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Preparation and Characterization of $CuInS_2$ thin film for Solar cell applications

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ABSTRACT

The $CuInS_2$ thin films were prepared by the Pulse Plating technique at different duty cycles in the range of 10 to 50% at temperature 80°C using conducting glass and titanium substrates. The films are exhibits tetragonal structure. Optical transmission spectra were exhibited interference fringes. A direct optical band gap value of 1.41eV was obtained. The refractive index was calculated by the envelop method. Electrical resistivity of the films was in the range of 15 to 33 ohm-cm. The films were characterized by the XRD, EDAX, and XPS were also evaluated.

Keywords: Semiconductor, I-III-VI$_2$, Solid thin films, Pulse Plating Technique, refractive index, Electrical resistivity.

I.INTRODUCTION

Conversion efficiencies of more than 30% have been achieved for tandem solar cell structures using III – V semiconductors [1]. Thus, limitation of the process temperature is one of the crucial problems in the fabrication of tandem solar cell structures. To avoid this limitation, we have focused on mechanical stacking using a lift-off process for fabrication of the top solar cell, because the lift-off process could enable the fabrication of a high-quality absorber layer on a conventional at the appropriate growth temperature for the top solar cell. Therefore, a lift-off process for $CuInS_2$-based thin films that are suitable for the absorber layers of the top solar cell is required [2-3]. Transfer of a $CuInS_2$ thin film grown on a Mo/Borosilicate glass substrate has been reported [4]. However, since the lift-off process itself was not the primary focus of the previous report, further investigation is required. However, since to investigate the transfer of $CuInS_2$ thin film is not the primary purpose of the previous report, the investigation on the transfer is insufficient.

Copper Indium Sulphide thin films are one of the promising absorber materials in Solar cells because of its high optical absorption coefficient (10^5 Cm^{-1}) and optimum optical band gap of 1.5eV. The material has been incorporate in photovoltaic structures resulting in considerable conversion efficiencies [5]. Both Pathan and Lokhande [6] authors have used the chemical bath deposition technique to deposit $CuInS_2$ thin films. The electrical resistivity of the films was of the order of 10 ohm cm, and showed p-type semiconductor electrical conductivity. On the other hand, some authors have preferred others routes to grow CIS thin films. Some of these are: Spray Pyrolysis [7], Sputtering [8], one stage Radio frequency reactive sputtering [9] and chemical bath deposition etc.,

The main purpose of the present work is to deposit good quality CIS thin films using Pulse Plating Technique method. In this work, $CuInS_2$ thin films were deposited by the pulse plating technique at different duty cycles in the range of 10 to 50 % and the films were characterized for their structural, optical and electrical properties.

II.EXPERIMENTAL DETAILS

1.1. Deposition of $CuInS_2$ thin films

$CuInS_2$ thin films were deposited on tin oxide coated glass substrates and titanium substrates at 80ᴼC temperature and at 10 to 50%. The precursor solution was 0.1 mol $InCl_3$, and 0.2 mol sodium thio sulphate used. The Deposition potential was fixed at -0.95V (Saturated Calomel Electrode). The deposition time was fixed as 1 hr in all the cases. Thickness of the films measured by gravimetry using a semimicro Mettler balance were observed to be in the range of 0.7 to 1 micrometers with increase of duty cycle form 10 to 50%. Four variable parameters are of primery importance in pulse plating. They are (i) Peak current density, (ii) Average current density, (iii) ON time (iv) OFF time. The sum of the ON and OFF times constitute one pulse cycle. The duty cycle is defined as follows.

$$\text{Duty cycle} = \text{ON time}/(\text{ON time}+ \text{OFF time}) \times 100\ \%.$$

2.2. Characterization studies

The films were characterized by X-ray diffractometer and with CuKα radiation at wavelength 1.54046 Aᴼ. Optical transmission Spectra were recorded using U 3400 UV-Vis-NIR spectrophotometer. Resistivity of the films was obtained from the slop of I-V plots. EDAX studies were made using a JOEL SEM with EDAX attachment. Electrical properties were studied by evaporating Indium ohmic contacts on the top surface of the films.

