

THE STUDY OF THE NONEQUILIBRIUM CHARGE CARRIER TRANSPORT MECHANISM THROUGH THE INTERFACE OF CdS/CdTe HETEROJUNCTIONS

S. Vatavu, I. Caraman^a, G. Rusu^b, V. Fedorov, P. Gaşin

Faculty of Physics, Moldova State University, 60 Mateevici str., Chisinau, Moldova

^aFaculty of Sciences, Bacau University, 157 Calea Marasesti, 600115 Bacau, Romania

^bFaculty of Physics, "Al. I. Cuza" University, 11 Carol Bd., 700506 Iasi, Romania

The analysis of charge carrier flow through CdTe, CdS and the interface layer, is done by the investigation of absorption spectra of CdS and CdTe layers thin film and photosensitivity spectra of SnO₂/CdS/CdTe/Ni solar cells. The ratio of the coefficient of ambipolar diffusion D and the recombination through the surface states rate S , has been determined.

1. Introduction

One of the perspective materials for solar energetics is considered to be thin film CdTe based heterojunctions (HJ) [1]. First of all, this priority is determined by the concordance between solar spectrum and the photosensitivity region of the CdTe based HJ, secondly, the absorption coefficient 10^5 cm^{-1} [2]. The value of absorption coefficient show that the nonequilibrium charge carriers generation processes take place in a layer of nm thickness [3], its electrophysical parameters depend on the annealing technique in presence of CdCl₂ [4].

Considering the presence and importance of the interface layer, in CdS/CdTe HJ, in the selection of the nonequilibrium charge carriers process, (its energetic diagram is shown in [5]) the analysis of charge carrier flow through CdTe, CdS and the interface layer, is done by the investigation of absorption spectra of CdS and CdTe layers (in the fundamental absorption band region) and of the photosensitivity spectra of SnO₂/CdS/CdTe/Ni HJ.

2. Experimental

The CdS and CdTe layers, components of SnO₂/CdS/CdTe/Ni solar cells have been deposited by CSS and HWT. The CdTe 1% Sb single crystals and CdS powder (undoped) have been used as compounds for evaporation. The thicknesses of CdS and CdTe layers for absorption measurement were 0.1-10 μm . The thicknesses of the films $>0.5 \mu\text{m}$ have been determined from the reflection or transmission interference, and the thicknesses less than 0.5 μm have been estimated from the optical density of the sample for certain wavelengths in the fundamental absorption region.

The absorption coefficient α has been determined from transmission and reflection measurements (T and $R=f(\hbar\omega)$) using [6], applicable for optical transmissions from $(1-R)/(1+R)$ up to ~ 0.1 .

The reflection, transmission and photosensitivity spectra have been measured by using a MDP-2 monochromator with a diffraction grid (1200 and 600 mm^{-1}). The 1000 W Xe lamp has been used as a light source, and the output signal has been registered by photomultiplier with a multialcaline photocathode sensitive in the 200-950 nm spectral range. The incident light on the surface of the sample for photoresponse studies has been registered by a thermoelement with 4V/W integral sensibility.

The low temperature measurements (78K), have been performed by placing the sample in a special liquid nitrogen cooled cryostat.

As evaporated CdS/CdTe heterojunctions have been annealed in presence of CdCl₂ at 690K for 15-60 min. Ni has been evaporated as back contact.

3. Results and discussion

The typical spectral distribution of the photosensitivity ($\Sigma = I_{sc}/N_{\text{photon}}$) for CdS/CdTe HJ, deposited by HWT and CSS are given in Figure 1 curves 1a, 1b respectively. As it came from the analysis of 1a and 1b (Figure 1) the photosensitivity region is limited by the band gap of CdTe and CdS 1.45 and 2.45 respectively. One can see that the photosensitivity of the HWT HJ increases up to 2.15 eV, while the same curve for CSS samples weakly decreases.

The spectral dependence of the photosensitivity of the CdS/CdTe HJ for the light coming from the CdTe side are given in Figure 1 curve 1c. One can see, that independently of the manufacturing technology for photon energies >1.8 eV, the photosensitivity decreases in the high photon energy region, reaching 2.9 eV.

