EFFICIENCY ENHANCEMENT IN CdS/CdTe THIN FILM SOLAR CELLS BY OPTIMIZING THE GROWTH OF CdS FILM AND CdTe SURFACE TREATMENT

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ABSTRACT

Transparent, homogenous Cadmium Sulfide (CdS) thin films were deposited by an optimized Chemical Bath Deposition (CBD) technique on Fluorine doped Tin Oxide (FTO) glass using a chemical bath containing Cadmium Chloride, Ammonium Chloride, Ammonium Hydroxide and Thiourea. Optimized CdS deposition time was one hour and the bath temperature was 65 °C. Cadmium telluride (CdTe) was deposited on CdS thin film by optimized Physical Vapor Deposition (PVD) method at 350 °C by using CdTe pellets. It was sintered at 400 °C to make a dense pn junction. The thickness of CdS and CdTe measured by stylus profiler were 0.115 and 7 µm respectively. To complete the solar cell Cu and Au metal contacts were deposited by thermal evaporation on CdTe/CdS/FTO. To enhance the efficiency, $CdCl_2$ heat treatment and NP etching was done on the CdTe surface. Among different methods used for the surface treatment of CdTe film the highest efficiency of 7.17 % with parameters of V_{oc} = 650 mV, J_{sc} = 25.04 mAcm^{-2} and fill factor of FF = 44 % was obtained for the cells with CdTe surface treated with a $CdCl_2$ liquid drop and annealed at 400 °C under N_2.

Keywards: Homogenous, Efficiency, Fill factor, Chemical Bath, Deposition and Physical Vapor Deposition.

1.INTRODUCTION

CdS material is one of the important semiconductors for application electro-optic devices due to direct and wide band-gap. In particular, hetero junction solar cells with a narrow band-gap base and wide band-gap window have been investigated in an attempt to develop efficient, stable, and low-cost solar cells. CdTe has a direct band gap of 1.5 eV at room temperature, which is an ideal match to the solar spectrum for photovoltaic absorber. It has been found that CdS can act as an excellent window for thin film CdTe solar cell. From the point of view of technology, a high efficiency CdS/CdTe solar cell requires a conducting substrate for improving cell performance[1,2]. The theoretically calculated efficiency for these solar cells is in the 28%–30% range[3]. The highest efficiency of the CdTe solar cell was recorded as 22.1% at the NERL in 2016[4]. It is evident that there is a difference between the experimental and theoretical values of the efficiency of CdS/CdTe. The main causes of efficiency loss are due to optical, electrical, and recombination losses. The structure of CdS/CdTe solar cell is shown in Fig.1.

This solar cell is composed of four types of thin films as follows:

1. Transparent conducting oxides layer (TCO), which is called front contact and has some required properties such as: highly transparent, highly conducting at room temperature and good adhesion to glass substrate.

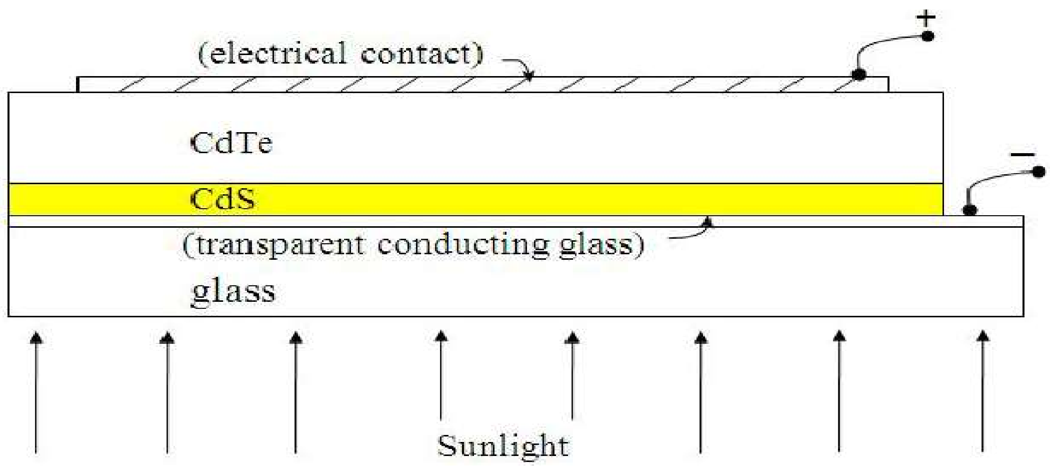

Fig.1. Structure of CdS/CdTe solar cell.

