



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/cm²) at 200W.m⁻² to (24.13 mA/cm²) 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 (~10⁵ 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.

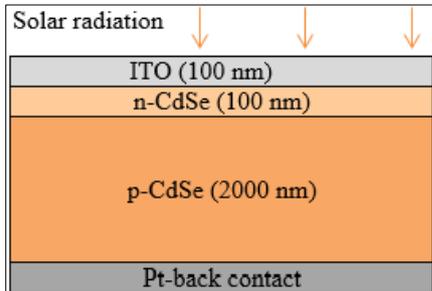


Fig 1: Structure of CdSe thin film solar cell

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/cm²), 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) [10]. The high resistance of the series has a significant impact on the performance of the solar cell (Wolf and

Rauschenbach., 1963) [21]. 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 $I_{mp} * V_{mp}$) and thus the fill factor of the cell decreases (Dadu *et al.*, 2002) [4]. Also, the decrease in efficiency with an increase in the intensity of illumination is due to the high series resistance (Wolf and Rauschenbach., 1963) [21], 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 *et 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 (Etaya *et al.*, 2020) [7].

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

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_0 , which decreases fast with increasing temperature values [Heriche *et al.*, 2017] [8], as shown in equation (5) [Tobnaghi *et al.*, 2013] [19].

$$V_{oc} = nkT/q [IL/I_0] \quad (5)$$

Where I_L and I_0 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_0 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

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°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].

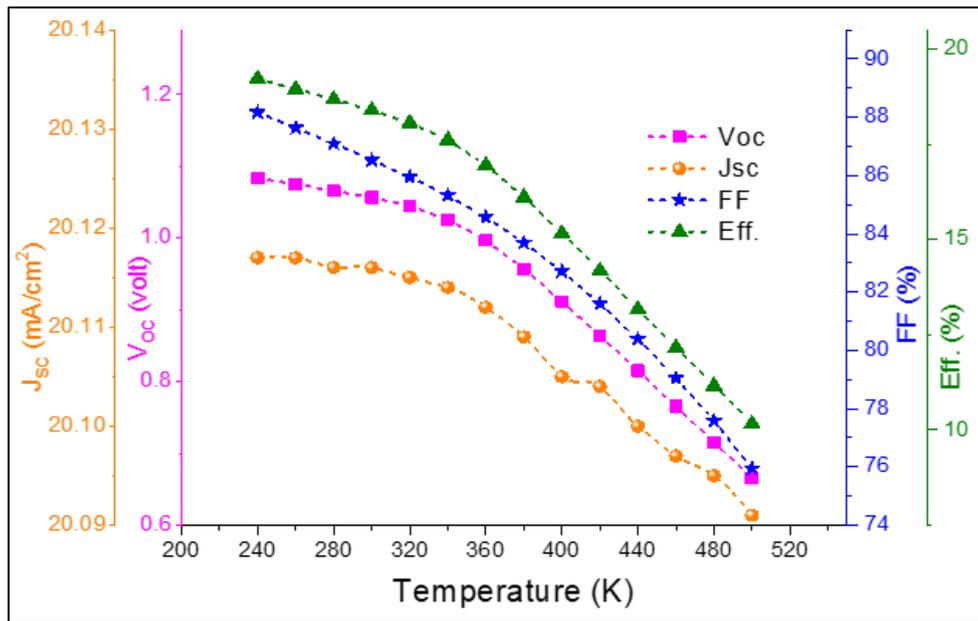


Fig 2: Effect of temperature variation on solar cell performance

$$J_{sc} = q \int_{h\nu=E_g}^{\infty} \frac{dN_{ph}}{dh\nu} d(h\nu) \quad (6)$$

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 J_{sc} rises linearly with increasing illumination intensity, increasing from (4.02 mA/cm²) at 200 W/m² to (24.13 mA/cm²) at 1200 W.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 J_{sc} [Islam *et al.*, 2021] [9]. While V_{oc} rises logarithmically only when the illumination intensity is equal to or less than 600 W.m⁻². The fill factor decreases with increasing light intensity, but the V_{oc} slightly decrease which is almost constant at (1.056 V) when the light intensity is (>600 W.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 (R_{sh}) [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] [21]. Thus, we note that increasing the intensity of illumination greatly affects the short circuit current, while V_{oc} 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