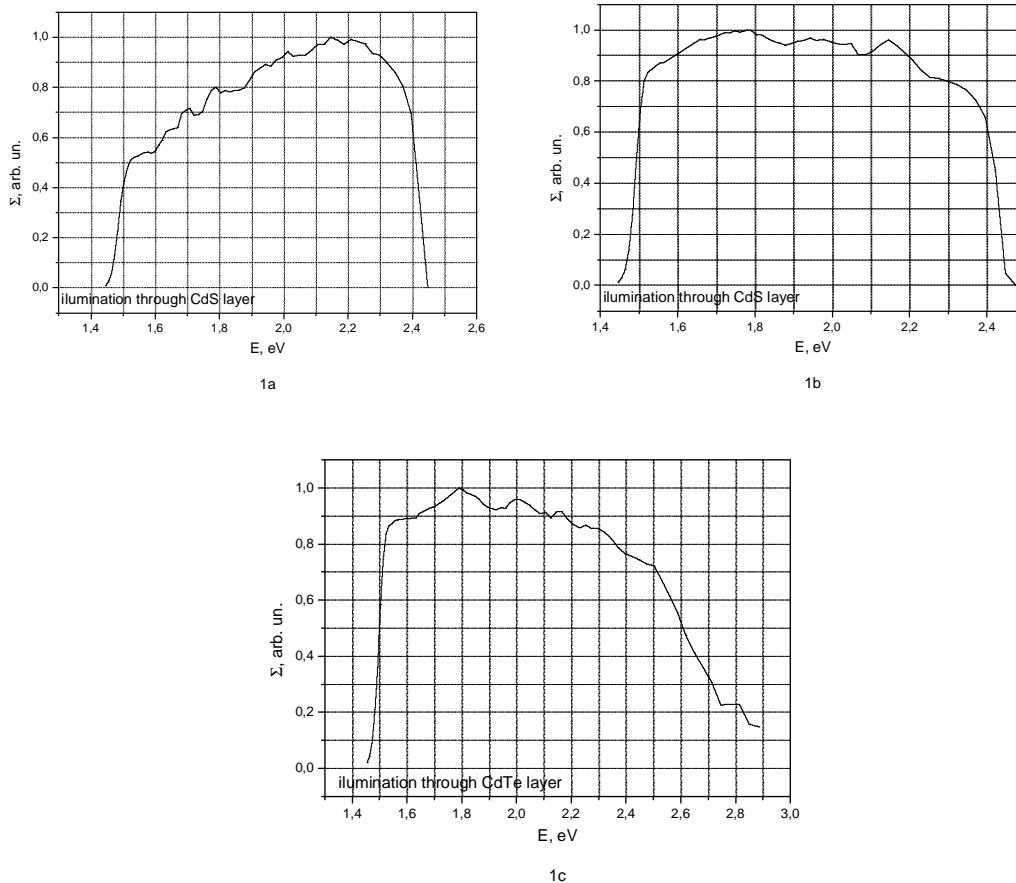


Fig. 1. The photosensitivity ($\Sigma = I_{sc}/N_{\text{photon}}$) spectral dependence (293 K) for SnO₂/CdS/CdTe/Ni HJ.

Let us follow the photosensitivity curve with elimination of CdTe layer (Figure 1 curve 1a). The charge carriers are passing along with the direction of the electric field, which is colinear with the light beam. In the 1.4-1.8 eV photon energy range, the photosensitivity increases along with the absorption coefficient. But for photon energies >1.8 eV, Σ decreases weakly, and the wing of this dependence reaches 2.9 eV. This decrease can be explained by the presence of a low concentration of interface states [7].

The illumination of the CSS CdS/CdTe HJ with a monochromatic light Σ is almost constant in the 1.65-2.1 eV range. At ~ 2.2 eV a low intensity maximum is present due to the activation of the second mechanism of the nonequilibrium charge carrier generation. It consists of optical transitions from the second valence subzone Γ_7 to the conduction band ($\Gamma_7 \rightarrow \Gamma_6$) [8]. Such a $\Sigma=f(\hbar\omega)$ dependence can be explained if one assumes that a solid solution $\text{CdS}_x\text{Te}_{1-x}$ is formed at the interface of CdS/CdTe. Its band gap increases with x or by decrease of the interface states. The studies of the PL spectra demonstrate vice versa: at the interface of the CdS/CdTe HJ the structural defects density is much higher than on the opposite side of CdTe.

It is known [9] that the HWT deposition technology of the CdTe layers onto CdS is 10 to 15 times longer than by CSS. The high temperatures and long exposure of the junction at this temperatures stimulate the formation of the solid solution $\text{CdS}_x\text{Te}_{1-x}$ by diffusion of the volatile component from the layers, especially of sulphur, its covalent radius (1.02 Å) is smaller than of tellurium (1.36 Å) or cadmium (1.48 Å). As one can see from Figure 1 in the ~ 1.5 -2.3 eV range, the photosensitivity increases ~ 2 times. The low photosensitivity increase of CdS/CdTe layers with photon energies can be explained if one assumes that an intermediary solid solution $\text{CdS}_x\text{Te}_{1-x}$ is formed and its band gap slowly increases from ~ 1.55 eV to ~ 2.25 eV (Figure 2).

