Journal of Nano- and Electronic Physics
Vol. **18** No 2, 02032(7pp) (2026)

Журнал нано- та електронної фізики
Том **18** № 2, 02032(7cc) (2026)

REGULAR ARTICLE

Exploration of the Electrical Behavior of GaAs/Ge Single Junction Solar Cell

M. Hebali[1,2,*], B. Kada[1,2], B. Ibari[1,2], M. Bennaoum[1,2], I.F. Bouguenna[1,2], A. Maachou[1,2], M. Altun[3]

[1] *Department of Electrotechnical, University Mustapha Stambouli of Mascara, 29000 Mascara, Algeria*
[2] *LSTE Laboratory, University Mustapha Stambouli of Mascara, 29000 Mascara, Algeria*
[3] *Department of Electronics and Communication Engineering, Istanbul Technical University, Istanbul, Turkey*

(Received 03 September 2025; revised manuscript received 20 April 2026; published online 29 April 2026)

In this paper, a mathematical model based on the equivalent circuit (single-diode model) was used to study the electrical behavior of a GaAs/Ge single junction solar cell. In order to validate the suitability of this proposed model, nominal values provided by the manufacturer such as photocurrent (I_{SC}), open circuit voltage (V_{OC}), maximum power ($P_{\max}$), form factor (FF) and efficiency (η) were exploited. A comparison between the nominal static characteristics, current-voltage (I-V) and power-voltage (P-V), and those obtained through the proposed model of this solar cell showed that they were very identical. Based on this proposed model, the impact of irradiance and temperature on these static properties and on the various electrical parameters of this solar cell was investigated. This study demonstrated the suitability of this proposed model in exploring how the electrical behavior of this solar cell is affected by changes in illumination and temperature, respectively. Despite the simplicity of this proposed model, it presents good behavior and high performance, making it the most suitable mathematical model for studying single-junction solar cells based on GaAs/Ge semiconductor technology. MATLAB software was used to simulate the proposed model and to analyze the performance of this solar cell.

Keywords: GaAs/Ge, Solar cell, Single junction, Modeling, Static characteristics, Electrical parameters.

DOI: 10.21272/jnep.18(2).02032 PACS numbers: 73.61. – r, 88.40.jm

1. INTRODUCTION

Energy is the main artery for the development and growth of countries, especially electric power, because of its wide utilization in daily life, whether when individuals, institutions or countries. Therefore, demand for electricity is increasing [1-3]. This is what makes scientific research seeks to find a permanent source of electric power [2]. Solar electrical energy is considered the most widely used in the world [4], especially photovoltaic energy, because this energy is the most readily available and non-polluting energy source [5-7]. This photovoltaic electricity is produced by direct conversion of sunlight into electricity [8-10], using the solar cells [6-11].

In addition to silicon technology, the Gallium Arsenide (GaAs) is among the most important semiconductors that have proven their worth in the solar cells technology because it possesses high electronic mobility [12], a direct-bandgap with a sharp absorption onset near the Urbach edge [5], and we found that the efficiency of solar cell in GaAs technology has reached 30.1 % under concentrated sun light [13]. This is what makes these cells are highly efficient devices. In addition to the manufacture of these cells, simulation is also a very powerful tool used in research to study the results of an action on an element without performing the experiment [14]. There are lots of software are exists in the field of modeling, simulation and analysis of photovoltaic cells [15-16]. Among them is MATLAB, which is characterized by ease of use, develops an accurate model, simulate the complex model, solar PV system and other engineering disciplines. Moreover, MATLAB is easily available in industrial, academic and research labs [15-17]. For this, many recent researches have focused on the study of solar cells using simulations [6], especially by MATLAB [13, 16, 18, 19].

In this work, we will study the electrical behavior of the GaAs/Ge single junction solar cell by studying the characteristics Current-Voltage (I-V) and Power-Voltage (P-V), then the study of the influence of solar irradiation and the temperature on both characteristics of this cell. To carry out this work, we will use MATLAB software as a tool for calculation and simulation.

2. GAAS/GE SINGLE JUNCTION SOLAR CELL

The single-junction solar cells based on GaAs/Ge semiconductor technology has been used in satellites as a good power supply. These solar cells mainly consist of GaAs semiconductor material deposited on a Ge substrate with anti-reflective (A/R) coating as shown in Fig. 1. The advantages of these materials (GaAs and Ge) are to capture a large number of photons, corresponding to a

---

[*] Correspondence e-mail: mourad.hebali@univ-mascara.dz

Cite this article as: M. Hebali et al., *J. Nano- Electron. Phys.* 18 No 2, 02032 (2026) https://doi.org/10.21272/jnep.18(2).02032

larger spectrum of light, and thus to obtain a better performance [20]. The datasheet parameters of the GaAs/Ge single junction solar cell are summarized in Table 1 [21].

