Solar Power Studies on n-CdSe$_{0.5}$Te$_{0.5}$/(aq) Ferro-Ferricyanide photoelectrochemical solar cells

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Abstract:
Photoelectrochemical (PEC) Solar Cells were made using thin film vacuum evaporated CdSe$_{0.5}$Te$_{0.5}$ (thickness ≈ 4000 Å) at 30 ± 1Å/sec on indium oxide coated glass plates at high vacuum ($\approx 10^{-5}$ torr) dipped in aqueous Ferro-Ferricyanide solution with graphite electrode as the counter electrode. The PEC solar cell efficiency was measured using AM 1.5 solar radiation for power conversion. The thin films were characterized by X-ray diffraction to ascertain the formation of CdSe$_{0.5}$Te$_{0.5}$and the bandgap of the semiconducting thin film was calculated by optical studies.

1. Introduction:

Photoelectrochemical (PEC) Solar Cell research has been a burning topic in recent years. The chalcogenide semiconductors like CdSe and CdTe have received importance due to their optical band gap being in the visible range thus qualifying them for use in solar power conversion to electricity [1,2]. In the present investigation we characterize the thin films of CdSe$_{0.5}$Te$_{0.5}$ for its structural properties, optical properties and study the Mott-Schottky plots of CdSe$_{0.5}$Te$_{0.5}$ and its junction with Potassium Ferrro-Ferricyanide in dark for their linearity at various frequencies from 1 kHz to 10 kHz. For power conversion studies we have studied CdSe$_{0.5}$Te$_{0.5}$ /(aq)Potassium Ferrro-Ferricyanide under white light AM 1.5 for solar power conversion efficiency studies.

2. Experimental:

Thin films of the alloy of CdSe$_{0.5}$Te$_{0.5}$ were prepared in a vacuum of 2×10^{-5} torr on a pre-coated In$_2$O$_3$ coated glass by thermal vacuum evaporation process with the substrate at room temperature. The rate of evaporation was 30 ± 1 Å/sec. AR grade reagents were used to prepare the aq. Ferro-Ferricyanide redox electrolyte with composition of 0.1M K$_4$Fe(CN)$_6$ + 0.3 M K$_3$Fe(CN)$_6$ + (aq) KOH was used in the experiment. Three electrode set up was used to perform photoelectrochemical measurements. The counter electrode was graphite and a reference electrode was saturated calomel electrode (SCE) attached very near to the thin film CdSe$_{0.5}$Te$_{0.5}$thin filmphotoelectrode. Ohmic contacts of Indium were made to the thin film CdSe$_{0.5}$Te$_{0.5}$ by evaporating Indium at the appropriate region. All the electrical measurements were made using Keithley multimeters for better accuracy. A Hitachi (Model No. U340) spectrophotometer was used to study the optical absorptionspectrum (of the films on bare glass plates) within therange 400-900 nm for the determination of the opticalbandgap. Photoelectrochemical solar cells were illuminated by white light SUNLUX Tungsten-Filament Lamp yielding a constant intensity of 100 mW/cm^2 under AM 1.5 conditions.

Monochromatic light was selected by using an ORIEL grating monochromator for spectral response studies.

3. Results and Discussion:

3.1 *X-ray Diffraction Studies:*

The as-grown thin films of $CdSe_{0.5}Te_{0.5}$ were characterized by X-ray diffraction (XRD) using Cu-Kα radiation with the help Ni-Filter. The XRD patterns were obtained for the diffracting angle 2θ varying from 5° to 90°. The XRD pattern as shown in Fig. 1 revealed that the films are polycrystalline. The obtained d-values and the peaks orientations match with the standard values of literature confirming the formation of $CdSe_{0.5}Te_{0.5}$ alloywith structure as hexagonal [6,7].The data is shown in Table 1.