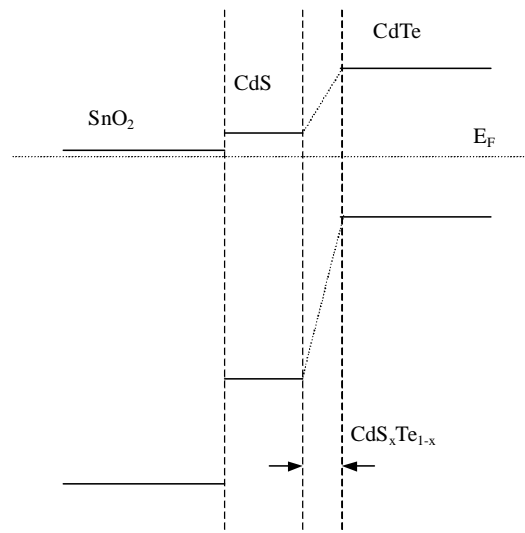


Fig. 2. The schematic energetic diagram of the SnO₂/CdS/CdTe solar cell

The photosensitivity spectral dependencies in the presence of an external electric field for the light coming from CdS side are presented in Fig. 3 (3a, 3b). The external voltage has a value 3-5 times higher than U_{oc} . The nonequilibrium charge carriers, by means of diffusion and external electric field, are moving through CdTe layer to the junction, participating in the ionization of capture levels inside the layer.

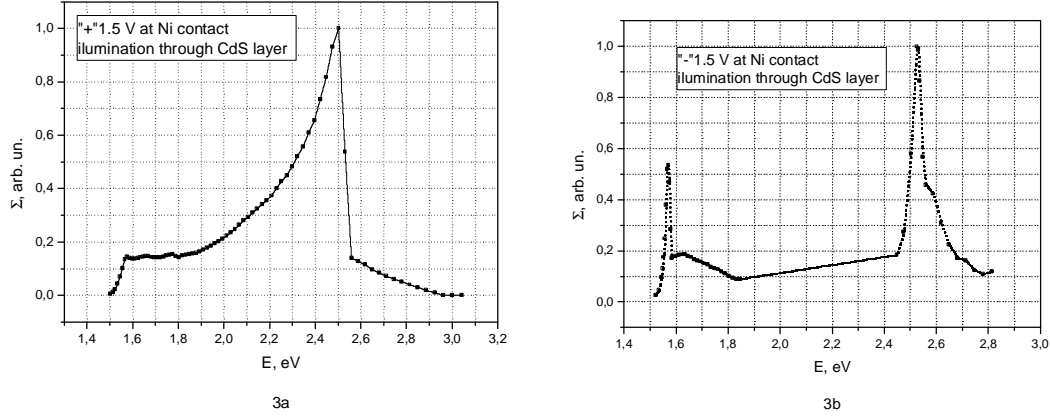


Fig. 3. The photocurrent spectral dependence for CSS CdS/CdTe HJ at 78 K, with an external electric field (2 V) applied.

Experimental data, which can confirm the model of an interface layer with a variable band gap, can be obtained from the analysis of photosensitivity spectral distribution of the $\text{SnO}_2/\text{CdS}/\text{CdTe}/\text{Ni}$ HJ with a presence of an external electric field much higher than U_{oc} . The typical photocurrent spectral dependence relative to the photons number at 78K is given in Figure 3. A 2 V external voltage was applied with different polarities. The external field applied to the junction stimulates the diffusion of nonequilibrium charge carriers (holes), generated in a nano-thick layer, into CdS. The photosensitivity increase with photon energy in the 1.6-2.45 eV region can only be explained if one supposes that the interface layer is formed of $\text{CdS}_x\text{Te}_{1-x}$ solid solutions and its band gap slowly increases from 1.6 up to 2.5 eV.

