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محاكاة تأثير العوامل البيئية على أداء الخلية الشمسية نوع 3C-SiC

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ملخص البحث:

لقد تم استخدام مادة 3C–SiC في هذا البحث المشوبة مع عنصرين وهما Al و Cr للحصول على خصائص شبه الموصل من النوع p و n على التوالي، بوصفها مكونا أساسيا في بنية الخلية الشمسية المستخدمة حاليا في هذه الدراسة إذ تركزت الدراسة الحالية على تأثير الظروف البيئية الرئيسة وهما (درجة الحرارة وشدة الاضاءة) على اداء الخلية الشمسية الحالية من نوع PIN. و تم اعتماد مستويات مختلفة من شدة الإضاءة من (250 إلى 1200) وات.م$^{-2}$و درجات حرارة متغيرة في المدى من (300 الى400) كلفن في المحاكاة. لقد أظهرت النتائج إلى أن شدة الضوء لها تأثير فعال على تيار الدائرة، حيث تزداد قيمة تيار الدائرة القصيرة J_{SC} خطيًا مع زيادة مستوى شدة الضوء الساقط. وكذلك، فقد أظهرت النتائج أن درجة الحرارة لها تأثير كبير على معلمات جهد الخلية. إذ لحظ أن جهد الدائرة المفتوحة V_{OC} ينخفض بشكل كبير لانخفاض تيار التشبع الذي يتناقص بدوره بسرعة مع زيادة درجة الحرارة.

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Simulation of the Influence of Environmental Factors on the Performance of 3C-SiC Solar Cells

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Abstract:

In this paper, a doped 3C-SiC with two dopant materials, Al and Cr to obtain p and n type semiconductors respectively, was used as a basic component in the solar cell structure which was used in the current study. The present study examined the impact of the main environmental conditions (temperature and light intensity) on the PIN solar cell. Simulation was accomplished for different levels of illumination from (250 to 1200) $W.m^{-2}$ and temperature from (300 to 400) K. The results revealed that illumination has a great impact on the current of the circuit, where the current of the short circuit J_{SC} increases linearly with increasing the level of intensity. The results show that the temperature has a sever influence on the voltage of the cell. The voltage of the open circuit V_{OC} considerably decreases due to the decrement in current of saturation that reduces directly with an increase in temperature.

1. Introduction

Nowadays energy of the sun is the most significant renewable source of energy, the most common ways to get benefit from solar energy are the solar collector that converts sunlight into heat and solar cells that converts sunlight into electricity [1-2]. Solar cells based on semiconductor materials is the most promising renewable energy source The most common material is the silicon solar cells which is the most popular type due to its availability [2]. Other generations based on a thin film technology which is also commercially available [3]. Organic and Perovskite based solar cells which have many manufacturing advantages made them promising new generation but they still suffer from low stability and efficiency [4]. Therefore, there must be a good candidate with promising photovoltaic properties to overcome all these disadvantages with low production cost and high efficiency. Silicon Carbide (SiC) material is the subject of this study, , it is a wide band gap semiconductor material that maintains excellent characteristics, including a wide band gap (more than 2 eV), elevated breakdown voltage (3.0 mV / cm), high thermal conductivity (3.7 W / cm ^{o}C), lower carrier concentration and good oxide structure capability [5]. A heterojunction structure based on this material had achieved a power conversion efficiency of 27.6 % in 2016 [6]. The photovoltaic parameters of an optimized 3C-SiC structure based on our previous work [7] are investigated in this paper under several conditions of temperature and illumination using a free simulation (Solar Cell Capacitance Simulator) software 1D-SCAPS which developed by Gent University. The efficiency of solar cells is generally studied for (STC)

Standard Testing Conditions, which are : 1000 $W.m^{-2}$ direct ordinary intensity of light, Air Mass of 1.5 (AM 1.5) and 300 K temperature. The PV cells behavior dramatically affected by the temperature as, in the applications of terrestrial, they are commonly face temperatures in the ranges from (288 K) 15 ºC to (323 K) 50 ºC [8] and to also temperatures higher than that in space applications and systems of concentrator [9]. Increasing temperature causes both FF and PCE to decrease, the efficiency degradation due to V_{OC} decrease [7–10].

The produced PV cells current is proportion directly to the irradiation, any change of the intensity of light causes a proportional change in the J_{SC} [10]. On the other hand, the open-circuit voltage V_{OC} is less sensitive to light intensity than the short circuit current, thus the efficiency and the whole performance of the cell will be influenced by the light intensity variation.

