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Effect of Thickness Variation of the N-Type Layer in CdS/CdTe Solar Cell

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Abstract: In this paper, we have prepared thin films by thermal evaporation on an ITO coated glass substrate. The thin film of an n-type material of CdS, having thickness as 100, 150 and 200 nm, and also deposited CdTe film having a thickness 1 μm over these films. We used the Silver paste to generate front and back contact for solar cell characterization. To increase the efficiency of solar cells the CdCl₂ treatment has done with heat treatment using the furnace at 4000 C for 30 minutes for crystalline the structure. The UV-VIS-NIR spectrometer had used to study the optical absorption between 300-1100 nm, its transmission graph shows that the solar cell absorbed wavelength below 800nm. To study the I-V characteristics of solar cells we have used Keithley constant current supply, the result showed that the efficiency of solar cell increase 6.42, 7.07 and 9.10% with increasing thickness of an n-type layer of CdS (100,150 and 200nm respectively) and the SEM was described surface morphology of thin films.

Keywords: Physical vapor deposition, Telluride, Semiconductor materials, thin-film solar cell.

1 Introduction

Nowadays the energy requirement of the world is increasing, while the fossil fuel limited, also it emits greenhouse gases causing global warming. It can utilize renewable energy such as wind and solar cells to overcome the shortage of energy; also they have a friendly environment. The II-VI group solar cell based on CdTe material has become a low-cost solar cell with efficiency having ~22% or higher [1] and cadmium sulfide (CdS) has used as a window layer material for CdTe based solar cell [2]. The CdTe thin-film solar cell reported highest lab-scale efficiency range of 18-24% [3-5], The CdTe based solar cell has examine as a good candidate for large scale module production, using various thin-film technologies such as sputtering [6], Chemical Vapor Deposition (MOCVD) [7], Closed Spaced Sublimation (CSS) [8], thermal evaporation [9] and Molecular Beam Epitaxy (MBE) [10], etc. these techniques have attempted to produce a thin film Photovoltaic. Close spaced sublimation (CSS) and thermal evaporation techniques can produce a homogeneous thin film. Cadmium chloride (CdCl₂) treatment on the solar cell is a key process to increase the efficiency of the solar cell, for this treatment firstly CdCl₂ dissolves in methanol then the mixture of both, put on CdTe film using the injection and place this film in a furnace for heat treatment. Besides,

we can also deposit CdCl₂ film by thermal vacuum evaporation [11].

Although there are many techniques, that can be used for improving the efficiency of the solar cells at a low cost. The CdTe/CdS thin-film solar cell efficiency has reached greater than 20% [12]. This type of solar cell has now considered as the most promising material for large scale production and also the fabrication method of CdTe based solar cells is suitable for large scale production. From the many decades, silicon-based solar cells dominated the market and an increase in manufacturing capabilities; thin-film PV cells are gaining significance in the market [13].

In this paper, we have used thermal evaporation method to deposit the thin film on a cleaned ITO coated glass substrate, there were three sets of CdS as 100, 150 and 200nm thickness, have prepared with CdTe over layer thickness 1 μm to make ITO/CdS/CdTe thin-film solar cell, Then treated with heat and CdCl₂. We had used the standard condition Air mass (1.5) for the I-V plot. The UV-VIS-NIR and SEM had used to study material characterization.

2 Experimental

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Cadmium telluride (CdTe) and Cadmium sulfide (CdS) material with purity 99.999%, used to prepare solar cells. Thermal evaporation method was used to deposit both CdTe and CdS layer, in this method CdS material was placed in a tungsten boat then evaporated on cleaned ITO coated glass substrate and deposited three different thicknesses as 100, 150 and 200nm, then all three films again placed in a chamber and deposited CdTe layer of 1 μ m. For CdCl₂ treatment, it was dissolved into methanol then put on CdTe top layer using the injection and annealed in a furnace at 400°C for 30 minutes. The transmission and absorption spectra of ITO/CdS/CdTe thin-film have been studied using a UV-VIS-NIR spectrophotometer in the range of 300-1100nm. The I-V characteristics carried out, using Keithley to calculate the efficiency of the solar cell. The scanning electron microscope (SEM) had used to see the surface morphology of the thin film.

