Abstract: Chemical bath deposition (CBD) method is used to deposit n-type Cadmium sulfide (CdS) thin film on Cd(In,Ga)S$_2$ solar cell. Different CdS thin film thicknesses were obtained via changing different deposition time (20, 30, 40 min). The thicknesses were determined of 89, 167, 247 nm by SEM. This paper mainly discussed the structural, optical properties and efficiency parameters of three different thicknesses of CdS thin films deposited on CIGS absorber layer using X-ray diffraction spectroscopy (XRD), scanning electrode microscope (SEM) and UV-Vis spectrophotometer. The result reveals that the thicknesses effect the transmittance at longer wavelength region more. The 89 nm CdS thin film device has the most high efficiency of 8.04%. $V_{oc}$ 0.45V, $I_{sc}$ 6.81 mA, FF 0.52. From the result, the proper thickness of CdS thin film is estimated of 50-100 nm.

Keywords: CBD, CdS, Buffer layer, CIGS, solar cells

I. INTRODUCTION

Cu(In,Ga)S$_2$ thin film solar cell is a type of photovoltaic (PV) devices which has demonstrated efficiencies about 19.3% [1]. The structure of CIGS devices consists of several stacks deposited on the soda-lime glass (SLG) as a substrate: SLG/Mo/p-CIGS/n-CdS/ZnO/ZnO:Al/Al grid. Cadmium sulfide (CdS) thin film is the n-type buffer layer deposited on CIGS absorber layer. There are some reasons for choosing CdS to be the buffer layer of CIGS solar cells: Good quality at the interface of CIGS/CdS, well lattice matching, less pin hole defect and etc. CdS thin film can be deposited on CIGS absorber layer completely and densely, forming well-quality p-n junction of devices. In addition, CdS thin film has large band gap than CIGS, which can lead to longer wavelength sunlight transmission into CIGS absorber layer, enhancing efficiency of the photovoltaic devices. There are some deposition ways for CdS thin film consisting sputtering, evaporation, and Chemical-bath-deposition. Among these ways, chemical-bath-deposition is a common process which is widely used to deposited CdS. CBD method is a reaction in liquid phase at lower temperature (60°C-90°C) which is an easy, low-cost process and widely used to deposit large area fabrication. In this paper, we chose the CBD method to deposit different thicknesses of CdS thin films on CIGS absorber layer, comparing the structural morphology, optical properties and efficiency parameter of CIGS solar cell devices.

Typical reactants of CBD for CdS thin film deposition reaction consists Cadmium salt, thiourea, and ammonia solution. Cadmium salt and thiourea mainly offer the source of Cd$^{2+}$ and S$^{2-}$ ions and ammonia solution is the role of complexing agent. The chemical mechanism of CBD for CdS was mentioned in many theses. According to Ortega-Borges and Linicot, they suggested the chemical mechanism of CBD for CdS thin film growth [2-3]. When Cadmium salt is added into ammonia complex solution, there is a reversible absorption of dihydroxo-cadmium in the site of substrate. The Cd$^{2+}$ ion will released by the decomplexation of Cd(NH$_3$)$_4^{2+}$.

$$\text{Cd(NH}_3)_4^{2+} + 2\text{OH}^- \rightarrow \text{Cd(OH)}_2 + 4\text{NH}_3$$ (1)

At the same time, thiourea is decomposed in the alkaline environment and the S$^{2-}$ ions is released into the solution.

$$\text{S(C(NH}_3)_2 + 2\text{OH}^- \rightarrow S^{2-} + \text{CN}_2\text{H}_2 + 2\text{H}_2\text{O}$$ (2)

If the ionic product of [Cd$^{2+}$] and [S$^{2-}$] exceeds the solubility product of CdS, the nucleation of CdS will occur at the substrate. The total reaction of CdS deposition can be written as the formula:

$$\text{Cd(NH}_3)_4^{2+} + \text{S(C(NH}_3)_2 + 2\text{OH}^- \rightarrow \text{CdS} + \text{CN}_2\text{H}_2 + 4\text{NH}_3 + 2\text{H}_2\text{O}$$ (3)

The factors which influence the reaction consist of the concentration of the Cadmium and Sulfur source, pH value of the solution, and deposition temperature and etc. In our work, we used CdSO$_4$ as Cadmium source and thiourea as sulfur source and 28 wt% ammonia as complexing agent. Fixed the concentration of reactant and changed deposition times to get different thicknesses of CdS on CIGS.

