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Effect of Temperature on Photovoltaic Solar Cell Cadmium Telluride Thin Film

Kishan C. Rathod[1*], Vishalkumar R. More[1], Jayashree S. Kshirsagar[1], Santosh R. Sonwane[1], Kallapa R. Sanadi[2], Pradip D. Kamble[3], Ganesh S. Kamble[4], Sandip V. Mahamuni[5], Muddsar L. Gaur[6], Yong-Chein Ling[7]

[1]Department of Chemistry, The New College, Kolhapur
[2]Department of Chemistry, Doodhsakhar Mahavidyalaya, Kolhapur
[3]Department of Physics, The New College, Kolhapur
[4]Department of Engineering Chemistry, KIT Engineering College, Kolhapur
[5]Department of Chemistry, Sadguru Gadage Maharaj College, Karad
[6]Department of Chemistry, C. B. Khedgi's Basaveshwar Science Raja Vijaysinh Commerce and Raja Jaysinh Arts College, Akkalkot
[7]Department of Chemistry, National Tsing Hua University, Hsinchu City
Email: *kishanchandurathod@gmail.com

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Abstract

Solar cell technology comes with unique temperature coefficients. These temperature coefficients are important and temperature of the solar cell has direct influence on the power output of a photovoltaic cells. CdTe is a very robust and chemically stable material and for this reason its related solar cell. Thin film photovoltaic technology is now the only thin film technology in the first top 10 producers in the world. The strong improvement in efficiency in the last 7 years was obtained by a new redesign of the CdTe solar cell device reaching a single solar cell. In this paper, we describe the fabrication process following the history of the solar cell as it was developed in the early years up to the latest development and changes. The configuration of fabricated cell is n-CdTe/NaOH (0.15 M) + S (0.15 M) + Na_2S (0.15 M)/$C_{(graphite)}$. The junction ideality factor was found to be 2.63, 2.13, and 1.89. The flat band potential is found to be −0.400, −0.450, −0.501 V. The barrier height value was found to be 0.523, 0.487, and 0.436 eV. The study of power output characteristic shows open circuit voltage, short circuit current, fill factor and efficiency were found to be 120 mV, 24.2 μA, 32.68%, 26.18%, and 19.73% and 0.63%, 0.37%, and 0.23%, respectively. The lighted ideality factor was calculated and found to be 3.26, 1.87, and 1.17. Spectra attain maximum value of current at λ = 580 nm and decrease with increase in wavelength. The photovoltaic cell characterization of the thin films is carried out by studying current-voltage characteristics in dark, capacitance-voltage in dark, barrier height measurements, power output characteristics.

Keywords

CBD, Power Output, Barrier Height, Photo Response, Spectral Response

1. Introduction

Solar generation of electricity has been an active area of research since shortly after Becquerel first discovered the photoelectric effect in 1839 [1]. Concerns over fossil fuel production as well as issues of pollution and climate change have spurred intensive research into photovoltaic (PV) as well as other renewable energy sources [2]. Solar is the most utilized of the "green" energy sources today. However, it has stalled with regard to market penetration [3]. Given that the total solar energy adsorbed by the Earth is ca. 1×10^{22} J per day, which is enough to meet the world's energy needs for a year, sunlight is not a limitation of adoption [4]. At present, the main barrier to mass adoption is the cost in comparison with hydrocarbon and coal, in particular the increasing abundance of cheap natural gas [5] [6]. CdTe solar cell thin film photovoltaic technology was introduced in the early fifties of the last century and it is now the only thin film technology in the first 10 top producers in the world [7] [8]. This is because CdTe is very robust and highly chemically stable and, also for this reason, can be deposited with a large variety of methods available making it very much ideal for production in large area [9]. T. Potlog *et al.* [10] demonstrated an efficiency of 15.8%, followed by the 16.5% record which was obtained at the National Renewable Energy Laboratories (NREL) by Wu X. *et al.* [11]. The main aim of this paper is to develop solar cells by the chemical bathe deposition method CdTe thin films heterojunction solar cells on the stainless-steel plate substrate and compare them with 10% efficiency CdS/CdTe solar cells fabricated at the Moldova State University [12]. However, the photovoltaic conversion efficiency does not exceed 16.5% [13] [14]. Therefore, this paper describes the results of the preparation and study of the photoelectrical properties of CdTe and thin film heterojunction solar cells [15] [16]. CdTe solar cells basically are a p-n junction semiconductor. When exposed to light, a dc current is generated. Photovoltaic solar cells offer several advantages, such as high reliability, low maintenance cost, no environmental pollution and absence of noise [17] [18] [19]. Usually, conversion efficiencies of photovoltaic devices decrease with increasing temperatures; in particular open circuit voltage reduces consistently and short circuit current slightly improves [20]. For CdTe, it has been observed that the decrease in open circuit voltage is remarkably less than for CIGS and silicon based solar cells, resulting in 20% more overall power generation in high temperature environment [21] [22].

