Available online at www.sciencedirect.com
ScienceDirect
Thin Solid Films 515 (2007) 6085–6088
thin solid films
www.elsevier.com/locate/tsf

Characterization of CBD–CdS layers with different S/Cd ratios in the chemical bath and their relation with the efficiency of CdS/CdTe solar cells

O. Vigil-Galán [a,*], A. Morales-Acevedo [b], F. Cruz-Gandarilla [a], M.G. Jiménez-Escamilla [a], J. Aguilar-Hernández [a], G. Contreras-Puente [a], J. Sastré-Hernández [a], E. Sánchez-Meza [a], M.L. Ramón-Garcia [c]

[a] *Escuela Superior de Física y Matemáticas-I.P.N., Edificio No. 9 U.P.A.L.M. 07738 México D. F., México*
[b] *CINVESTAV-IPN, Electrical Engineering Departament, Av. IPN No 2508, 07360 México D. F., México*
[c] *Centro de Investigaciones en Energía.UNAM. Privada Xochicalco s/n Col. Centro Temixco. CP. 62580 Morelos, México*

Available online 30 January 2007

Abstract

In previous papers we have reported the improvement of the efficiency of CdS/CdTe solar cells by varying the thiourea/$CdCl_2$ ratio (R_{tc}) in the chemical bath solution used for the deposition of the CdS layers. In this work, a more complete study concerning the physical properties of Chemical Bath Deposited (CBD) CdS layers studied by photoluminescence, X-ray diffraction and optical spectroscopy are correlated to the *I–V* characteristics under AM 1.5 sunlight and the spectral response of CdS/CdTe solar cells. It is confirmed that the optimum R_{tc} for the CBD CdS films is $R_{tc}=5$, since in this case the best solar cells were obtained and these films show the better optical and structural characteristics.

Keywords: CdS thin films; Physical properties; CBD growth method; Solar cell characterization

1. Introduction

N-type CdS used as the window material for hetero-junction solar cells usually has a high absorption coefficient causing the reduction of the useful current delivered from the cell to the load. In order to improve this, several proposals have been made for improving the spectral response in the blue region of the sun spectrum [1].

We have considered possible changes in the CdS properties by varying the chemical composition. In previous work [2,3] we have demonstrated that the photovoltaic performance of CdS/CdTe solar cells improves when the CBD–CdS layers are prepared with increasing thiourea/$CdCl_2$ ratios in the solution. The maximum value for the energy conversion efficiency η was obtained for $R_{tc}=5$ and 6 and a drop of efficiency was observed for R_{tc} above these values. This means that around $R_{tc}=5$–6, the optimum for the solar cell parameters is obtained. The aim of this work is to correlate the CdS thin film properties with those of the solar cells made with such layers.

2. Experimental

CdS layers were deposited on glass and conducting glass substrates by the CBD technique by varying the thiourea to $CdCl_2$ concentration ratio in the bath solution, named as R_{tc}. All thin films were grown at 75 °C, adjusting the deposition time in order to obtain films with similar thickness [5]. $CdCl_2$ thermal annealing of the CdS–CBD samples was carried in a similar way as the one reported in reference [3]. Solar cells were prepared following the same experimental conditions reported in reference [2].

X-ray diffractograms (XRD) were recorded in a small-angle X-ray diffraction system using a Rigaku D/MAX-2200 difractometer in FLAT position with Cu Kα radiation. The incidence angle was 1°. The CdS layers composition was determined by energy dispersive spectroscopy (EDS) using a JEOL 6360-LV microscope. A step profiler was used for thickness measurements (Sloan Dektak III). Optical transmission data were measured with

* Corresponding author. Fax: +52 5586 2957.
E-mail addresses: osvaldo@esfm.ipn.mx, vigil46gg@yahoo.com.mx (O. Vigil-Galán).

0040-6090/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.tsf.2006.12.094

Table 1
Short circuit current (J_{sc}), open circuit voltage (V_{OC}), fill factor (FF) and efficiency (η) for CdS/CdTe solar cells with different R_{tc} ratios in the CdS bath

R_{tc}	J_{sc} (mA/cm^2)	V_{OC} (mV)	FF (%)	η (%)
1	20.8	617	55.2	7.1
4	21.8	699	55.3	8.4
5	23.8	740	70.5	12.4
6	21.1	726	69.0	10.6
7	20.5	702	65.0	9.4

These parameters were measured under AM1.5 illumination.

a Lambda 35 UV/VIS Perkin–Elmer double beam spectrophotometer in the 350–1000 nm wavelength range. Electrical measurements were performed by using indium as ohmic contact. Photoluminescence (PL) measurements at 10 K and room temperature were done in the 1.4–2.6 eV energy range

I–V characteristics of the solar cells were measured under 100 mW/cm^2 illumination (measured with a calibrated solar cell). Spectral response measurements for the solar cells were made illuminating the CdS side and detecting the signal on the copper–gold and SnO_2:F contacts.

