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Study of quantum efficiency variation and power conversion efficiency of 2% Indium doped $CdSe_{0.2}Te_{0.8}$/Polysulphide photo electrochemical solar cells

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Abstract: Thin films of 2% Indium doped $CdSe_{0.2}Te_{0.8}$ were grown by thermal evaporation in a vacuum of 5×10^{-5} torr pressure on a precoated In_2O_3 coated glass plates. The thin films were characterized by X-ray diffraction (XRD) for structural determination, Optical absorption studies for band gap determination and an aqueous polysulphide comprising of (aq) 1M Na_2S+ 1 M NaOH + 1M S was used as a redox electrolyte for fabrication of photoelectrochemical solar cells. The XRD pattern showed that the film exhibited a crystalline nature with zinc blende (cubic) structure with lattice constant a_o= 4.22 Å. The optical absorption studies indicated that the semiconductor exhibits direct band gap with energy gap, $E_g \approx$ 1.45 eV. The doping of 2% indium enhances the conductivity and thus the solar power conversion efficiency of η= 1.6 % for the as grown thin films was obtained. The fill factor of 5% was obtained under AM 1.5 white light illumination with intensity of 100 mW/cm^2. The quantum efficiency of the photoelectrochemical solar cell was maximum for yellow ($\lambda \approx 570\, nm$) was found to be close to 55%. The results are discussed in this paper.

1. Introduction

Chalcogenide based semiconductors have shown wide application in photovoltaic cells. The band gap of Cd-Se-Te alloy can be tailored to suit the visible spectrum thus these type of semiconductors have wide potential in fabrication of solar cells. Many of the researchers have shown that the Cd-Se-Te in bulk is photoreceptive and in the thin film form too it has a scope in fabrication of photoelectrochemical solar cells [1-3]. Application of suitable redox electrolyte like polysulphide in conjunction with the semiconducting thin film 2% Indium doped $CdSe_{02}Te_{08}$ can show photoeffects. This fact is explored in this paper. For a thin film solar cell to have high efficiency the fill factor should be high. Apart from this the series resistance should be as low as possible and the shunt resistance should be high.

2. Experimental

Highly pure 99.999% Indium, Cd, Se and Te granules were taken in quartz ampoule with appropriate weights as per the stoichiometric ratio of the alloy to get the desired 2% Indium doped $CdSe_{0.2}Te_{0.8}$ alloy in a vacuum of $\approx 5 \times 10^{-5}$ torr and heated to $550\,^oC$ for 12 hours in a muffle furnance for homogeneous alloy formation. The alloy was *in situ* shaken after every 1 hour to get a uniform homogenous alloy. After step wise cooling of the alloy in the muffle furnace, the alloy was brought to room temperature eventually. The quartz ampoule was broken to get the alloy. The alloy was grinded in an agate mortar and pestle with addition of ethanol to obtained a uniform power form particles of small size. The powder was cleaned and put in an Molybdenum boat for thermal evaporation. A precleaned glass plates and precoated In_2O_3 glass plates were kept in the vacuum chamber to get many sample thin films simultaneously. The alloy was evaporated for 55 seconds to get a thickness of the thin film ≈ 450 nm using quartz crystal monitor. The samples were kept in a vacuum of $\approx 5 \times 10^{-5}$ torr and exposed to air only for fabrication of photoelectrochemical solar cell. The Cu-K_α was used as target for X-ray generation. A Bontoon capacitance meter was used to study the Mott-Schottky plots in dark. Saturated Calomel Electrode (SCE) was used very near to the semiconducting electrolyte to measure the voltage with respect to SCE in the dark. The optical absorption studies of the as-grown thin films were subjected to Shimadzu photospectrometer (Made in Japan) for regions of UV-VIS-IR. The absorption coefficients were in the order of $\approx 10^4\ cm^{-1}$. The photoelectrochemical cell was fabricated using as grown thin film on a glass plate with counter electrode made of graphite. A freshly prepared aqueous redox electrolyte of (aq) 1 M Na_2S + 1 M NaOH + 1M S was used in double distilled water. The photoelectrochemical cell was air tight and exposed to tungsten halogen lamp which simulated as white light under AM 1.5 conditions with constant illumination intensity of 100mW/cm^2. Keithley Voltmeters and Ammeters were used for power output characteristics studies.