III. RESULTS AND DISCUSSION

3.1. X-ray diffraction studies

The X-ray diffraction patterns of the thin films deposited at different duty cycle is shown in Figure 1. The recorded spectrum of the sample was taken at room temperature in a 2ɵ range of 0 to 80ᴼC using CuKα radiation of wavelength 1.54056Aᴼ. From the diffraction pattern, the d- spacing and hkl values for each diffraction peak in the corresponding spectrum of sample were identifies. The peaks corresponding to (1 1 2), (2 0 0), (2 0 4), (3 1 2), (4 0 0) and (3 1 6) reflections are observed in all the calses. It is observed that as the duty cycle increased, the peaks are observed in height and also become sharper with increase in different duty cycles. Using the tetragonal structure equation the lattice parameter values of $CuInS_2$ were calculated and compared with the reported values from Joint committee on Powder Diffraction Standards (JCPDS).

3.2. EDAX studies

The $CuInS_2$ films depositd at different duty cycles indicated that the composition ratio of the films deposits at duty cycles 50%. EDAX measurement indicated that Cu/In ratio increased from 1.2 to 1 as the duty cycle increased. For the films deposited at 50% duty cycle the Cu/In ratio was 1 and the percentage of the copper and indium were 42% in Figure 2.

3.3. XPS spectrum analysis

The XPS Spectrum is shown in Figure 3 (a,b,c), Reveals that the binding energy values of Cu-$2p_{3/2}$, In-$3d_{5/2}$ and $3d_{3/2}$, s-2p, peaks in the XPS Spectrum of the films deposited at 50% duty cycle. The binding energy of Cu-$2p_{3/2,}$ In-$3d_{5/2}$, and s-$2p_{1/2}$peaks are observed at 932eV, 444.7eV and 162.5eV respectively, which agree with that reported by other workers for spray pyrolysis method [10].

3.4. Transmission spectrum analysis

The transmission spectrum of the $CuInS_2$ thin films deposited at 50% duty cycle is shown in Figure 4. The spectrum exhibits interference fringes and the value of the refractive index was estimated by envelop method [11]. The transmission spectrum was recorded for $CuInS_2$ thin film in the photon energy region of 0.6eV to 1.8eV.

$$n= [N+ (N_2-n_s^2)]^2$$

$$N= (n_s^2+1)/2 + 2n_s \times [(T_{max}-T_{min})/T_{max}T_{min}]$$

Where n_s is the refractive index of the substrate, T_{max} and T_{min} are the maximum and minimum transmittances at the same wavelength in the fitted envelop curve on a transmittance spectrum. The value of the absorption coefficient (α) was calculated using the relation

$$\alpha = 1/d \ln [(n-1) (n-n_s)/(n+1) (n-n_s)] \times [(T_{max}/T_{min})^2+1]/ [(T_{max}/T_{min})^2-1]$$

where'd' is the thickness of the film and the other parameters have the usual meaning as given for equation. The optical bandgap of the film was estimated to be 1.41eV from a plot of $(\alpha h\nu)^2$ versus Photon energy is shown in Figure 5. The values of the optical bandgap and refractive index are agreed well with the earlier report [12].

3.5. Electrical resistivity studies

The electrical resistivity of the $CuInS_2$ films deposited at different duty cycles was studies by providing Indium ohmic contacts (0.1 cm^2) on the top of the film surface and the resistance was measured between the top Indium ohmic contact and the calculated from the resistance values and it was observe that the resistivity increased from 15 ohm cm to 33 ohm cm with increase of duty cycle. The value of the resistivity is lower than earlier report (180-1,400 ohm cm) [13-14]. In our study the Cu/In ratio varied in the range of 1.03 to 0.93 as the different duty cycle increased from 10 to 50%.