3 Results and Discussion

3.1 Transmission Spectra

The transmission spectra of CdS/CdTe thin films with varying thickness of the CdS layer had been observed by UV-VIS-NIR spectrophotometer in the range 300-1100nm shown in Figure 1. We can see it is zero below 800nm. It was increasing suddenly, for wavelength greater than 800nm. And with increasing thickness of the CdS layer from 100 to 200nm, the transmission was decreasing.

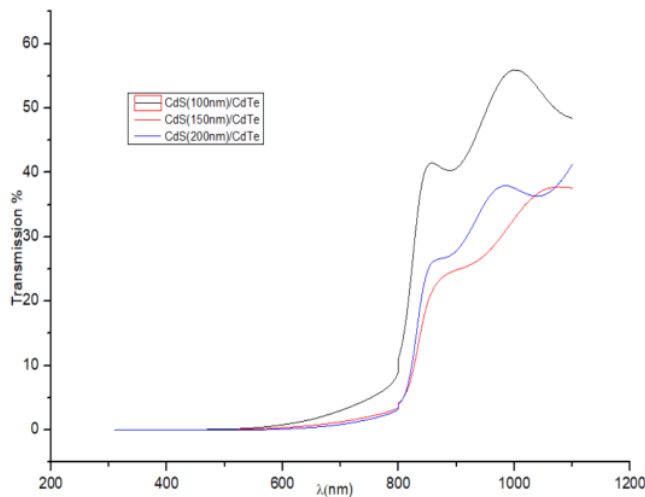


Fig.1: Transmission spectra of ITO/CdS/CdTe thin film.

3.2 Absorption Spectra

I had observed the absorption spectra of thin films using a UV-VIS-NIR spectrophotometer, shown in Figure 2.

This absorption spectra show that below 800nm absorption is high, as compared to the wavelength greater than 800nm. The absorption had increased with increasing CdS

thickness; these results may be because of crystallinity and an increase in grain size, this result also verified with our SEM results that show, it had increased the grain size with thickness. By increasing grain size the probability of charge recombination is decreasing and the lifetime of charge carrier is increasing, which is in good agreement to increase the efficiency of the solar cell. This result also verifies the data of I-V characteristics.

The essential absorption occurs because of electron excitation, from the valance band to the conduction band. The optical band gap of these spectra can be calculate using Tauc relation.

$$(\alpha h\nu) = A (h\nu - E_g)^n$$

Where E_g is the bandgap of the material, A is a constant, α is an absorption coefficient, $n = \frac{1}{2}$ for directly allowed bandgap as in our case, and $n=2$ for indirect forbidden bandgap material.

The direct bandgap values can calculate, from the intercept of $(\alpha h\nu)^2$ against the photon energy ($h\nu$) shown in Figure 3. This shows the change in the optical band of CdTe and CdS with various thicknesses.

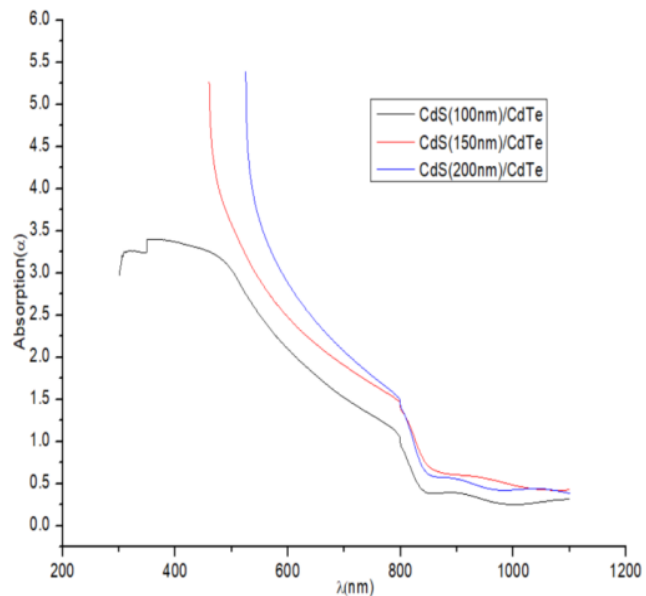


Fig.2: Absorption spectra of ITO/CdS/CdTe solar cell.