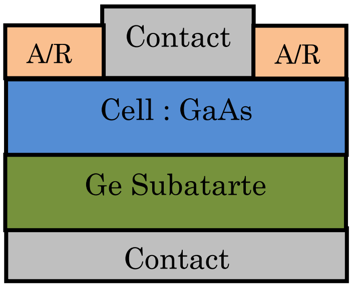


Fig. 1 – Structure of the GaAs/Ge single junction solar cell [21]

3. SOLAR CELL MODEL

The photovoltaic cell model closest to reality represents this cell as a current source that models the conversion of light flux into electrical energy in parallel with a diode that models the *p-n* junction and a shunt resistor R_{sh} represents the current of leakage, the latter are connected in series with another resistor R_s represents the resistance of contact and connection [22-23] as shown in Fig. 2.

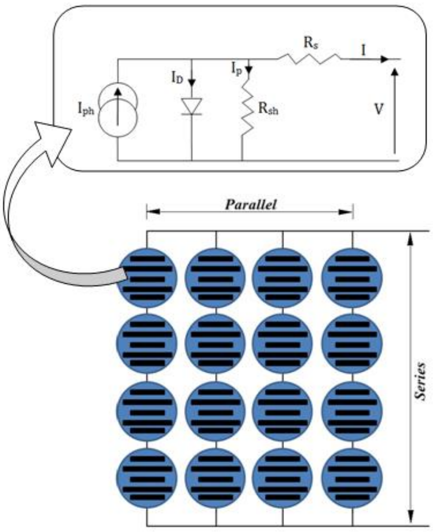


Fig. 2 – Equivalent circuit of a real photovoltaic cell and module

A photovoltaic cell alone cannot provide enough power to supply a load or the power grid. For this it is necessary to associate these cells between them to form a module in order to provide more power. It is then necessary to introduce two new parameters N_s and N_p, respectively representing the number of cells in series and in parallel [24-25]. The current expression of the photovoltaic cell becomes:

$$I = N_P I_{SC} - N_P I_0 \left(e^{\frac{V}{n N_S V_T} + \frac{R_S I}{N_P V_T}} - 1 \right) - \frac{V}{R_{sh}} - \frac{R_S}{R_{sh}} I \qquad (1)$$

With I_{SC} is Short-circuit current, R_{sh} is shunt resistance characterizing the recombination losses of carriers due to structural defects of the material and R_S is series resistance characterizing the Joule effects losses in the semiconductor and the losses through the collection grids and the ohmic bad contact of the cell.

In this work, we propose that the value of the resistance R_S is very small (≈ 0 Ω) and the value of the resistance R_{sh} is very large (→ ∞) [23], that is to say, we will consider our cell as an ideal solar cell to simplify the calculations, that is to say, we will consider our cell as an ideal photovoltaic cell to simplify calculations. In this case, the current I_d of our single-junction solar cell is given by the following expression (2):

$$I_d = N_P I_{SC} - N_P I_{0S} \left(e^{\frac{V}{n N_S V_T}} - 1 \right) \qquad (2)$$

n is the ideality factor of the *p-n* junction diode in the photovoltaic cell, and V_T the thermal voltage defined by:

$$V_T = \frac{kT}{q} \qquad (3)$$

$$I_{OS} = I_{or} \left(\frac{T}{T_r} \right)^3 \left(e^{\frac{q E_{G0}}{nk} \left(\frac{1}{T_r} - \frac{1}{T} \right)} \right) \qquad (4)$$

Where I_{OS} and I_{or} are the reverse saturation current and saturation current of the solar cell, respectively, T_r is the reference temperature (T_r = 298.18 °K) and E_{G0} is the gap of the semiconductor at 300°K.

$$I_{SC} = \left(I_{sct} + K_I (T - T_r) \right) \frac{S}{100} \qquad (5)$$

With K_I is the temperature coefficient of the short-circuit current.