1. Methodology

The characteristics of (J-V) curve of a single diode model of the PV cell are usually described as given in equation (1) [11], which constructed from five variables called photo generated current (I_{ph}), current of reverse saturation (I_o), factor of diode ideality (n), resistance of series (R_s) and resistance of shunt (R_{sh}). These variables have a strong and direct effect on the (J–V) curve shape of a solar cell at any level of light intensity and temperature and therefore determine the values of the parameters of the performance [11].

$$\boldsymbol{I = I_{ph} - I_o\left[\exp\left(\frac{\beta}{n}(V + IR_s) - 1\right] - G^{*}(V + IR_s)} \qquad \textbf{(1)}$$

In equation (1) β= q/kT is the inverse thermal voltage, q is the charge of the electron , T is the temperature, k is Boltzmann constant , $G^{*}= 1/R_{sh}$ is the conductance of shunt R_{sh} [12], and n is the diode ideality factor.

The impact of light intensity on the photovoltaic parameters is represented by its effect on V_{OC} and J_{SC}, open-circuit voltage V_{OC} as a function of irradiation can be express in the following equation [10]:

$$\boldsymbol{V_{OC} = V_{OCn} + \frac{nkT}{q}\ln\left(\frac{A}{A_n}\right)} \qquad \textbf{(2)}$$

Where: V_{OCn}, A, and A_n are the open-circuit voltage, the irradiance, and the irradiation under nominal conditions respectively, while the relationship that links I_{SC} with the irradiance can be written in the equation (3) [10]:

$$\mathbf{I_{SC} = K_A * A} \qquad \textbf{(3)}$$

Where K_A is a constant represents the relative variation of I_{SC} as a function of illumination**.**

Many attempts were achieved to study the dependency of solar cell parameters to the major conditions of the environment, the irradiation and the temperature [11-15]. The behavior of the PV cell is affected by light intensity variance as its performance variables, i.e. Open-circuit voltage (V_{OC}), short-circuit current density (J_{SC}), fill factor (FF) and efficiency (η). These parameters are directly related to the

characteristics of the cells, that is resistance of series (R_s), resistance of shunt (R_{sh}), ideality factor of the diode (n) and the current of reverse saturation (I_0) [10]. The behavior of solar cells could be greatly affected by the inner series resistance. The maximum output power of the PV cell is the area of the maximum area of a rectangle which is achieved inside the output characteristics curve. The rectangle area increases by increasing the "sharpness" of the knee in the photovoltaic output characteristics. At increasing the light intensity, the internal series resistance causes a larger of these characteristics. Solar cells are normally designed for best performance at radiation intensities as obtained at the earth's surface [13]. The lowest-resistance solar cell demonstrates a repetitive increase in power output with an increase in light intensity, while the limited R_S values induce the highest output to enhance less quickly with increasing light intensity, this influence is successively increased with the rising of resistance of series and illumination [13]. For photovoltaic cells with small values of series resistance or with fairly low illumination rates so the influence of series resistance could be ignored. This is demonstrated in the situation that the multiplication of IR_S should be negligently low in comparison to the V node voltage. When this requirement is not satisfied, a decrement in the voltage of the ends will be equal to the multiplication of the inner resistance of series R_S and the difference in the current generated by light [13], thus a reduction in efficiency with increasing light intensity in some solar cells is due to the high value of R_S.
On the other hand, the temperature has a significant impact on the photovoltaic parameters. At excessive values of temperature, some of the parameters as electron and hole mobility, concentrations of carrier and the material band gap will be influenced that leads to a reduction in the cell efficiency [14]. The reduction in a semiconductor band gap with increasing temperature could be seen as an increment in the electron energy inside the material. Smaller amount of energy is needed to destroy the bond. In the band gap of the semiconductor model of bond, the decrement in the energy of bond decreases the band gap too. As a result, the large values of temperature decreases the band gap. V_{OC} is the highly influenced parameter by temperature, the variance of V_{OC} with the temperature can be expressed by equation (4) [15]:

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

Where E_g is the energy gap of the material.

1. Cell Structure and input parameters

The current study is based on an optimized PIN structure of 3C-SiC that constructed from five layers. A double buffer consists of Cr-doped n-(3C-SiC) layer with a band gap of 1.139 eV based on a research done by Lu in 2019 [16], and n^+ (3C-SiC) layer with a band gap of 2.39 eV, a middle intrinsic (3C-SiC) layer placed between the buffer and absorber with a band gap of 2.39 eV. An absorber layer of Al-doped p-(3C-SiC) also based on Lu work [16], and a window layer of n-SnO_2 with 3.6 eV band gap. The cell structure is depicted in figure (1). Each layer of this cell has an optimum thickness and carrier concentration that gives the best cell performance. The cell under Standard Testing Conditions (300 K temperature, AM 1.5, and light intensity of $1000W.m^{-2}$) produces an efficiency of 30.27 %, FF of

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82.74%, J_{SC} of 47.636 mA.cm^{-2}, and V_{OC} of 0.768 V. The cell's parameters that are utilized in the current simulation illustrated in the table (1).

