

PHOTOELECTROCHEMICAL SOLAR CELLS BASED ON ELECTRO-CO-DEPOSITED CdSe/ZnSe DOUBLE LAYER PHOTOELECTRODES

R. K. ALONEY*, J. K. DONGRE, B. P. CHANDRA, M. RAMRAKHIANI

Department of Post Graduate Studies & Research in Physics & Electronics, Rani Durgavati

University, Madhya Pradesh, Jabalpur, 482001, India

Binary films of CdSe/ZnSe have been prepared onto titanium substrate by electro-co-deposition technique in an aqueous acidic electrolyte employing different current density and deposition time duration. The photovoltaic cells are formed with these photoelectrodes. The cell configuration CdSe/ZnSe/1M NaOH-Na₂S-S/C (graphite) is used for studying the photovoltaic characteristic under illumination of 1950 lux light intensity to evaluate various cell parameters such as; short-circuit current (I_{sc}), open circuit voltage (V_{oc}), power output (P_o), fill factor (ff) and efficiency ($\eta\%$). It is found that the V_{oc} , I_{sc} , P_o , ff and $\eta\%$ increase with increasing current density (J_D). The CdSe/ZnSe films show best performance at current density $J_D = 10 \text{ mA/cm}^2$. The solar cell studies have also been carried out with various deposition time duration (t_m). In double layer photoelectrodes the larger band gap material absorb the shorter wavelength portion of the incident light and the longer wavelength portion passes to smaller band gap material and is absorbed by it. Thus, both layers contribute to photocurrent and larger portion of incident light is converted into electrical power.

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1. Introduction

The reserve of fossil fuel and wood are depleting very fast, as a results of which energy production is becoming expensive day by day. The search for alternative source of energy has led to rapid strides in the utilization of solar energy. Conversion of solar energy into electrical energy through photovoltaic process is the most important and desirable route of the obtaining electricity. The presently available solar cells are manufactured from highly pure and perfectly crystalline materials and P-N junction is obtained by using very sophisticated technology, which makes them quite expensive. But, the polycrystalline photoelectrochemical (PEC) solar cell provides an economic chemical route for trapping solar energy. The PEC cells convert radiant optical energy directly in to the electrical energy. Solar cell energy based on the thin film material offers the promises of much higher mass –specific power (MSP) and low cost. While, thin film single junction solar cell efficiencies rival those of silicon single crystal cells, multijunction device offer significantly higher efficiencies. Donna [1] has suggested that the triple junction of III-V solar cell can give conversion efficiency of 30% at AMO (air-mass-zero) condition. In the multijunction solar cell, total cell efficiency can be increased by stacking multiple cells having band gap tuned to convert the spectrum passing through the upper cells to the lower cells. In multibandgap layered photoelectrode, if light is first incident on larger band gap material it absorbs shorter wave length portion and the longer wave length portion passes to smaller band gap material and absorbed by it [2]. Thin film photovoltaic modules based on Cu-In-Ga-Se(CIS) and CdTe are already being

*Corresponding author: r_aloney2006@rediffmail.com

produced with high quality and solar conversion efficiency of 10%, with values up to 14% expected in the near future[3]. A metamorphic GaO.44InO.56p/GaO.92In.08As/Ge 3-junction solar cell has reached a 40.7% efficiency at 240 suns, under the standard reporting spectrum for terrestrial concentrator cells(Am1.5 direct,low-AOD,24.0 w/cm²,25 °C), and experimental lattice matched 3-junction cells have now also achieved over 40% efficiency, with 40.1% measured at 135 suns. Four-junction solar cells limited by radiative recombination can reach over 58% in principle and practical 4 -junction cell efficiencies over 46% are possible with the right combination of band gap [4]. Thus many layers contribute to photocurrent and larger portion of light is converted into electrical power. Solar cell technology is a developed area of microelectronics however, there is need to search new material or novel structure in order to improve the efficiency and stability so as to compete the other existing method of electricity generation. The use of thin films of semiconductor in solar cells is very much desirable to achieve material economy. Cadmium selenide (CdSe) and zink selenide (ZnSe) films having band gap 1.7 eV and 2.58 eV respectively and high photosensitivity in the visible region of the spectrum can be used in PEC cells [5]. Friedmam etal have obtained 30.2% efficiency from GaInP/GaAs monolithic two-terminal tandem concentrator cell [6]. We have studied photovoltaic effect in PEC solar cell using double layer of electrodeposited polycrystalline photoelectrode with CdSe/ZnSe film which have proper band gap for solar spectrum. Use of two layers with suitable band gap utilizes larger part of solar spectrum and higher efficiency is expected.

