Optical Characterization of CdTe Films for Solar Cell Applications

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Abstract: Optical constants for thermally evaporated CdTe thin films have been studied by reflectance, absorbance and transmittance method over the wavelength range 400-1200 nm. Optical parameters like the absorption coefficient, optical band gap, refractive index, extinction coefficient and the complex dielectric constant have been determined and found to be in agreement with values reported by other workers. Optimal thickness for CdTe film, as absorber material in solar cells, has been determined to be 1200nm.

Key Words: CdTe. Optical Properties, Solar Cells.

1. INTRODUCTION

Cadmium Telluride (CdTe) is a perfect absorber material for use in solar cells [1]. Its direct band gap of 1.45eV is close to the peak value of the solar spectrum for maximum energy conversion. Cadmium Telluride as an absorber has received much attention [2,3] because of its optical properties.

Cadmium Telluride makes an excellent pair with Cadmium Sulfide to form a hetero-junction solar cell. CdS with a band gap of 2.4eV makes a good window material [4]. Both Cadmium Telluride and Cadmium Sulfide films can be made by a variety of methods like chemical bath deposition, close space sublimation and thermal evaporation [5-7]. Thermal evaporation of these films is a convenient method for fabricating CdTe/CdS thin film solar cells not only for the ease and simplicity of the method but also to the fact that the process lends itself to large scale production.

Thickness of CdTe films is one of the important parameters in determining the efficiency of the solar cells. If the absorber layer is too thin then not all the solar photons will be absorbed and the conversion efficiency will be low. On the other hand, too thick a film would increase the distance photo-generated carriers would have to travel before being collected. Since the carriers are lost by recombination in transit, this will result in a reduced efficiency.

Optical constants have an important bearing on optimal thickness. In the study reported here, transmittance and reflectance data on thermally evaporated CdTe films of various thicknesses has been analyzed over the visible spectrum to calculate the optical constants like the absorption coefficient, the optical band gap, extinction coefficient, the refractive index and the dielectric constant. This has been done to determine any correlation if any, between the film thickness and the optical constants which may be relevant to the CdTe/CdS hetero-junction solar cells.

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2. EXPERIMENTAL

Cadmium telluride thin films were deposited onto cleaned glass substrates by using Edward 306 vacuum evaporation system. Prior to evaporation the substrates were carefully cleaned in a detergent to remove any dust and grime. This was followed by a degreasing sequence in methanol. Substrates were dried under a hot air blower and were immediately loaded into the evaporation chamber.

CdTe supplied by Alfa-Aesar having a purity of 99.999% has been used. CdTe was evaporated from a molybdenum boat in vacuum better than 10^{-5} mbar. The source to substrate distance was kept constant at 15cm. Deposition rate and thicknesses for all films were monitored during deposition using an Edwards FTM7 film thickness monitor that is connected to a quartz crystal which is placed close to the substrate in the vacuum chamber. A fixed evaporation rate of ~10nm/sec was used for depositing all samples. Samples with thicknesses in the range 100nm to 1200nm were fabricated for optical measurements. The exact values of film thicknesses were obtained from a computerized film thickness measuring system.

Optical reflection, transmission and absorption spectra of the evaporated films were measured at normal incidence using a JASCO V-70 UV/VIS/NIR spectrophotometer. The spectrophotometer has two light sources; a Deuterium lamp with output in the range 200 to 350 nm for use in the ultraviolet region (UV), and a Halogen lamp with emissions from 340 to 2500 nm for use in the visible (VIS) and near infrared (NIR) regions.

3. RESULTS AND DISCUSSION

Transmission, reflection and absorption data has been used to obtain useful optical parameters such as the absorption coefficient, the optical band gap, extinction coefficient, the refractive index and the dielectric constant.