In the case of a one solar cell ($N_P = 1$ and $N_S = 1$), the current expression for this model is written as:

$$I_d = I_{SC} - I_{0S} \left(e^{\frac{V}{n V_T}} - 1 \right) \qquad (6)$$

Substituting Eq. 3, 4 and 5 into Eq. 6, we get the following statement:

$$I_d = \left(I_{sct} + K_I (T - T_r) \right) \frac{S}{100} - \left[I_{or} \left(\frac{T}{T_r} \right)^3 \left(e^{\frac{q E_{G0}}{nk} \left(\frac{1}{T_r} - \frac{1}{T} \right)} \right) \right] \left(e^{\frac{V}{n V_T}} - 1 \right) \qquad (7)$$

4. RESULTS AND DISCUSSION

4.1 Validation of the Proposed Model

To investigate the evolution of the current and power of the GaAs/Ge single junction solar cell as a function of voltage, we have varied the voltage V from 0 to 1.1 V. The voltage values of V were chosen according to the factory data and in order to distinguish the different operating regions of this solar cell.

Figs. 3-a and 3-b respectively show the evolution of current and power as a function of the polarization voltage of the GaAs/Ge single junction solar cell at room temperature 300 °K and at irradiance intensity (AMO Sunlight) 135.3 mW/cm^2.

The experimental properties (static characteristics and electrical parameters) and those obtained by our model of the GaAs/Ge single junction solar cell are very identical as shown in Fig. 3 and Table 1; this shows that this solar cell studied is of high manufacturing quality. This allows the study of the electrical behavior of this cell using our model proposed in this work.

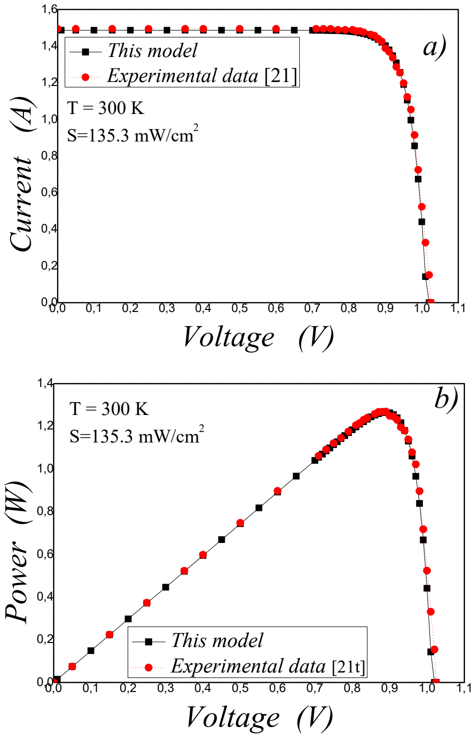


Fig. 3 – Characteristics of GaAs/Ge single junction solar cell, a) *I-V* and b) *P-V*

Table 1 – Electrical parameters of GaAs/Ge single junction solar cell at $T = 300$ °K and $S = 135$ mW/cm^2

Parameters	This model	Experimental data [21]
I_{sc} (A)	1.487	1.4945
V_{oc} (V)	1.02	1.025
I_{max} (A)	1.421	1.42514
V_{max} (V)	0.89	0.89
P_{max} (W)	1.26469	1.2683746
FF (%)	83.382122	82.799507
η (%)	18.9448	19

4.2 Solar Irradiation Effect

The effect of irradiation on the static characteristics of the GaAs/Ge single junction solar cell was studied based on the proposed model by varying the illumination between 20 mW/cm^2 and 140 mW/cm^2 at room temperature. From the simulation, we obtained the characteristics of the following Figs. 4-a and 4-b.

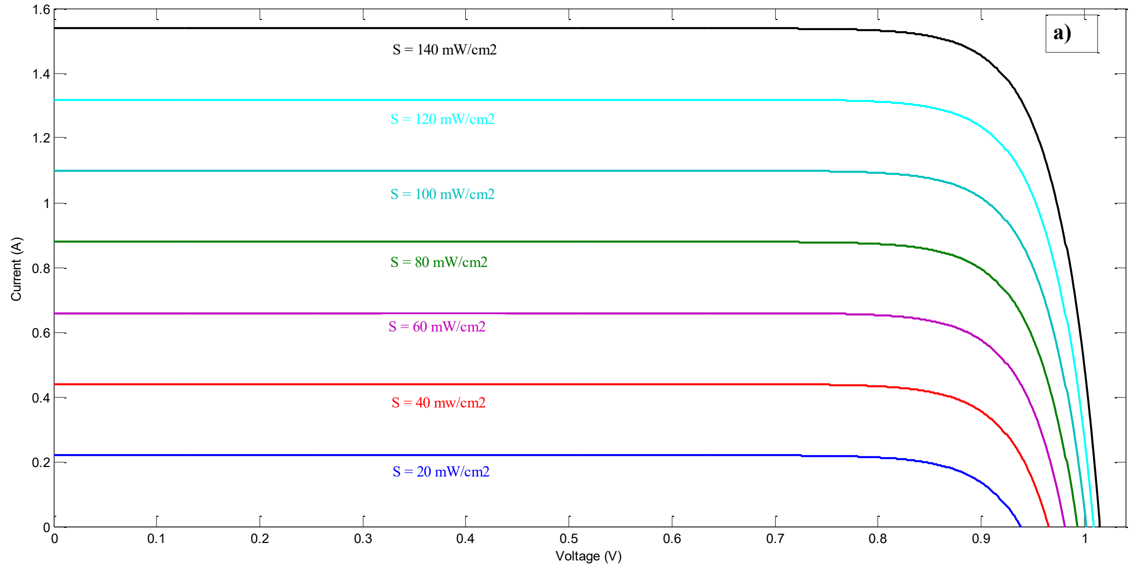
These Figs. (4.a and 4.b) were used to extract the variation of the electrical parameters of this cell as a function of the illumination. These parameters are shown in Table 2.