Sr. No.	Observed d value (Å)	CdSe[6]		CdTe[7]	
		d value (Å)	(hkl)	d value (Å)	(hkl)
1	3.2890	3.2901	(101)		
2	2.5321	2.554	(102)		
3	2.3491			2.289	(220)
4	1.7870	1.750	(201)		
5	1.4581	1.452	(203)		

Table 1. The observed and standard *d* values of CdSe and CdTe
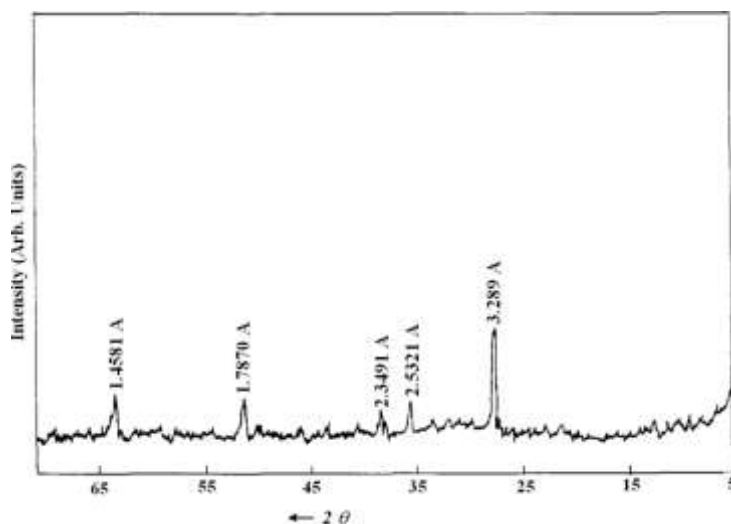
Fig. 1. A typical X-ray diffraction pattern of as grown $CdSe_{0.5}Te_{0.5}$ thin film.

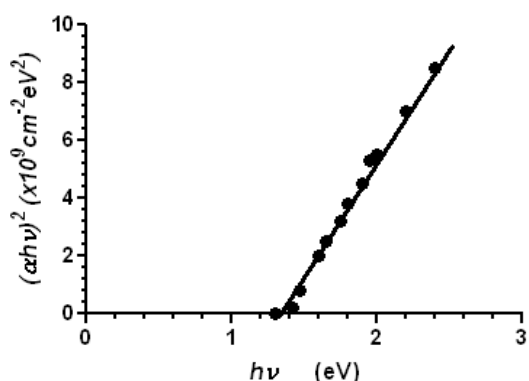### 3.2 *Optical Absorption Studies:*

The thin films of $CdSe_{0.5}Te_{0.5}$ were characterized for optical absorption studies in a spectrophotometer between the wavelength of $\lambda \approx 300\text{-}900$ nm at room temperature. For permitted direct transmissions in the optical region the absorption coefficient, α is given by [3]

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

Where ν is the frequency of incident light, h is the Planck's constant, E_g is the bandgap of the semiconductor and the constant, A given by [3]:

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

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.

Fig. 2. A plot of $(\alpha h\nu)^2$ vs $h\nu$ for an as-grown CdSe$_{0.5}$Te$_{0.5}$ thin film for optical absorption studies.

The plot of $(\alpha h\nu)^2$ vs $h\nu$ is a straight line (Fig. 2) with intercept on the hν axis at $\alpha = 0$ is the optical band gap, $E_g = 1.42$ eV well within the optical region and agrees with the literature [1].

3.3 *Mott-Schottky Plots*

The Capacitance- Voltage (C-V) studies in dark for the CdSe$_{0.5}$Te$_{0.5}$/(aq) Ferro-Ferricyanide structure at room temperature were performed at different frequencies of 1kHz, 5 kHz and 10 kHz (Fig 3). The amplitude of the a.c. signal was peak to peak voltage of 20 mV.

The variation of space charge capacitance, C, with applied potential, V in dark is given by the Mott-Schottky relation as [4,5] :

$$\frac{1}{C^2} = \left[\frac{2}{\epsilon_o \epsilon_s q N_D}\right]\left[V - V_{FB} - \left(\frac{k_B T}{q}\right)\right]$$
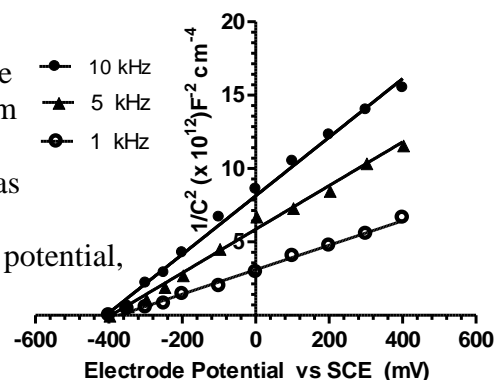
Where q = charge, N_D = Donor Concentration, V_{FB} is the flat band potential, T is the temperature, ϵ = permittivity of the semiconductor, ϵ_o.= permittivity of free space.