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3.1. Absorption Coefficient and the Determination of the Band Gap

Absorption of radiation in a semiconductor**,** CdTe in this case, is a fundamental process. Only those incident photons whose energy exceeds the band gap energy are absorbed. In such case;

$$h\nu \geq E_g$$

Where, hν is the energy of incident photons and E_g is the band gap, both are usually expressed in eV. Radiation travelling in the absorbing medium (CdTe) is continuously absorbed and produces hole-electron pairs. Consequently, the transmitted wave is continuously attenuated. The relationship between the incident intensity I_0 and the transmitted intensity I_T is given by the famous Beer-Lambert's law;

$$I(d) = I_0 \exp - \alpha d \qquad (1)$$

where d is the thickness of the film and α is the absorption coefficient.

Transmittance of light through the CdTe film can be further processed by considering reflections from the two faces of the film; (i) between air and the film and (ii) between the film and glass substrate as shown in Fig. (**1**)

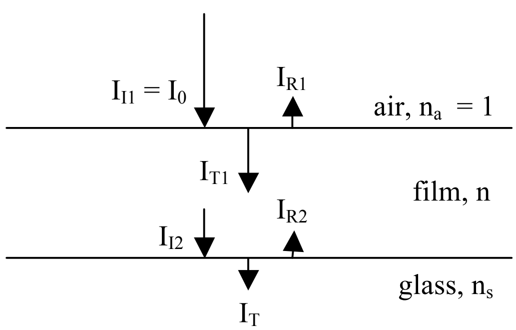

Fig. (1). Reflection and transmission of light at normal incidence by semiconducting thin films.

Considering a normal incidence, the reflected intensity from the front surface is

$$I_{R1} = I_0 R_1 \qquad (2)$$

Where, R_1 is the reflectance from the front surface given by I_{R1}/I_0. The transmitted intensity I_{T1} into the film just below the top surface is given by;

$$I_{T1} = (1 - R_1) I_0 \qquad (3)$$

It is this intensity which suffers attenuation according to Beer-Larmbert`s law, equation (1), as light propagates in the film. After traveling a distance d, the intensity I_{12}, is given by the relation;

$$I_{I2} = (1 - R_1) I_0 \exp - \alpha d \qquad (4)$$

Ignoring multiple reflections in the film, the transmitted radiation (transmittance $T = I_T/I_0$) through the film becomes;

$$T = I_T / I_0 = (1 - R)^2 \exp - \alpha d \qquad (5)$$

Here a simplifying assumption has been made, that $R_1 = R_2 = R$, where R_1 and R_2 are the reflectances at the air-film and the film-glass interfaces respectively.

Equation (5) above can be solved to give the absorption coefficient α,

$$\alpha = (1/d) \text{ lin } \left[(1 - R)^2 / T \right] \qquad (6)$$

Equation (6) was used to determine the absorption coefficient for CdTe film.

The absorbance and the transmittance spectra of CdTe film of various thicknesses are shown in Figs. (**2** and **3**). The calculated value of α is shown plotted in Fig. (**4**).

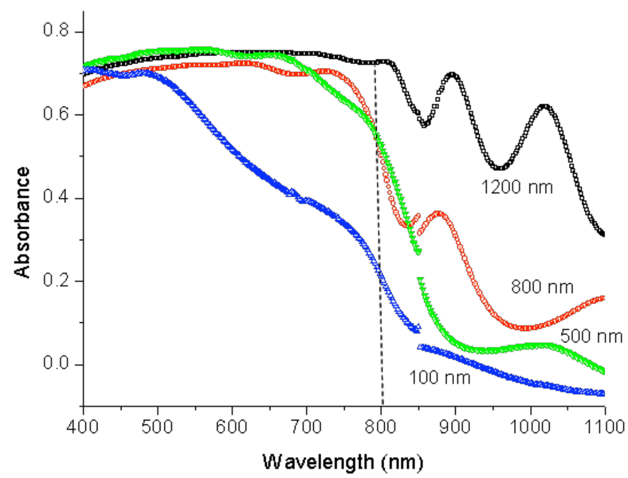

Fig. (2). Absorbance of CdTe films of different thicknesses.

The absorption coefficient α shows a sharp increase with thickness, with films of 1200 nm thickness absorbing almost all incident light down to 800nm. This represents the optimal thickness of the CdTe absorber layer. Increasing the thickness any further will not result in enhanced absorption.