2. Experimental

The photoelectrodes were prepared by electro-co-deposition of CdSe and ZnSe films on titanium (99.9%) substrate from an aqueous acidic electrolyte CdSO₄ (0.1M)/SeO₂ (0.3M) and ZnSO₄ (0.1M)/ SeO₂ (0.3M) and H₂SO₄ (0.5M) respectively. First CdSe was deposited for certain time duration with a definite current density and then ZnSe was deposited over it for same time duration with same current density. The deposition time duration was varied from 20/20 minutes to 120/120 minutes and current density was varied from 2mA/cm² to 10mA/cm². The film surfaces were cleaned after every successive deposition by double distilled water.

The photovoltaic effect was studied using a semiconductor/liquid rectifying contact obtained by dipping photoelectrode (area1.5cm²) in polysulphide electrolyte consisting of (NaOH/Na₂S/S) each 1M. A conventional two electrode configuration for PEC cell is used with graphite as a counter electrode and various single and double layers of CdSe and ZnSe onto titanium as a photoelectrode. The experimental setup is shown in fig.1. The photoelectrode was illuminated by a 200W tungsten lamp with an intensity of 1950 lux. The output characteristics were recorded by varying a resistance in the external circuit and cell parameters were obtained.

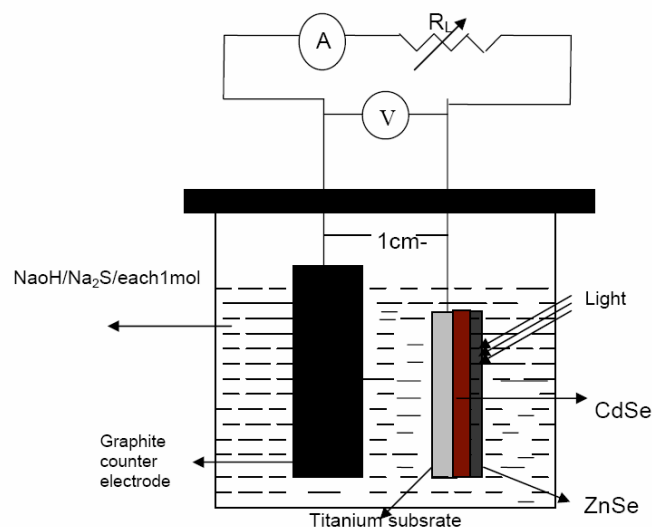


Fig1: An experimental setup of double layer CdSe/ZnSe PEC solar cell.

3. Results and discussion

It was observed that the solar cell parameters are influenced by deposition time duration and current density, used for preparation of photoelectrodes.

3.1 Effect of Deposition Time

Fig.2a shows the output characteristics of PEC solar cells having photoelectrodes prepared with different deposition time duration with constant current density $J_D = 10 \text{ mA/cm}^2$. The V_{oc} , I_{sc} , power output, fill-factor and efficiency of cells are given in Table I. The variation of cell parameters with deposition time duration is shown in fig.2b and 2c. It is seen that short-circuit current (I_{sc}), open circuit voltage (V_{oc}), fill factor (ff), power output (P_o) and efficiency ($\eta\%$) increase with increasing the deposition time duration up to 50/50 minutes and then decrease with further increase in deposition time duration. It has been reported that as the deposition time duration is increased the films attain maximum thickness and thereafter thickness decrease with further increases in deposition time duration [7]. This is attributed to the increase in rate of dissolution than the rate of deposition after attaining the maximum thickness. The best performance is obtained for the binary CdSe/ZnSe films deposited by 50/50 minutes.

Table I. Solar cell parameter of PEC cells with photoelectrodes prepared from various depositions time duration.