In this paper, we reported the effect of temperature on the photovoltaic properties of n-type CdTe thin films (CdTe - Room Temperature, CdTe - 318 K, CdTe - 328 K); it can be prepared chemical bath deposition method using an

ITO coating (Indium Tin Oxide) glass substrate. Solar cell performance decreases with increasing temperature, fundamentally owing to increased internal carrier recombination rates, caused by increased carrier concentrations. The operating temperature plays an important role in the photovoltaic conversion process. The result of the current voltage (I-V) and capacitance-voltages (C-V) characteristics are evaluated to understand the electrical conduction involved, barrier height, power out curves, photo response and spectral response parameters are studied.

2. Experimental Details

2.1. Substrate Cleaning

The deposition was completed on commercially available ITO coating glass substrate size is 25 × 75 × 2 mm dimensions. This ITO coating glass substrate was cleaned by acetone followed by rinsing in alcohol and lastly stored in double distilled water before use.

2.2. Reagents and Preparation of Solutions

Analytical grade chemicals cadmium sulphate, triethanolamine and sodium telenosulphite (Na_2TeSO_3) were used. The solutions were prepared in double distilled water.

2.3. Synthesis of Cadmium Telluride Thin Film

The deposition of cadmium telluride thin film on ITO coating glass substrate is used in a reactive solution. Cadmium sulphate solution, 10 ml (0.25 M), complexed with 10 ml of (1 M) triethanolamine (TEA), 10% 10 ml ammonium solution were mixed with 10 ml of (0.25 M) sodium telenosulphite solutions in 100 ml capacity beaker at high temperature 347 K. The total volume of the reaction mixture was made to 80 ml by adding double distilled water [23]. The reaction mixture was reserved kept in an oil bath. The substrate was mounted on a particularly planned substrate holder and rotated in reaction mixture with a rate of 65 ± 5 rpm, at high temperature, maintained the pH constant of the reaction mixture. After 7 h, the glass substrate covered with films were removed, washed with distilled water, dried naturally and kept in dark desiccator. **Figure 1** is shown by the experimental deposition of the CdTe solar thin film.

2.4. Construction and Working of Photovoltaic Cell

Solar radiation is the electromagnetic radiation emitted by the sun. Solar radiation interacts with the earth's atmosphere to create three types of irradiances at ground level. Solar cell is the semiconductor device that converts the light into electrical energy. The electrons of the semiconductor material are joined together by the covalent bond. The electromagnetic radiations are made of small energy particles called photons. When the photons are incident on the semiconductor material, then the electrons become energised and starts emitting

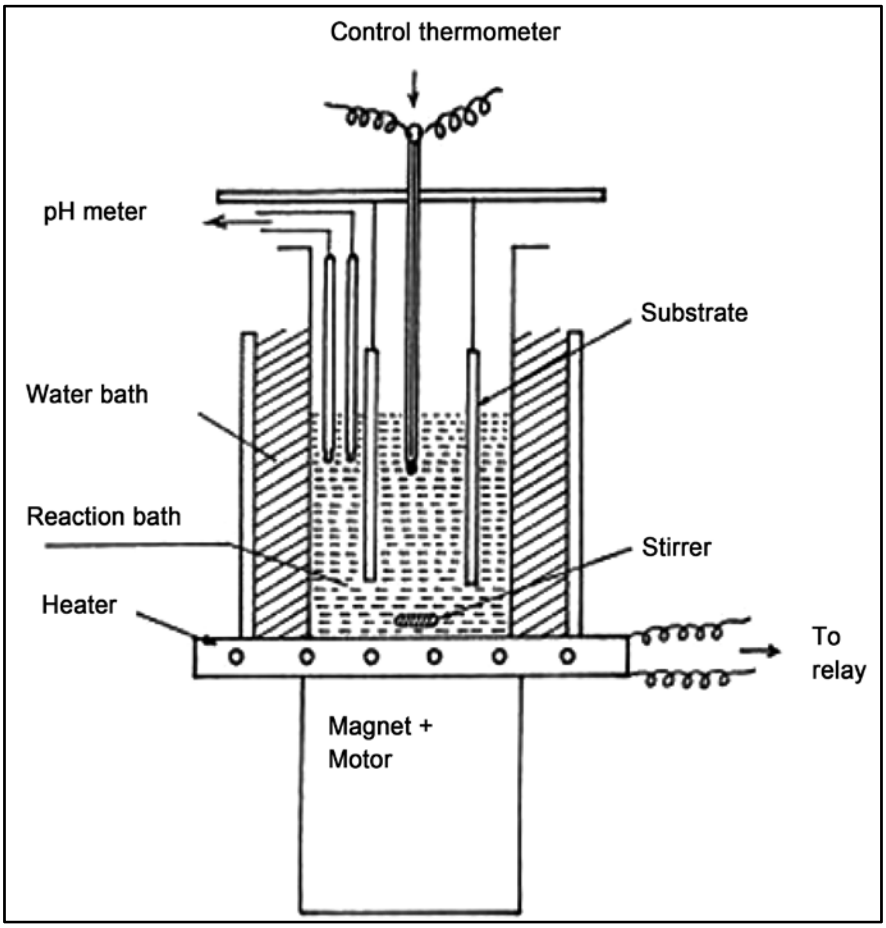

Figure 1. Experimental setup of CBD method deposition of thin film.

solar energy is shown in Figure 2. A simple photovoltaic solar cell is formed a p-n junction diode. The schematic of the p-n junction device is shown in Figure 3. The penetration depends on the deposition thickness of the thin films. Electron hole pairs are mainly created in the depletion region and due to the built in potential and electric field because, electrons move to the n-type region and the holes move to the p-type region. When the external load is applied, the excess electrons travel through the load to recombine with the excess holes. The electrons and holes are also generated with the p-type and n-type regions. The thinner thin films absorb the higher light in the n-type region and thicker thin films absorb the lower light in the p-type region. Electron hole pairs are generated in these regions can also contribute to the current. Generally, these electron-hole pairs that are generated within the minority current carrier diffusion length of thin films for electrons in the p-type region and holes in the n-type region.

