as a second material.

Theoretical calculations, as well as expermental studies, showed that the II-VI compounds under the terrestrial conditions are almost an ideal material with the band gap of 1.45 eV which could provide a solarcell efficiency of 27.5% [2].

Thin layer SCs with a CdS-CdTe p-n heterojunction are widely used in solar energetics owing to relatively low cost technology of their fabrication [1, 2]. These SCs with the area of 1 cm^2 are expected to reach theoretical efficiency. The recent studies and experiments place CdS/CdTe heterojunctions among the three main compounds used in photovoltaic conversion of solar energy conversion. It was shown that thin layer CdS/CdTe hetrojunction based SCs has an efficiency of 16.5% [4].

2. Equipment and results of measurements

For the fabrication of large area CdS-CdTe heterojunctions, standard glass plates with dimensions of 65 x 80 mm^2 covered with a SnO_2 conducting layer were used. The reaction chamber where the HJ components were grown consists of two main components: an evaporator block (EB) and a substrate block (SB).

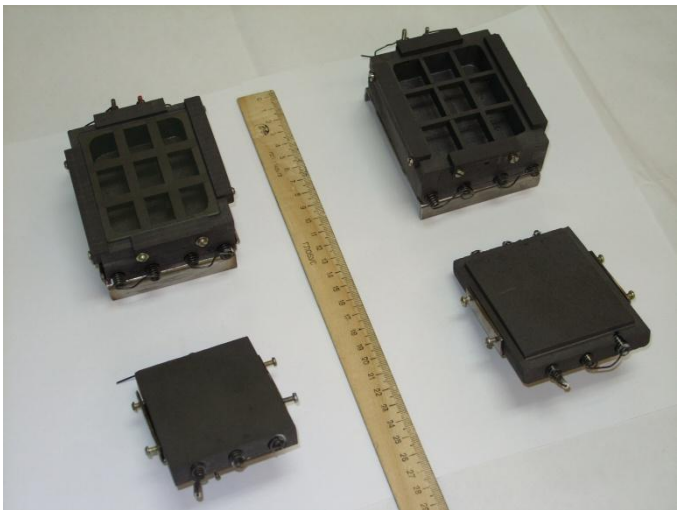


Fig.1

The substrate block is a graphite plate along which the tungsten spirals are located. During their heating due to a high value of thermal conductivity, the heat is uniformly transmitted to the entire substrate surface. EB is a rectangular graphite chamber with the relatively massive bottom along which the tungsten spirals are embeded. The chamber walls have a height of h ≈ 20 mm and a thickness of 8 mm. The above characteristics are needed for providing the main conditions of a "quasi-closed volume." Each block is heated by separate spirals and the temperatura is controlled by thermocouples.

The HJ fabrication of sheer CdS and CdTe layers is excluded because of the impossibility of collecting the charge carriers generated in the central part of the heterostructure: the closer the current picking electrode is to the generated charge carrier, the higher is the SC efficiency. Therefore, the structure consists from nine similar elements grown on a single glass plate. Each element represents a rectangular sample with dimensions of 20 x 15 mm; between the elements, there are SnO_2 strips with a width of 3 mm for the further metallization.

For the separation of HJ of nine elements, in each EB, a graphite screen was mounted. The width of the graphite edges for the CdTe layer was larger than for the CdS layer. This provides the impossibility for cadmium telluride to reach the perimeter of the CdS layer. The screen edges have a low height, and their bottom part is situated high from the bottom of the reaction chamber; therefore, the evaporated material is distributed by a uniform flow over the entire substrate surface, the thickness discrepancy between any nine elements does not exceed 10%.

The modules were made on a single glass plate, the positioning of each element along the given plate is so that the obtained module contents nine SCs with an area of 3 cm^2, which have a common front contact. Thin SnO_2 or ITO layers were used as a front contact. The following necessary stage on the module fabrication was the sensibilization of the CdTe layer, which was necessary for the solar modules of large area.

For this purpose, the freshly prepared CdS-CdTe elements of the module, according to the elaborated technological process, were treated in a $CdCl_2$ solution. The plate was submerged and kept for 1.5-2 h in a bath especially designed to the dimension of the panel, and then dried in an air flow and further placed in a furnace for heat treatment. After the heat treatment, the CdTe layer surface was cleaned from the salt spots and inclusions. The etching was carried out according to a special regime with the clearly detailed etching time elaborated for CdS-CdTe SCs. The surface of CdTe after the etching was thoroughly washed and dried in a dry air flow.