Deposition Time (min)	V_{oc} (mV)	I_{sc} (mA)	Power Output $10^{-6}(\text{mW/cm}^2)$	Fill factor %	Efficiency (η %)
20/20	135	0.045	4431	48	1.03
25/25	156	0.035	4900	89	1.14
30/30	200	0.050	6000	60	1.40
40/40	150	0.062	6985	75	1.63
45/45	155	0.078	9225	78	1.6
50/50	300	0.090	18620	90	4.3
60/60	180	0.275	20000	40	4.6
120/120	165	0.015	1029	41	0.2

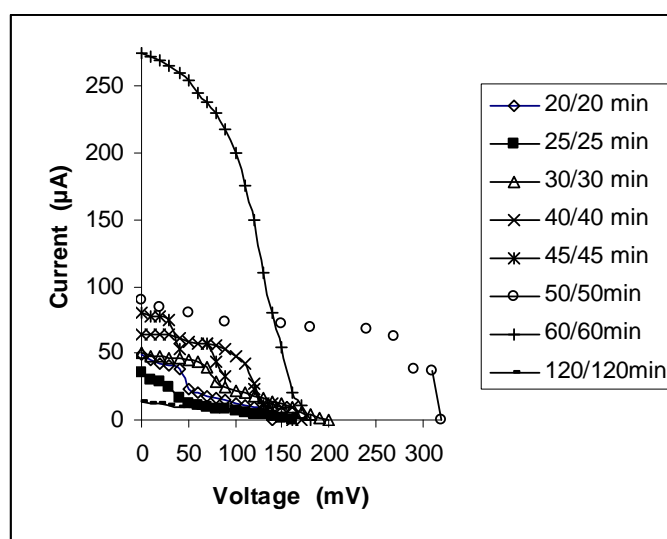


Fig2a: Output characteristics of PEC cells having photoelectrodes prepared from different deposition time duration.

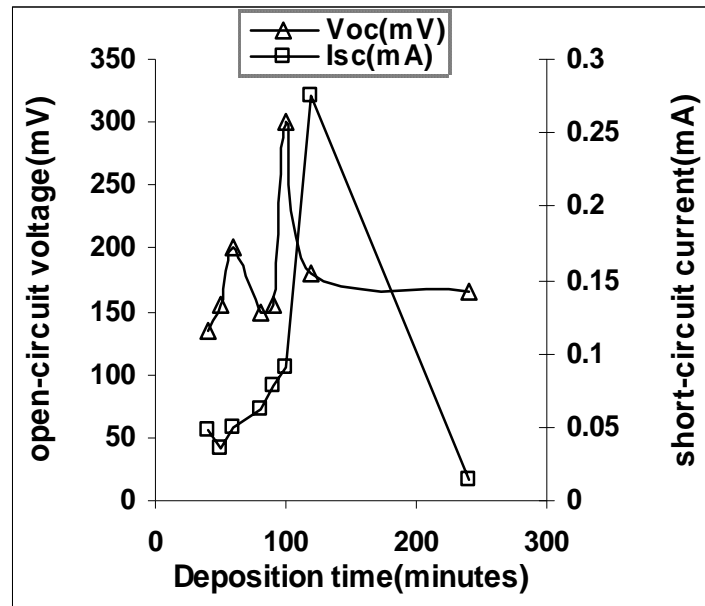


Fig2b: Variation of solar cells parameters V_{oc} and I_{sc} with deposition time duration of photoelectrodes.

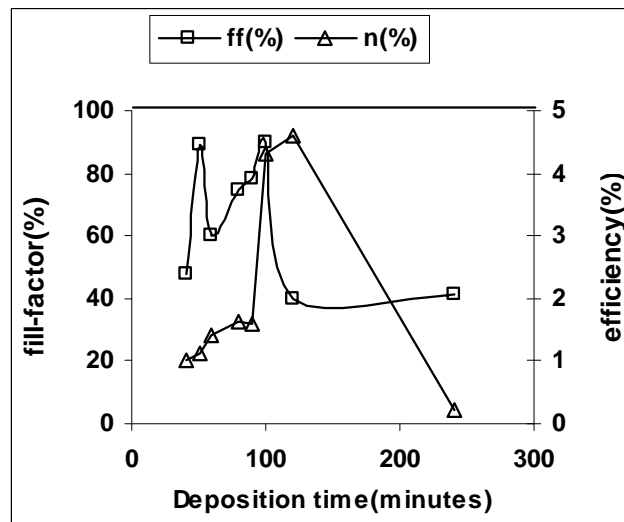


Fig2c: Variation of solar parameters fill-factor and efficiency with deposition time duration of photoelectrodes.