2.5. Fabrication and Characterization of a PV Cell

A calomel electrode is used as reference electrode and sulphide-polysulphide as electrolyte is shown in Figure 4. Photovoltaic cell is consisting in three electrode configurations are used in experiment. Cadmium telluride as photoanode,

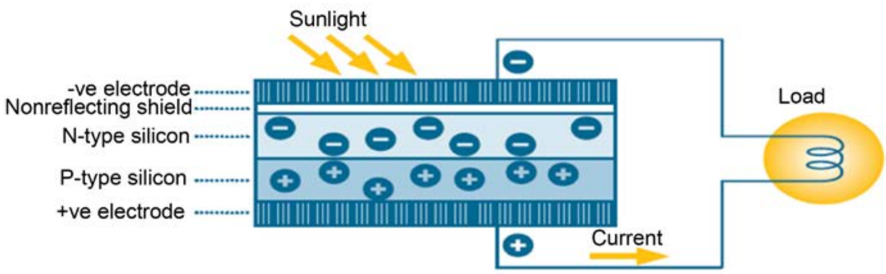

Figure 2. Construction and working of solar cell.

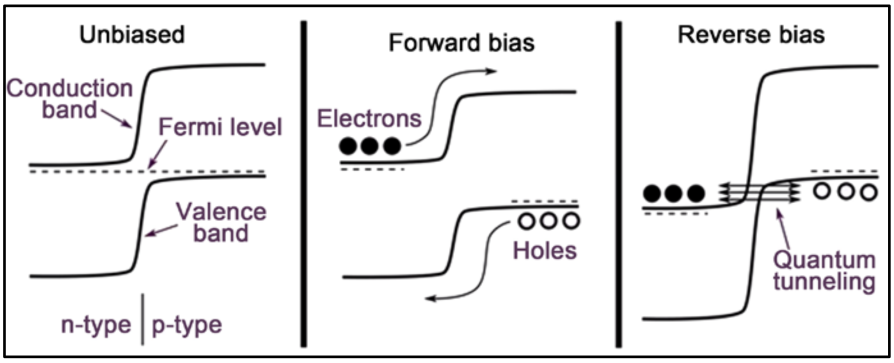

Figure 3. Formation of the p-n junction diode in the solar cell.

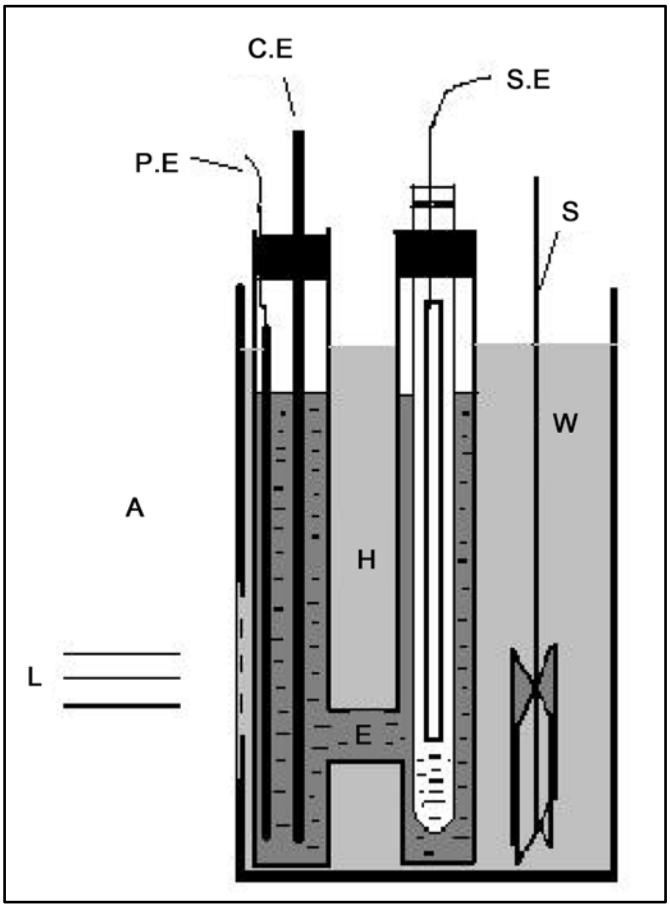

Figure 4. A Schematic diagram of photovoltaic solar cell electrode.

CoS-treated graphite rod as a counter electrode. This electrode is acts as a photocathode. A small amount of tellurium was added in electrolyte to stabilize the dissolution of photoelectrode [24].