IV.CONCLUSION

The $CuInS_2$ thin films were prepared by the single step Pulse Plating technique at different duty cycles in the range of 10 to 50% at temperature 80ºC. The $CuInS_2$ are interesting materials for solar cell devices. The results of this study clearly indicate that the $CuInS_2$ thin films can easily be obtained by a pulse electro deposition technique. EDAX was confirmed the ratio of Cu/In and sulphide of CIS thin film. The XPS was confirmed binding energy values of thin film. The films resistivity was obtained in the range of 15-33 ohm-cm. From the X-ray diffraction, it was confirmed that the films belong to tetragonal structure. The optical transmittance of the films confirms the transparency of the films and confirmed that interference fringes, refractive index value of 1.2 and optical band gap 1.41eV. By the absorption coefficient and the optical bang gap of the films, we can achieve the desired material, which is suitable for the fabrication of various solar cell devices, because of its less optical band gap.

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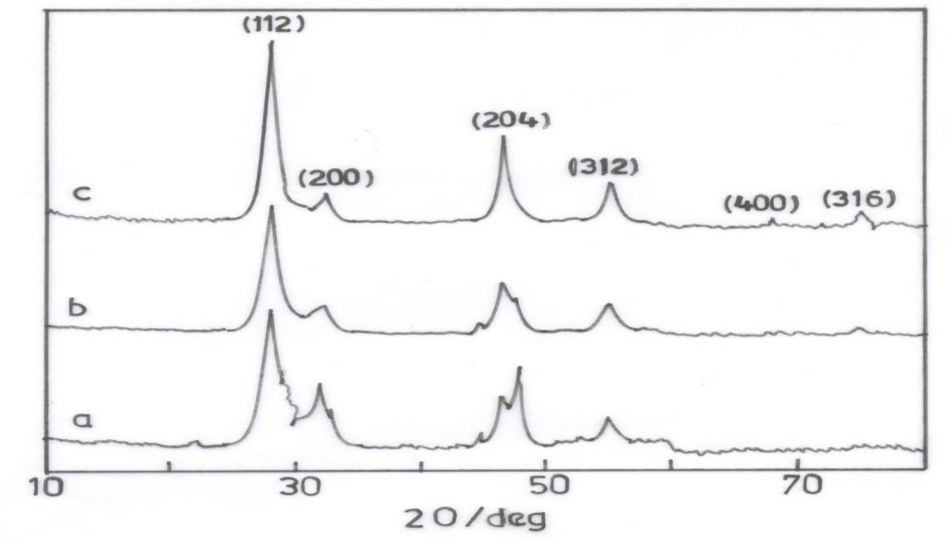

