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A Study on the Optical Properties of Co-evaporated $CuInSe_2$ Thin Films for High Efficiency Inorganic Solar Cell

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Abstract

Co-evaporation is one of the prominent techniques used to prepare the $CuInSe_2$ thin films. For this study, the co-evaporated $CuInSe_2$ thin films on glass substrate were used maintaining the temperature between 400ºC and 500ºC in a conventional diffusion pump vacuum chamber at about 10^{-5} torr pressure. Shimadzu spectrophotometer (model 3100) was used to investigate the optical properties of these films. It was found from the study that the absorption co-efficient of these films were quite high in the order of 10^4/cm. The band gap of these films was found at 1.03 eV. Moreover, the study showed that the film material maintains a constant refractive index from UV to NIR region. These indicate that the films used in this study can be utilized for high efficiency inorganic solar cell.

Keywords: *Absorption co-efficient, Band gap, Extinction co-efficient, Refractive index, Thin film.*

1. Introduction

Since the conventional energy resources are confined and will be consumed very soon, the shortage of energy throughout the world is inevitable in the near future. Hence, it has become an urgent need to find out a source in lieu of the fossil resources [1]. According to the solar radiation data of GIS based Geospatial Toolkit (GeT), National Aeronautics and Space Administration (NASA) and Surface Metrology and Solar Energy (SSE), the average solar radiation varies with a range of 4×10^5 kWh/m^2 [2]. Therefore, solar energy can be referred as the best alternative if it is used in a cost-effective manner. For this reason, further research is going on to find out the high efficiency, low cost and long lasting solar cells.

There are several existing solar cell technologies nowadays. Among those, thin film technology is considered as one of the most promising way because of its stability, flexibility and durability. Even though, the typical thickness of thin film solar cell is usually between 1 to 2 microns and can harvest an output of 1.5kW/kg [3].

Among various materials for thin film solar cells, copper indium diselenide (I-III-VI compound) has been considered as one of the most promising candidate as it has comparatively a better conversion efficiency of 21.7% [4]. Due to its ideal band gap and high absorption coefficient, it has great electrical and optical properties. Furthermore, CIS is an easy and cost-effective procedure to produce films over large areas at room temperature [5].

Several methods can be utilized to produce $CuInSe_2$ solar thin films such as Electrodeposition, Evaporation, Sputtering, Stacking Element Layer, Flash Evaporation, Screen-printing, Spray pyrolysis, Closed Spaced Selenization, MOCVD, UV Laser Ablation and Molecular Beam Expitaxy [6]. Among all the techniques, thermal co-evaporation is referred as the best one [7].

In this research, a couple of CuInSe2 thin film samples were prepared by thermal co-evaporation technique with different substrate temperature and thickness. The optical properties of these films were investigated and demonstrated.

2. Sample Preparation

Co-evaporation method was used to prepare the film on heated glass substrates in a diffusion

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pump vacuum chamber under pressure of the order of 10^{-5} torr having a thickness of 2.4 μm. By placing a carbon block at the center, a crossed Cu-In source arrangement was made. Here, tungsten boat was used for copper and alumina coated tantalum boat for indium. High capacity graphite Knudsen cell was used as the selenium source. Electron Impact Emission Spectroscopy (EIES) detection system was used to provide a feedback to the sources of copper and indium. Using that feedback, their deposition rates were regulated. Whereas, a quartz crystal monitor was used to measure the deposition rate of selenium. At first, the glass substrates were cleaned in decon solution, ultrasonic bath and then refined in deionised water and isopropyl alcohol.

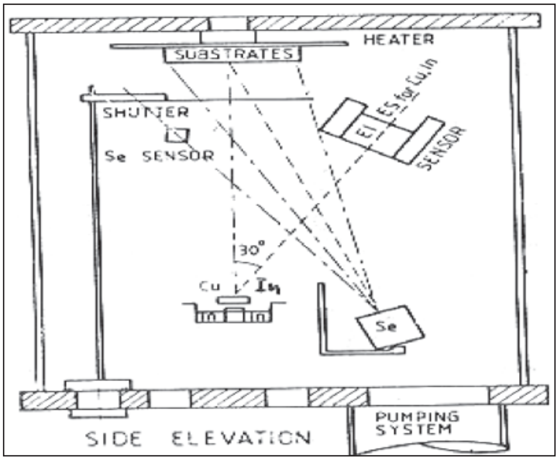

Fig. 1: Co-evaporation arrangement for $CuInSe_2$ film deposition.