The Mott-Schottky plot is used to determine the flat band potential One-kilohertz frequency is used to determine the flat band potential. The illuminated area of electrode was 3.0 cm^2. The illumination intensity was measured with a (Meco) Lux meter. The type of conductivity exhibited by the film is determined by nothing the polarity of the emf developed in PV cell under illumination. The current-voltage (I-V) characteristic in dark has been plotted. The junction ideality factor has been determined by plotting the graph of log I versus V. The fill factor and power conversion efficiency of the cell is calculated from photovoltaic power output characteristics. The fill factor and power conversion efficiency of the cell is calculated from photovoltaic power output characteristics. The power output characteristic has been obtained for a PV cell at a constant illumination of 30 mW/cm^2.

3. Results and Discussion

3.1. Conductivity Type

Photovoltaic solar thin film cell shows dark voltage and dark current even in the dark. The polarity of this dark voltage was negative towards semiconductor electrode. The sign of the photo voltage gives the conductivity type of CdTe. This suggests that CdTe is an n-type conductor which has also been proved from TEP measurement studies [22] [25]. A solar cell of CdTe with configuration n-CdTe/ NaOH (0.15 M) + S (0.15 M) + Na_2S (0.15 M)/$C_{(graphite)}$ was formed.

3.2. I-V, C-V Characteristics in Dark

The photovoltaic effect is the direct conversion of light into electricity in solar cells. When solar cells are exposed to sunlight, electron excite from the valence band to the conduction band creating charged particles called electrons. Solar cell of cadmium telluride thin films current-voltage (I-V) characteristics in dark have been studied in ITO coating glass materials at CT-RT, CT-318 K, and 328 K and shown in **Figure 5**. The characteristics are non-symmetrical indicating the formation of rectifying type junction [26]. Using famous ideal Schottky diode equation junction ideality factor is calculated from the equation [27] [28].

$$I = \frac{I_0 e^{ev}}{n_d kT} \quad (1)$$

where, I, is the forward current in dark, I_0, reverse saturation current, v, applied forward bias voltage and n_d is the junction ideality factor. The value of junction ideality factor (n_d) can be determined of the linear regions of the log$I$ versus volt (V) at temperature CT-RT K, CT-318 K, and CT-328 K is shown in **Figure 6**. The ideality factor was found to be 2.63, 2.13, and 1.89. The higher value of n_d' suggests the dominance of series resistance as well as structural imperfection. It

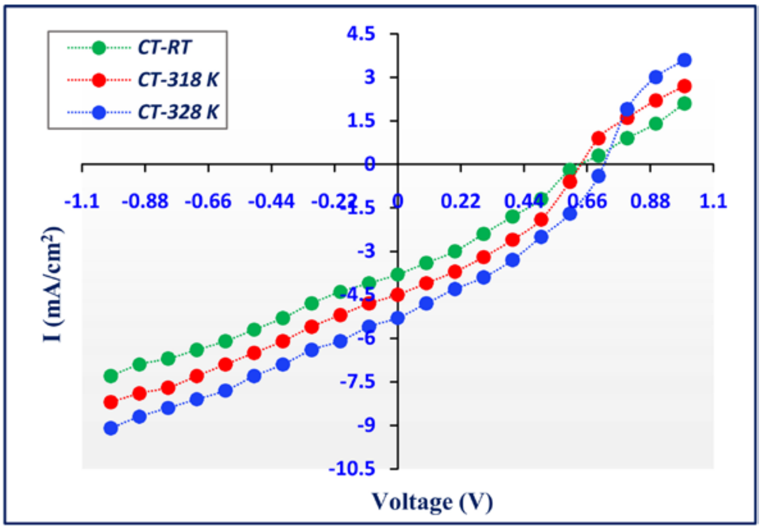

Figure 5. I-V characteristics of CdTe photoelectrode (in dark).

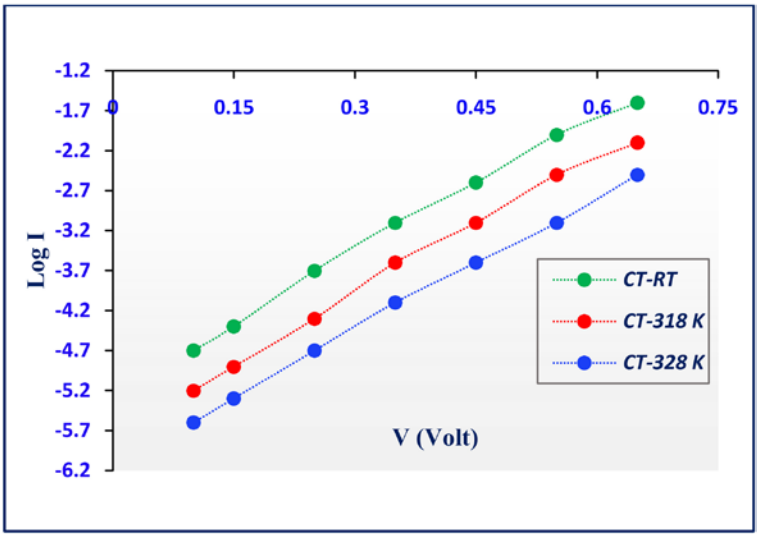

Figure 6. Determination of junction ideality factor of CdTe photoelectrode.

also suggests that average transfer across the semiconductor electrolyte interface with significant contribution from surface states and deep traps [29].