The main difficulty in the fabrication of CdS-CdTe SCs is the preparation of a good ohmic contact to the CdTe active layer. After the treatment on the given panel, on the surface of active layer of CdS-CdTe SC, a Sb_2Te_3 thin layer was deposited by vacuum evaporation [3] using specially made screens corresponding to SC dimensions and positioning. The technology and regimes of the deposition of the Sb_2Te_3 layer were also elaborated for CdS-CdTe SCs with dimensions up to 1 cm^2.

A small amount of Sb_2Te_3 was placed in a specially designed evaporator for large-surface layer deposition and evaporated. After the deposition of the Sb_2Te_3 thin layer, without opening the vacuum unit, a thin Ni layer was deposited. The same succession of double contact fabrication was also elaborated for SCs with dimensions up to 1cm^2. The studies of the efficiency of the given elements showed that, after the procedure of double contact fabrication, the fill factor of the SC reaches values of FF = 0.54-0.56. The efficiency of the SCs with dimensions of 1 cm^2 is 10-12%.

The factor that limits the efficiency of the module is also the totality of the losses on the front contact resistance. Glass plates covered with a SnO_2 layer are far from perfection. After all fabrication procedures for CdS-CdTe SC and especially after annealing and etching, the resistance of the SnO_2 layer of 50-60 Ohm changes, and the resistance of the separation stripes became 2-3 times higher. For this purpose, we prepared a screen for marking and positioning the module elements during the deposition of a frontal screen of current picking electrodes. These procedures lead to two positive effects:

First, the metal contact screen sharply decreases the total resistance of the subcontact region.

Second, being current picking, this screen sharply increases the current picking on the entire module surface. The surface of the current picking screen is 0.15% of the active area of the entire solar module.

The figures below show the CdS-CdTe SC module:

1. A glass plate with SnO_2 and the deposited CdS layer. One can clearly see the stripes of the frontal SnO_2 electrode (Fig. 2).
2. A frontal view if the CdS-CdTe module in the working regime (Fig.3).
3. A view of the CdS-CdTe module from the side of the back contact with the deposited two-layer contact cover from CdTe active layer side and current picking contact screen to the front collecting electrode (Fig. 4).

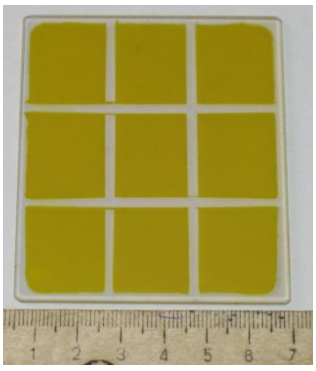


Fig.2

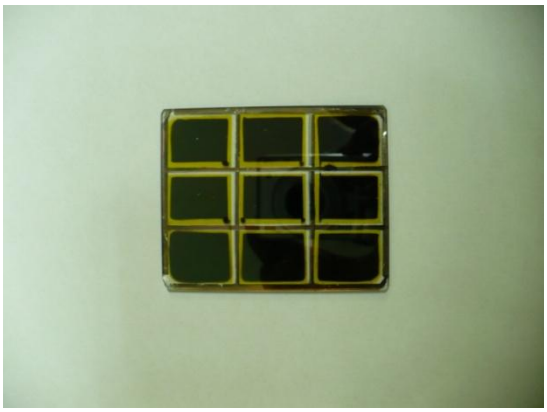


Fig. 3

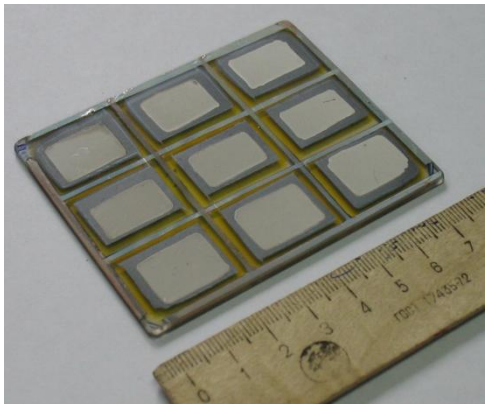


Fig. 4

For the measurement of the energetic parameters of the CdS-CdTe SC module, the design of the measurement block was developed, which allowed measuring both a separate module element and all possible configurations of the module element connections. The only condition in this module design is that the module elements must be connected in parallel with one another. The measurement block is presented in Figs. 5 and 6.



Fig. 5



Fig.6

The design of the measurement block makes it possible to carry out measurements along with the operation of solar flux tracking if the measurement is carried out under natural conditions and gives the possibility of measurements at a steady flux of an artificial light with an obligatory control of the radiation intensity.

As one can see from Table 1, the energetic parameters of the module are rather high. However, the low IU fill factor sharply decreases the efficiency of the given module.

