Fabrication and characterization of photovoltaic cell with novel configuration ITO/n-CuIn$_3$Se$_5$/p-CIS/In

R Geethu$^1$, R Jacob$^1$, P V Sreenivasan$^2$, T Shripathi$^3$, Okram G S$^3$ and R R Philip$^1$*

$^1$Thin film research lab, Union Christian College, Aluva, Cochin, Kerala, India.
$^2$Department of Chemistry, Union Christian College, Aluva, Cochin, Kerala, India.
$^3$UGC-DAE CSR, Khandwa Road, Indore-452 001, M P, India.

E-mail: reenatara@rediffmail.com

Abstract: A novel configuration ITO/n-OVC CuIn$_3$Se$_5$/p-CIS/In solar cell has been fabricated by multisource vacuum co-evaporation technique on soda lime glass substrates. The pn junction is formed with ordered vacancy compound as the n counter part for the p type CuInSe$_2$. The structural, compositional, hall coefficient, optical and electrical properties of the p and n layers have been studied respectively by X-ray diffraction, Energy Dispersive Analysis of X rays, optical absorbance and conductivity measurements. Current density-Voltage measurements enabled the determination of efficiency of the device.

1. Introduction:
The chalcopyrite semiconductor compound copper indium diselenide (CuInSe$_2$), owing to their good photovoltaic properties, has become a promising candidate for solar-cells applications [1, 2]. The broad range of optical band gaps and carrier mobilities offered by ternary ABX$_2$ semiconductors, as well as their ability to form various solid solution and to accommodate different dopants, has led to their emergence as technologically significant device materials, including application in photovoltaic solar cells both as single-crystal materials (up to 12% efficient) and as polycrystalline thin films (at least 9.4% efficient), light-emitting diodes, and in various non-linear optical device[3].

Generally Cadmium Sulphide films are used as conducting window layers in the fabrication of heterojunction solar cells with CIS. The present work is based on the preparation of CdS free solarcell with a configuration ITO/n-OVC /p-CuInSe$_2$/In. Here indium tin oxide (ITO) will act as the contact layer at the n region and indium at the active region.

2. Experimental technique:
A modified form of Gunther’s three temperature method [4] has been used for the deposition of p-CIS and n-OVC CIS. 99.99 % pure elemental Cu and In were evaporated from two separate electrically heated molybdenum boats and 99.999% Se was evaporated from a glass crucible kept in a molybdenum basket. The deposition was done in the atmosphere of Se at a pressure of $10^{-5}$ Torr. The evaporation was done in a uniform manner by adjusting the flux through each boat and taking care to adjust the flux conditions and vacuum to the optimised conditions to obtain the films of the required composition. The solar cell fabrication was in three stages. The first stage was the coating of n OVC, on suitably masked ITO coated soda lime glass substrates, in vacuum at substrate temperature of
623K. After ensuring the formation of n-layer by structural, compositional and conductivity type characterization using X-ray diffraction (XRD), Energy dispersive analysis of X-rays (EDAX), Hall coefficient measurement and hot probe method respectively, the films were again suitably masked and p-CuInSe$_2$ was deposited on it at substrate temperature 623K. Indium was deposited at room temperature over p-CIS layer to serve as the electrode contact on the p-side.

X-ray diffraction (XRD) using a Rigaku D MaxC X-ray diffractometer with CuKα1 as source radiation was used to determine the phases and crystallographic structure of the films. Compositional characterization was done by taking EDAX by using a Link 10000, a Cambridge instrument. Hall effect measurements were done placing the film in a magnetic field of 3600 Gauss and by measuring the voltage for different currents by four probe method. The dark conductivity and photoconductivity at room temperature were measured using Keithley 2611A source meter, using silver paste for ohmic contact. Optical absorbance measurements were performed with a Hitachi U-3410 UV-Vis-NIR spectrophotometer. Dark and photo conductivity measurements were done using a Keithley 2611A source meter and an FHS lamp. The J-V characteristics of the ITO/n-OVC/p-CIS/In solar cell was studied using a Keithley 2611A source meter, using an FHS lamp (82V, 300W) for illumination of the cell from the substrate side.