2. CdS layer, also called window layer. This layer is used as the n-type semiconductor. CdS has some desirable properties such as: relatively high transparency, not too thick to favor the absorption in the CdTe absorber layer, not too thin to avoid the short circuiting, relatively large conductivity to reduce the electrical solar cells losses, and higher photoconductivity to not alter the solar cell spectral response.

3. CdTe layer is called the absorber which is made on top of the CdS layer and is used as the p-type semiconductor. Since CdTe has an ideal band gap energy of 1.5 eV and high absorption coefficient, a thin layer of CdTe is sufficient to absorb most of the incoming sunlight.

4. Metal contact layer which is called the back contact and is deposited on the top of the CdTe layer. This layer must have a high work function (>4.5 eV) to form the ohmic contact with CdTe layer. Commonly Cu, Au, Ti and Ni have been used as the metal contact layer. In this work we have used Cu and Au.

There are several techniques used for deposition of CdS thin films such as chemical bath deposition (CBD), vacuum evaporation (VE), spray pyrolysis, electro-deposition (ED), etc. Among these techniques, CBD presents several advantages over other techniques for film processing since it involves relatively simple and very economical equipment facilities, films can be fabricated on large and irregular surfaces, low temperature processing and controllable film thickness[6]. Moreover, CBD gives the best photoconductivity and morphological properties such as roughness and low pinhole density when compared to films processed by other techniques. It is possible that uniform films with good adherence and reproducibility can be obtained by CBD method [2.6.8]. The optical and structural properties of CBD CdS thin films obtained in this work were analyzed.

There are some major techniques used to fabricate CdTe thin film such as physical vapor deposition (PVD), closed space sublimation (CSS), chemical vapor deposition (CVD), chemical bath deposition (CBD), pulsed laser deposition (PLD), electro-deposition (ED), sputtering technique, and atomic layer epitaxy (ALE). The method of deposition should be economical, easily scalable, and easy to handle and can give good conversion efficiency of the device. Physical vapor deposition (PVD) was used to deposit the CdTe thin film on the CdS substrate.

2. MATERIALS AND METHODS

Transparent, homogenous CdS thin films were deposited by CBD on Microscope glass substrate, Fluorine-tin-oxide (FTO) glass substrate and indium-tin-oxide (ITO) glass substrate. Substrates were cleaned ultrasonically using base, acid, De-Ionized water (DI water) and then heated with Isopropyl alcohol. Cleaned substrates were fixed vertically inside the chemical bath using a specially designed sample holder. Substrates were placed into DI water as it is being heated. When the water bath reached 70°C, Cadmium Chloride ($CdCl_2$ (0.04M)), Ammonium Chloride (NH_4Cl (0.64M)), thiourea ($CS(NH_2)_2$ (0.20M)) and ammonium hydroxide (NH_4OH (1M)) were added to the water one by one. Then the deposition temperature was maintained as 65 °C. Slides were taken out after one hour deposition times. The films were rinsed well by deionized water. UV-VIS absorbance and transmission spectra were taken for the CdS thin films in the wavelength range of 300 nm to 900 nm by using a UV VIS- 2450 (SHIMADZU) spectrophotometer. Energy band gap (E_g) values were extracted by plotting (Absorbance × Photon Energy) ^{2} versus Photon Energy. Sheet resistances and photo conductivity were measured by four probe technique for the CdS thin film on microscopic glass plate.

Fig.2.Deposition of CdS thin films on Microscope glass plate, FTO glass plate and ITO glass plate by CBD method.

To make a CdS/CdTe thin film solar cell, CdTe thin film was deposited on the top of FTO/CdS thin film by Physical vapor deposition (PVD – thermal evapuration) method at 350 °C by using CdTe pellets at University of Illinois at Chicago, USA. It was sintered at 400 °C to make a dense pn junction. Copper and gold were deposited on the top of FTO/CdS/CdTe to make a metal contact layer by PVD-thermal evaporation method. The photovoltaic performance of the fabricated solar cells was measured under illumination of 1 sun (air mass 1.5). $CdCl_2$ treatment was done to enhance the efficiency further more. $CdCl_2$ [1] drop was put on the top of the CdTe and in was sinter under the N_2 environment. After the $CdCl_2$ treatment Cu and Au were deposited on the top of CdTe respectively by Physical vapor deposition (PVD – thermal evaporation) method at University of Jaffna.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Transmission and absorbance spectra were taken to the CdS thin film on FTO, ITO and microscopic glass substrate to optimize the suitable substrate and it was shown in Fig.3.