3.2. Determination of the Gand Gap

In the region of photon absorption associated with inter-band transitions, absorption coefficient α depends on the energy of the photons. According to the model proposed by Mott and Davis [8] and Tauc [9], photon energy dependence of α is given by the relation;

$$\alpha h\nu = A (h\nu - E_g)^n \qquad (7)$$

where hν is the energy of the photons and ν is its frequency. The exponent "m" is determined by the nature of the process. It takes the value 0.5 for the direct transitions and 2 for indirect transitions. For the case of direct transition, equation (7) becomes,

$$[\alpha h\nu]^2 = A(h\nu - E_g) \tag{8}$$

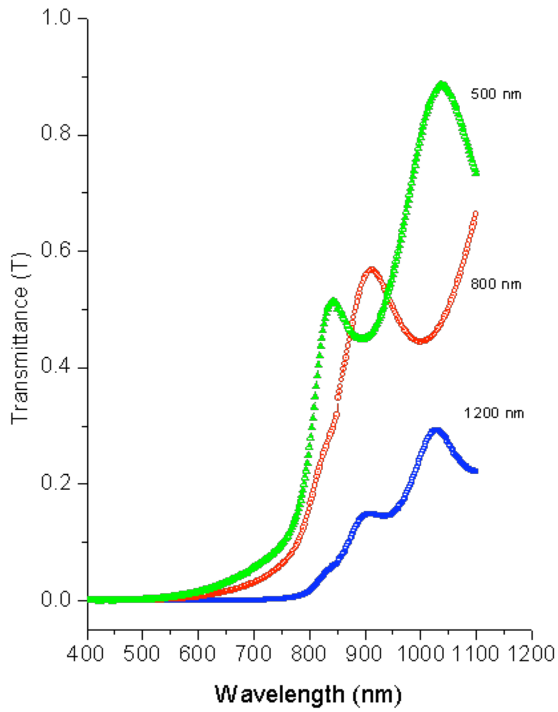

Fig. (3). Transmittance of CdTe films of different thicknesses.

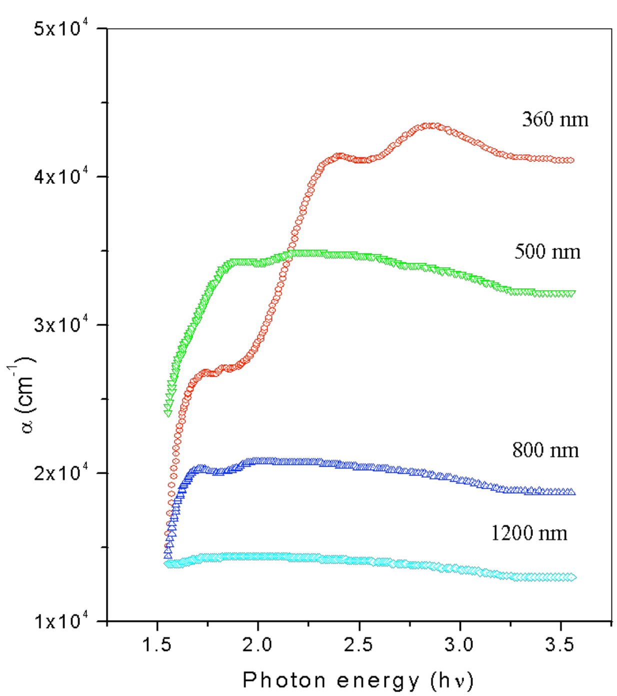

Fig. (4). Variation of the absorption coefficient α with photon energy for CdTe films of varying thicknesses.

A plot of $(\alpha h\nu)^2$ versus hν should yield a straight line with intercept at α = 0 giving the value of E_g in electron volts. Such a plot is shown in Fig. (**5**) and gives a value of the band gap ~ 1.46 eV. This is in excellent agreement with the accepted value for CdTe [1].

