The role of the CdS buffer layer in the CuInS$_2$ Thin film solar cell

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Abstract - In this contribution, we report some studies on cadmium sulphide CdS thin films grown by Chemical Bath Deposition (CBD) process. The effect of the single and multiple dips deposition processes by using novel chemical bath on the thickness of the CdS obtained are investigated. The obtained results were used to study the influence of the layer thickness of the CdS on the performance of CuInS$_2$ based solar cells. Several hetero-junctions of ZnO/CdS/CuInS$_2$ type with different thickness of the CdS layer have been prepared and the devices properties are measured under AM1.5 solar spectrum.


1. INTRODUCTION

To date the Cadmium sulphide CdS has received the most attention due to its very important role as the best heterojunction partner for CuInX$_2$ (X = S, Se…) and CdTe photovoltaic solar cells. A thin CdS films is deposited as intermediate layers to improve the interface properties and as chemical buffer layer to protect the CuInX$_2$ or CdTe during the subsequent processing. ZnO/Thin CdS (CBD)/Cu(In,Ga)Se$_2$ and ITO or SnO$_2$/ Thin CdS (CBD)/CdTe solar cells have demonstrated a good stability and high efficiency approaching respectively 15.8 % [1]. Many techniques including electrodeposition [2], spray pyrolysis [3], vacuum evaporation [4], and chemical bath deposition CBD [5] have been used to produce the CdS thin layers. Among this deposition process, CBD appears to be a relatively simple, inexpensive method to prepare a reproducible and homogeneous film at low temperatures.

2. EXPERIMENTAL DETAILS

The as deposited thin CdS layers is grown by chemical bath deposition (CBD) using an aqueous solution containing a cadmium chloride CdCl$_2$ and the SC (NH$_2$)$_2$ used respectively as the cadmium and the sulphur ions source, ammonium hydroxide NH$_4$OH and the ammonium chloride NH$_4$Cl as the complexing agents.

The CdS films are formed from the reaction between dissolved cadmium ions and thiourea molecules in alkaline solutions. According to the literature [6, 7] it has been pointed that the film can be formed in general by two different mechanisms: i) the direct reaction of the ions at the surface of the substrates through ions-by-ions deposition via metastable complex comprising Cd

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and S agents and/or ii) the cluster-by-clusters deposition via CdS colloidal particles formed in the solution.

\[
\text{Cd}^{2+} + \text{S}^{2-} \rightarrow \text{CdS} \quad \text{(Simple ion-by-ion mechanism)}
\]

\[
\text{Cd(OH)}_2 + \text{S}^{2-} \rightarrow \text{CdS} + 2\text{OH}^-
\quad \text{(Simple cluster hydroxide mechanism)}
\]

The details on the experimental set-up and the optimal deposition parameters of the as-deposited CdS thin films were similar to those previously reported [8].

The effect of the thickness on the structural, optical and the surface morphology of CdS layers are investigated by operating single and multiple dip processes using novel bath solutions. In the case of single dip process, the substrate was coated only once and the thickness of the grown films ranged from about 20 to 40 nm. For multiple dips process the substrate was coated at least two times and at most three times. The thickness yield after the first coating was found to be 50%. The thickness of the film grown by three-dip process was between 80 and 100 nm.

The structure of CuInS\(_2\) based cell tested in this work is illustrated in Figure 1. The CuInS\(_2\) layer serves as a p-doped absorber while the CdS and also the ZnO layers constitute the n-doped windows part of the p-n junction. The separated carriers from the electron-hole pairs are collected at the electric contacts in each end of the cell: ITO in the front and Hg contact in the back. The light is coming from below. The copper indium disulphide (CuInS\(_2\)) absorber and the zinc oxide (ZnO) window layers have been deposited via spray pyrolysis process whereas the chemical bath deposition (CBD) methods were used to deposit a cadmium sulphide (CdS) buffer layers. Earlier we reported the detail of the preparation of CuInS\(_2\) and ZnO thin films by spray pyrolysis process [9, 10].