The solar cells of capacitance are measurements as a function of applied voltage provided useful information such as type of conductivity, depletion layer width and flat band potential (V_{fb}). The flat band potential of a semiconductor gives information of the relative position of the fermi levels in photo electrode as well as the influence of electrolyte and charge transfer process across the junction [5]. This is also useful to measure the maximum open circuit voltage (V_{oc}) that can be obtained from a cell. Measured capacitance is the sum of the capacitance due to depletion layers and Helmholtz layer in electrolyte which is neglected by assuming high ionic concentration [24]. Under such circumstances, V_{fb} can be obtained using Mott-Schottky relation by standardizing with saturated calomel electrode (SCE).

$$c^{-2} = \frac{2}{q\varepsilon_s\varepsilon_0 N_d} \times \frac{V - V_{fb} - kT}{q} \quad (2)$$

where the terms involved have meaning, C^{-2} is space charge capacitance per unit area, q the electronic charge, ε_s is the dielectric constant of the semiconductor electrode, ε_0 is the permittivity of the free space, N_d the donor density, k the Boltzmann constant, T the absolute temperature, V the applied potential and V_{fb} is the flat band potential. The $1/C^{-2}$ versus voltage (mV) plots (Mott-Schottky plot) were constructed for the samples ITO coating glass material CT-RT K, CT-318 K, and CT-328 K are shown in Figure 7. Intercepts of plots on voltage axis determine the flat band potential value of the junction. The flat band potential value found to be CT-RT −0.401, CT-318 K −0.450, and CT-328 K −0.501 (SCE) for CdTe-polysulphide redox electrolyte, which is a measure of electrode potential at which band bending is zero. The non-linear nature of the graph is an indication of graded junction formation between CdTe and polysulphide electrolyte may be possible reasons for deviation from linearity in C-Vplot.

3.3. Barrier Height Measurements

The barrier height, Φb is the energy difference between the edge of the conduction band band and the redox Fermi level of the electrolyte. This potential prevents most of the photo generated charge carriers (hole and electron) from passing from one to the other. However, these carriers under a biasing potential, can get enough to cross the barrier. The photovoltaic solar cell cadmium telluride thin films barrier height was determined by measuring the reverse saturation current (I_o) through the junction at different temperature from 370 to 315 K. The reverse saturation current flowing through junction is related to temperature as [30].

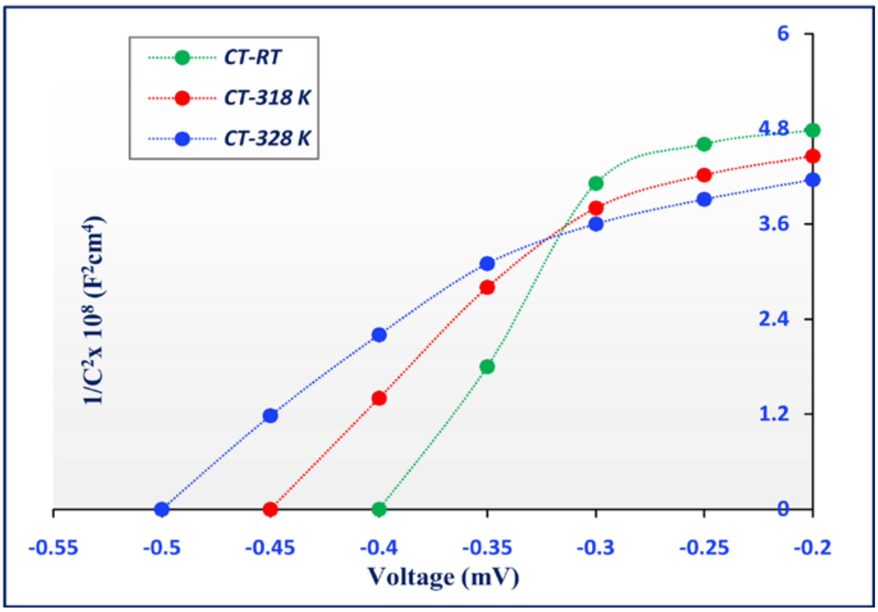

Figure 7. C-V plots (Mott-Schottky plots) of CdTe photoelectrode.

$$I_0 = AT^2 \exp\left[\frac{\varphi_\beta}{kT}\right] \tag{3}$$

where, A is Richardson constant, k the Boltzmann constant, Φ_β is the barrier height in eV. To determine the barrier height of the photo electrode, a graph of $\log(I_0/T^2)$ with $1000/T$ was plotted. The plot of $\log(I_0/T^2)$ with $1000/T$ for representative sample CT-RT K, CT-318 K, and CT-328 K is shown in **Figure 8**. From the slope of the linear region of plots, the barrier height was determined. The barrier height value is found to be 0.523, 0.487, and 0.436 eV.

