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Temperature and Illumination Intensity Effects on the Electric Parameters of (n-CdSe/p-CdSe) Solar Cell using SCAPS

Maha K Abdl Ameer [1*], **Laith M Altaan** [2]
[1-2] Department of Physics, College of Science, University of Mosul Mosul, Iraq

* Corresponding Author: **Maha K Abdl Ameer**

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Abstract
In this article, a p-type and n-type of CdSe thin film were used as a fundamental component of the solar cell used the SCAPS. The current study is to investigate the effect of environmental parameters such as temperature and illumination intensity on the performance of the proposed cell composed of (ITO/n-CdSe/p-CdSe/Pt). Simulations were carried out for various value of temperature ranging from (240 to 500)K and various levels of illumination ranging from (200 to 1200) $W.m^{-2}$. The findings revealed that the open circuit voltage is the most temperature-affected parameter, as the open circuit voltage drops from (1.0836V) at 240°K to (0.6656V) at 500°K with rising temperature, due to the saturation current decreasing with increasing temperature. The results also reveal that the intensity of illumination has a significant impact on the short-circuit current density, since the current density increases directly with the intensity of illumination from (4.02 mA/cm^2) at $200W.m^{-2}$ to (24.13 mA/cm^2) at $1200W.m^{-2}$. These findings are discussed in this study.

Keywords: Solar cell, CdSe thin film, SCAPA

1. Introduction

Scientists turned to renewable energy centuries back because not only are fossil fuels harming the environment, but they are also predicted to be depleted in the next centuries. As a result, scientists concentrated their efforts on developing alternate and sustainable energy sources, where the sun is one of the most essential sources of this energy (Al-Hattab *et al*., 2021) [1]. Thus, solar cells have become an important source of technology and sustainable energy for human civilization (Al-Hattab *et al*., 2021) [1]. Thin film technology arose and competed directly with silicon because of its low cost and great efficiency (Kuddus *et al*., 2021) [11]. Thin film techniques depend significantly on the features of semiconductor materials, which include compounds consisting of the periodic table's second and sixth elements, such as CdSe, CdS, CdTe, and others (Reyes, 2020) [15]. In the layers of the present solar cell, cadmium selenide film was employed. Which has a direct energy gap of 1.74eV, that is close to the standard spectrum of AM1.5 solar radiation, and a high absorption coefficient (~10^5 eV) and may thus be used as a window layer or an absorber layer in solar cells (Patel *et al*., 2019) [12]. Where Rosly *et al.*, use CdSe as a window layer in the solar cell and investigated its influence on cell performance using the SCAPS simulation program (Rosly *et al*., 2019) [16]. Using the same software as before, Yasin *et al* employed CdSe as a buffer layer and investigated its influence on cell performance (Yasin *et al*., 2020) [22]. While Dey *et al*. employed CdSe as an absorber layer and investigated its influence on cell performance using the AMPS simulation program (Dey *et al*., 2017) [6]. CdSe is a semiconductor with electrical, chemical, and optical characteristics in the visible region of the spectrum, which allows it to be used in a wide range of applications such as optoelectronic devices, thin-film transistors, nanosensing, and high-efficiency solar cells, and others (Reyes, 2020) [15]. CdSe thin films may be created using a different types of deposition techniques, including chemical bath deposition, and solvothermal deposition, and electrochemical deposition, among others (Reyes, 2020) [15]. In this research, the SCAPS simulation program was used to study the effect of environmental factors (temperature and level of illumination intensity) on the performance of an ideal solar cell consisting of (ITO/n-CdSe/p-CdSe/Pt).

2. Simulation model and device structure

The optimum structure pn-CdSe solar cell was used in this work, which consists of three layers, namely ITO, n-CdSe, and p-CdSe, where ITO represents the n-type window layer of the cell, n-CdSe is the buffer layer of the cell, and p-CdSe represents the absorber layer of the cell, with gap energies of 3.6, 2.16, and 1.74 eV respectively, Which were taken from several studies.