Different parameters of these films are given below in **Table 1.**

Table-1: Technological Parameters of the films.

Sample no.	Chamber pressure (torr)	Substrate temp (^oC)	Deposition time (min)	Thickness d (μm)
E - 40	10^{-5}	400	3	2.0
E - 11		500		1.9

3. Results

A large number of techniques have been developed for semiconductor characterization. We used spectrophotometric technique to study the different optical properties of our films. The concept of transmission, reflection and absorption processes of the incident light by a thin film is shown in Fig. 2.

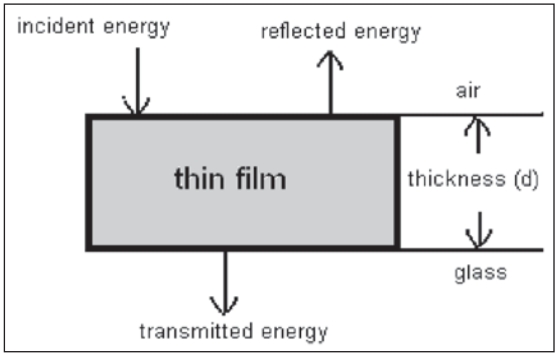

Fig. 2: Concept of transmission, reflection and absorption process of light.

Transmittance for a particular radiation is the ratio of the radiation transmitted through a surface to the radiation falling on it. It is usually expressed in percentage. The observed transmittance of these films are shown in Fig. 3.

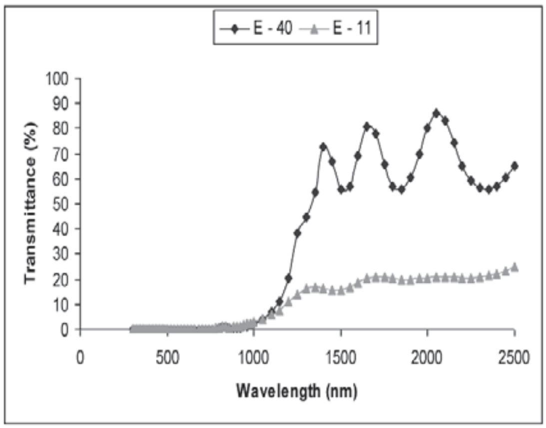

Fig. 3: The transmittance curve for the $CuInSe_2$ films.

Reflectance for a particular radiation is the ratio of the radiation reflected by a surface to the radiation falling on it. It is also expressed in percentage. The observed reflectance of these films are shown in Fig. 4.

Absorptance is the ratio of the radiation absorbed by a surface to the radiation incident on it for that particular radiation. It is often expressed in percentage. The observed absorptance of these films are shown in Fig. 5.

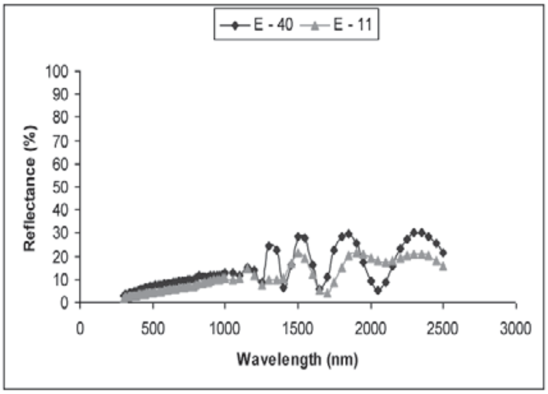

Fig. 4: The reflectance curve for the $CuInSe_2$ films.

The optical absorption coefficient α for these films is calculated using the formula [8]:

$$\alpha = \left(\frac{1}{d}\right)\ln\left\{\left(\frac{(1-R^2)}{T}\right)\right\} \quad (1)$$

Where R, T and d represent reflectance, transmittance and film thickness respectively. The absorption coefficients thus calculated are plotted against the wave length which is given in Fig. 6.

