THE CARACTERIZATION OF THE CdS-BASED SOLAR CELL HETEROJUNCTIONS

T. Potlog, V. Botnariuc, L. Gorceac, N. Spalatu, N. Maticiuc, S. Raievschi

Department of Physics, Moldova State University,
60, A. Mateevici str. MD 2009, Chisinau, Moldova
E-mail: tpotlog@gmail.com

Abstract–*The CdS-based solar cell heterojunctions (HJ) have been obtained by growth of CdS at relatively lower temperature using the close space sublimation method (CSS). Investigation of the photovoltaic characteristics shows an efficiency of about 12 % for InP/CdS and 9.6 % for CdS/CdTe solar cell HJ. The analysis of the forward dark current-voltage and the capacitance-voltage characteristics indicate a tunnelling recombination current which flows through states near or at the interfaces of a thermal energy of about 0.62 eV for CdS/CdTe and 0.42 eV for InP/CdS solar cell heterojunctions. The solar energy conversion efficiency is influenced by the interface states through the open circuit voltage and the fill factor.*

Keywords: *solar cell heterojunction, dark forward-bias current, capacitance-voltage and photovoltaic characteristics.*

1. INTRODUCTION

This paper is dedicated to the heterojunction solar cells in which the wide band–gap material is CdS. There are many reasons to focus on CdS as one of the components of the HJ solar cell. First, CdS is a relatively cheap material and thin films of good quality are relatively easy to produce using inexpensive technique like evaporation, sputtering, close space sublimation, etc. This is an important consideration from an economic of viewpoint. Second, the bandgap of CdS (E_g=2.42 eV) is wide enough so that it absorbs very little AM1 sunlight and the electron mobility is high enough to ensure low resistivity in the material whose carrier concentration is low enough so that free-carrier absorption can be neglected. CdTe from II-VI and InP from III-V compounds have a band gap of 1.5 eV and 1.34 eV respectively, which are very close to the optimum value for solar energy conversion and they are also chemically stable compounds. Analysis of the literature on CdS-based HJ solar cells leads to the conclusion that the highest efficiency is obtained in the structure in which the mismatch between the two crystal lattices is the lowest, namely, in the *n*CdS/*p*InP HJ solar cell [1-2]. However, high efficiency has been reported in HJ between CdS and CdTe [3-5] in which the lattice mismatch is greater than that between CdS and InP. In order to clarify the role that the interface plays in the efficiency of the CdS-based heterojunctions we have fabricated and analyzed *n*CdS/*p*InP and *n*CdS/*p*CdTe solar cell HJ in which the mismatch is ~ 0.3% and ~ 10%, respectively. The CdS layer is prepared in both cases by the close space sublimation technique. Optimum growth conditions for CdS in this experiment are lower temperatures (T_s = 320^{o}C, T_{ev} = 540^{o}C) than those reported elsewhere. The measurement and analysis of the temperature dependence on the dark and the illumination current-voltage (*J-U)* and capacitance-voltage *(C-U)* characteristics of the devices proved to be a particularly important source of information about the nature of the interface region.

2. SOLAR CELL HETEROJUNCTIONS PREPARATION

The InP/CdS solar cell heterojunctions were fabricated by growing a layer of *n*/CdS through close space sublimation on the *p*/InP crystal substrates. The polished, monocrystalline (111)-oriented plates with the carrier concentration, resistance and mobility of p=1-3·10^{18} cm^{-3}, ρ=1—2 Ω·cm, 65-70 cm^2/V·s, respectively were used as substrates in the preparation of the InP/CdS heterojunction. Before depositing the CdS layer the surface of the InP has been etched in a 1% bromine in a methanol solution for 1.5-2 min. The CdS/CdTe solar cell heterojunctions were fabricated by consecutively growing the CdS and CdTe layers, by close space sublimation on SnO_2/glass substrates [6]. CdTe films were deposited at a source and substrate temperature of 350^{o}C and 540^{o}C respectively. After the CdTe layer is deposited onto the CdS the structures were held in $CdCl_2$:H_2O saturated solutions and

978-1-4244-5781-6/10/$26.00 © 2010 IEEE

then annealed in the air at 420°C for 25-30 min. The growth process of the *n*/CdS layers was carried out at a source and substrate temperature of 350°C and 540°C, respectively for both types of solar cell heterojunctions. The back contact to the monocrystalline substrate InP was made by the thermal evaporation of Ag+5%Zn alloys. The contact grid to the *n*/CdS layer with an area not more than 0.1 *S* (*S* is the cell's total area) was obtained by indium evaporation with subsequent annealing in hydrogen atmosphere at a temperature of 250°C. In the case of CdS/CdTe the back contact was made by evaporating Te/Ni, for CdS the SnO_2 was used.