3.4. Power Output Characteristics

Solar cell is illuminated with the light of constant intensity, the current voltage characteristics shift in the four quadrants; this behavior is in accordance with the theory of solar cells acting as electricity generator Photovoltaic solar cell may operate over a wide range of voltages and currents. By applying the resistive load on an irradiated cell continuously from a short circuit (from zero) to a very high value of open circuit it is possible to determine the maximum power point ($P_m = V_m \times I_m$), that is the load for which the cell can deliver maximum electrical power. The Energy conversion efficiency (η "eta") of a cell is the percentage of power converted of the observed light to electrical energy, and collected and are shown by the following equation.

$$\eta = \frac{P_m}{E \times A_c} \tag{4}$$

where E is power of input light (mW/cm^2) and A_c is the surface area of the cell in cm^2. Another measuring term in the overall behavior of a cell is the fill factor (ff), which is the ratio of the maximum power ($V_m \times I_m$) divided by the short circuit current (I_{sc}) and open circuit voltage (V_{oc}) in light current voltage (I-V)

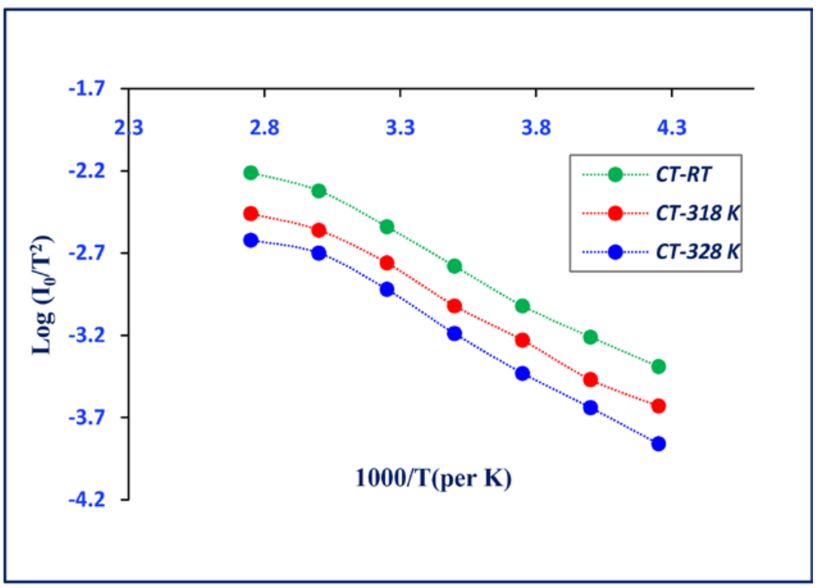

Figure 8. Determination of barrier height measurement of CdTe photoelectrode.

characteristics of the cells can be measured by the following equation.

$$ff = \frac{P_m}{V_{oc} \times I_{sc}} = \frac{\eta \times E \times A_c}{V_{oc} \times I_{sc}} \quad (5)$$

The open circuit voltage and short circuit current are found to be 120 to 80 mV and 23.6 to 18 μA, respectively. The power efficiency conversion factor can be studied by the following equation.

$$\eta_{\max} = \left[V_{redox} - V_{fb}\right] \times \frac{e}{E_g} \quad (6)$$

where V_{fb} is the flat band potential, V_{redox} the electrolyte redox potential and E_g is the energy band gap. It is important to note here that V_{oc} and η depends on V_{fb} and E_g. The photovoltaic power output characteristics for a cell under illumination of 30 mW/cm^2 shows **Figure 9** CT-RT K, CT-318 K and CT-328 K. The calculation shows the fill factor is 32.68%, 26.18%, and 19.73%. The power conversion efficiency is found to be 0.63%, 0.37%, and 0.23%. The low efficiency may be due high series resistance and interface states which are responsible for recombination mechanism [7] [21] [24]. The value of series resistance and shunt resistance were found to be 800 (Ω), 1000, and 1200 (Ω), respectively.

3.5. Study of Photo Response

The solar cell photo response is studied by the logarithmic variation of open circuit voltage with incident light intensity was observed from photo response measurements whereas short circuit current follows almost a straight-line path. **Figure 10** shows variation of short circuit current and open circuit voltage of sample CT-RT K, CT-318 K and CT-328 K which were measured as function of light intensity whereas, variation of open circuit voltage as a function of light intensity was shown in **Figure 11**. The photo electrode-electrolyte interface