Table 2 – Electrical parameters as a function of the illumination of the GaAs/Ge single junction solar cell

Parameters S (mW/cm^2)	I_{SC} (A)	V_{OC} (V)	V_{max} (V)	P_{max} (W)	FF (%)
20	0.2198	0.938	0.818	0.1711	82.98
40	0.4396	0.965	0.844	0.3537	83.37
60	0.6593	0.981	0.857	0.5407	83.59
80	0.8791	0.993	0.87	0.7305	83.68
100	1.099	1.001	0.879	0.9224	83.84
120	1.319	1.009	0.889	1.116	83.85
140	1.538	1.021	0.895	1.311	83.48

The GaAs/Ge single junction solar cell generates a photocurrent (short-circuit current) in the presence of sunlight, which evolves linearly as a function of the illumination intensity directed at the surface of this solar cell. As for the V_{OC} voltage, it also increases with the sunlight intensity, but to a lesser degree [26]. This leads to an increase in the maximum power P_{max} available as shown in Table 2 and Figs. 4a and 4b.

According to Table 2, it is not possible to make an exact judgment on the evolution of form factor FF as a function of the variation in illumination for the GaAs/Ge single junction solar cell. But the optimal value of this factor (83.85 %) corresponds to the illumination value $S = 120$ mW/cm^2.



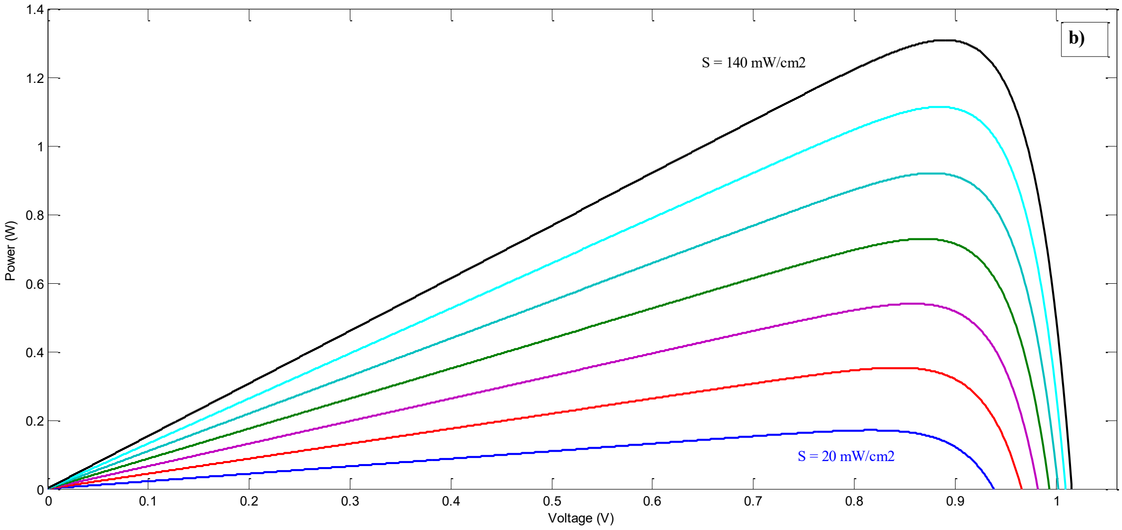


Fig. 4 – Irradiation effect on the static characteristics of the GaAs/Ge single junction solar cell, a) I-V, b) P-V