Figure1. X-ray diffraction pattern of $CuInS_2$ films (a) 9 % (b) 33 % (c) 50 %

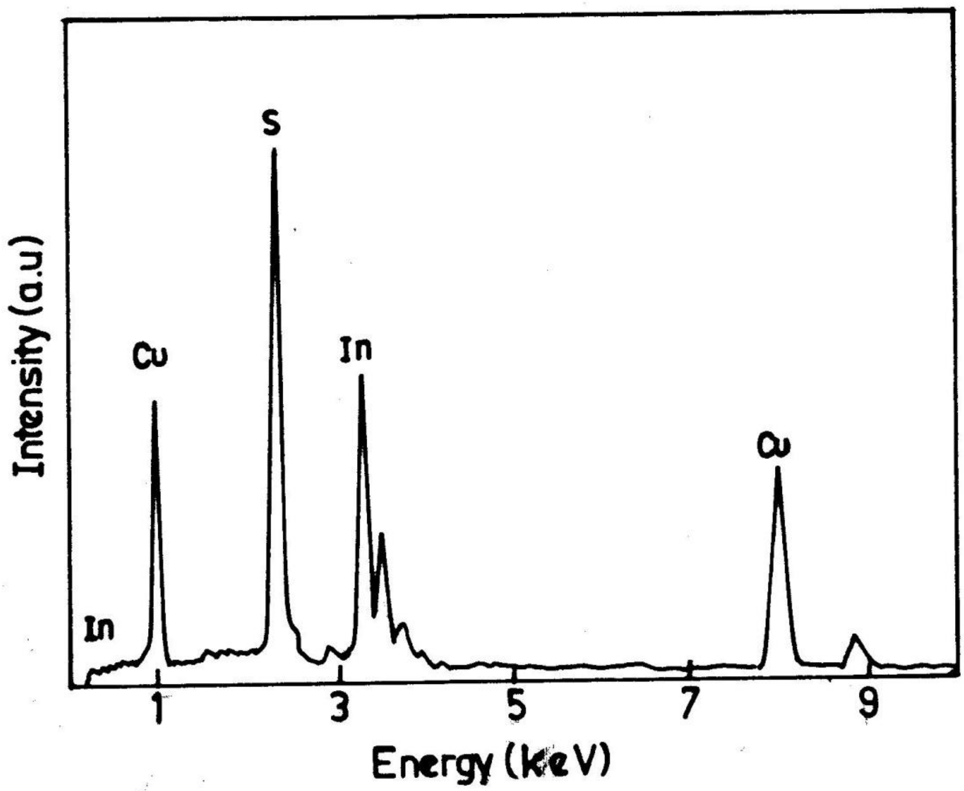

Figure 2. EDAX spectrum of $CuInS_2$ films

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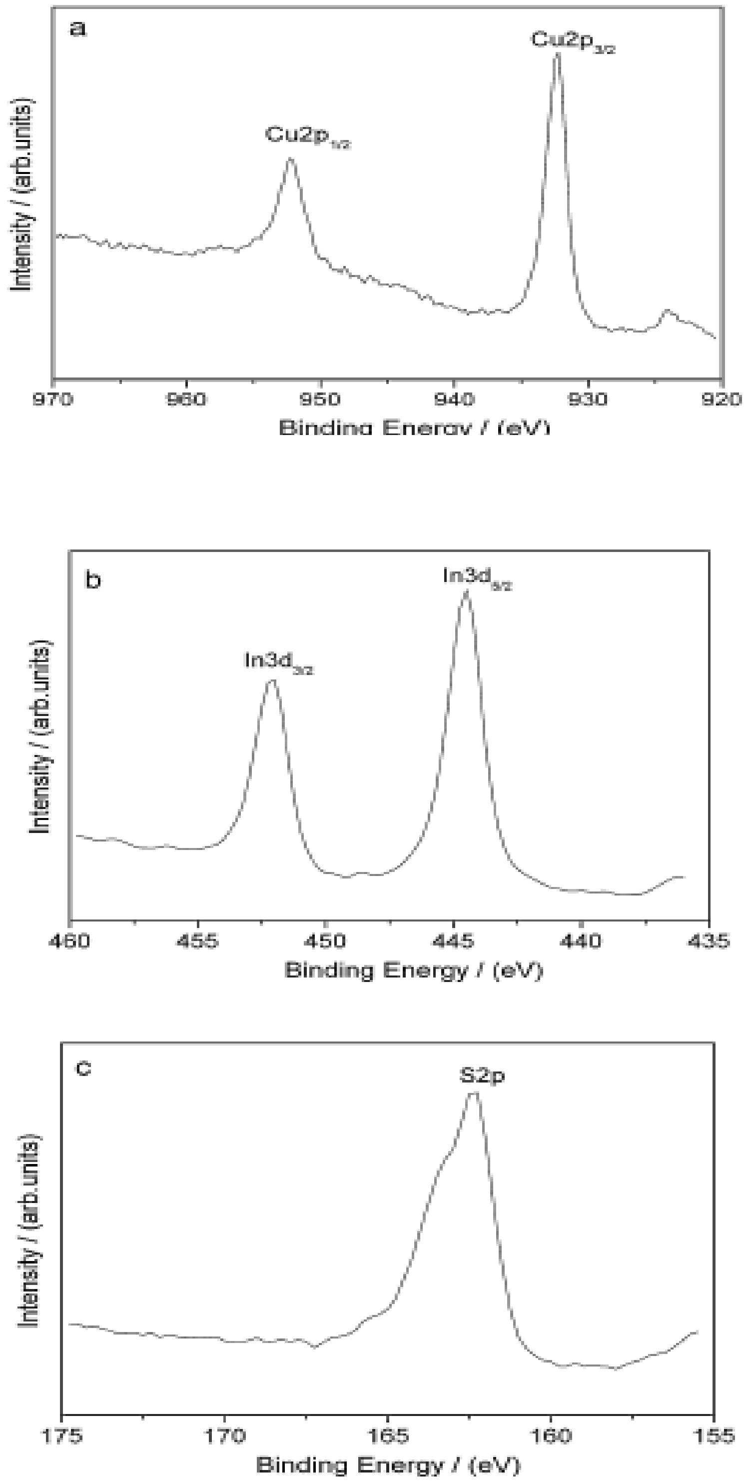