3. Results and Discussion

3.1 XRD Studies for structure determination of 2% In doped $CdSe_{0.2}Te_{0.8}$ alloy thin films

Power XRD studies using Cu-K_α radiation of λ= 1.542 A showed that the thin films are polycrystalline in nature. The interplanar spacing, d values were compared with those of literature. The miller indices corresponding to the peaks obtained were referred to those of literature [4]. It is seen that the thin films have more tendency of Zinc Blende structure preference. The lattice constant as obtained on calculation from the powder XRD data yielded a_o= 4.22 Å. Figure 1 shows a typical XRD pattern of the as grown thin films.

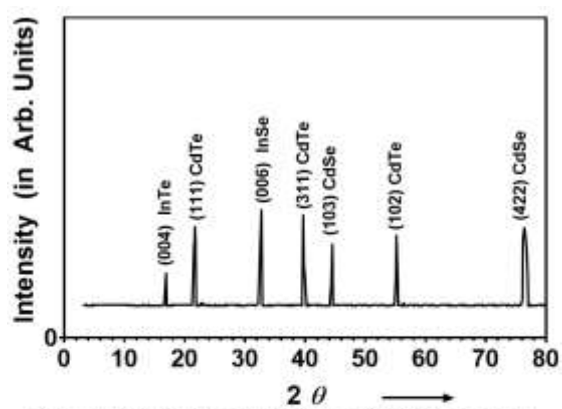

Fig. 1. A typical XRD plot of 2% In doped $CdSe_{0.2}Te_{0.8}$ thin film for the as grown thin film.

There are some peaks corresponding to InTe and InSe. The atomic radii of Indium is less than Te and Se. So Indium has more tendency of occupying sites vacant for Se and thus enhancing the conductivity of the alloy.

3.2 Optical Absorption studies of the as grown 2% In doped $CdSe_{0.2}Te_{0.8}$ alloy thin films

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The as-grown thin films of 2% In doped $CdSe_{0.2}Te_{0.8}$ alloy deposited on glass were subjected to optical absorption studies in the region of UV-VIS-IR region. The optical absorption studies were done using an optical absorption spectrophotometer, Jeol (Made in Japan) in the wavelength range of $\lambda = 350\ nm$ to $750\ nm$. Figure 2 shows a typical plot of $(\alpha h\nu)^2$ vs $(h\nu)$. Here α is the absorption coefficient, h is the Planck's constant and ν is the frequency of the incident light. It is seen that the curve rises at an energy of $\approx 1.45\ eV$ indicating that the straight line intercept on the energy axis is the band gap $E_g \approx 1.45$ eV. For permitted direct transmissions in the optical region the absorption coefficient, α is given by Pankov [5]

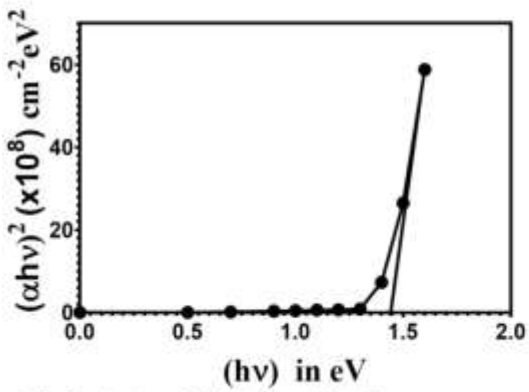

Fig. 2. A plot of $(\alpha h\nu)^2$ vs $(h\nu)$ for an as grown 2% Indium doped $CdSe_{0.2}Te_{0.8}$ thin film

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

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:

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

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. The optical absorption constant was in the order of $\approx 10^4 cm^{-1}$ indicating that the thin film shows good absorption in the visible light. Therefore, the variation of $(\alpha h\nu)^2\ vs\ h\nu$ will be a straight line plot with intercept on the $h\nu$ axis at $(\alpha h\nu)^2 = 0$ gives the direct optical band gap of the semiconducting 2% In doped $CdSe_{0.2}Te_{0.8}$ was around $E_g \approx 1.45$ eV [6].