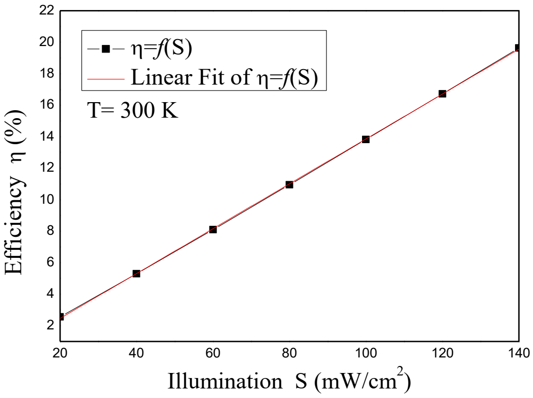


Fig. 5 – Efficiency vs illumination of the GaAs/Ge single junction solar cell

The solar irradiation effect on the efficiency of the GaAs/Ge single junction solar cell is represented in Fig. 5.

The obtained results show that the efficiency of the GaAs/Ge single junction solar cell increases linearly as a function of the solar irradiation, which enables us to predict the behavior of this cell.

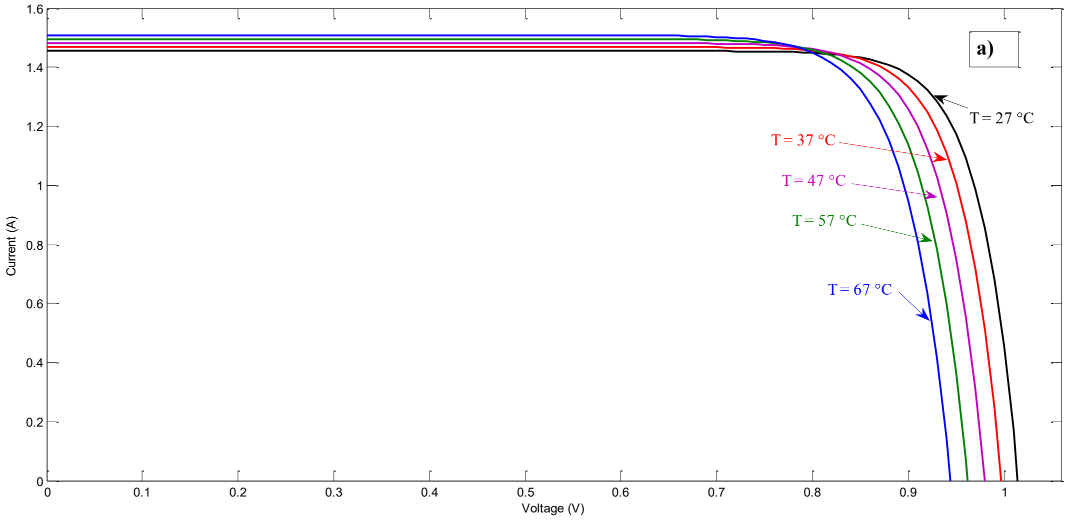
From this figure, we have shown that the efficiency of the GaAs/Ge single junction solar cell is directly proportional to the illumination. At room temperature, the efficiency curve η(S) in Fig. 5 can be fitted to the following equation:

$$\eta(S) = -0.38648 + 0.14247\ S \tag{8}$$

4.3 Temperature Effect

Temperature is one of the most important physical factors in the electrical behavior and performance of solar cells and other electronic and optoelectronic components. So, to study the influence of temperature on the different characteristics of the GaAs/Ge single junction solar cell at an illumination of S = 135.3 mW/cm^2, we varied the temperature from 27 °C to 67 °C. From the simulation, we obtained the characteristics of the following Figs. 6a and 6b.

The open circuit voltage V$_{OC}$ decreases significantly as a function of the temperature variation because the recombination is affected by the change in temperature, such that recombination is higher at elevated temperatures, which is expressed by an increase in diode saturation current. This current in turn is directly