The dark current-voltage and the capacitance-voltage characteristics were measured by conventional methods. Photovoltaic characteristics were carried out on a solar simulator with the spectrum AM1.5.

3. RESULTS AND DISCUTIONS

3.1. Dark Current Voltage Characteristics

Fig.1 shows the dark current-voltage characteristics of the CdS/CdTe solar cell heterojunctions at various temperatures. In heterojunctions, it is well known that, if the current transport is dominated by a thermal process, the current-voltage relationship takes the form [7]:

$$J = J_0(\exp\frac{qU}{AkT}) \quad (1),$$

while if tunneling dominates, the *J-U* relationship has the form:

$$J = J_0(\exp BU) \quad (2)$$

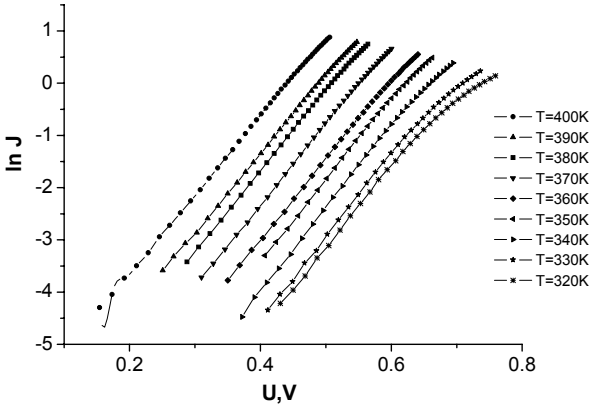


Fig. 1. The ln I=f(V) curves for the CdS/CdTe solar cell heterojunction.

To establish the nature of our *J-U* characteristics, we have estimated the saturation current J_o, the ideality factor (*A)* and the constant (*B)* for these characteristics. J_o is obtained by extrapolating *ln J* versus *U* curves to zero and the values of A and B are calculated from the slopes.

Fig. 1 shows the *lnJ* versus *U* characteristic for the CdS/CdTe solar cell HJ for temperatures between 320 K and 400 K. At low-bias voltage the slope of the *lnJ* versus *U* characteristics for the CdS/CdTe heterojunction is temperature independent with B varying from 17.1 to 15.0. At the voltages higher than 0.6 V the factor A lying in the range of 1.9 to 2.1 and the magnitude of *ln* J_o versus *1/T* is a linear function (Fig. 2) with activation energy obtained from the slope equal to 0.62 eV. For the InP/CdS heterojunction also, we can see two slopes, first with the constant B varying from 12.9 to 11.8, the second with the ideality factor *A* varying from 1.8 to 2.5.

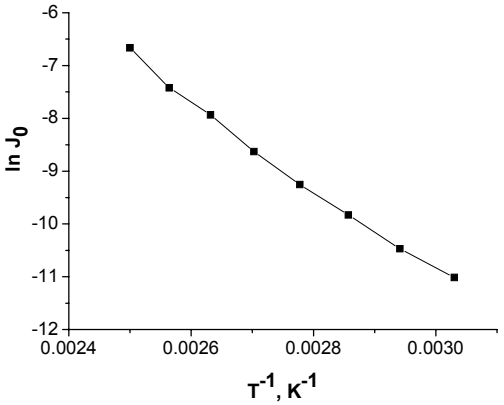


Fig. 2. The ln I_o = f (T^{-1}) dependence of the InP/CdS solar cell heterojunction.

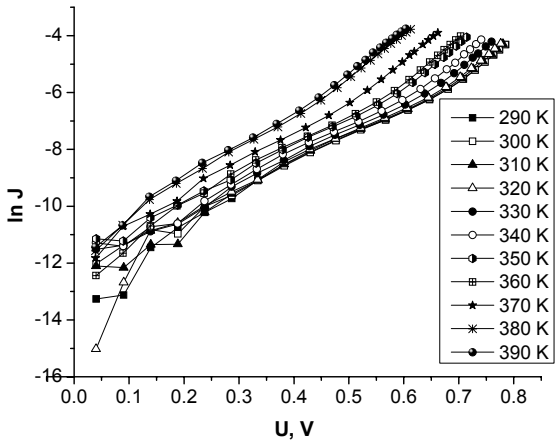


Fig. 3. The ln I=f(V) curves for InP/CdS solar cell heterojunction.