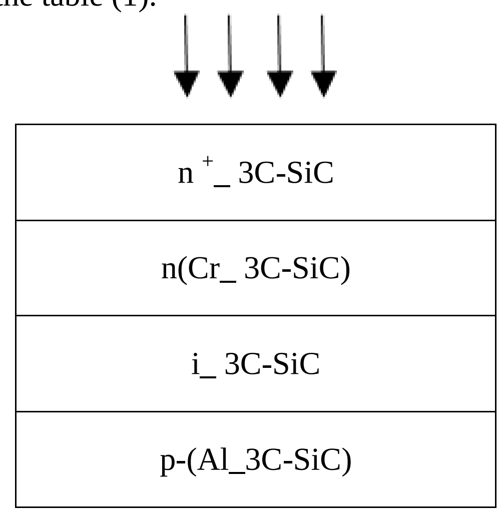

Fig. (1) 3C-SiC PIN cell structure.

Table (1). Simulation main parameters.

Parameters	**n^+(3C-SiC)**	**n-Cr(3C-SiC)**	**i(3C-SiC)**	**p-Al(3C-SiC)**	**n-SnO_2**
Thickness (µm)	0.1	0.1	2.5	3	0.2
Donor density N_D (cm^{-3})	10^{22}	10^{19}	10^{15}	10^{1}	10^{18}
Acceptor density N_A (cm^{-3})	10^{5}	10^{2}	10^{15}	10^{15}	10^{2}
Band Gap (eV)	2.39	1.139	2.39	1.454	3.6
Electron affinity (eV)	3.830	3.830	3.830	3.830	4.50
Dielectric permittivity (relative)	9.720	9.720	9.720	9.720	9
CB effective density of states (cm^{-3})	$1.55*10^{19}$	$1.55*10^{19}$	$1.55*10^{19}$	$1.55*10^{19}$	$2.2*10^{18}$
VB effective density of states (cm^{-3})	$1.163*10^{19}$	$1.163*10^{19}$	$1.163*10^{19}$	$1.163*10^{19}$	$1.8*10^{19}$
Electron thermal velocity (cm.s^{-1})	10^{7}	10^{7}	10^{7}	10^{7}	10^{7}
Hole thermal velocity (cm.s^{-1})	10^{7}	10^{7}	10^{7}	10^{7}	10^{7}
Electron mobility (cm².Vs^{-1})	$6.50*10^{2}$	$6.50*10^{2}$	$6.50*10^{2}$	$6.50*10^{2}$	10^{2}
Hole mobility (cm².Vs^{-1})	40	40	40	40	25

2. Results and Discussion

The performance of the cell which represented by the photovoltaic parameters; J_{SC}, V_{OC}, FF, and the efficiency η, investigated under different values of temperature and light intensity. SCAPS simulation software is organized in many panels in which the user can set several parameters. The software opens with an action panel where it is easy to set the operating point of work such as (temperature and illumination), and a list of calculations will carry out such as I-V and other calculations [14].

4.1 Light intensity

Changing the intensity level of illumination on a PV cell affects all solar cell parameters. The current generated by light is directly proportion to the flux of photons and thus J_{SC} is proportional to the irradiance directly [14-15]. While V_{OC} must increase logarithmically with the light intensity according to the equation (5):

$$V'_{OC} = V_{OC} + \frac{nkT}{q} \ln A \qquad (5)$$

Where V'_{OC} is the voltage of open circuit at intensity of light that is = 1000 W.m^{-2}. The series resistance has a stronger impact on the performance at high intensity, while the shunt resistance has a higher impact on the performance of the cells at low light intensity.

The first step of the study is making the temperature constant at 300 K and start to change the light intensity from 250 to 1200 W.m^{-2} to study the change in the photovoltaic parameters. Table (2) implies that the current parameter increases linearly with increasing light intensity, while the V_{OC} increases logarithmically only for A (light intensity) equal or less than1000 W.m^{-2}, and for A higher than 1000 W.m^{-2} V_{OC} is almost constant. The results indicated that increasing the irradiation level has a significant impact on the short-circuit current, as the light intensity increases the J_{SC} increases from 11.924 to 57.149 mA.cm^{-2}, the reason behind this is that high light intensity implies higher absorption of photons, increased carrier generation and therefore a high value of J_{SC}. The fill factor FF lessens with higher irradiation intensity (A>500 W.m^{-2}), while V_{OC} is almost constant at a value of 0.76 V, due to the effect of the high series resistance [10].