3.3 Mott-Schottky plots of 2% In doped $CdSe_{0.2}Te_{0.8}$/(aq) Polysulphide structure in dark

The capacitance vs voltage studies were performed on the 2% In doped $CdSe_{0.2}Te_{0.8}$/(aq) Polysulphide structure in dark. As per Mott & Shottky [7,8] the variation of $1/C^2$ vs Voltage showed a straight line at a frequency of 1 MHz. As per the Mott-Schottky equation:

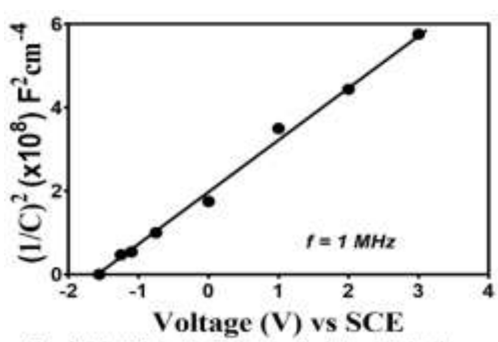

Fig. 3. Mott-Schottky Plots in dark for 2% Indium doped $CdSe_{0.2}Te_{0.8}$ thin film/(aq) Polysulphide cell

$$\frac{1}{C^2} = \left[\frac{2}{\epsilon_o \epsilon_s q N_D}\right] \left[V - V_{FB} - \left(\frac{k_B T}{q}\right)\right]$$

The straight line indicates that there is a formation of depletion width in dark when the semiconducting 2% In doped $CdSe_{0.2}Te_{0.8}$ is in contact with a redox polysulphide electrolyte. The Mott-Schottky plots yield various other parameter of the semiconductors like Donor Concentration N_D and Flat band potential V_{FB}. These parameters are crucial for the assessment of solar cell parameters.. The donor concentration, N_D obtained was $\approx 2 \times 10^{18} cm^{-2}$, depletion width, $\omega \approx 0.0325\ \mu$m, Flat Band potential was $V_{FB} \approx$ -0.56 Volts vs SCE.

3.4 Quantum Efficiency studies under different coloured light illumination

Quantum efficiency studies were performed for 2% In doped $CdSe_{0.2}Te_{0.8}$/(aq) Polysulphide photoelctrochemical solar cells under different colours of illumination. The photocurrent obtained was recorded with variation of wavelength, λ. Figure 4 shows the photocurrent density vs Wavelength, λ. It is seen the photocurrent density is maximum at a wavelength, $\lambda \approx 570\ nm$. This is due to response of the photoelectrochemical solar cell as per the solar spectrum. There is more charge separation at this wavelength there by maximum conversion of light to electric current. The quantum efficiency, Q_F was calculated from the relation:

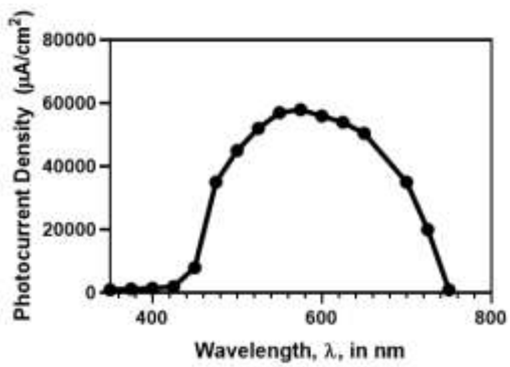

Fig. 4. Photocurrent density with wavelength plot for 2% Indium doped $CdSe_{0.2}Te_{0.8}$/ (aq)Polysulphide PEC Solar Cell

$$Q_F = \frac{I_{ph} . h . \nu}{q \times Intensity\ \ of\ Light\ at\ \lambda}$$

Where I_{ph} is the photocurrent at wavelength of light, λ; h is the Planck's Constant; ν is the frequency of light corresponding to wavelength, λ; q is the electronic charge. It is seen that the Q_F was the highest for the yellow ($\lambda \approx 570\ nm$) colour $\approx 55\%$.

It is seen from Fig. 5 that quantum efficiency for the as grown thin films used in the photoelectrochemical cells was highest for yellow colour, $Q_F \approx 55$ % when the applied potential was varied from -300 mV_{SCE} to 800 mV_{SCE}. The Quantum Efficiency variation with applied potential shows a rise in Q_F but as the applied potential was increased beyond

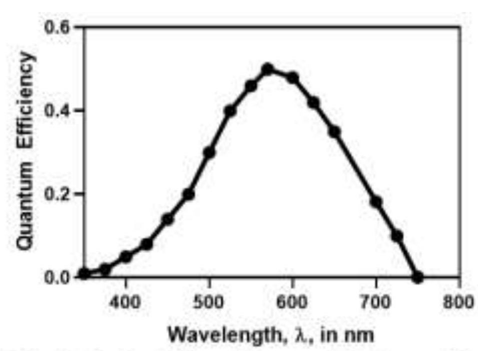

Fig. 5. A plot of variation of Quantum Efficiency with wavelength for 2% Indium doped $CdSe_{0.2}Te_{0.8}$/ (aq) Polysulphide PEC Solar Cell