3.2 Effect of current density

In order to study the effect of current density on the PEC cells parameters, the films of CdSe/ZnSe were deposited on the titanium substrate for constant deposition time 60/60 minute with various current densities (J_D) ranging from 2 mA/cm² to 10 mA/cm². The output characteristics of these cells are shown in fig.3a. The solar cell parameters corresponding to photoelectrodes prepared with different current densities are given in Table II. Fig.3b and 3c shows the variation in PEC cell parameters corresponding to different J_D . It can be seen that all the cell parameters increase gradually with increasing the current density and attain maximum value for double layer of CdSe/ZnSe films from current density $J_D = 10$ mA/cm². At still higher current densities, the films are not found to adhere properly to the substrate and get dissolved in the electrolyte. The film deposited at optimum current densities were gray/black in appearance and adhered well to the substrate. However, films deposited at more positive current densities were distinctly red/brown in appearance that means poor coverage on substrate of the films [8]. It is

clear that the films deposited at current density $J_D = 10 \text{ mA/cm}^2$ gave the best performance for PEC solar cell.

Table II. Solar cell parameter of PEC cells with photoelectrodes prepared from various current densities.

Sample	Current Density (mA/cm ²)	V _{oc} (mV)	I _{sc} (mA)	Power Output 10 ⁻⁶ (mW/cm ²)	Fills Factor %	Efficiency (η %)
CdSe	1	85	0.0 19	1615	23	0.3
CdSe	2	120	0.0 92	7600	69	1.77
ZnSe	1	121	0.0081	980.1	45	0.22
ZnSe	2	165	0.134	984.9	38	0.23
CdSe/ ZnSe	2	140	0.152	11516	66	4.4
CdSe/ ZnSe	2.5	315	0.160	1904	23	2.6
CdSe/ ZnSe	3.5	260	0.208	35445	76	8.3
CdSe/ ZnSe	4.5	270	0.219	42885	58	10
CdSe/ ZnSe	5	330	0.1425	30954	77	7.2
CdSe/ ZnSe	7	340	0.1606	34850	60	8.16

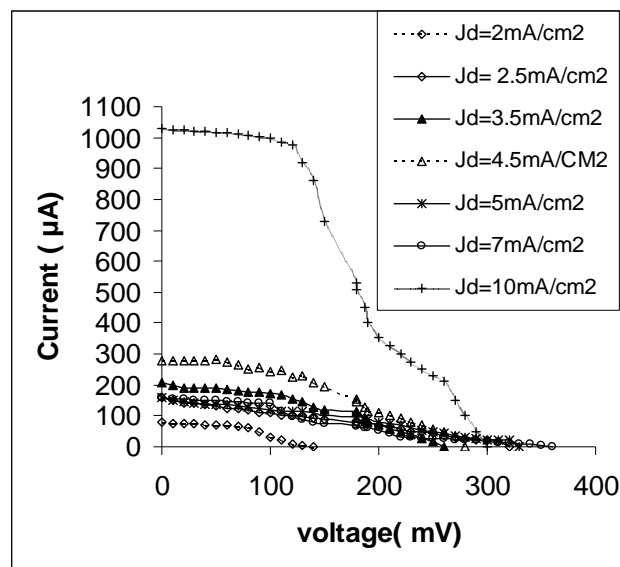


Fig3a: Output characteristics of PEC cells having photoelectrodes prepared from different current density.

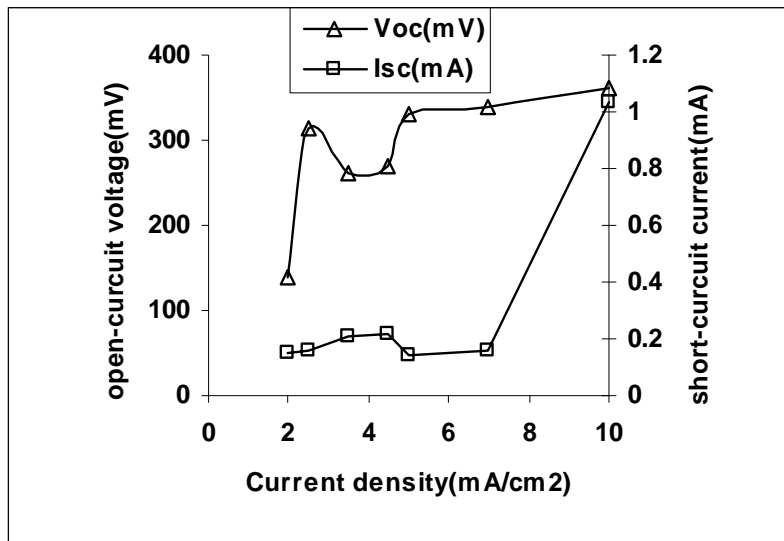


Fig3b: Variation of solar cells parameters V_{oc} and I_{sc} with current density of photoelectrodes.