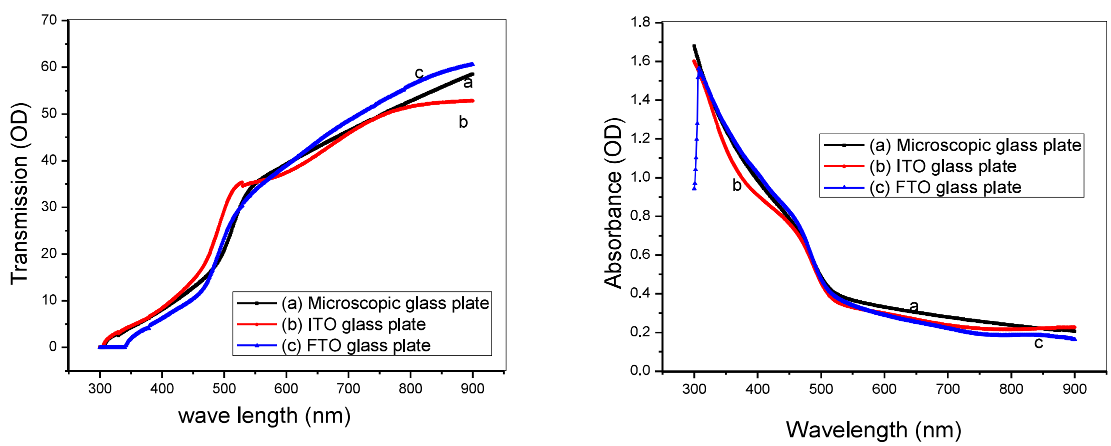

Fig.3.The optical transmission and absorbance spectra of CdS films on Microscopic glass plate, ITO glass plate, FTO glass plate.

The function of cadmium sulphide (CdS) is to allow energetic short-wavelength photons to pass to the absorber (CdTe) with minimum absorption loss. The CdS thin film on FTO glass substrate shows that behavior. It is allowing the energetic short-wavelength photons to pass to the absorber (CdTe) with minimum absorption loss.

Using the absorption of UV-VIS spectrum and Beer Lambert's law we can measure the energy band gap of CdS thin films. From the Beer Lambert's formula the absorption coefficient α is related with absorption (A) and thin film thickness (t) given by

$$\alpha = 2.303 \frac{A}{t} \tag{1}$$

Near the absorption edge absorption coefficient α related to the band gap is given by

$$(\alpha h\nu) = k(h\nu - E_g)^n \tag{2}$$

Where k is Boltzmann's constant, E_g is energy band gap (separation between valance and conduction bands) and n is constant that is equal to ½ allowed for direct band gap semiconductor like CdS[2].

$$(Ah\nu)^2 = K(h\nu - E_g) \tag{3}$$

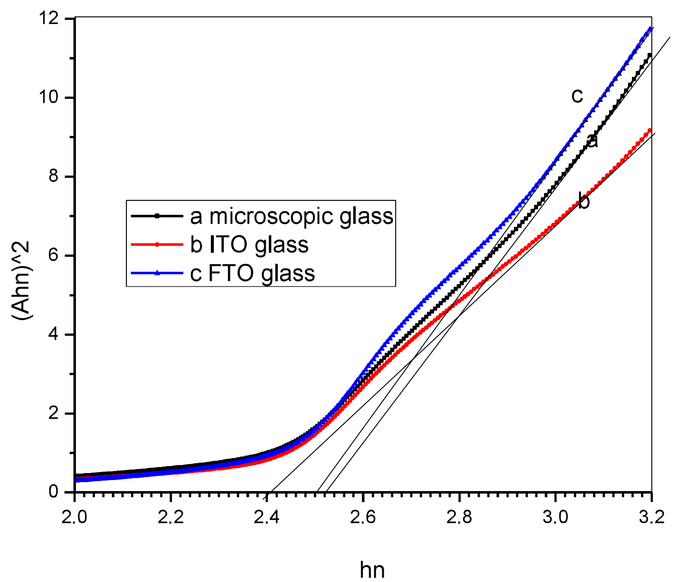

Fig.4.Energy band gap vurses incident energy of the photon graph for CdS thin film on different substrates.