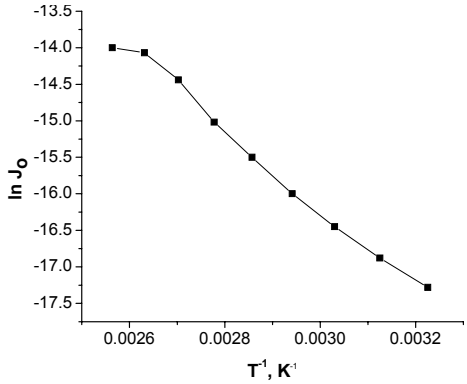


Fig. 4. The ln I_o = f (T^{-1}) dependence on the InP/CdS solar cell heterojunction.

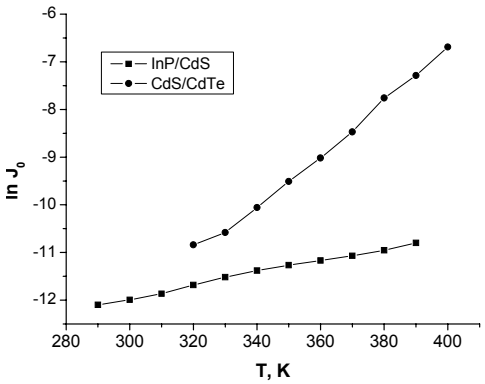


Fig. 5. The ln J_o = f (T) dependence of the InP/CdS and CdS/CdTe solar cell heterojunctions.

Figure 3 shows a plot of *lnJ =f (U)* for the InP/CdS solar cell heterojunction. Figure 4 illustrates the dependence of ln J_o as a function of T^{-1} for the InP/CdS solar cell heterojunction with the activation energy 0.46 eV. Figure 5 shows that the value of the tunneling current of CdS/CdTe solar cell heterojunction is higher than that of the InP/CdS. These results can be qualitatively explained as a tunneling-dominated current due to carriers from the valence band of the *p* –type material or the conduction band of the *n*-CdS tunneling into the interface states where they recombine. The concentration of the interface states is the sum of concentrations of extrinsic states introduced by processing of intrinsic states resulting from lattice mismatch dislocations. Thus the lower values of J_o in the InP/CdS solar cell HJ probably result from reduced lattice mismatch between these two materials.

3.2. Capacitance-Voltage Characteristics

The InP/CdS device exhibited linear $1/C^2$ versus reverse-bias voltage *U* characteristics as shown in Fig. 6. The slope of the characteristics yields a value of doping concentration ($6.9\times 10^{17}cm^{-3}$) on the InP side of the junction in agreement with the known value, the C^{-2}=0 intercept occurs at 0.5 V. The CdS/CdTe HJ exhibited a voltage-independent capacitance. Obviously, the C^{-2}=0 intercept values are too high to be attributed to the diffusion barrier height.

Charged interface states modify the depletion regions in the two materials comprising the junction. We applied the Anderson model [7] to our HJ and calculated the expected diffusion potentials.

Using the values of electron affinity of 4.38 eV and 4.28 eV for InP and CdTe, respectively, and the known values of doping concentrations, we obtained the values of the diffusion potential of 1.0V for both heterojunctions between these semiconductors and the CdS. The electron affinity value of 4.5 eV was taken for CdS. In InP/CdS devices, the C^{-2} =0 intercepts are less than the calculated diffusion voltages. In the CdS/CdTe solar cell HJ according to Donnelly and Milnes model [7] the C^{-2} =0 intercept U_{Di} is related to the true diffusion voltage U_D through the relation $U_{Di} + U_D - \Phi_m - BQ_{is}^2$ where Φ_m is the electric dipole at surface, Q_{is} in the charge in the interface states and *B* is a known function of the properties of the two semiconductors, as observed in CdS/CdTe devices $U_{Di} > U_D$. The experiments reported here do not provide data which could lead to a separation of the contributions of Q_{is} and Φ_m to U_{Di}.

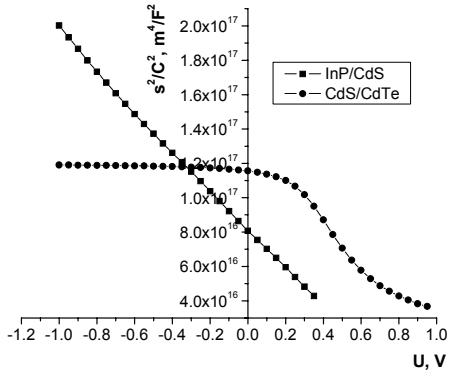


Fig. 6. Capacitance-voltage characteristics of the InP/CdS and CdS/CdTe solar cell heterojunctions.