II. DETAILS EXPERIMENTAL

The structure of CIGS solar cell is SLG/Mo/p-CIGS/n-CdS/ZnO/ZnO:Al/Al grid. First the soda lime glass was chosen as the substrate. After cleaning procedure in the DI water, Mo back contact was first deposited on soda lime glass by sputtering. CIGS absorber was deposited by sputtering selenization. After absorber layer deposition, the samples were immersed into reaction solution consisting 0.003M CdSO$_4$, 0.03M thiourea, 1.6M NH$_4$OH at room temperature. Then the bath was heated to 60°C by hot
plate stirrer and the CdS thin films were deposited on CIGS. Different thicknesses of CdS buffer layers were deposited via changing different deposition time (20, 30, 40 min). After deposition of CdS on CIGS, the i-ZnO and AZO (98wt% Zno, 2wt% Al$_2$O$_3$) window layer and Al grid electrode were deposited by sputtering, completing the whole solar cell devices.

The optical properties were measured by UV-Vis spectroscopy, obtaining the optical transmission of different thicknesses CdS. Surface morphologies were investigated by scanning electron microscopy (SEM). Structural characterizations were obtained using 18-kW X-ray Diffraction (XRD, CuKα, α=1.5418). Current-voltage characteristics were measured under AM1.5 standard spectrum, obtaining open circuit voltage ($V_{OC}$), short circuit current ($I_{SC}$), fill factor (FF) and efficiencies (η) of cell devices.

**1. RESULTS AND DISCUSSION**

The GI-XRD patterns of CdS for 2 different thicknesses were shown in Figure 1. From the patterns of Figure 1, the CdS diffraction peaks can be found at 20 values of 26.98°, 44.78°, 53.06°, corresponding to the orientation (111), (220), and (311). The intensity of the (220), (311) peaks are more obvious when increasing the deposition times of CBD. The peaks orientation of (111), (220), (311) are similar to the orientation of cubic structure. However, the hexagonal peaks are not obtained from the XRD patterns [4-6]. Thus, we judged the CdS structure is likely the cubic rather than hexagonal. Figure 2 shows the XRD patterns of CdS/CIGS/Mo/SLG at different CdS thicknesses. The judgement of CdS peaks is difficult in the patterns of CdS/CIGS/Mo/SLG since the CdS peaks locations are close to CIGS peak’s, which causes the (111/112) and (204/220) orientation overlapping at 26.98°, 44.78°. Optical transmittance of different thicknesses of CdS is shown in Figure 3. The optical transmittance at longer wavelength region decreased more when increasing the thickness. This result may cause weak absorption of CIGS absorber layer since the band gap of CIGS absorber layer is about 1.1-1.2ev [7], corresponding to the wavelength about 1127 nm. Surface morphologies of different thicknesses of CdS thin films were shown in Figure 4. The coverage of CdS thin film on CIGS absorber layers becomes more dense when adding deposition time. Nevertheless, when the thickness of CdS thin film increases, the collection of carriers will be more difficult since the path of carrier collection becomes longer. Table 1 reveals that the efficiency decreases when the thicknesses of CdS increase. Thus we speculate the proper thickness of CdS thin films is about 100 nm. Table 1 shows the efficiency parameters of CIGS solar cell devices for 3 different thicknesses CdS. The best efficiency of the three samples is 87 nm CdS device. The 87 nm CdS device has open circuit voltage $V_{OC}$ 0.45V, short circuit current $I_{SC}$ 6.81mA, fill factor FF 0.52, efficiency η 8.04%. With the CdS thickness increasing, the $I_{SC}$ drop more obvious than $V_{OC}$.
Chemical-Bath Deposition For Different Thickness CDS Buffer Layer on CIGS Solar Cell

Fig. 5. I–V Curves for different thicknesses CdS buffer layer.

Table 1: The efficiency parameters of different CdS thin film thicknesses.

<table>
<thead>
<tr>
<th>Sample</th>
<th>V_{OC}(V)</th>
<th>I_{SC}(mA)</th>
<th>FF</th>
<th>η(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(89nm)</td>
<td>0.45</td>
<td>6.81</td>
<td>0.52</td>
<td>8.04</td>
</tr>
<tr>
<td>B(167nm)</td>
<td>0.45</td>
<td>6.16</td>
<td>0.5</td>
<td>7.02</td>
</tr>
<tr>
<td>C(247nm)</td>
<td>0.42</td>
<td>5.09</td>
<td>0.49</td>
<td>5.28</td>
</tr>
</tbody>
</table>

CONCLUSIONS

In this research, we compared the structural characterization, optical properties, and surface morphology of the different thicknesses of CdS thin film on CIGS solar cell. We found that when the thickness of CdS increases, the optical transmittance of longer wavelength region drops more than in short wavelength region. This may be the main reason which reduces the efficiency when adding the thickness of CdS thin film. In the three CdS thicknesses devices, the 89 nm CdS has most high efficiency. From the result, we speculated the proper thickness of CdS is about 50-100 nm.

REFERENCES


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