Studies on CdSe thin film/(aq) photoelectrochemical solar cells using pre-coated SnO_2 grown over glass substrates

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Abstract: Thin films of CdSe of thickness 5000 Å were grown by vacuum evaporation in a pressure of 5×10^{-5}torr on a precoated conducting SnO_2 glass plates. The structure of the as-grown thin films of CdSe was studied by X-ray diffraction and showed hexagonal symmetry with lattice constants as $a_o \approx$ 5.634 Å and $c_o \approx$ 7.342 Å. The as-grown thin films of CdSe were also studied for optical absorption and showed direct optical transition in the optical region. The band gap was found to be $\approx 1.76\, eV$. The junction of thin films of CdSe with (aq) polysulphide showed photoelectrochemical effects on illumination with white light of 100 mW/cm^2 under AM 1.5 conditions with solar power conversion efficiency of 1.76 %. The results obtained are analyzed and discussed.

1. Introduction

There has been a lot of work done using chalcogenide thin films of semiconducting CdSe in the application to Solar Cells [1-2]. The semiconducting CdSe material has been used both in bulk form and thin film form for application to solar cells. The photoelectrochemical solar cells with CdSe with aq. Redox electrolyte has been fabricated by many workers. There has been a number of variations in substrates on which CdSe has been grown. Most of the substrates were Indium Tin Oxide (ITO) grown over glass plates. Very less work has been cited on CdSe photoelectrochemical solar cells on precoated SnO_2 coated glass plates [3].

2. Experimental

The bulk CdSe alloy was initially prepared by stoichiometrically weighing highly pure AR grade pure Cd and Se (99.999%) in a quartz crystal ampoule. The ampoule was evacuated to a pressure of 5×10^{-5} torr to avoid any presence of oxygen in the sealed quartz ampoule. The ampoule was heated by programmed muffle furnace for 12 hours with initially at 450 °C maintained at that temperature for 2 hours so that Cadmium melts and diffuses into Selenium. The furnace was further heated to 650 °C for Selenium to melt till 12 hour time was completed so that a homogenous alloy was formed. The furnace was subsequently cooled to room temperature using stepwise cooling so that there are no cracks in the composite alloy. This alloy was grinded using mortar and pestle to form a uniform powder. The alloy powder was transferred in a Tantalum boat inside the vacuum chamber which was subsequently evacuated to a pressure of 5×10^{-5} torr. Pre-coated Tin Oxide (SnO_2) on glass plates were kept at a distance of 70 cm in frame consisting of sample holders. A current of 20 A was passed through the Tantalum boat for 45 seconds to coat CdSe thin films of thickness of 5000 Å. The thickness of the as-grown thin films was monitored using quartz crystal monitor. The as-grown thin films of CdSe were kept in an air tight desiccators to avoid any moisture contamination. The thin film samples of CdSe was used for structural studies using X-ray powder diffraction where target used to generate characteristic K_α X-rays of wavelength of 1.542 Å was Copper. The angle of scanning was varied from 5^o to 80^o. The Perkin Elmer spectrophotometer was used in the region of UV-VIS-IR for optical absorption and band gap measurement. An aq redox electrolyte comprising of pure deionized water 1 M NaOH + 1 Na_2S and I M S was used with pH of 10.2. The CdSe coated semiconductor on precoated SnO_2 was used as a photoanode and graphite as an counter electrode with separation of 2 mm in an air tight compartment. The photoelectrochemical solar cell set up was used by 100 W Tungsten Halogen lamp of intensity 100 mW/m^2 solar light intensity under AM 1.5 conditions. The connecting wires were connected using Pb-Tin alloy solder so that an ohmic contact is realized with the CdSe thin film. The voltage and currents were measured by Keithley voltmeters and ammeters.

3. Results and Discussion

3.1 X-ray diffraction Studies

The as-grown thin films of CdSe were characterized by powder X-ray diffraction Both the bulk powder and the thin film was used. It is seen that the peaks obtained for the bulk are more and for thin film grown by a proper evaporation direction sets the preference of planes for the growth of the thin films. The *d* values of the as grown thin films match close to other workers [6]. It is seen that the miller indices for the reflecting planes tally well with the literature [6]. The lattice constants a_o and c_o were calculated using the following equations [5] :

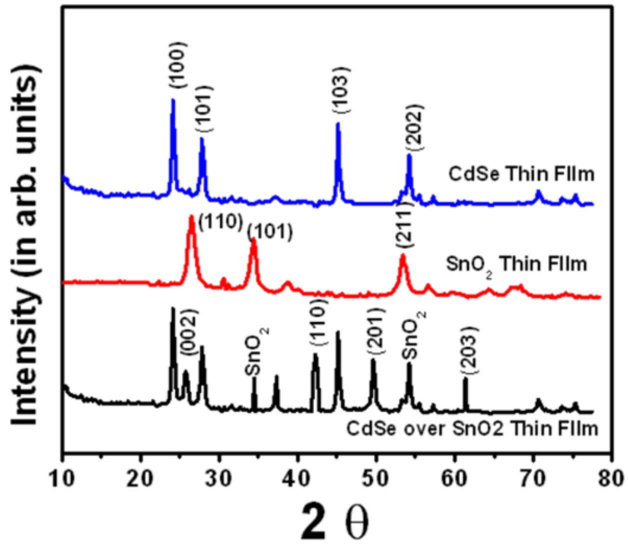

Fig. 1. The XRD pattern of CdSe thin film, SnO_2 thin film and CdSe over SnO_2 Thin film

$$\frac{1}{d^2} = \frac{4}{3}\left(\frac{h^2 + hk + k^2}{a_o^2}\right) + \frac{l^2}{c_o^2}$$