3. Results And Discussions

The structural characterization has been done by using X-ray diffraction in order to ascertain the formation of n-OVC and p-CIS and the lattice constants has been calculated to check the lattice matching between the two layers. The values obtained showed agreement with the early observed results [5-6]. After ensuring the formation of n and p type layers from hall measurement in conjunction with hot probe technique conductivity has been determined. The n and p type films were found to have conductivity in the order $1.66 \Omega^{-1} m^{-1}$ and $3.58 \times 10^4 \Omega^{-1} m^{-1}$ respectively. A carrier density of the order of $2 \times 10^{15}/cm^3$ and $1.9 \times 10^{19}/cm^3$ has been obtained in the n and p films from Hall effect measurement.

The absorption coefficients of the as prepared n and p type CIS films are determined from the absorbance and the transmittance spectra using equation (1)

$$T = (1-R)^2 \exp(-A) = (1-R)^2 \exp(-\alpha d) \quad (1)$$

where A is the absorbance, $\alpha$ the absorption coefficient, d the film thickness (0.1$\mu$m), R the reflectance and T the transmittance of the films [7].The absorbance and transmittance of the films for different wavelength are shown in figure 1a and 1b. The band gap has been determined from the equation

$$\alpha h\nu = A_c (h\nu - E_g)^\gamma \quad (2)$$

where $\alpha$ is the absorption coefficient, $\gamma$ is a constant which is equal to 1/2 and 3/2 for allowed and forbidden direct transitions respectively and equal to 2 and 3 for allowed and forbidden indirect transitions in which the photons are involved, $A_c$ is a constant and $E_g$ is the optical band gap [8]. Copper indium selenide compounds are direct band gap materials [9] so that the extrapolation of straight line portion to x-axis in the graph with $h\nu$ along x-axis and ($\alpha h\nu)^2$ along y-axis gives the optical band gap value of the material. The optical band gaps of the as prepared films were found to be $\sim 1.3 \text{ eV}$ and $\sim 0.9 \text{ eV}$ respectively for n and p films.
Fig. 1. (a) Absorbance spectrum of n OVC, inset shows the transmittance spectrum

Fig. 1. (b) Absorbance spectrum of p-CIS, inset shows the transmittance spectrum

The enhanced band gaps for OVC’s indicate that if illuminated from the n-OVC side, photons with lesser energy could pass without absorption or generation of carriers in the OVC to the p-side, thereby resulting in carrier generation in the p-CIS. Carrier separation could then occur at the junction, resulting in external photon generated current. The photosensitive nature of the films has been confirmed by doing photocurrent measurements.

The efficiency of the solar cell has been calculated from the J-V characteristics shown in the figure 2. The open circuit voltage and short circuit current ~ 0.05V and ~1.8mA/cm² measured in a typical cell of the above configuration at an illumination intensity of 20 W/m² is shown in figure 2. The efficiency has been calculated ~0.31%. The cell configuration has the advantage that once optimising conditions are determined, the n- and p-type layers for pn junction formation can be deposited in a single coating simply by adjusting the flux. The possibility for lattice matching and prevention of losses is greater. The cell shows the scope to be developed into a higher efficiency system by optimising the thickness of the junction layers and by reducing the series resistance. Here, the measurement is limited by the low irradiation intensity 12-20W/m² that could be given using the
lamp used. The results indicate the possibility of obtaining better efficiency of the solar cells under standard measurement conditions.

\[ 
\begin{array}{c}
-2.55 \\
-2.04 \\
-1.53 \\
-1.02 \\
-0.51 \\
0.00 \\
0.005 \\
0.05 \\
0.10 \\
0.15 \\
\end{array} 
\]

Voltage (v)

| J (mA/cm²) | V(m,Um) |
|------------|---------|
| illumination intensity = 20W/m² |

**Figure 2.** J-V characteristics of a solar cell

### 4. Conclusion

The structural, compositional and optical analysis confirms the formation of the n OVC and p CIS layers with lattice matching and with an enhanced band gap for n compared to p. The hall and conductivity measurements in dark and under illumination reveal the semiconducting and photosensitive nature of the films. From the J-V characterization the efficiency of the cell is determined.

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