3. Results and discussion

3.1. Solar cell performance

Table 1 shows the values of the main parameters of the solar cells obtained with different R_{tc} ratio in the CdS bath solution. As it can be observed, the values of J_{sc}, V_{oc}, FF and η reach their higher values for $R_{tc}=5$ and then drop for bigger R_{tc}.

The values of the ideal diode factor (n) and saturation current (J_0) of the fabricated solar cells with $R_{tc}=5$ were calculated under dark and illumination conditions [2]. Under illumination the above parameters were 1.4 and 9×10^{-11} A cm^{-2}, respectively. However in dark conditions $n=2.1$ and $J_0=6\times10^{-9}$ A cm^{-2}, respectively, which are not representative of the measured solar cell open circuit voltages shown in Table 1. The above results show that diode characteristics change under illumination due to the photoconductive properties of the CdS and CdTe layers.

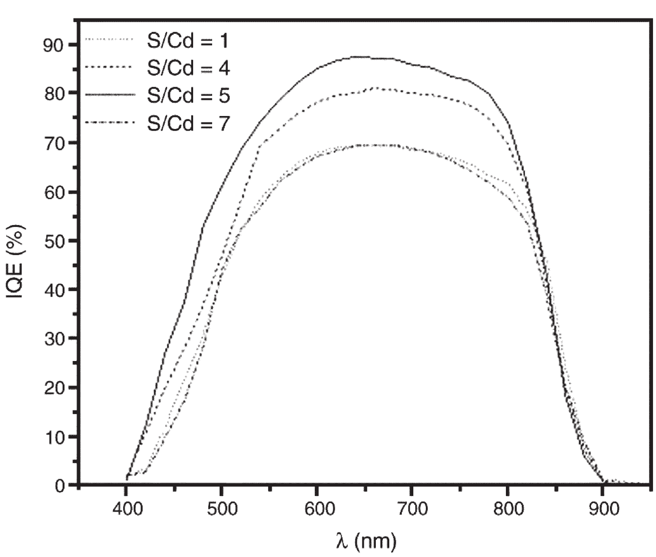

Fig. 1. Internal quantum efficiencies (IQE) spectra of the CdS/CdTe solar cells made with different R_{tc} values. The spectral response of solar cells with $R_{tc}=6$ (none shown) was similar to ones with $R_{tc}=1$ and 7.

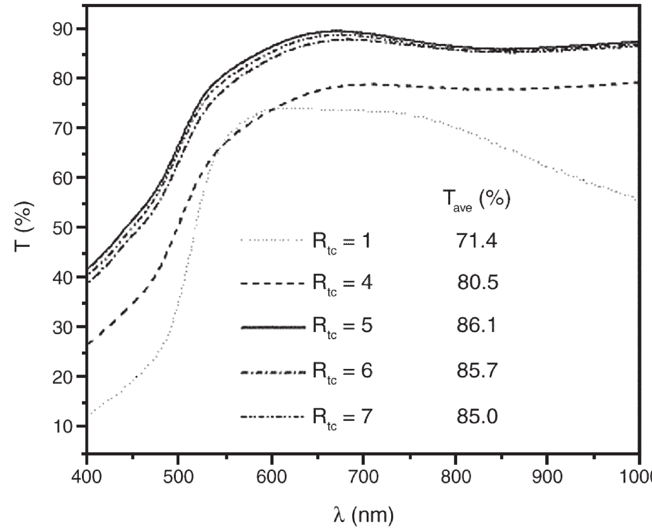

Fig. 2. Optical transmission spectra of CBD–CdS films grown at different R_{tc} values.

In Fig. 1 the internal quantum efficiency variation shows that changes in the R_{tc} value affects not only the characteristics of the absorption coefficient of the CdS layer, but it also does modify the CdS/CdTe interface and the bulk properties of the CdTe layer since the internal quantum efficiency changes in the whole wavelength range. A further and more in-depth study of these effects is required, and it will be carried out in future work.

3.2. CBD–CdS thin film properties

The CBD–CdS thin films properties are summarized as follows:

- A shift in the transmission spectra of the CdS films is in correspondence with the one observed for the internal quantum efficiency spectra of the cells (see Figs. 1 and 2).
- High optical transmission and large bandgap values of the window material, with the highest average optical transmission for $R_{tc}=5$.
- Changes in the thickness of the layers (Table 2), which can be explained by changes in the CBD–CdS thin film growth kinetics with the variation of R_{tc} [4].

Table 2
Thickness (d), average transmission (T_{av}) and band gap energy (BGE) of the CBD–CdS layers for different R_{tc} values

R_{tc}	Thickness (nm)	T_{av} (%)	BGE (eV)
1	110.4	71.4	2.39
4	86.4	80.5	2.50
5	81.8	86.1	2.48
6	84.0	85.7	2.49
7	86.2	85.0	2.48