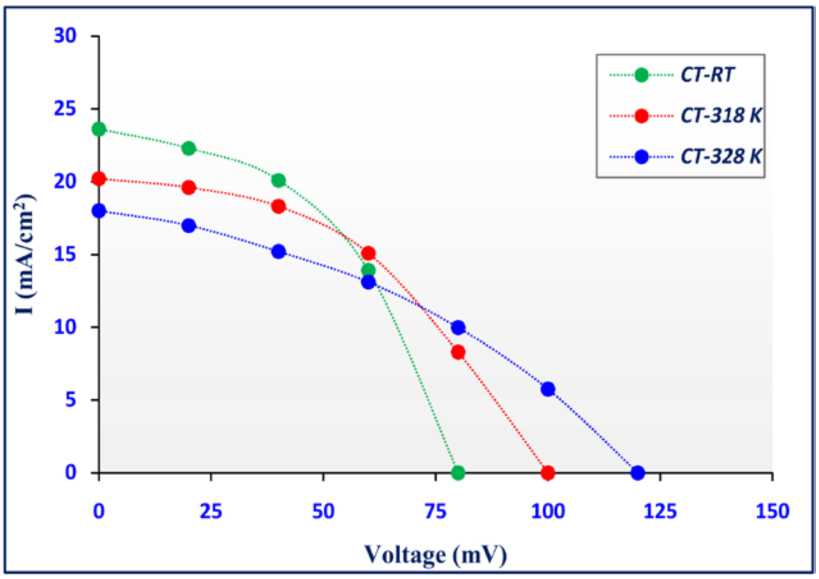

Figure 9. Power output curves for CdTe photoelectrode.

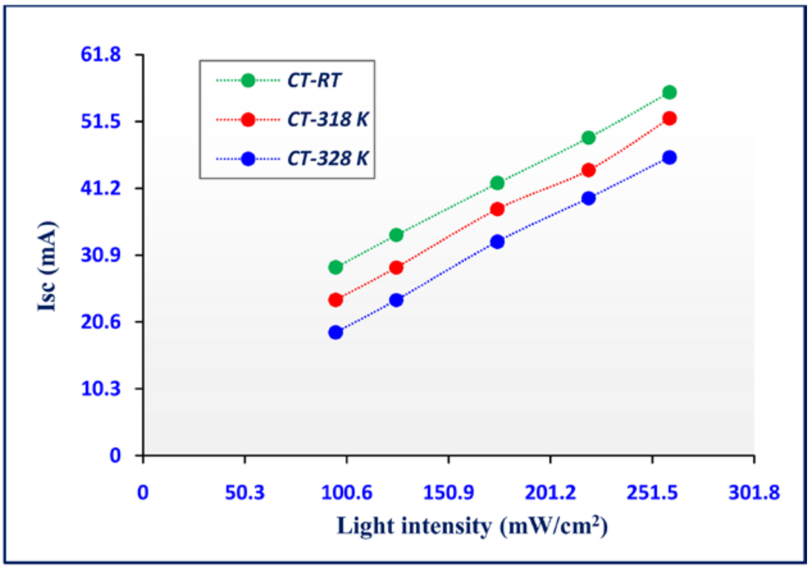

Figure 10. Photo response as a function of I_{sc} for CdTe photoelectrode.

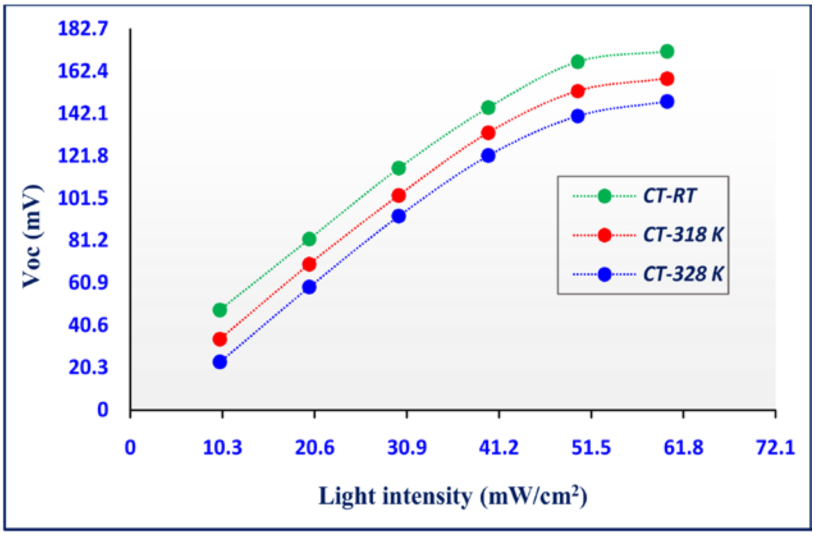

Figure 11. Photo response as a function of V_{oc} for CdTe photoelectrode.

modeled as a Schottky barrier solar cell it is possible to represent the current-voltage relationship [20] [21].

$$I = I_{ph} - I_d = I_{ph} - I_0 \exp\left(\frac{q_v}{n_d kT}\right) - 1 \tag{7}$$

where, I_{ph} the photocurrent densities, I is the net current density, I_0 the reverse saturation current density, I_d the dark current density, V the applied bias voltage and n_d is the junction ideality factor. In bias voltage condition $V > 3kT/q$ and at equilibrium open circuit conditions