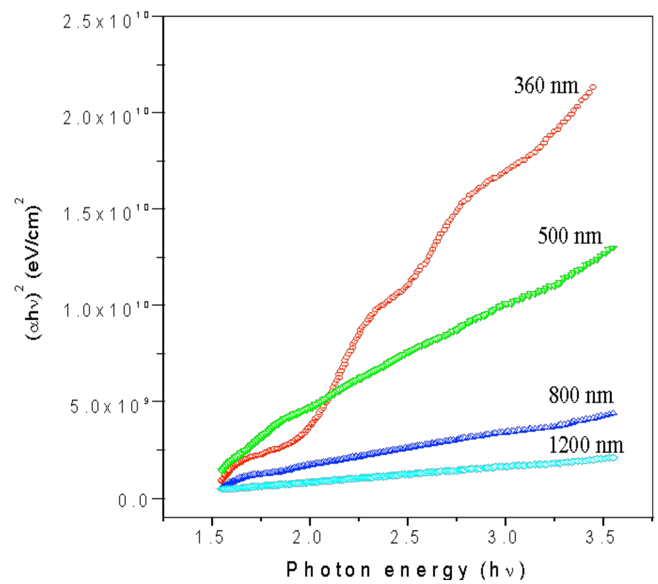

Fig. (5). Plots for $(\alpha h\nu)^2$ against hν for CdTe films of different thicknesses.

3.3. The Reflectance and Determination of the Refractive Index

The reflectance of a film for a light wave incident normally from air, with refractive index $n_a = 1$, on a medium of complex refractive index n^* is given by the following relation [10],

$$R = \frac{(n^* - 1)^2}{(n^* + 1)^2} = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2} \tag{9}$$

The complex refractive index of the film is given by;

$$n^* = n + ik \tag{10}$$

where n is the refractive index and k the extinction coefficient of the film. Knowing the value of the absorption coefficient α, the extinction coefficient can be calculated using the relation [10],

$$k = \frac{\lambda}{4\pi}\alpha \tag{11}$$

where λ is the wavelength in free space. Solving equation (9) for the refractive index n gives;

$$n = \frac{(1+R) + \left[(1+R)^2 - (1-R)^2(1+k^2)\right]^{1/2}}{1-R} \tag{12}$$

The refractive index of the film has been evaluated from the reflectance data at normal incidence using equation (12) in the wavelength range 400-800 nm. The calculated values n and k are plotted as a function of photon wavelength and are shown in Fig. (**6** and **7**) respectively. The value of the refractive index is found to decrease with the increase of wavelength of the incident photon. Whereas, the refractive index increases with decreasing film thickness. Both these trends are consistent with the reported behavior of CdTe films [3]. The rise and fall observed are due to interference of light between the upper and lower surface of the film. The extinction coefficient increases with increasing wavelength in the visible region of the spectrum followed by a sharp decline.

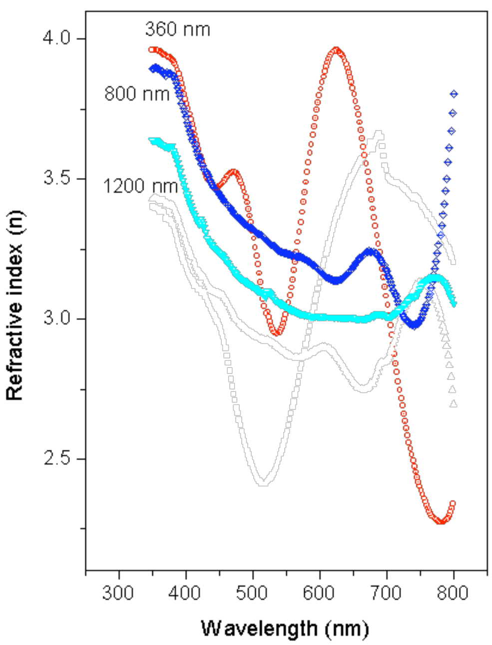

Fig. (6). Calculated values of the refractive index n verses wavelength for CdTe films 360, 800 and 1200nm thick.