Table (2) Cell's parameters variation with light.

Light intensity A (W.m^{-2})	**V_{OC} (V)**	**J_{SC} (mA.cm^{-2})**	**FF (%)**	**η (%)**
250	0.7593	11.924	83.19	30.13
500	0.7661	23.835	83.09	30.34
750	0.7678	35.739	82.92	30.34
1000	0.7680	47.636	82.74	30.27
1200	0.7677	57.149	82.60	30.20

It is evident that the open circuit voltage is much less sensitive to the light factor. The cause of the slight reduction in efficiency was the decrease in the fill factor, that mostly depends on two solar cells parameters; the high values of R_S series resistance and the change in the shape of the dark J-V curve. Figure (2) shows the impact of irradiance on the cell parameters.

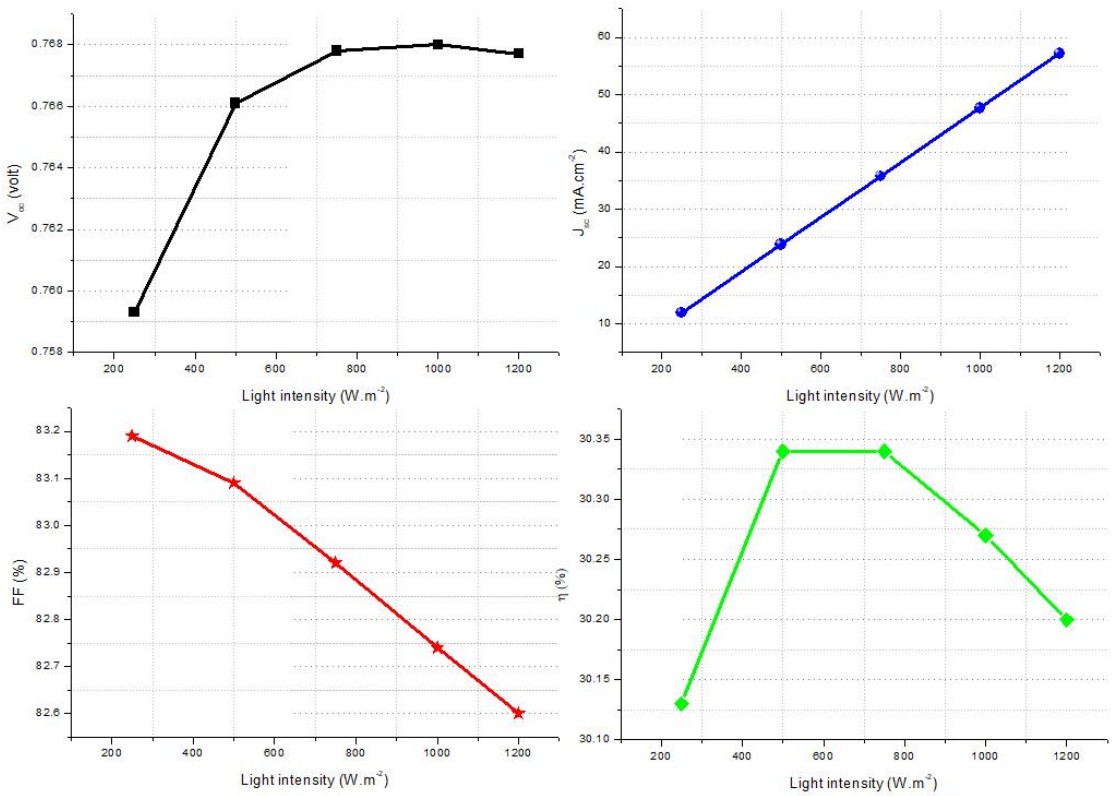

Fig. (2) The impact of light intensity on the cell parameters.