Figure 3. XPS Spectra of $CuInS_2$ films

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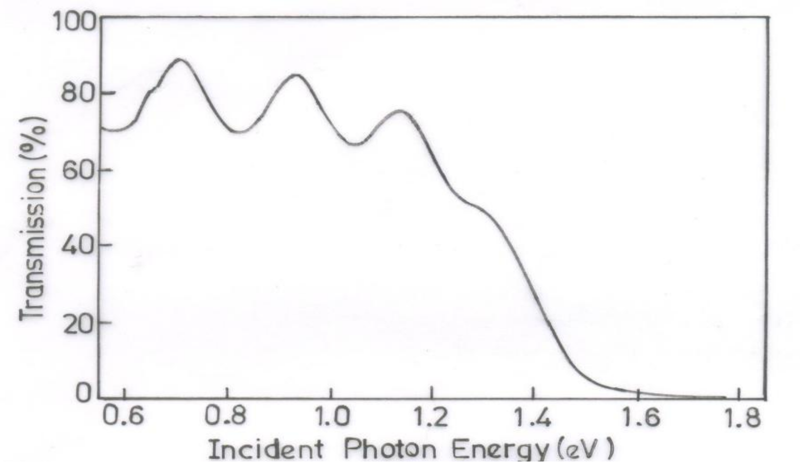

Figure 4. Transmission spectrum of $CuInS_2$ films

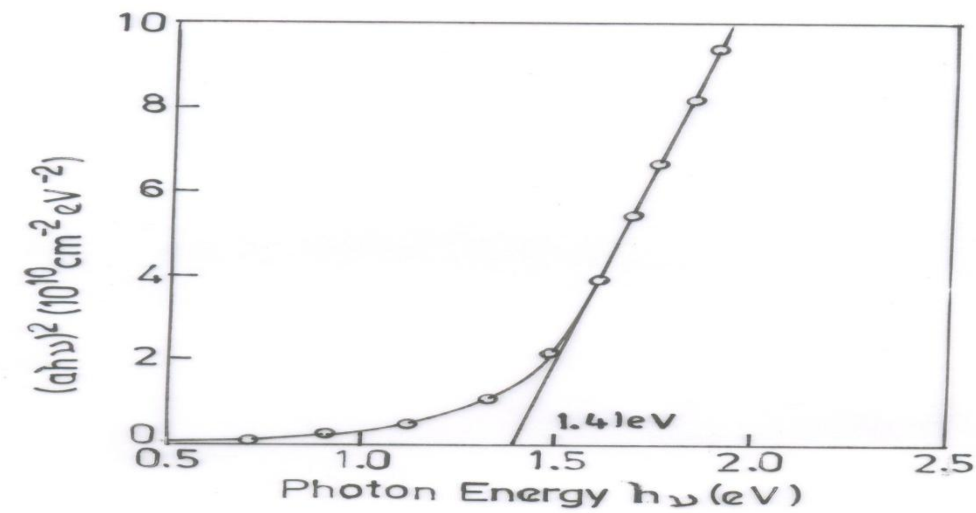

Figure 5. $(\alpha h\nu)^2$ vs hν plot of $CuInS_2$ films