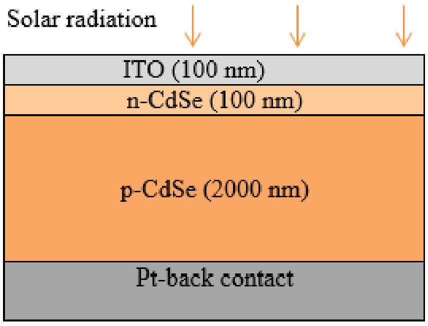

Fig 1: Structure of CdSe thin film solar cell

Each layer in this cell has an optimal thickness and concentration, which were studied under standard conditions, of temperature (300K) and illumination intensity (AM1.5 (1000W.m^{-2}) using SCAPS, which developed by Gent University's Department of Electronics and Information System (ELIS) (Qu *et al.*, 2019) [13]. The user may add up to seven layers, for each layer there are numerous parameters that can be defined as follows: electron affinity, energy gap, dielectric permittivity, donor and acceptor density, conduction and valence band density, electron and hole mobility, and thickness (Qu *et al.*, 2019) [13] (Rai and Dwivedi., 2020) [14]. Under standard conditions, the optimal structure of the proposed cell produces Eff. (18.39%), FF(86.53%), Jsc(20.12mA/cm^2), and Voc (1.0566V). The construction of the suggested solar cell is depicted in Figure (1), and the parameters of the solar cell used in the current simulation and the right and back contacts parameters are shown in the table (1) and table (2) respectively.

Table 1: Simulation Parameters for ITO/n-CdSe/p-CdSe solar cell layers.

Parameter	**ITO** (a*)	**n-CdSe** (b*)	**p-CdSe** (c*)
Thickness (nm)	100	100	2000
Band gap E_g (eV)	3.6	2.16	1.74
Electron affinity χ (eV)	4.5	4.3	4.56
Dielectric permittivity (relative)	8.9	10.6	10.6
CB effective density of state N_C (1/cm^3)	2.2×10^{18}	2.2×10^{18}	2.75×10^{18}
VB effective density of state N_V (1/cm^3)	1.8×10^{19}	1.8×10^{19}	2.8×10^{19}
Electron thermal velocity (cm/s)	10^7	10^7	10^7
Hole thermal velocity (cm/s)	10^7	10^7	10^7
Electron Mobility μ_n (cm^2/Vs)	20	100	650
Hole Mobility μ_p(cm^2/Vs)	20	50	50
Shallow uniform donor density N_D(1/cm^3)	10^{18}	10^{17}	0
Shallow uniform acceptor density N_A (1/cm^3)	0	0	10^{16}

a* (Kuddus *et al.*, 2021) [11] (Anware *et al.*, 2017) (Al-Hattab *et al.*,2021) [1], b* (Rosly *et al.*, 2019) [16] (Tung *et al.*, 2018), c* (Dey *et al.*, 2017) [6].

Table 2: Contact electrical properties

Parameters	**Right contact***	**Back contact**
Work function (eV)	Flat band	5.7(d*)
Surface Recombination Velocity of electron(cm/s)	10^7	10^5*
Surface Recombination Velocity of hole(cm/s)	10^5	10^7*

* SCAPS Library, d* (Derry *et al.*, 2015)

3. Methodology and theoretical analysis

The voltage-current (I-V) characteristics curve of solar cells can be described by equation (1), which includes several main parameters named (photo generated current I_{ph}, ideality factor n, reverse saturation current I_o, series resistance R_s, and shunt resistance R_{sh} that affect the cell's parameters (V_{OC}, J_{SC}, FF, Eff.) with the change of both temperature and illumination (Chegaar *et al.*, 2013) [3].

$$I = I_{ph} - I_o\left[\exp\left(\frac{q(V+R_s I)}{nKT}\right) - 1\right] - \frac{V+R_s I}{R_{sh}} \quad (1)$$

Where q is the absolute value of electron's charge, T is the temperature, and K is Boltzmann constant. The influence of light intensity on cell parameters is illustrated by its effect on short circuit current and open circuit voltage, which is given as follows (Chegaar *et al.*, 2013) [3].

- The short circuit current is directly proportional to the light intensity, as indicated in the following equation (2):

$$I_{SC} = K_E * E \quad (2)$$

Where K_E is a constant that represents the change in short-circuit current I_{SC} as a function of irradiance and E is irradiance.