Optical transmission of the films was recorded at 300 K using a Shimadzu double beam spectrophotometer in the wavelength range 250 to 1100 nm. The structures of the films were studied by using a Rigaku X-ray powder diffractometer with Cu K\(_\alpha\) radiation.

### 3. RESULTS AND DISCUSSIONS

#### 3.1 Structural and optical investigations of CBD CdS thin films

As is well known, CdS can exist in two crystalline structures: the hexagonal (Wurtzite) phase and the cubic (zincblende) phase. We report in Figure 1 the comparative X-ray diffraction spectrums of CdS films grown by simple and triple dip processes on glass slide substrates. These spectrums showed that the films have highly oriented crystallites with a preferential orientation along the c-axis ((002) direction) perpendicular to the substrate plane. In the case of thicker films shown in Fig. 1(b) the (002) diffraction line localised at approximately 26.9° and the weak others at approximately 25°, 29.5° and 48.4° match with the (100), (101) and (103) diffraction lines of hexagonal phase CdS. The present result concerning the hexagonal structure of as-grown CBD CdS film is in good agreement with the ones reported by several other authors [11, 12].

Fig. 2 shows the optical transmittance spectrum for wavelengths of 200–1100 nm for CdS films deposited under the deposition conditions with different thickness. The spectra show an average transmission of above 70% was obtained in the visible range. From these spectra, we can also observe the presence of a sharp cut-off suggesting a direct band gap and interference fringes.
characteristic of thick films. In both CdS films, the optical transmission spectrum of the as-deposited film displays its absorption edge at about 500 nm suggesting that increasing of thickness does not affect the optical band gap. The determined band gap value is comparable with previously reported values (2.40 eV) [13, 14].

3.2 Device performance of ZnO/CdS/CuInS_2 cell

Table 1 summarizes the performance parameters of ZnO/CdS/CuInS_2 cells without and with two different CdS buffer layers thickness. In the case of the as-grown device without CdS buffer layer, the cell efficiencies are relatively quite poor, with low $V_{OC}$, $J_{SC}$ and FF compared to those of the standard CdS device. The same result observed by [15] has been explained by a high surface recombination due to a physical damage of the CuInS_2/ZnO interface and unfavourable conduction band alignment between the ZnO and CuInS_2. Solar cells with the CdS buffer layer have relatively the best performance. One notices however according to these results that the smallest CdS thickness of 60 nm is sufficient to achieve the increase of $V_{OC}$, whereas with further increasing CdS thickness $V_{OC}$ slightly redreases and the $J_{SC}$ decrease remarkably what one can explain by the photon absorption looses in the window layer in the case of thicker CdS buffer layer.

![Fig. 1: The x-ray diffraction spectrums of CdS thin film prepared at 75°C from a) single dip process b) triple dip process](image1)

![Fig. 2: Optical transmittance spectrums in the wavelength range of 250-1100 nm for CBD CdS films prepared at 75 °C by using multiple dip processes: a) single, b) double, and c) triple.](image2)

<table>
<thead>
<tr>
<th>Thickness (nm)</th>
<th>$V_{OC}$ (mV)</th>
<th>$J_{SC}$ (mA/cm²)</th>
<th>FF (%)</th>
<th>$\eta$ (%)</th>
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<tbody>
<tr>
<td>0</td>
<td>206</td>
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<td>35</td>
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<td>60</td>
<td>270</td>
<td>28</td>
<td>43</td>
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<td>100</td>
<td>247</td>
<td>12,5</td>
<td>40</td>
<td>1.2</td>
</tr>
</tbody>
</table>

4. CONCLUSION

In this work we used the chemical bath deposition process CBD for for growing uniform and reproducible CdS buffer layer within a sprayed CuInS_2 based solar cell. These results indicate that the CBD process is best suited for thin film deposition because of simplicity, least expenses to produce uniform, adherent and reproducible large area thin films for solar related applications.
On the hand the device performance was found to be dependent on the CdS layer thickness and an optimum thickness of CdS is very important for high efficiency solar cells.

REFERENCES