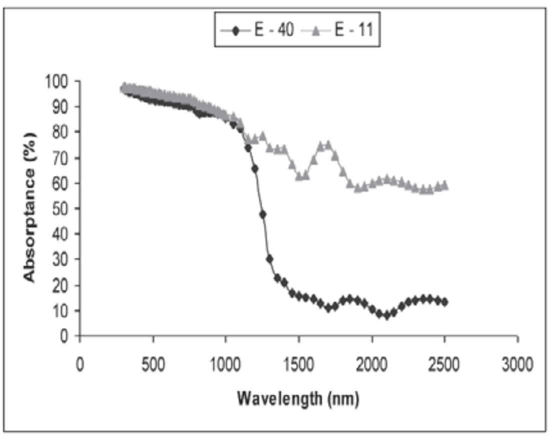

Fig. 5: The absorptance curve for the $CuInSe_2$ films.

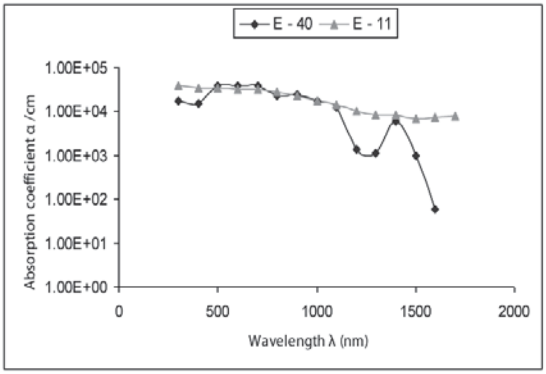

Fig. 6: Plot of absorption coefficient (α) vs. wavelength (λ) for the $CuInSe_2$ films.

The general expression for the absorption by excitation of electron across a direct band gap E_g is given by [9]:

$$\alpha = \left(\frac{A}{h\nu}\right)\left(E_g - h\nu\right)^{\frac{1}{2}} \quad (2)$$

Where hν is the photon energy. Thus a plot of $(\alpha h\nu)^2$ against hν will give the value of E_g and such a plot is shown in Fig. 7.

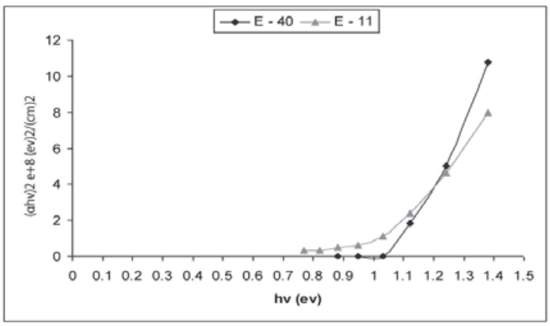

Fig. 7: Plot of $(\alpha h\nu)^2$ vs. photon energy (hν) for the $CuInSe_2$ films.

The complex refractive index is given by:

$$\eta = n - ik \quad (3)$$

where, the real part, n is called refractive index and the imaginary part, k is the extinction co-efficient. The refractive indices, n of these films are then determined from T_{max} and T_{min} which can be obtained from the transmittance curves at long wavelengths of the incident light using the following equations:

$$n = [H + (H^2 - \eta_a{}^2\eta_g{}^2)^{1/2}]^{1/2} \quad (4)$$

where,

$$H = \left[\frac{(\eta_a{}^2+\eta_g{}^2)}{2}\right] + 2\eta_a\eta_g\left[\frac{(T_{max}-T_{min})}{(T_{max}\times T_{min})}\right] \qquad (5)$$

and,

$\eta_a = 1$, $\eta_g = 1.5$

To determine the refractive indices of these films, T_{max} and T_{min} was obtained from Fig. 3.
The plot of refractive indices of these films as a function of wavelength is shown in Fig. 8.

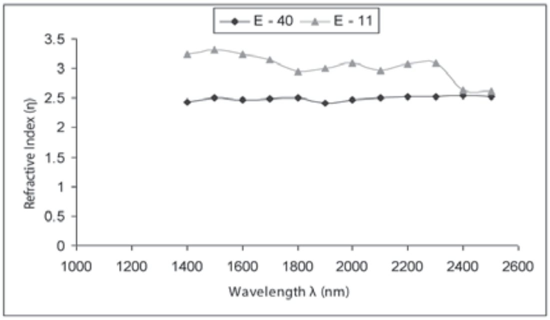

Fig. 8: Plot of refractive indices for $CuInSe_2$ films E- 11 and E- 40.