- While the relationship between open circuit voltage and light intensity is as follows:

$$V_{oc} = V_{ocn} + \frac{nKT}{q}\ln\left(\frac{E}{E_n}\right) \quad (3)$$

Where V_{OCn} and E_n represent the open circuit voltages, and illumination under the nominal conditions, respectively (Chegaar *et al.*, 2013) [3]. The performance of the photovoltaic cell (open circuit voltage, short circuit current, fill factor and conversion efficiency) is affected by the change in temperature and illumination intensity, which are proportional to the series resistance, parallel resistance, ideality factor, and reverse saturation current (Kandil *et al.*, 2011). The high resistance of the series has a significant impact on the performance of the solar cell (Wolf and Rauschenbach., 1963). The series resistance is parasitic in solar cell, it works to reduce the maximum output power (which is defined as the point near the inflection of the isotropic curve (I-V), which corresponds to the rectangular area under the characteristics curve represented by the output characteristics of the curve Imp*Vmp) and thus the fill factor of the cell decreases (Dadu *et al*., 2002). Also, the decrease in efficiency with an increase in the intensity of illumination is due to the high series resistance (Wolf and Rauschenbach., 1963), and one of the main factors impacted by illumination intensity is the short circuit current, which increases directly with increasing illumination intensity (Tobnaghi *et al*., 2013) [19].

On the other hand, the parameters of the cell are greatly affected by the increase in temperature, where the mobility of the electron-hole and the concentration of carriers, the density of carriers and energy gap are affected by the increase in temperature (Dey *el al*., 2017) [6], and that the parameters most affected by the temperature is the open circuit voltage, so V_{OC} decreases with increasing temperature (Tobnaghi *et al*., 2013) [19]. Higher temperature values reduce the energy gap. The relationship between open circuit voltage and temperature can be expressed by the equation (4) below (Et-taya *et al*., 2020).

$$\frac{dV_{OC}}{dT} = \frac{V_{OC}}{T} - \frac{E_g/q}{T} \quad (4)$$

4. Results and discussion:

The performance of a solar cell is affected by environmental factors such as temperature and illumination intensity. The influence of temperature and light intensity on cell performance was investigated in this part of this study. The results reveal that all parameters of the solar cell, which are the open circuit voltage, short circuit current, fill factor, and conversion efficiency, are affected by the change of both temperature and intensity of illumination. The open circuit voltage is the most parameter impacted by temperature, as it decreases with increasing temperature, causing both the efficiency and the fill factor to decrease [Singh and Ravindra, 2012] [18]. The short circuit current density is the most impacted by varying the intensity of lighting, and it increases directly with rising illumination intensity, but the open circuit voltage is less sensitive to intensity of light than the short circuit current density [Tobnaghi *et al*.,2013] [19] [Chegaar *et al*., 2013] [3].

4.1. Effect of temperature

Among the most essential aspects of solar cell performance is the examination of the influence of operating temperature on solar cell structure. The temperature variations are needed to analyze the thermal stability of solar cells. The performance of this cell at higher temperatures is investigated in this study. The electron-hole mobility, carrier concentration, density of states, and band gap of the materials are all affected by high working temperatures [Dey *et al*., 2017] [6]. This study included high operation temperatures ranging from 240 – 500°K. Figure (2) shows the performance of V_{OC}, J_{SC}, FF, and Eff. as a function of temperature. As shown in the figure (2), solar cell performance deteriorates at non-ideal temperatures. The simulation results showed that increasing temperature has a large effect on V_{OC}; as the temperature rises, the V_{OC} decreases and, as a result, the cell's efficiency declines. The decrease in V_{OC} is due to the fact that it is directly dependent on the current density of saturation I_O, which decreases fast with increasing temperature values [Heriche *et al*., 2017] [8], as shown in equation (5) [Tobnaghi *et al*., 2013] [19].

$$Voc=nkT/q \quad [IL/Io] \quad (5)$$

Where I_L and I_o are light generated current and reverse saturation current respectively. The increase in temperature from 240 to 500°K increased the saturation current, and therefore the V_{OC} decreased from (1.0836 to 0.6656 V), lowering the fill factor and efficiency of the solar cell from (88.17 to 75.95%) and (19.22 to 10.16%) respectively [Singh and Ravindra. 2012] [18]. Furthermore, greater temperatures lower the band-gap, decreasing the overall performance of the cell. Lower band-gaps result in increased intrinsic carrier concentration and saturation current density [Tobnaghi *et al*., 2013] [19]. Finally, the influence of temperature on J_{SC} and V_{OC} could be clearly observed in the fill factor parameter, which may be defined as the ratio of maximum output power to the product of V_{OC} and J_{SC}. As the temperature raises, I_O rises, and therefore V_{OC} falls, lowering the fill factor and, thus, the efficiency of the PV cell will decrease.