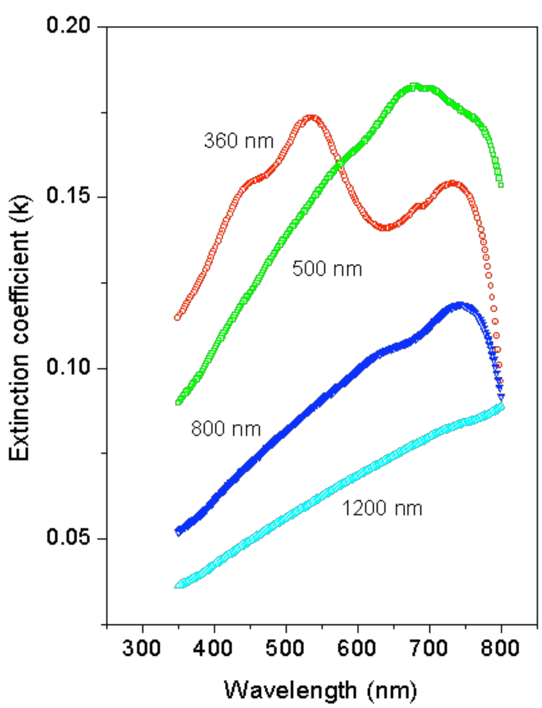

Fig. (7). Calculated values of the extinction coefficient k plotted as a function of photon wavelength.

The complex relative dielectric constant ε^* of a conducting medium is related to the complex refractive index of the medium through the relation [11],

$$(n^*)^2 = \varepsilon^* = \varepsilon' + \varepsilon'' \tag{13}$$

where ε' and ε" are the real and imaginary parts of the relative dielectric constant. By substituting equation (10) into equation (13), ε' and ε" can be obtained.

$$\varepsilon' = n^2 - k^2; \qquad \varepsilon'' = 2nk \tag{14}$$

Fig. (**8**) shows a plot of ε' and ε" against the photon wavelength for a 500 nm thick CdTe film. It is found that the real part remains nearly constant with wavelength whereas, the imaginary part decrease followed by a peak that may well be an interference effect.

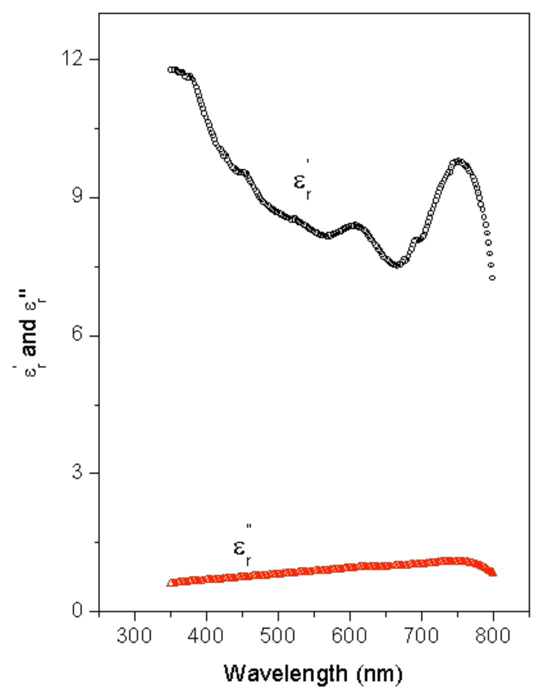

Fig. (8). Plots of ε' and ε" against photon wavelength for a 500 nm thick film

4. CONCLUSIONS

Thermally evaporated thin films of CdTe have been characterized optically. Optical parameters such as the absorption coefficient α, the energy gap E_g, the refractive index n, the extinction coefficient k and the complex dielectric constant have been calculated from the experimental data using straight forward calculations. Due to the high absorption coefficient, a film thickness of 1200 nm completely absorbs visible radiation. Solar cells with an absorber layer in this range are expected to yield high efficiency. Thinner film would lose energy as it will not be completely absorbed, whereas, thicker film would make the collection of photo generated carriers inefficient, as some of them will be lost by recombination before being collected.

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