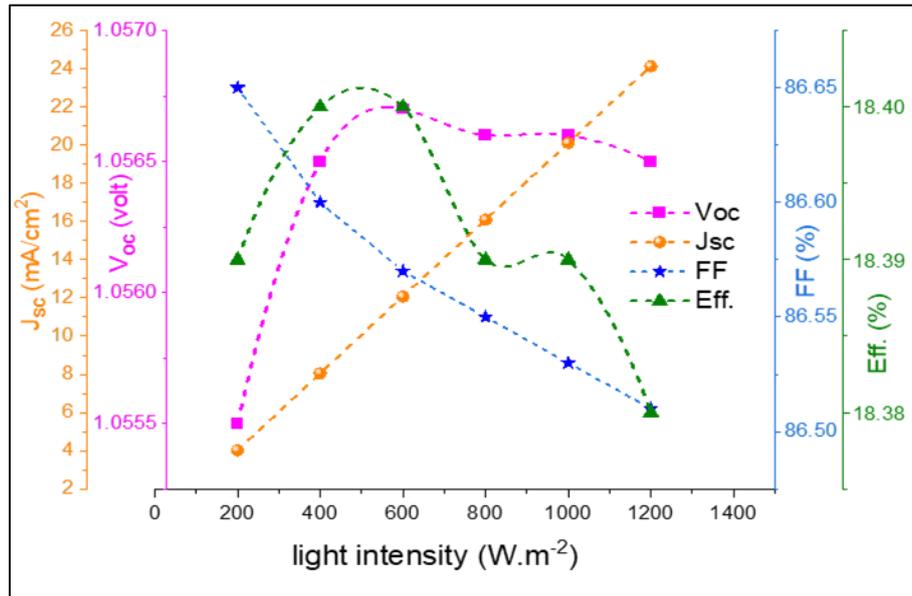


Fig 3: Effect of light intensity on solar cell performance

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°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/cm²) 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.

References

- Al-Hattab M, Khenfouch M, Bajjou O, Chrafih Y, Rahmani K. Numerical simulation of a new heterostructure CIGS/GaSe solar cell system using SCAPS-1D software. *Solar Energy*. 2021;227:13-22.
- Anwar F, Afrin S, Satter S, Mahub R, Ullah SM. Simulation and performance study of nanowire CdS/CdTe solar cell. *International Journal of Renewable Energy Research*. 2017;7(2):885-893.
- Chegaar M, Hamzaoui A, Namoda A, Petit P, Aillerie M, Herguth A. Effect of illumination intensity on solar cell parameters. *Energy Procedia*. 2013;36:722-729.
- Dadu M, Kapoor A, Tripathi K. Effect of operating current dependent series resistance on the fill factor of a solar cell. *Solar Energy Materials and Solar Cells*. 2002;71(2):213-218.
- Derry GN, Kern ME, Worth EH. Recommended values of clean metal surface work functions. *Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films*. 2015;33(6):060801.
- Dey M, Hasan M, Amin R, Dey M. Numerical analysis of efficient cadmium selenide solar cell. In: 2017 3rd International Conference on Electrical Information and Communication Technology (EICT); 2017. p. 1-4. IEEE.
- Et-taya L, Ouslimane T, Benami A. Numerical analysis of earth-abundant Cu₂ZnSn (S_xSe_{1-x}) solar cells based on Spectroscopic Ellipsometry results using SCAPS-1D. *Solar Energy*. 2020;201:827-835.
- Heriche H, Rouabah Z, Bouarissa N. New ultrathin CIGS structure solar cells using SCAPS simulation program. *International Journal of Hydrogen Energy*. 2017;42(15):9524-9532.
- Islam MT, Kumar A, Thakur AK. Defect density control using an intrinsic layer to enhance conversion efficiency in an optimized SnS solar cell. *Journal of Electronic Materials*. 2021;50(6):3603-3613.
- Kandil MK, Majida SA, Asma MAA, Latifa MA, Ibrahim MK, Adel AG. Investigation of the performance of CIS photovoltaic modules under different environmental conditions. *Smart Grid and Renewable Energy*; c2011.
- Kuddus A, Mostaque SK, Hossain J. Simulating the performance of a high-efficiency SnS-based dual-heterojunction thin film solar cell. *Optical Materials Express*. 2021;11(11):3812-3826.
- Patel SL, Chander S, Purohit A, Kannan MD, Dhaka MS. Understanding the physical properties of CdCl₂ treated thin CdSe films for solar cell applications. *Optical Materials*. 2019;89:42-47.
- Qu J, Zhang L, Wang H, Song X, Zhang Y, Yan H. Simulation of double buffer layer on CIGS solar cell with SCAPS software. *Optical and Quantum Electronics*. 2019;51(12):1-14.
- Rai N, Dwivedi DK. Numerical modelling for enhancement of output performance of CIGS based thin film solar cell using SCAPS 1-D simulation software. In:

- AIP Conference Proceedings. 2020;2220(1):140021. AIP Publishing LLC.
15. Reyes Verdugo LA. Low-dimensional II-VI group semiconductor heterostructures development for photosensitive materials application; c2020.
 16. Rosly HN, Rahman KS, Harif MN, Yusoff Y, Wafi A, Matin MA, *et al.* High efficiency CdTe thin film solar cells with CdSe as a prospective window layer from numerical optimization. *Test Engineering & Management*. 2019;81:5647-5653.
 17. Shoewu O. Effect of absorber layer thickness and band gap on the performance of CdTe/CdS/ZnO multi-junction thin film solar cell; c2018.
 18. Singh P, Ravindra NM. Temperature dependence of solar cell performance—an analysis. *Solar Energy Materials and Solar Cells*. 2012;101:36-45.
 19. Tobnaghi DM, Madatov R, Farhadi P. Investigation of light intensity and temperature dependency of solar cells electric parameters; c2013.
 20. Tung HT, Thao NT, Vinh LQ. The reduced recombination and the enhanced lifetime of excited electrons in QDSSCs based on different ZnS and SiO₂ passivation. *International Journal of Photoenergy*. 2018.
 21. Wolf M, Rauschenbach H. Series resistance effects on solar cell measurements. *Advanced Energy Conversion*. 1963;3(2):455-479.
 22. Yasin S, Waar ZA, Al Zoubi T. Development of high efficiency CZTS solar cell through buffer layer parameters optimization using SCAPS-1D. *Materials Today: Proceedings*. 2020;33:1825-1829.