The optical band gap of CdS had been decreasing with increasing thickness of the CdS layer from 2.07 to 1.92 eV and for the CdTe band gap is 1.45eV, these observed bandgap data are in a good agreement with result [14]. The bandgap decrease with increasing thickness [15], in the following paper CdS thin film had deposited, on the cleaned glass substrate using the CBD method. The CdS atoms concentration had increased and found that the bandgap of CdS was decreasing from 2.45 to 2.35eV,

which was well-matched with our data. The CdS thin film had deposited onto a glass substrate, using the spray pyrolysis technique, using cadmium acetate and thiourea

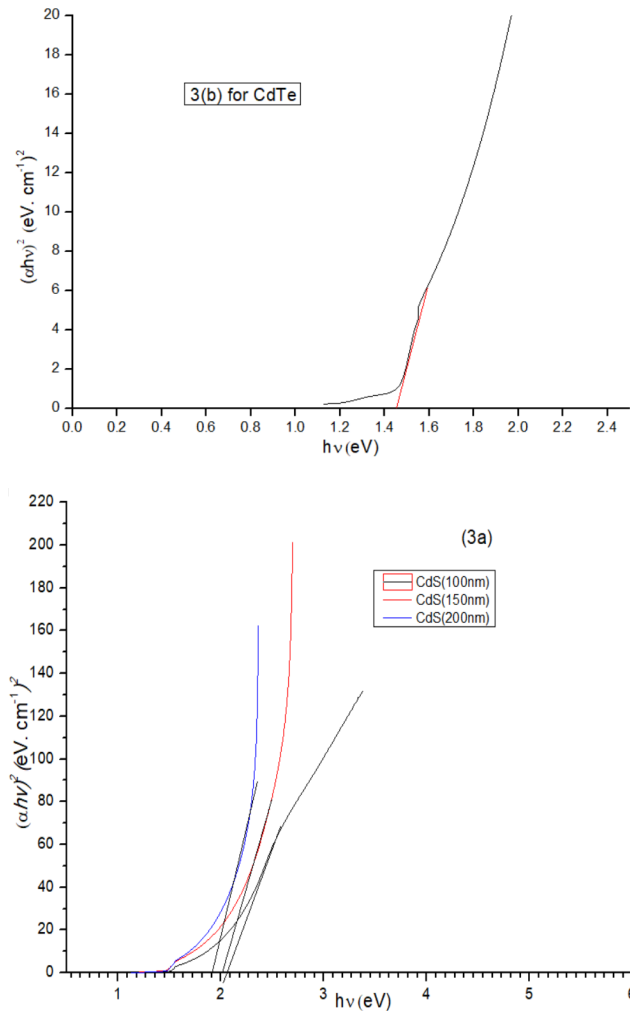


Fig. 3: The plot between $(\alpha hv)^2$ versus $h\nu$ to calculate the band gap (a) for CdS and (b) for CdTe.

precurea solution for different deposition time at 573K [16], they increased CdS layer thickness from 110nm to 250nm and found that the bandgap of CdS had decreased from 2.48eV to 2.15eV. The CdS layer had been deposited on a glass substrate using an evaporation method under the pressure of 10^{-6} Torr.[17], they have observed the absorption spectra between 300-900nm and found that by increasing the thickness of the CdS layer from 290 to 2550nm, the bandgap varied from 2.43 to 1.96eV. We had also observed the same result in this paper.

The absorption was increasing with CdS thickness. I obtained this result because of an increase in crystallinity and our SEM results had justified the increase in grain size. The bandgap value for thin films has shown in table 1

3.3 Extinction Coefficient

The relation between extinction coefficient (k) and photon energy ($h\nu$) within the range of 300-1100nm noticed. The extinction coefficient (k) can be calculated using the well-known formula.

$$K = \alpha \lambda / 4\pi$$

Figure 4, shows the plot between extinction coefficients (k) versus energy ($h\nu$), which gives the details about the crystallinity and grain size of the thin film.