Table 3: Effect of temperature variation on solar cell parameters

Temperature(K)	V_{OC} (V)	J_{SC} (mA/cm^2)	FF (%)	Eff. (%)
240	1.0836	20.117	88.17	19.22
260	1.0750	20.117	87.64	18.95
280	1.0660	20.116	87.1	18.68
300	1.0566	20.116	86.53	18.39
320	1.0446	20.115	85.95	18.06
340	1.0262	20.114	85.32	17.61
360	0.9968	20.112	84.57	16.95
380	0.9571	20.109	83.69	16.11
400	0.9117	20.105	82.71	15.16
420	0.8641	20.104	81.6	14.18
440	0.8152	20.1	80.39	13.17
460	0.7656	20.097	79.05	12.16
480	0.7157	20.095	77.58	11.16
500	0.6656	20.091	75.95	10.16

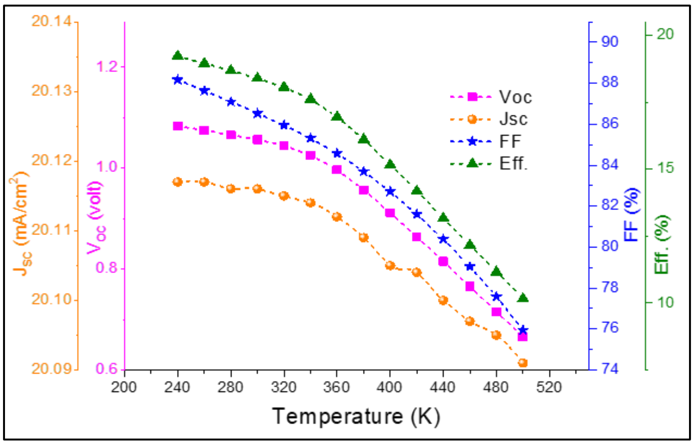

Fig 2: Effect of temperature variation on solar cell performance

4.2. Effect of illumination

The optimum cell structure was established in this research under standard conditions, which included a standard light intensity of 1000w.cm^{-2}, an air mass of 1.5 (AM1.5), and a temperature of 300^{o}K. The influence of illumination intensity on the performance of the ideal cell was studied in this research using the SCAPS simulation software, which offers control over operational factors such as temperature and illumination via the work panel after selecting the operating point of the solar cell [Shoewu, 2018] [17]. Changing the intensity of the illumination has an effect on all photovoltaic cell characteristics since the photovoltaic current is directly proportional to the photon flux, and therefore the short circuit current is related to the illumination, as indicated in the equation (6) below [Tobnaghi *et al.*, 2013] [19] [Singh and Ravindra., 2012] [18].

$$Jsc = q \int_{hv=Eg}^{\infty} \frac{dN_{ph}}{dhv} d(hv) \quad (6)$$

Where N_{ph} is the flux of initial photon? The results demonstrated that raising the amount of light intensity has a clear influence on the short-circuit current, as Jsc rises linearly with increasing illumination intensity, increasing from (4.02mA/cm^2) at 200 W/m^2 to (24.13mA/cm^2) at 1200W.m^{-2}, The reason for this effect is that increasing the intensity of light leads to an increase in photon density, which leads to an increase in carrier production and so raises Jsc [Islam *et al.*, 2021] [9]. While V_{OC} rises logarithmically only when the illumination intensity is equal to or less than 600W.m^{-2}. The fill factor decreases with increasing light intensity, but the Voc slightly decrease which is almost constant at (1.056V) when the light intensity is (>600W.m^{-2}), due to the effect of series resistance [Chegaar *et al.*, 2013] [3]. Series resistance has a substantial influence on solar cell performance at high-intensity. Whereas shunt resistance has a large effect on cell performance at low-intensity. the photo-generated carriers increase dramatically with increasing light intensity, which changes the resistance value and affects FF, FF decreases as the intensity of light increases due to the decrease in shunt resistance (Rsh) [Islam *et al.*, 2021] [9]. The conversion efficiency increases logarithmically when the illumination is less than 400W.m^{-2} [Chegaar *et al.*, 2013] [3]. as shown from figure(3) The efficiency increases with increasing illumination intensity, then the efficiency decreases by a small percentage which is appear nearly constant at illumination intensity greater than 600W.m^{-2}. The reason for this small decrease in efficiency is the decrease in the fill factor and open circuit voltage, which depends on the series resistance [Kandil *et al.*, 2011] [10] [Wolf and Rauschenbach., 1963]. Thus, we note that increasing the intensity of illumination greatly affects the short circuit current, while Voc is less sensitive to illumination than the short circuit current.