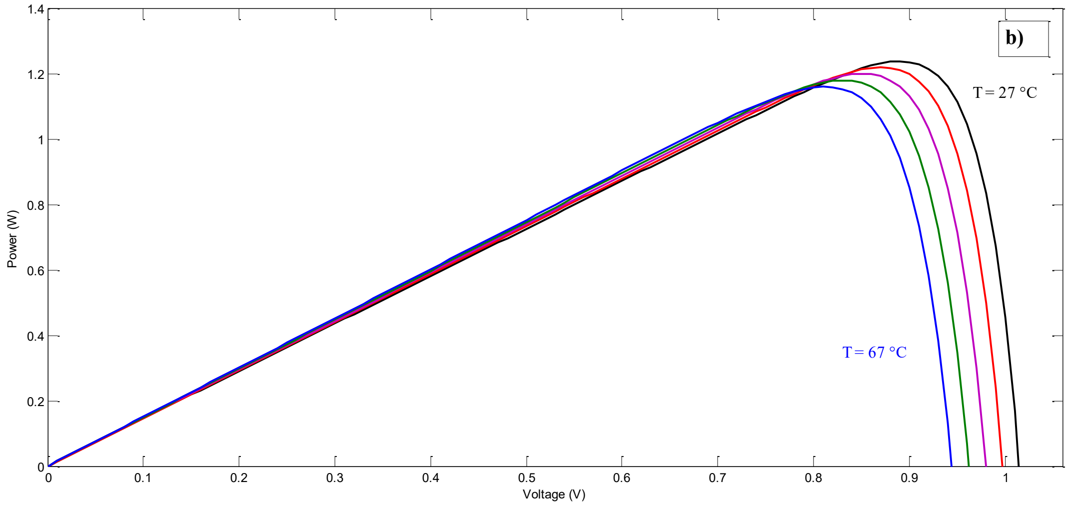


Fig. 6 – Temperature effect on the static characteristics of the GaAs/Ge single junction solar cell, a) *I-V*, b) *P-V*

influenced by the recombination, gap and temperature where it increases with decreasing gap and increasing temperature [26].

On the other hand, when the temperature increases, the photocurrent Isc increases slightly. This is due to the fact that the gap of semiconductor materials decreases at high temperature, allowing lower energy photons to be absorbed and thus more electron-hole pairs to be generated [26]. This leads to a decrease in the maximum power P_{max} available as a function of the temperature as shown in Table III. From this table, we have also shown that the form factor FF of the GaAs/Ge single junction solar cell is considerably reduced depending on the temperature variation.

Table 3 – Electrical parameters as a function of the temperature of the GaAs/Ge single junction solar cell

Parameters T (°C)	I_{SC} (A)	V_{OC} (V)	V_{max} (V)	P_{max} (W)	FF (%)
27	1.487	1.020	0.890	1.264	83.38
37	1.501	0.997	0.875	1.221	81.59
47	1.515	0.979	0.853	1.202	81.04
57	1.529	0.962	0.835	1.182	80.35
67	1.543	0.944	0.818	1.161	79.70

Fig. 7 shows the influence of temperature on the efficiency of the GaAs/Ge single junction solar cell. According to the results obtained, the efficiency of this solar cell decreases significantly in the temperature range below 37°C, in contrast to the range above 37 °C, the efficiency decreases slightly as shown in Fig. 7. In two temperature ranges, the efficiency curve $\eta(T)$ in this figure can be fitted to the following equations:

$$\eta(T) = 20.67362 - 0.06441\ T \quad for\ \ T < 37°C \tag{9}$$

$$\eta(T) = 19.40633 - 0.02996\ T \quad for\ \ T > 37°C \tag{10}$$

These results indicate that the temperature has an adverse effect on the electrical performance of the solar cell. That is to say, when cells operate at high temperatures, they lose their characteristics and aging rapidly [27]. Therefore, a heat removal system, ventilation or cooling is required. For this purpose and in recent years, several cooling methods have been used, with the aim of cooling solar cells and improving their electrical performance, such as passive cooling, active cooling, cooling based on phase change materials (PCMs), as well as hybrid cooling based on PCM with other additives such as nanoparticles, porous metal or hybrid nanoparticles coupled with flat heat pipes (HP-PCM) [28-30].

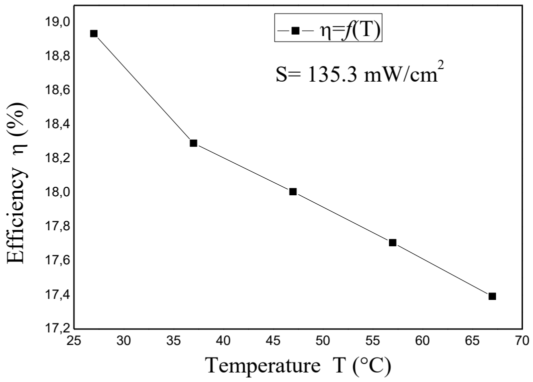


Fig. 7 – Efficiency vs temperature of the GaAs/Ge single junction solar cell

The results clearly show the dependence of the electrical behavior of the GaAs/Ge single junction solar cell on the variation in climatic parameters, because the electrical parameters of this cell depend on the variation in temperature and in illumination. In addition, these semiconductors materials (GaAs and Ge) are characterized by high thermal conductivity and high optical absorption.