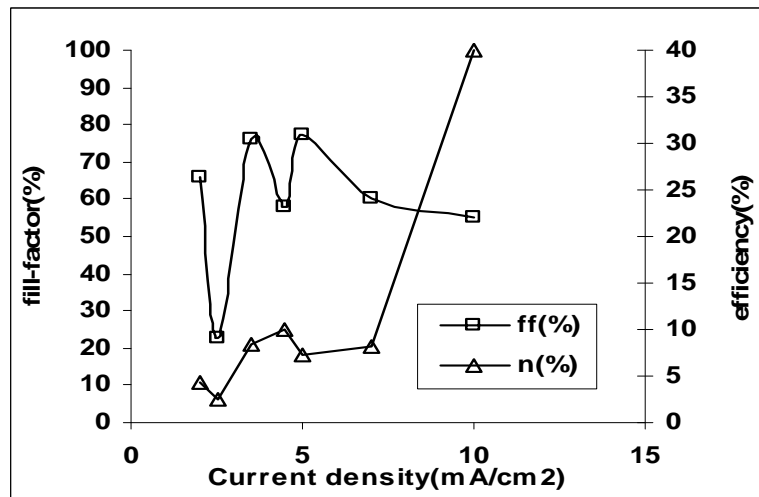


Fig3c: Variation of solar parameters fill-factor and efficiency with current density used of photoelectrodes.

3.3 Photoelectrochemical Solar Cells Characterization for Single and Multilayer Films

In order to improve the performance of PEC cells double layer photoelectrode were prepared by electro-co-deposition of CdSe, ZnSe and CdSe-ZnSe at current density 10 mA/cm² and deposition time 60/60 minutes. Fig.4a shows the output characteristics and the cell parameters are given in Table III. It is clearly observed that ZnSe gives very poor performance with $\eta = 5\%$ because of its large band gap only small portion of the light spectrum is utilized to generate electron and holes. CdSe shows better results with $\eta = 15\%$ but a double layer of CdSe/ZnSe of same thickness gives much higher values of cell parameters and an efficiency of 40%. Multi bandgap layers of different semiconducting materials convert larger portion of optical energy into electricity.

Table III. Performance of cell parameters at $J_D = 10 \text{ mA/cm}^2$ for CdSe, ZnSe, CdSe/ZnSe layers.

Sample	Current Density (mA/cm^2)	V_{oc} (mV)	I_{sc} (mA)	Power Output $10^{-6}(\text{mW/cm}^2)$	Fills Factor %	Efficiency (η %)
CdSe	10	250	0.640	67560	42	15.8
ZnSe	10	210	0.280	21450	38	5.0
CdSe/ ZnSe	10	360	1.031	171737	55	40

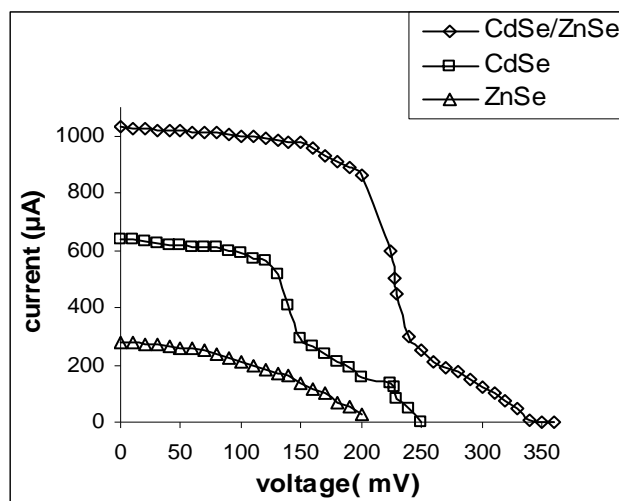


Fig4a: Output curves for single and double layer films of CdSe and ZnSe.

5. Conclusions

The studies on the PEC solar cells with electro-co-deposited double layers of CdSe/ZnSe photoelectrode have shown that the performance of the PEC cells is improved by increasing deposition time duration but for deposition time duration greater than 60/60 minutes causes dissolution of films and lower values of cell parameters. The performance is improved by increasing the current density (J_D) during preparation of photoelectrodes but at $J_D > 10 \text{ mA/cm}^2$ the films do not adhere to substrate properly. Comparing the performance of photoelectrode with single and double layers of CdSe-ZnSe, CdSe/ZnSe, it is found that multibandgap layers gives good results with η as high as 40%.

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