Table 4: Effect of light intensity on solar cell parameters

Light intensity (W.m^{-2})	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eff. (%)
200	1.0555	4.02	86.65	18.39
400	1.0565	8.05	86.6	18.40
600	1.0567	12.07	86.57	18.40
800	1.0566	16.09	86.55	18.39
1000	1.0566	20.11	86.53	18.39
1200	1.0565	24.13	86.51	18.38

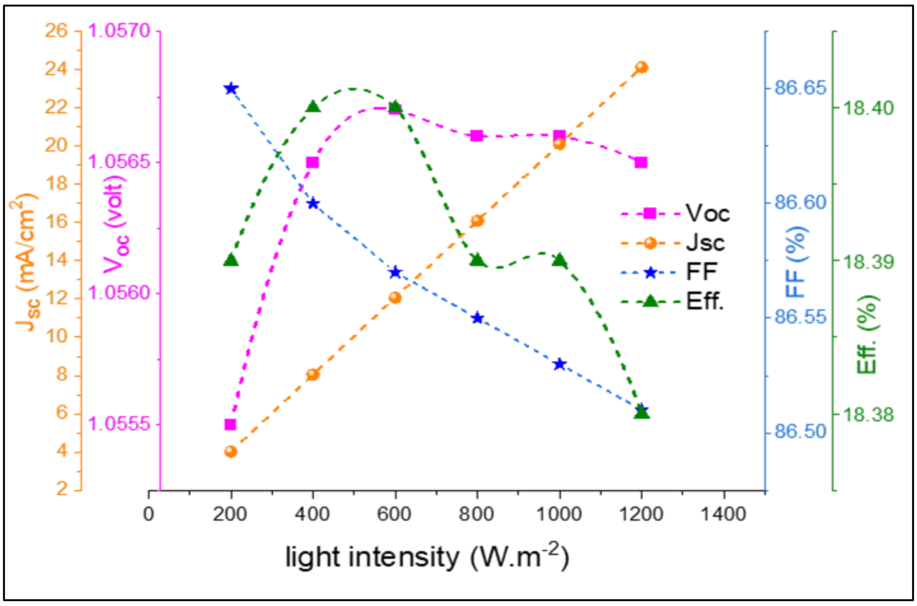

Fig 3: Effect of light intensity on solar cell performance

5. Conclusions

The performance of a solar cell (photovoltaic cell) is influenced by environmental conditions such as temperature and illumination intensity, which influence the solar cell's output characteristics. In this work, SCAPS-1D simulation software was used to test the influence of temperature and light intensity on the performance of the proposed cell. This is achieved by gradually increasing the temperature from (240 – 500^{o}k) in increments of 20. The simulation results showed that the efficiency and fill factor decrease from (19.22 to 10.16%) and from(88.17 to 75.95%) respectively with increasing temperature, and that the open circuit voltage Voc is greatly affected by temperature, so Voc decreases with increasing temperature from (1.0836 to 0.6656 V), due to an increase in the cell's reverse saturation current with increasing temperature. On the other hand, the effect of the intensity of illumination on the performance of the solar cell was studied, where the results showed that the short circuit current is the most affected parameter by changing the intensity of the illumination, and therefore current increases from (4.02 to 24.13 mA/cm^2) with an increase in the intensity of illumination, while the open circuit voltage Voc and the efficiency Eff increase Logarithmically, then it begins to decline at the level of illumination (>600 w.m-2) due to the high resistance of the series. And therefore, efforts should be made to reduce the high series resistance of the solar cells so that they may be used at high illumination intensity.

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