According to the various results obtained, the model (single-diode model) proposed in this work can be applied to study and evaluate the characteristics of other single junction solar cells, especially those that are characterized by high manufacturing quality.

5. CONCLUSION

This research paper presents a mathematical model (single-diode model) that allows the study of the electrical performance of the GaAs/Ge single junction solar cell. This model uses the parameters provided by manufacturers and includes the effects of irradiation and temperature. The results obtained through the proposed model showed good agreement with that of the manufacturer's data sheet of this solar cell, and this further confirms the effectiveness of the proposed model. The simulation results show that an increase in light significantly increases energy generation while a change in temperature reduces the idealism and energy produced of this cell.

REFERENCES

1. B.O. Saracoglu, O.S. Ohunakin, D.S. Adelekan, J. Gill, O.E. Atiba, I.P. Okokpujie, et al., *Energy Rep.* **4**, 586 (2018) https://doi.org/10.1016/j.egyr.2018.09.002.
2. F. Zhou, F. Qin, Z. Yi, W. Yao, Z. Liu, X. Wud, et al., *Phys. Chem. Chem. Phys.* **23**, 17041 (2021) https://doi.org/10.1039/d1cp03036a.
3. F. Zhao, J. Lin, Z. Lei, Z. Yi, F. Qin, J. Zhang, et al., *Phys. Chem. Chem. Phys.* **24**, 4871 (2022) https://doi.org/10.1039/d1cp05119a.
4. C. Dondariya, D. Porwal, A. Awasthi, A.K. Shukla, K. Sudhakar, S.R. Murali Manohar, et al., *Energy Rep.* **4**, 546 (2018) https://doi.org/10.1016/j.egyr.2018.08.002.
5. E. Rahman, A. Nojeh, *Nat. Commun.* **12**, 1 (2021) https://doi.org/10.1038/s41467-021-24891-2.
6. M. Hebali, M. Barka, A. Baghdad Bey, M. Abboun Abid, M. Benzohra, D. Chalabi, et al, *ICTACT J. Microelectron.* **4**, 665 (2018) https://dx.doi.org/10.21917/ijme.2018.0115.
7. A.K. Shukla, K. Sudhakar, P. Baredar, *Energy Build* **128**, 99 (2016) https://doi.org/10.1016/j.enbuild.2016.06.077.
8. F. Zhao, X. Chen, Z. Yi, F. Qin, Y. Tang, W. Yao, et al., *Sol. Energy* **204**, 635 (2020) https://doi.org/10.1016/j.solener.2020.05.030.
9. A.J. Nozik, *Nano Lett.* **10**, 2735 (2010) https://doi.org/10.1021/nl102122x.
10. U. Dhankar, S. Dahiya, R. Chawla, P. Kumar, N. Gupta, *Silicon* **14**, 10755 (2022) https://doi.org/10.1007/s12633-022-01804-6.
11. M. Berka, M. Hebali, A. Baghdad Bey, Z. Mahdjoub, *Majlesi J. Mechatron. Syst.* **7**, 9 (2018).
12. M. Hebali, M. Bennaoum, H.A. Azzeddine, B. Ibari, A. Maachou, D. Chalabi, *J. Nano- Electron. Phys.* **15**, 01019 (2012) http://dx.doi.org/10.21272/jnep.15(1).01023.
13. A. Baghdad Bey, A. Talbi, M. Hebali, M. Berka, F. Ducroquet, *Int. J. Adv. Sci. Eng.* **5**, 1064 (2019) http://dx.doi.org/10.29294/IJASE.5.3.2019.1064-1071.
14. M. Hebali, M. Bennaoum, H.A. Azzeddine, B. Ibari, M. Benzohra, D. Chalabi, *J. Nano- Electron. Phys.* **12**, 06029 (2020) http://dx.doi.org/10.21272/jnep.12(6).06033.
15. L. Fara, D. Craciunescu, *Energy Procedia* **112**, 595 (2017) https://doi.org/10.1016/j.egypro.2017.03.1125.
16. Vinod, Raj Kumar, S.K. Singh, *Energy Rep.* **4**, 701 (2018) https://doi.org/10.1016/j.egyr.2018.09.008.
17. C. Qi, Z. Ming, *Phys. Procedia* **24**, 94 (2012) https://doi.org/10.1016/j.phpro.2012.02.015.
18. A. Dev, S. Berclin Jeyaprabha, *Proceedings of the International Conference on Applied Mathematics and Theoretical Computer Science*, 268 (2013).
19. Y.E. Yağan, K. Vardar, M.A. Ebeoğlu, *IOSR J. Electr. Electron. Eng.* **13**, 01 (2018) https://dx.doi.org/10.9790/1676-1302030111.
20. S. Chtita, Y. Chaibi, A. Derouich, *IEEE International Symposium on Advanced Electrical and Communication Technologies (ISAECT)*, 1 (2018) https://doi.org/10.1109/ISAECT.2018.8618840.
21. Datasheet: http://www.spectrolab.com/DataSheets/SJCell/sj.pdf.
22. J. Royer, T. Djiako, E. Schiller, B. Sada Sy, E. Schiller, Le pompage photovoltaïque, Édition Multi mondes. *IEPF, Université d'Ottawa, EIER, CREPA* (1999).
23. Y. Lin, X. Li, D. Xie, T. Feng, Y. Chen, R. Song, et al., *Energy Environ. Sci.* **6**, 108 (2013) https://doi.org/10.1039/C2EE23538B.
24. A. Al Tarabsheh, M. Akmal, M. Ghazal, *Electronics* **10**, 1 (2021) https://doi.org/10.3390/electronics10091046.
25. A. Hassani, M. Maamoun, R. Tadrist, A. Nesba, *Int. J. Power Electron. Drive Systems (IJPEDS)* **8**, 1335 (2017) http://doi.org/10.11591/ijpeds.v8.i3.pp1335-1344.
26. P. Vorasayan, *Spatially Resolved Measurement of Thin Film Silicon Solar Modules by Laser Beam Induced Current (LBIC) System* (Loughborough University: 2010).
27. M. Hebali, M. Bellil, B. Ibari, H.A. Azzeddine, M. Bennaoum, A. Maachou, et al., *The 1st International Conference on Electrical Engineering and Modern Technologies (CIETM'22), Souk Ahras, Algeria* (2022).
28. M. Sharaf, S.S. Yousef, A.S. Huzayyin, *Environ. Sci. Pollut. Res.* **29**, 26131 (2022) https://doi.org/10.1007/s11356-022-18719-9.
29. R. Gad, H. Mahmoud, S. Ookawara, H. Hassan, *J. Energy Storage* **57**, 106185 (2023) https://doi.org/10.1016/j.est.2022.106185.
30. Z. Xu, Q. Kong, H. Qu, C. Wang, *Case Stud. Therm. Eng.* **41**, 102667 (2023) https://doi.org/10.1016/j.csite.2022.102667.