3.3. Photovoltaic Characteristics

The photovoltaic characteristics have been investigated at the illumination of

heterojunctions through the wide band gap semiconductor–CdS. Fig. 7 shows the light loading characteristics of both solar cell heterojunctions. The measurements carried out on a solar simulator with the spectrum AM1.5 showed that the best photovoltaic parameters were achieved with InP/CdS HJ. Table 1 includes the photovoltaic parameters: J_{sc}, U_{oc}, FF and efficiency for both heterojunctions. The series resistance and dark J-U characteristics determine the fill factor. The main source of the FF decrease is an increase in J_o. To a second approximation the diode factor (A) value can influence FF, if R_s becomes high enough, but even though increase the R_s itself, which is much more important than enhanced A value [8]. Such a low value of FF of CdS/CdTe cells is explained by the high value of R_s.

Table 1. Photovoltaic parameters: 1-CdS/CdTe; 2- InP/CdS.

HJ	J_{sc}, mA/cm^2	U_{oc}, V	FF, %	η, %	R_s, Ω·cm^2	R_{sh}, Ω·cm^2
1	22,75	0,81	51,87	9,56	10,68	2917,4
2	16,75	0,793	83,1	12,04	2,51	1780,8

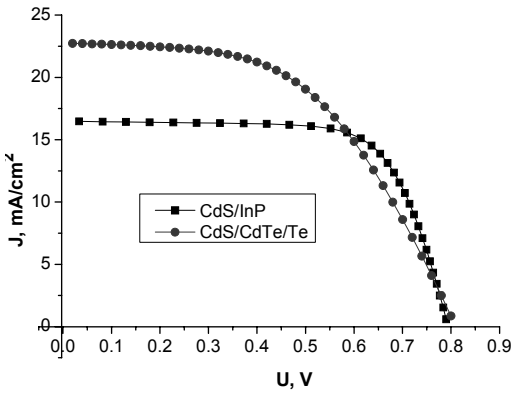


Fig. 7. Current-voltage load characteristics of the InP/CdS and CdS/CdTe solar cell heterojunctions.

4. CONCLUSIONS

In both solar cell heterojunctions studied the J-U and C-U characteristics in the voltage range of interest for photovoltaic devices exhibit a recombination dominated tunneling current. The interface states involved in the tunneling are approximately 0.62 eV in the case of CdS/CdTe HJ and o.46 eV in the InP/CdS HJ below the conduction band of CdS. The study of C-U ecuations has shown that a surface and charged interface states play an important role in both the dark and illuminated characteristics of the solar cell heterojunctions. In both cases the efficiency is limited by the U_{oc} and FF, which depend on the series resistance. The lower efficiency of CdS/CdTe HJ is attributed to the larger mismatch between the two semiconductor materials.

Acknowledgement–This work has been supported by the EU 7th FP project FLEXSOLCELL GA-2008-230861.

References

[1] A. Yoshikawa, Y. Sakai . "High efficiency nCdS/pInP solar cells prepared by the close-spaced tehnique", *Solid State Electronics*, **20**, pp. 133–137, 1977.

[2] F. Himrana, N.M. Pearsall, R. Hill, "High efficiency indium phosphide solar cells with thermally evaporated cadmium sulphide window layers". *The 18th IEEE Photovoltaic Spec. Conf.*, .pp. 338–343, 1985.

[3] B. McCandless, K. Dobson, "Processing options for CdTe thin film solar cells", *Solar Energy*, **77**, pp. 839–856, 2004.

[4] T. Aramoto, F. Adurodija, Y. Nishiyama, T. Arita, A. Hanafusa, K. Omura and A. Morita, "A new technique for large-area thin film CdS/CdTe solar cells", *Solar Energy Materials and Solar Cells*, **75**, pp. 211–216, 2003.

[5] M. Emziane, K. Durose, N. Romeo, A. Bosio, and D.P. Halliday, "Effect of $CdCl_2$ activation on the impurity distribution in CdTe/CdS solar cell structures", *Thin Solid Films*, **480–481**, p. 377, 2005.

[6] T. Potlog, L. Ghimpu, P.Gashin, A. Pudov, T. Nagle, J. Sites, "Influence of annealing in different chlorides on the photovoltaic parameters of CdS/CdTe solar cells", *Solar Energy Materials and Solar Cells*, **80**, pp. 327–334, 2003.

[7] R.B. Bird, W.E. Stewart, E.N. Lighfoot. "Transport Phenomena", *John Wiley& Sons*, p. 125–129, N.Y. 1960.

[8] H. Zhao, A. Farah, D. Moreland C.S. Ferekides, "The effect of impurities on the doping and V_{oc} of CdTe/CdS thin film solar cells", *Thin Solid Films*, **517**, pp. 2365–2370, 2009.