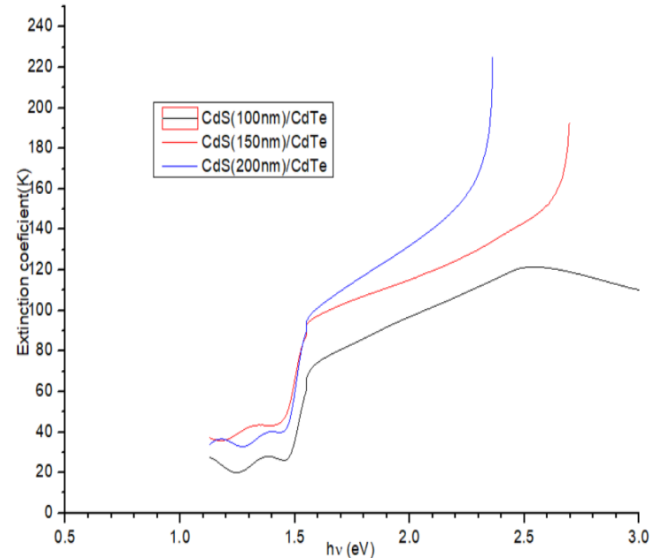


Fig. 4: The plot between extinction coefficients (k) versus energy ($h\nu$).

There is a little constant in the extinction coefficient below 1.45eV, but at this energy, the extinction coefficient was increasing abruptly, and for energy greater than 1.45eV it has been increasing. While it has been increased the extinction coefficient with increasing CdS thickness for all three thin films, or it is decreasing regarding wavelength. It had increased the crystallinity and grain size. Resultant, the absorption increased with increasing CdS layer thickness. The CdS layer has been deposited by chemical and spray pyrolysis of different thickness [18], they have plotted a graph between extinction coefficient and wavelength, and got that the extinction coefficient has decreased with increasing the thickness, which had well-matched with our results.

3.4 I-V Characteristic of Solar Cell

The I-V characteristics of ITO/CdS/CdTe solar cells (area 1cm²) had taken in the standard condition of AM1.5 using Keithley. The I-V curves of the solar cell with various

thickness of the CdS layer had shown in Figure 5, to calculate the fill factor and efficiency of the solar cell.

Table 1: Fill factor and Efficiency.

Thin film	Bandgap	V_{oc}	I_{sc}	Fill factor	Efficiency
CdS(100nm)/CdTe	1.47 and 2.07eV	0.18	1.44	0.47	6.42%
CdS(150nm)/CdTe	1.45 and 2.04eV	0.29	1.42	0.33	7.07%
CdS(200nm)/CdTe	1.45 and 1.92eV	0.46	1.41	0.40	9.10%

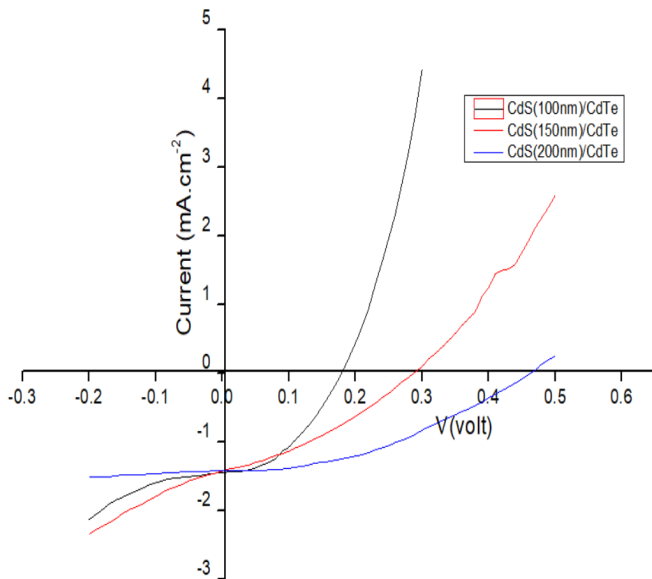


Fig.5: Current-Voltage characteristic of ITO/CdS/CdTe solar cell.