100 mV_{SCE} the quantum efficiency showed almost constant nature, This shows that the applied potential doesnot bend the bands further (> 100 mV vs SCE) thus making the Q_F a constant quantity. The high value of quantum efficiency (Q_F) indicates that the thin films are more receptive to illumination due to presence of Indium which facilitates the quick separation of minority carriers created in the depletion width to the external circuit apart from minimizing the ohmic contact losses. Also presence of Indium in small quantities in the semiconducting thin film helps to reduce the series resistance (R_s) and increase the shunt resistance (R_{sh}).

3.5 Solar Power Conversion Efficiency white light illumination

Solar power conversion Efficiency studies were carried out for the 2% In doped $CdSe_{0.2}Te_{0.8}$/(aq) Polysulphide photoelctro-chemical solar cell under AM 1.5 illumination with intensity of illumination of 100 mW/cm^2. Figure 5 shows a solar power ouput characteristics of a typical plot of 2% In doped $CdSe_{0.2}Te_{0.8}$/(aq) Polysulphide photoelctrochemical solar cell. It is seen that the photocurrent vs photovoltage profile has power output. The Short circuit current (I_{sc}) was ≈ 5000 mA/cm^2 and open circuit voltage V_{oc} ≈ 550 mV under AM 1.5 white light illumination. The fill factor (FF) obtained was ≈ 55 %. The efficiency of the solar cell was calculated using the equation below [9]:

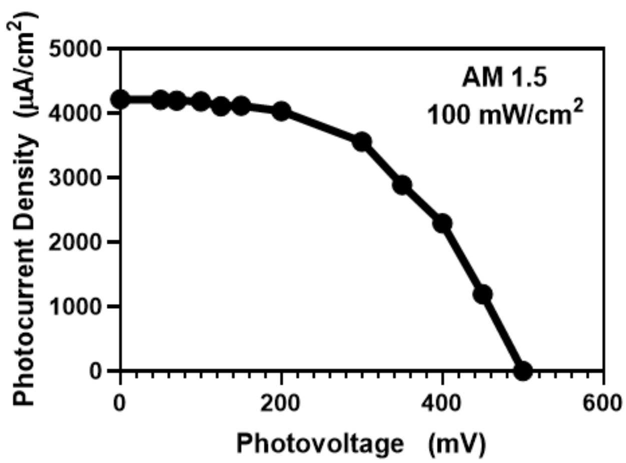

Fig. 6. Power Output Characteristic of 2% Indium doped $CdSe_{0.2}Te_{0.8}$/ (aq)Polysulphide PEC Solar Cell

$$\eta = \frac{P_{output}}{P_{input}} \times 100$$

Where P_{output} is the output electrical power and P_{input} is the input solar power ≈ 100 mW/cm^2 for white light illumination in our case. The fill factor (FF) was calculated using the formula [10,11] :

$$F.F. = \frac{V_m J_m}{V_{OC} J_{SC}}$$

where V_m and J_m are the photovoltage and photocurrent density at maximum power output and V_{OC} and J_{SC} are the Open Circuit voltage (at J_{SC} = 0) and Short Circuit current density (at V_{OC} =0).

4 Conclusions

The thin films of 2% Indium doped $CdSe_{0.2}Te_{0.8}$ were studied for powder XRD diffraction. The structure of the as-grown thin films was Zinc Blende (Cubic) with lattice constant, $a_o \approx 4.22$ Å. The band gap of the 2% Indium doped $CdSe_{0.2}Te_{0.8}$ thin film was $\approx$ 1.45 eV. The Mott-Shottky plot was linear. The donor concentration was, $N_D \approx 2 \times 1018cm{-}2$. At the semiconductor-electrolyte junction the depletion width in the semiconductor, ω, was $\approx 0.0325\ \mu m$ and the flat band potential was $V_{FB} \approx$ -0.56 Volts vs SCE. The quantum efficiency Q_F was highest for yellow colour at $\lambda \approx 570\ nm$ was nearly 55 %. Doping of Indium in small amounts acts as a conductivity enhancer and helps to facilitate the quick separation of minority generated carriers to the external circuit to low series resistance and high shunt resistance, leading to enhancement of quantum efficiency and solar power conversion efficiency [12]. The other treatments like annealing of the thin film and etching of the thin film might have an improving effect on the performance of the photoelectrochemical cell.

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