$I_{ph} = I_d$ and $V = V_{oc}$ thus,

$$V_{oc} = \frac{n_L kT}{q} \times I_n \frac{I_{sc}}{I_0} \tag{8}$$

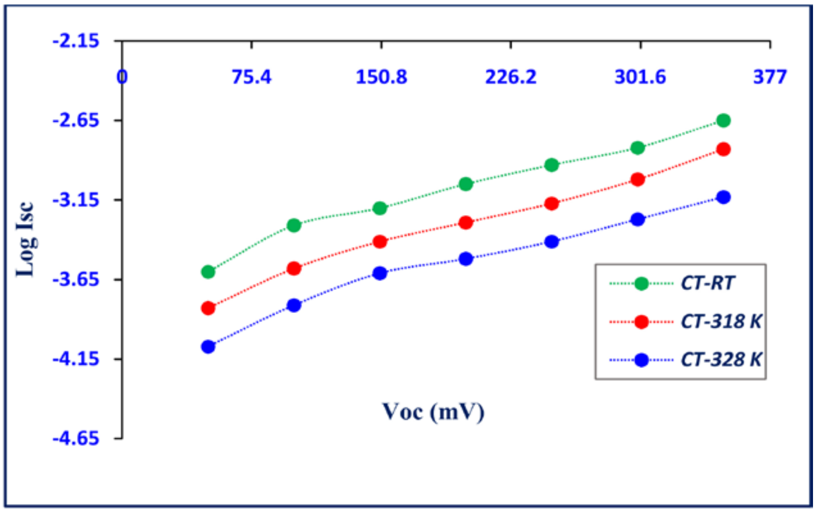

Figure 12. Determination of lighted ideality factor for CdTe photoelectrode.

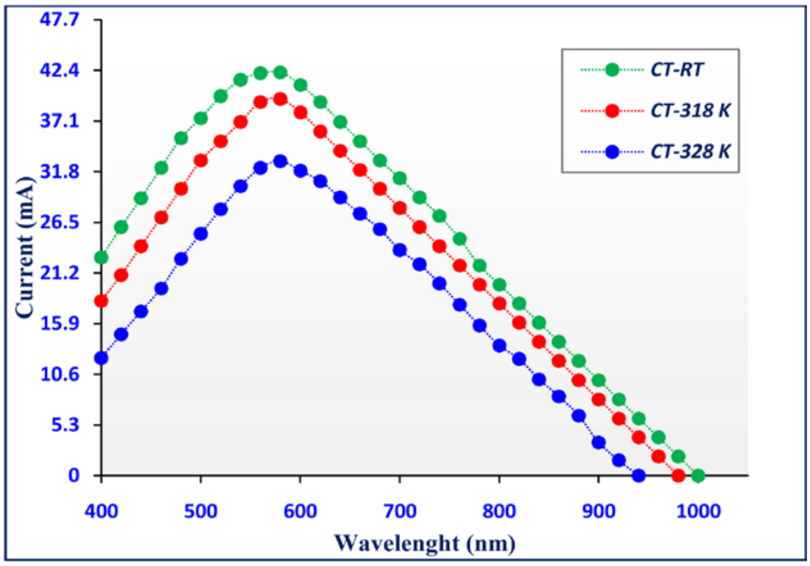

Figure 13. Determination of spectral response for CdTe photoelectrode.

where, V_{oc} is the open circuit voltage and I_{sc} is the short circuit current. As $I_{sc} \gg I_0$, a plot of $\log I_{sc}$ against V_{oc} should give a straight line and from the slope of the line the lighted ideality factor can be determined. Figure 12 shows the plot of $\log I_{sc}$ with V_{oc} for CdTe photoelectrode sample CT-RT K, CT-318 K and CT-328 K. The lighted ideality factor was calculated and found to be 3.26, 1.87, and 1.17 respectively.

3.6. Study of Spectral Response

Photovoltaic solar cell temperature increases absorption of current is decreases with increasing the wavelength. Spectral response of CdTe solar cell is studied by the current verse's wavelength the shorter wavelength is high current absorption and higher the current value and higher wavelength are low current absorption and lower the current value. Photovoltaic cell is one of the most powerful techniques to measure the performance of the spectral response cell qualitatively. Therefore, the spectral response of a cell has been recorded in the 400 - 1000 nm wavelength range. The photocurrent action spectra were examined and are shown in **Figure 13**. It is seen that spectra attain maximum value of current at $\lambda = 580$ nm and decreases with increase in wavelength. The decrease in current on longer wavelength side may be attributed to non-optimized thickness and transition between defect levels. The maximum current is obtained corresponding to $\lambda = 580$ nm.

4. Conclusion

In this paper, the effect of temperature on photovoltaic solar cell thin films has been prepared on ITO coating glass substrate by the chemical bath deposition method which is the cheaper solution-based deposition technique. The results indicated that for the CdTe efficiency and the fill factor were increased to 0.63%, 0.37%, and 0.23% to 32.68%, 26.18%, and 19.73% respectively. The observed enhancement is due to increased open-circuit voltage, and improved photoelectrode absorption. The observed conversion efficiencies are found to be lower due to lack of post preparative treatments. The photovoltaic cell can be easily fabricated using CdTe photo anode, sulphide-polysulphide as electrolyte, CoS-treated graphite rod as a counter electrode. A saturated calomel electrode was used a reference electrode. The various performance parameters were determined for CdTe photo electrode. Solar energy is a very precious gift from God that human being ever had and we can make benefit from it by converting solar energy into electricity. Photovoltaic solar energy is clean, safe and is almost free maintenances. The lighted ideality factor was found to be decreased (3.26, 1.87, and 1.17) with increase in temperature on the photovoltaic solar cells.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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