It is seen that the plots are linear with Flat Band Potential, V$_{FB}$≈ -0.40 V$_{SCE}$ at room temperature for all frequencies of 1 kHz, 5 kHz and 10 kHz. It is seen that there is dispersion of the plots with variation of frequencies. This indicates that in the as-grown thin films, we have contribution from back ohmic contacts due to irregular electrode surface. The surface states on the semiconductor side contribute to the space charge capacitance and responsive to the impressed signal. There could also be non-uniform distribution of donor concentration at the surface in touch with the electrolyte this leads to dispersion of the plots [9,10].

3.4 *I -V Characteristics of CdSe$_{0.5}$Te$_{0.5}$/(aq) Ferro-Ferricyanide photoelectrochemical Cells*

The I-V characteristics of the as-grown thin films of CdSe$_{0.5}$Te$_{0.5}$ with junction of (aq) Ferro-Ferricyanide phoelectrochemical cells were studied. A counter graphite electrode was used under white light (AM 1.5) illumination. The cell exhibited a power conversion efficiency of 1.5% with fill factor of 55%, the series resistance R_s as calculated from the curve yields a value of 70 Ω and shunt resistance of 6500 Ω by a method given by Coutts [8]. The low value of shunt resistance is due to grain boundaries in the polycrystalline thin films. For an ideal solar cell, R$_s$≈ 0 and R$_{sh}$≈ ∞. In our case the series resistance is not close to zero due to

the fact that thin films contain defects which might be columnar and of the same size of the thickness of the thin film. In such a case attaining zero value of series resistance is not possible. Also the external contacts to the thin films produce some resistance thus decreasing the fill factor. A typical I-V characteristics of the PEC cell is shown in Fig. 4.
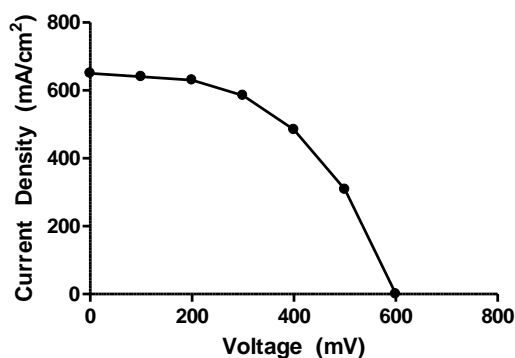
Fig. 4: A typical plot of power output $CdSe_{0.5}Te_{0.5}$/(aq) Ferro-Ferricyanide photoelectrochemical
Cell under AM 1.5 white light illumination.

4. Conclusions:

The structural and optical properties of vacuum evaporated thin films of $CdSe_{0.5}Te_{0.5}$ were studied. The thin flims of $CdSe_{0.5}Te_{0.5}$ exhibited hexagonal structure and the interplanar spacings of the as-grown thin films matched with the literature. The Mott-Schottky plots for the $CdSe_{0.5}Te_{0.5}$/(aq) Ferro-Ferricyanide photoelectrochemical cell in dark exhibited straightline pattern. On changing the impressed frequency from 1kHz to 10 kHz the plots exhibited dispersion. This shows that the grain boundaries on the surface of the semiconductor in conjuction with electrolyte responded with the frequency due to impurity trapping of charge carriers, surface states and uneven penetration of the electrolyte into the semiconductor causing dispersion of the Mott-Schottky plots. The I-V characteristics or the solar power conversion of the cell under AM 1.5 white light of intensity 100 mW/cm^2 yield a solar power conversion efficiency of 1.5%. The fill factor and the series and the shunt resistance were calculated from experimental results.

References:
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