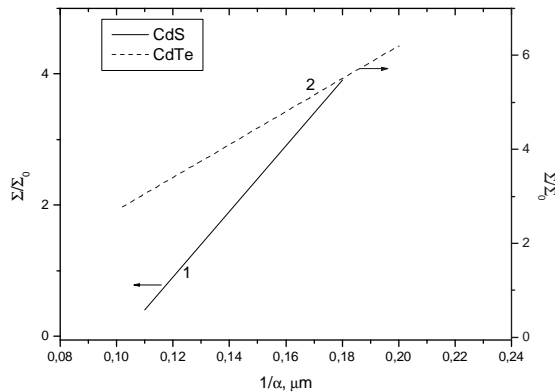


Fig. 4. The dependence of the normalized photosensitivity on $1/\alpha$ for CdS (1) and CdTe (2) layers, components of the CSS $\text{SnO}_2/\text{CdS}/\text{CdTe}/\text{Ni}$ HJ.

The sharp photoconductivity increase in the 2.5-2.55 eV region is caused by the increase of CdS absorption coefficient by four orders of magnitude. As one can see in Figure 3a the increase of the photon energy from 2.55 up to 3.0 eV, the photosensitivity slowly decreases. This decrease can be attributed to the presence of low lifetime states at SnO_2/CdS interface and $\text{CdS}/\text{CdS}_x\text{Te}_{1-x}$. In this region the absorption coefficient increases from $6 \cdot 10^4 \text{ cm}^{-1}$ to $1.5 \cdot 10^6 \text{ cm}^{-1}$.

Σ for $\hbar\omega > 2.5 \text{ eV}$ for CdS film and $\hbar\omega > 1.55 \text{ eV}$ for CdTe depend not only on the absorption coefficient but on the ratio of the ambipolar recombination rate S and the diffusion coefficient D . The correlation between these coefficients has been established [10]:

$$\Sigma \sim 1 + [S/D] \cdot \{L/(L+\alpha)\} \quad (1)$$

where L is the average diffusion length of the charge carriers.

The $\Sigma/\Sigma_0=f(1/\alpha)$ has been plotted at 78K using the photosensitivity and absorption plots, considering that $1/\alpha \ll L$, is given in Figure 4. The D/S equal to $0.02 \mu\text{m}$ for CdTe and $0.105 \mu\text{m}$ for CdS has been determined.

4. Conclusions

The photosensitivity region of CdS/CdTe HJ manufactured by CSS and HWT is in the 1.45-2.45 eV range, determined by the band gap of CdTe and CdS respectively.

The $\text{CdS}_x\text{Te}_{1-x}$ solid solutions are formed between HWT CdS and CdTe layers. Their band gap slowly increases from 1.55 eV up to ~ 2.25 eV. The photosensitivity increase for CSS CdS/CdTe HJ with photon energy can be also explained by the model considering the presence of $\text{CdS}_x\text{Te}_{1-x}$ solid solutions.

At direct polarization of the external electric field applied to CdS/CdTe HJ the photocurrent/number of photons ratio increases with photon energy in the 1.6-2.5 eV range (78K) and slowly decreases for energies >2.55 eV.

As it came from the analysis of the absorption and photosensitivity spectra of CdS/CdTe HJ with the presence of an external electric field, the ratio of the coefficient of ambipolar diffusion D and the recombination through the surface states rate S , has been determined. $D/S=0.02$ for CdTe and $0.105 \mu\text{m}$ for CdS, components of $\text{SnO}_2/\text{CdS}/\text{CdTe}/\text{Ni}$ solar cells.

References

- [1] I. M. Dharmadasa et al., *Semicond. Sci. Technol* **17**, 3128 (2002).
- [2] Iu. Caraman et al., *Physics of low-dimensional structures* **7/8**, 1 (2001).
- [3] D. L. Bätzner et al., *Thin Solid Films* **361-362**, 463 (2000).
- [4] M. Caraman, P. Gasin, S. Vatavu, *Thin Solid Films* **480-481**, 254 (2005).
- [5] P. Nollet et al., *Thin Solid Films* **431-432**, 414 (2003).
- [6] Ю. И. Уханов, *Оптические свойства полупроводников*, Наука, Москва, 1977 (in Russian).
- [7] *Теллурид кадмия (Сб. статей)*, под ред. Б. Н. Вул, Наука, Москва, 1968 (in Russian).
- [8] *Физика и Химия соединений $A^{II}B^{VI}$* , под ред. С.А. Медведева, Мир, Москва, 1970 (in Russian) (The Physics and Chemistry of $A^{II}B^{VI}$ compounds, edited by S. A. Medvedev, Mir, Moscow, 1970).
- [9] K. L. Chopra, S. R. Das, *Thin Film solar cells*, New York; London, 1983.
- [10] В. А. Петрисевич, *ФТТ* **46**, 461 (1962).