It shows, with increasing the thickness of the CdS layer Short circuit current (I_{sc}) is constant but the Open circuit voltage (V_{oc}) had increased, resultant the efficiency of the

solar cell was increasing. For CdS thickness varied as 100, 150, and 200nm the efficiency of the solar cell had achieved 6.42, 7.07, and 9.10%. Therefore the thicker CdS layer absorbs more photons at the same time the recombination losses decreased with increasing thickness. The resultant a drastically changed has been investigated in efficiency. In the CdS/CdTe thin-film [19], by changing the thickness of the CdTe layer from $1\mu\text{m}$ to $10\mu\text{m}$ the efficiency of the solar cell had changed from 14.33 to 20.79%.

3.5 Scanning Electron Microscope (SEM)

I had taken the SEM images from top of the thin film at the CdTe side, that image shows that the layer of CdTe had deposited uniformly all over the CdS layer, and there is no pinhole found in the surface of CdTe layer. This is in a convenient situation for solar cell characteristics. The Grain size had increased with increasing the thickness of the CdS layer. The CdS layer had been deposited for 30, 40 and 60 min on the PbS layer [20], they found that the grain size and crystallinity has been increased with increasing thickness of CdS layer due to reduction in peak broadness in XRD pattern. An increase in grain size is useful to increase the lifetime of charge carrier and less probability of charge carrier recombination increasing the solar cell efficiency.

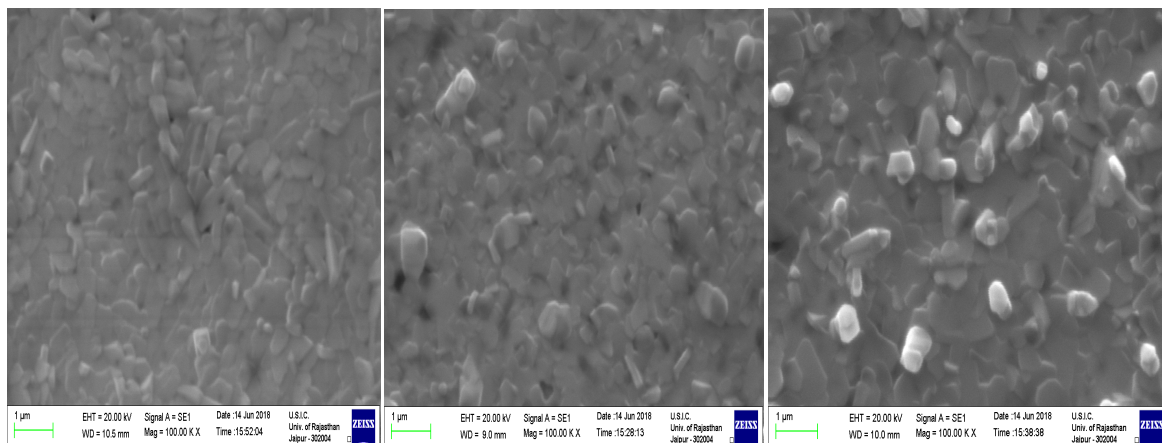


Fig. 6(a): CdS(100nm)/CdTe .

Fig. 6(b): CdS(150nm)/CdTe .

Fig.6(c): CdS(200nm)/CdTe.

4 Conclusions

Both CdS and CdTe thin films had been deposited on ITO coated glass substrate using a thermal evaporation method, and then the CdCl₂ and heat treatment had done. The optical band gap of thin films has been observed 2.07, 2.04, and 1.92eV for the thickness of CdS layer 100, 150 and 200nm respectively, and 1.45eV for CdTe thin film. This is in good agreement to increase the property of the solar cell. The I-V plot of thin-film had taken using Keithley in the condition of AM1.5, the efficiency of solar cells with various thickness of CdS as 100, 150 and 200nm had got 6.42, 7.07 and 9.10% respectively, so we concluded, by the increase in thickness, efficiency is also increasing, it may be because of the increase in grain size, crystallinity of material and the increase in carrier lifetime. This is justifying by SEM results. The Scanning electron microscope (SEM) had used for surface morphology, the surface deposited uniformly and there is no pinhole found and the grain size and crystallinity had increased with thickness, which is in good property to increase the solar cell characteristic.

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