4.2 Temperature

The simulation was performed at irradiance level of 1000 $W.m^{-2}$, and the temperature was varying from 300 to 400 K in a step of 20. Figure (3) shows the effect of temperature on the cell parameters. The results of simulation proved that increasing temperature has a dramatic impact on V_{OC}, as the temperature increases the V_{OC} decreases and consequently the efficiency of the cell decreases. The reduction in the V_{OC} is because V_{OC} directly depends on the current of saturation I_0 that reduces rapidly as well with raising values of temperature [17-18]. As temperature increases from 300 to 400 K saturation current the reverse increases and thus V_{OC} reduces from 0.768 to 0.516 V, which decreases the fill factor and thus the efficiency of the solar cell from 30.27% to 18.10%. Furthermore higher temperature reduces the band gap, thus affecting the cell whole performance [19-20]. Band gaps with smaller values producing a relatively high value of intrinsic carrier concentration n_i where ($\mathbf{n_i \propto e^{-Eg}}$), which produces a lower V_{OC} as well. Equation (6) shows the relation between V_{OC} and n_i [18]. Table (3) depicts the current structure behavior at the temperature values ranging from 300 to 400 K.

$$\mathbf{V_{OC} = \frac{kT}{q} \ln\left(\frac{(N_A+\Delta n)\Delta n}{n_i^2}\right)} \quad \mathbf{(6)}$$

Where N_A is the concentration of acceptor atoms.

Table (3) current structure outputs at variable temperature.

Temperature (K)	**V_{OC} (V)**	**J_{SC} (mA.cm^{-2})**	**FF (%)**	**η (%)**
300	0.768	47.636	82.74	30.27
320	0.730	47.612	81.74	28.42
340	0.672	47.587	80.03	25.62
360	0.621	47.571	78.19	23.11
380	0.567	47.562	76.07	20.54
400	0.516	47.563	73.72	18.10

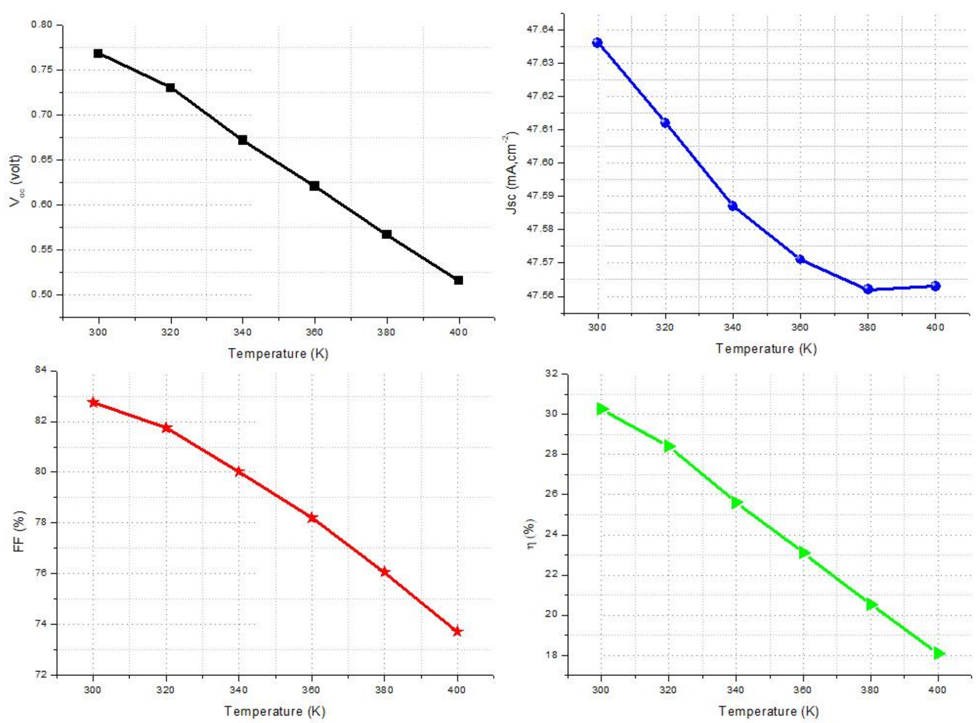

Fig. (3) The impact of temperature variation on cell parameters.

3. Conclusion

The performance of PV cells depends on the conditions of the environment and the cell output change with varying in temperature and illumination. The produced current of the PV cells is proportion directly to the illumination, as the intensity of the light increases the short-circuit current increases. The preceding analysis also highlights the impact of series resistance on PV cell measurements and the precaution to be held in their estimation. The results implied that the reduction of efficiency at a higher intensity of light resulted from elevated values of resistance of series. In summary, for the beneficial PV cells applications at elevated radiation levels, the lessening of series resistance must be emphasized, in addition to the importance of taking into consideration the type of application of these photovoltaic modules under higher and lower irradiance level, for outdoor and indoor usages. On the other hand and depending on the simulation results, the most important aspect is the temperature dependency of the voltage, which reduces with rising temperature. As the temperature rises, the reverse saturation current increases, and thus V_{OC} lessens that also significantly reduces the fill factor and therefore the solar cell efficiency.

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