These elements with an active area of 1 cm^2 were used to prepare solar modules with an area of 4 cm^2. The design of the module assembling allowed connecting elements in electric circuits of different configurations .The energetic parameters of the module consisting of 4 elements are: I_{sc} = 25.6 mA, U_{cd} = 2.9-3 V, FF = 0.410, and η = 9.51% at the radiation of AM2.

Table 1. Solar module: measurements were carried out at a radiation of 80 mW/cm^2

N,element parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Isc/cm^2, mA	18.6	19.1	17.6	19.0	17.4	18.4	16.6	17.5	17.5
Ucd, mV	790	786	797	800	788	787	789	790	791
Pmax, mW	6.8	5.7	7.3	7.1	6.1	7.0	5.9	5.2	6.3
FF	0.287	0.287	0.264	0.275	0.275	0.287	0.277	0.260	0.280

For the module that consists of two elements with an area of 2 см^2, the following energy parameters were obtained: I_{sc} = 22 mA, U_{cd} = 1.56 V, FF = 0.412, and $\eta \approx 9\%$. The possibility to assemble modules from separate elements allows designing the photoelectric solar batteries for the power supply of low power electronic devices: radio receivers, mobile phones, etc.

Table 2 lists the energetic parameters of CdS-CdTe module consisting of nine SC, which were measured under the conditions of artificial illumination with the intensity AM2 (80 mW/cm^2)

Table 2

N'element parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Isc, mA	35.40	33.76	35.85	34.20	34.40	34.90	35.91	34.20	34.40
Ucd, mV	790	786	787	800	786	787	789	788	791
Pmax, mW	12.86	11.41	12.97	12.58	11.89	12.35	13.02	10.51	12.24
FF	0.46	0.43	0.46	0.46	0.44	0.45	0.46	0.39	0.45

It is evident from Table 2 that the main energetic parameters of the module are homogeneous in their values. I_{sc} for each of nine elements differs not more than by 4%, open circuit voltage U_{cd} differs by 1.2-1.4%, and the maximum power in the working power changes by P_{max} 11-13 mW. The main factor limiting the efficiency of the elements is the low value of IV dependence fill factor.

It was proved that the charge carrier collection factor in the module elements is the imperfection of the back contact to the CdTe layer. The use of a two-layer contact to CdTe, such as Sb_2Te_3+Ni, allowed increasing the IV dependence FF to 0.52-0.54.

The use of the deposition of a metallic screen on the frontal collecting electrode allowed increasing the value of the module short circuit current I_{sc}.

The carried out studies of thin-film photovoltaic modules revealed that the main problem in the increasing of the efficiency of CDS-CdTe modules is the preparation of effective ohmic contacts to the module elements and the protection of the back surface from the environment influence.

The testing of the photovoltaic module based on CdS-CdTe heterojunctions carried out on July 15, 2010 in Chisinau showed the following parameters: short circuit current I_{sc} = 270 mA, open circuit voltage U_{cd} = 0.786 V, FF = 0.46, power discharged in the load $P_{max} \approx$ 100 mW, and efficiency $\eta \approx 8.2\%$ at a radiation power of 53 mW/cm^2.

4. Conclusions

1. A technology for the preparation of CdS/CdTe heterojunction was developed using a quasi-closed volume technique of succesive deposition of CdS and CdTe thin layers on glass substrates covered with a conducting SnO_2 thin layer ($\rho \sim 10^{-3}$ Ω·cm).

2. In the case of using Sb_2Te_3+Ni double contact, the SC fill factor achieves values of FF = 0.54-0.56. The efficiency of the SC with dimensions of 1cm^2 achieves 10-12%.

3. At 300 K and illumination with an integral light with an incident power of 100 mW/cm^2, the CdS/CdTe hetrojunctions have the following photoelectrical parameters U_{cd} = 0.798 V, I_{sc} = 22.1 mA/cm^2, FF = 0.54, and η = 10.00%.

4.On the basis of a CdS/CdTe thin layer hetrojunction, the technology for the preparation of photovoltaic modules with an area of 52 cm^2 which contain nine SCs with the active area of 3 cm^2 each was developed.

5. The testing of the photovoltaic module based on CdS-CdTe heterojunctions carried out on July 15, 2010 in Chisinau showed the following parameters: short circuit current I_{sc} = 270 mA, open circuit voltage U_{cd} = 0.786 V, FF = 0.46, power discharged in the load $P_{max} \approx$ 100 mW, and efficiency $\eta \approx 8.2\%$ at a radiation power of 53 mW/cm^2.

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