Fig.4 shows the energy band gap vs incident energy of the photon for CdS thin films on different substrates along with the extrapolated straight lines to get the points of intersection to extract the E_g values. The energy band gap values of CdS thin film on microscopic glass plate, ITO glass plate and FTO glass plate were 2.52 eV, 2.50 eV and 2.40 eV respectively. Energy band gap of CdS thin film on microscopic glass substrate shows a wider energy band gap even though the microscopic glass substrate can't be used as the front contact at the CdS/CdTe thin film photo voltaic solar cell because it doesn't have a conducting surface. For the solar cell purpose we need to deposit CdS thin film on the top of a conducting surface. FTO and ITO have been used as conducting substrates. Comparison of the energy band gaps of the CdS thin films deposited on FTO and ITO glass substrates shows that CdS on FTO shows a wider energy band gap than CdS on ITO. Based on the results from Fig.3 and 4, FTO was chosen as the front contact layer for fabrication of CdS/CdTe thin film solar cells.

4. THICKNESS MEASUREMENTS

Thickness of the CdS thin film on microscopic glass substrate was measured by profillo meter at University of Illinois, Chicago, USA. Thickness of CdS on FTO glass plate was 115 nm.

5. PHOTOVOLTAIC PERFORMANCE OF CDS/CDTE SOLAR CELL

The photocurrent density versus voltage (J–V) curves for CdS/CdTe hetro junction solar cell under the same illumination conditions is shown in Fig.5.

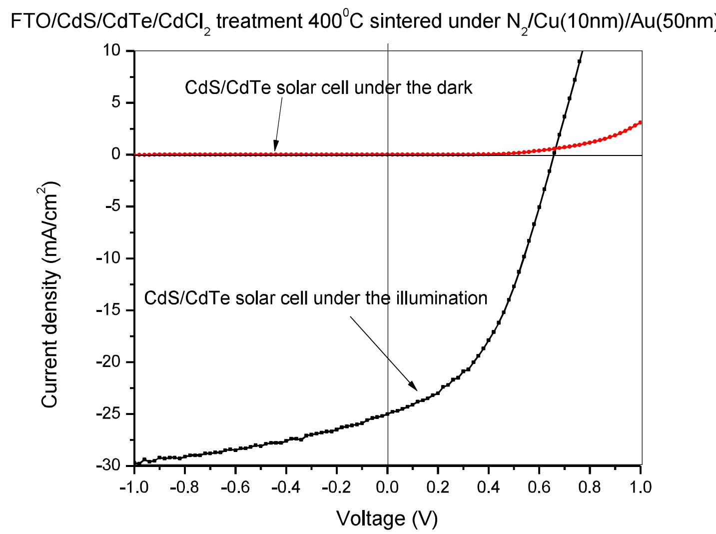

Fig.5.Current density verses voltage graph for CdS/CdTe solar cell under the dark and under the illumination of A.M 1.5

The short circuit current density Jsc=0.04 $mAcm^{-2}$, open circuit voltage, Voc=470mV, the fill factor, FF=26, and the efficiency, η=0.05% were observed from current density voltage measurements for the FTO/CdS/CeTe/Cu/Au Solar Cell without any efficiency enhancement treatment. At the same time, the short circuit current density Jsc=25.04 $mAcm^{-2}$, open circuit voltage, Voc=650mV, the fill factor, FF=44, and the efficiency, η=7.17% were observed from current density voltage measurements (Fig.5) for the FTO/CdS/CeTe($CdCl_2$ treatment)/Cu/Au solar cell with $CdCl_2$ efficiency enhancement treatment.

6. CONCLUSION

FTO glass substrate was more suitable to deposit CdS thin films than a FTO glass substrate for the fabrication of CdS/CdTe thin film solar cells. $CdCl_2$ treatment on top of FTO/CdS/CdTe was shown to enhance the efficiency of FTO/CdS/CdTe/Cu/Au solar cell.

7. REFERENCES

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