Дослідження електричної поведінки одноперехідних сонячних елементів GaAs/Ge

M. Hebali[1,2], B. Kada[1,2], B. Ibari[1,2], M. Bennaoum[1,2], I.F. Bouguenna[1,2], A. Maachou[1,2], M. Altun[3]

[1] *Department of Electrotechnical, University Mustapha Stambouli of Mascara, 29000 Mascara, Algeria*
[2] *LSTE Laboratory, University Mustapha Stambouli of Mascara, 29000 Mascara, Algeria*
[3] *Department of Electronics and Communication Engineering, Istanbul Technical University, Istanbul, Turkey*

Для дослідження електричної поведінки одноперехідного сонячного елемента GaAs/Ge було використано математичну модель, засновану на еквівалентній схемі (однодіодній моделі). Для підтвердження придатності запропонованої моделі було використано номінальні значення, надані виробником, такі як фотострум (I_{SC}), напруга холостого ходу (V_{OC}), максимальна потужність (P_{max}), форм-фактор (FF) та коефіцієнт корисної дії (Ω). Порівняння номінальних статичних характеристик, вольт-амперної залежності (I-V) та потужності (P-V), з тими, що отримані за допомогою запропонованої моделі цього сонячного елемента, показало, що вони дуже ідентичні. На основі цієї запропонованої моделі було досліджено вплив опромінення та температури на ці статичні властивості та на різні електричні параметри цього сонячного елемента. Це дослідження продемонструвало придатність запропонованої моделі для дослідження того, як на електричну поведінку цього сонячного елемента впливають зміни освітленості та температури відповідно. Незважаючи на простоту запропонованої моделі, вона демонструє хорошу поведінку та високу продуктивність, що робить її найбільш придатною математичною моделлю для дослідження одноперехідних сонячних елементів на основі напівпровідникової технології GaAs/Ge. Для моделювання запропонованої моделі та аналізу продуктивності цього сонячного елемента було використано програмне забезпечення MATLAB.

Ключові слова: GaAs/Ge, Сонячний елемент, Один перехід, Моделювання, Статичні характеристики, Електричні параметри.