Using the formula given in the literature [5] we have precise values of the lattice constants using the value of wavelength of X-ray, λ as per the equations given below:

$$a_o = \frac{\lambda}{\sqrt{3}\,Sin\theta}\sqrt{(h^2 + hk + k^2)} \quad \& \quad c_o = \frac{\lambda}{2sin\theta}\, l$$

The lattice constants $a_o \approx 4.561$ Å and $c_o \approx 7.657$ Å were found to match with the literature [6]. indicating the structure of the as grown thin film of CdSe and bulk alloy exhibits Hexagonal symmetry. These values tally well with those values as given in the literature. Figure 1. shows a typical powder X-ray diffraction pattern for as-grown thin film of CdSe, SnO_2 thin film and CdSe grown over SnO_2.

3.2 Optical Absorption Studies

The thin films of CdSe were subjected to optical absorption studies in the range of 300 nm to 800 nm spanning UV-VIS-IR region. . For permitted direct transmissions in the optical region the absorption coefficient, α is given by [7]

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

Where ν is the frequency of incident light, h is the Planck's constant, E_g is the bandgap of the semiconductor and the coefficient, A^* is given by:

$$A^* \approx q^2\left(\frac{2m_e^* m_h^*}{m_e^* + m_h^*}\right)\left(nch^2 m_e^*\right)^{-1}$$

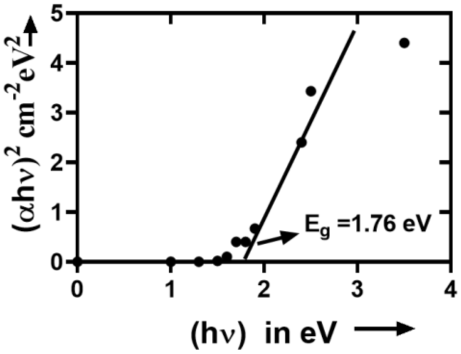

Fig.2. Optical Absorption Plot for CdSe thin film.

Where m_e^* and m_h^* are the effective electron and hole masses respectively, c is the speed of light, h is the Planck's constant and n is the refractive index.

Figure 2.0 shows a plot of $(\alpha h\nu)^2\ vs\ h\nu$. The intercept on the energy axis gives the direct band gap. ≈ 1.76 eV. This tallies well with other researchers [6].

3.3 Solar Power conversion Studies

The solar power converstion studies were done on as grown CdSe thin film on SnO_2 with (aq) redox Polysulphide when the photoelectrochemical solar cell was illuminated with white light of 100 mW/m^2 intensity under AM 1.5 conditions. The solar power conversion efficiency was calculated as per the formulae given by [8]. A typical plot consisting of variation of photocurrent density vs photovoltage under AM 1.5 white light illumination is shown in Fig. 3

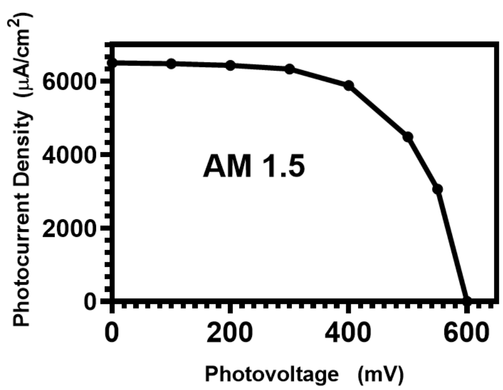

Fig. 3. Solar Output plot of CdSe/SnO_2/(aq) Poly-sulphide Photoelectrochemical Solar Cell

The as grown thin films showed a solar power conversion efficiency of 1.8%. This low value is due to small grains in the thin film which forms a junction with the redox electrolyte. This also leads to low band bending. Thus depletion width in the semiconductor region is small and therefore the solar cell efficiency is small. Figure 3. shows a typical variation of photocurrent density with photovoltage under AM 1.5 conditions. It is seen that the photoelectrochemical solar cell is able to do useful work and produce electricity under illumination.

4. Conclusions

The as-grown thin films of CdSe on precoated SnO_2 glass plates by thermal vacuum evaporation showed a hexagonal structure. The powdered XRD studies were done on CdSe, SnO_2 and CdSe over SnO_2. It was found that the XRD pattern of CdSe over SnO_2 showed peaks of SnO_2 and CdSe material. The lattice constants obtained for CdSe from experimental results match well with those of earlier workers. On studying the thin films for optical absorption on bare glass plates, it was found that semiconducting thin films of CdSe also showed a direct band gap of $\approx 1.76\, eV$. The thin films of CdSe grown over SnO_2 coated glass plates when subjected to photoelectrochemical studies showed solar power conversion. The obtained power conversion efficiency of CdSe photoelectrochemical solar cell was $\approx 1.8\%$. It was low due to the fact that the as-grown thin films by vacuum evaporation had a lot of defects which contribute to scattering of minority carriers generated on white light illumination. The solar power conversion efficiency could be improved by reducing the grain boundaries by modifying the thin film growth process.

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