The extinction coefficient k is determined from the following equation:

$$e^{\left(\frac{-4\pi kt}{\lambda}\right)} = e^{(-\alpha t)} \qquad (6)$$

where, α is the absorption coefficient of the film and λ is the wavelength of the incident light. A plot of extinction coefficients for $CuInSe_2$ films E- 11 and E- 40 is shown in Fig. 9.

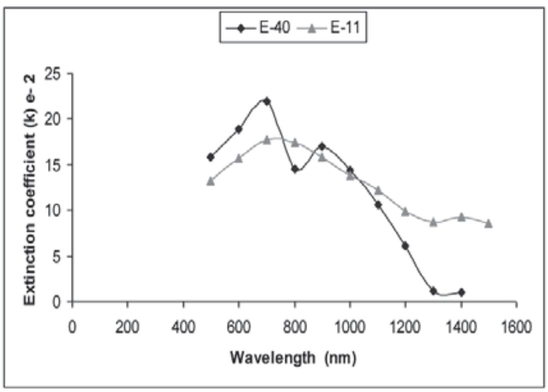

Fig. 9: Plot of extinction coefficients for $CuInSe_2$ films E- 11 and E- 40.

4. Discussion

In the UV to visible wavelength range the transmittance (%) is very low but in the visible to near infra-red (NIR) region transmittance increases and show oscillatory nature in the NIR region (Fig. 3). The reflectance (%) also increases (5%-20%) with wavelength from UV to visible range (Fig. 4). The absorptance (%) of these films are very high (Fig 5). The absorption coefficients of the film material are high in the order of 10^4/cm (Fig. 6). The band gap of the $CuInSe_2$ thin film is found to be 1.03 eV (E-40) and 1.00 eV (E-11) (Fig. 7). It is cleared that the band gap is changing with temperature which is mainly due to the reduction of crystal defects. Because of The film material maintains a constant refractive index from UV to NIR region (Fig. 8). It is found that there is a decrease in the refractive index with the increase in the film thickness. But the extinction coefficient varies between $1x10^{-2}$ to $20x10^{-2}$ (Fig. 9).

5. Conclusion

The study of $CuInSe_2$ thin films by spectrophotometer for determining its optical properties is very important for its various applications. The optical properties of $CuInSe_2$ are solely dependent on their preparation condition. In our study, band gap energy of two $CuInSe_2$ thin films (E- 11, E- 40) was found to be 1.03 eV having the values of absorption coefficient of the order of 10^4 per cm. Moreover, these films have refractive index of ~3 and extinction coefficient of $\sim 15x10^{-2}$. All these studies suggest that $CuInSe_2$ is a suitable material for fabrication of thin film solar cells.

References

[1] M. A. S. Bhuiyan, IIUM Eng. J., 14, 105 (2013).

[2 M. A. H. Mondaland M. Denich, 14, 2401(2010).

[3] G. Han, S. Zhang, P. P. Boix, L. H. Wong, L. Sunand S. Y. Lien, Progress in Mater. Sci. 87, 246 (2017).

[4] P.Jackson, D.Hariskos, R.Wuerz, O. Kiowski and A.Bauer, Phys. Stat. Sol., 1 (2014).

[5] L. Li, Y. Ma, G. Gao,W. Wang, S. Guo, J. Youand J. Xie., J. Alloy.Comp., 65, 774 (2016).

[6] T. D.Lee and A. U.Ebong., Renewable and Sustainable Energy Rev., 70, 1286 (2017).

[7] M. A. Islam, A. M. M. T. Karim, M. Julkarnain, A. K. M. Badrul, M. K. R. Khanand K. A. Khan, Surfaces and Interfaces, 8, 170 (2017).

[8] S. Baco, A. Chikand F. M. Yassin, J. Sc. and Tech., 4, 61 (2012).

[9] J. R. Cárdenas and H.Sobral,Materials, 607, 101 (2017)

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