

Optimization of Solar Cell Efficiency Through Thickness and Temperature Control: Insights from PC1d Simulations

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Article Info	ABSTRACT
Article history: Received , 15/03/2025 Revised , 15/05/2025 Accepted , 06/06/2025	This study, conducted using PC1d simulation, explores how absorber layer thickness and operating temperature affect the performance of silicon-based solar cells. By varying the thickness of the n-region from 50 μm to 250 μm, the results showed that increasing thickness significantly enhances the efficiency, primarily due to improved photon absorption and increased generation of charge carriers. Subsequently, temperature was varied from 15 °C to 35 °C using the optimal 250 μm thickness. It was observed that lowering the temperature led to better electrical performance, with improvements in open-circuit voltage, fill factor (FF), and overall efficiency. In contrast, higher temperatures caused a degradation in performance despite a slight increase in short-circuit current. These findings confirm that solar cell efficiency improves when thickness is increased and temperature is reduced.
Keywords: PC1d Thickness temperature Silicon Solar cell	

I. Introduction

Interest in solar energy technology has grown recently as a result of the need for sustainable and clean energy sources throughout the world [1]. Because photovoltaic (PV) cells can directly convert sunlight into electricity, they have become a crucial solution among them [2]. The market has been dominated by silicon-based solar cells in particular because of their long-term stability, availability, and efficiency [3]. Understanding the impact of different physical and material characteristics is crucial to maximizing the performance of these cells [4]. The thickness and the temperature of the semiconductor layers, particularly the base and emitter regions, is one such crucial element [5]. Light absorption, carrier collecting efficiency, and eventually the solar cell's overall current-voltage (I-V) and power -voltage (P-V) properties are all impacted by layer thickness and temperature [6]. This study is to investigate the effects of layer thickness and temperature of the semiconductor layers on the electrical performance of silicon solar cells using the PC1d modeling tool. This study looks at how different thickness and temperature values impact the (I-V) and (P-V) characteristics and overall efficiency in an effort to provide guidance for the creation of more efficient and cost-effective solar cells.

II. Simulation Method

The principles of the unidimensionality of personnel computers (PC1d) Fig-1, which form the basis of simulation calculations, are presented in this section. PC1d is a simulation program that uses final elements as a framework for calculations to simulate semi-conducting devices. PC1d includes library files that provide the properties of crystal semi-conductor materials, such as silicon, that are used in solar cell technology. The four main components of this study are the apparatus, the area, the stimulation, and the findings [7].

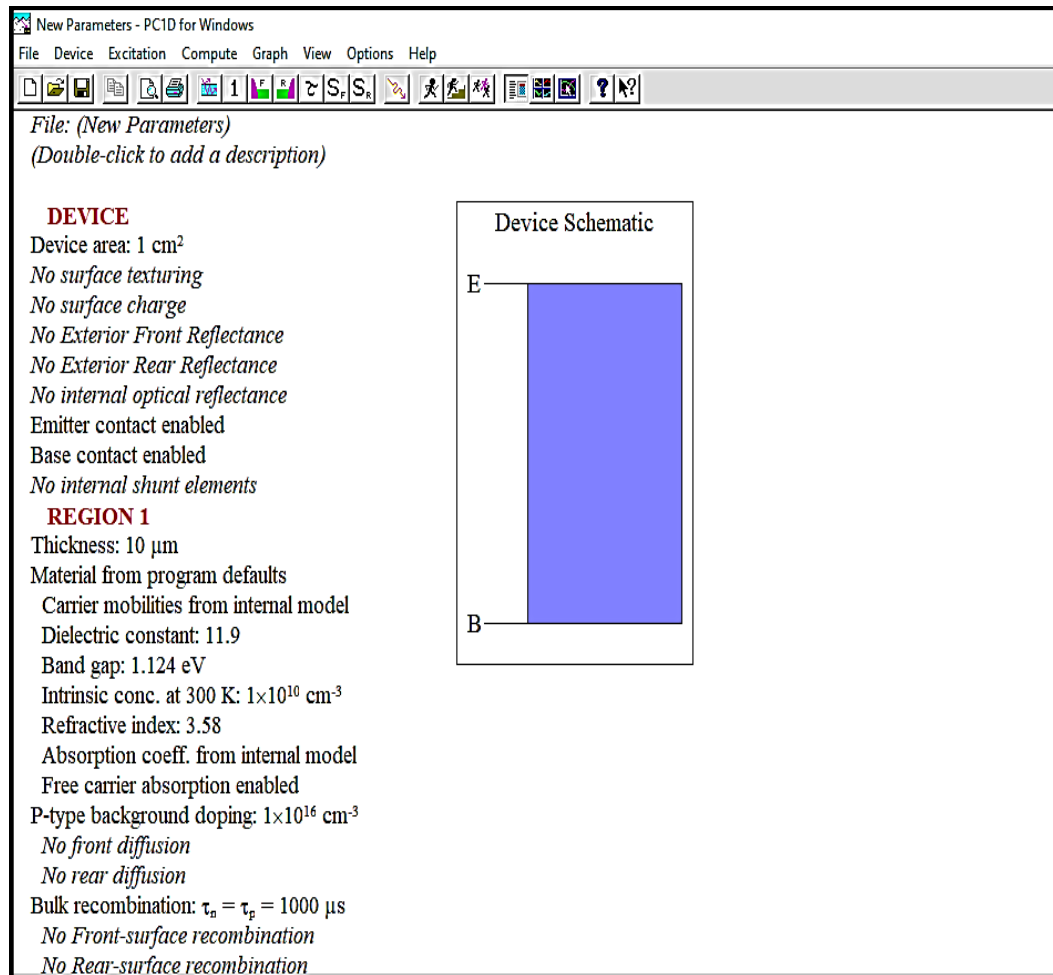


Figure.1: PC1d's main window.

We differentiate fundamentally parts [7]:

- The device section includes general information about the device we wish to emulate.
- The region section introduces key component device characteristics like as material type, thickness, and doping type. The graphic above shows a single area, however other areas can be added or removed. At least one region must be present.
- The excitement section is where we introduce our device's excitement characteristics, which will be used to imitate its behavior. For example, in the case of solar cells, it is in this section that we will solve the irradiation as well as the operating temperature and other factors.
- The portion results: it is in this part that we will have, in particular, following the start of the simulation, the values of I_{cc} , V_{oc} , and the power max for the simulation of solar cells.
- The device schematic is merely a strategy for the dispositive that we construct. It can change instantaneously as one affects the characteristics of regions .

Table 1. Parameters of the solar cell model.

Parameters	Values
Device Area	100 cm ²
Front surface texture depth	3 μ m
Exterior front reflectance	10 %
Base contact	0.015 Ω
Internal conductor	0.3 s
Thickness	50-250 μ m (testing conditions)
Dielectric constant	11.9
Band gap	1.124 eV
Intrinsic concentration	1.10 ¹⁰ cm ⁻³
P-type background doping	1.513.10 ¹⁶ cm ⁻³
First front diffusion (N-type)	2.87.10 ²⁰ cm ⁻³
Bulk recombination	7.205 μ s
Front surface recombination	1.10 ⁶ cm/s
Rear surface recombination	1.10 ⁵ cm/s
Temperature	15-35 °C (testing conditions)
Constant intensity	0.1 W cm ⁻²
Spectrum	1.5 g.spc

III. Results and discussion

A variety of parameters, including the fill factor (**FF**) and overall efficiency (**η**) , are calculated to evaluate the performance of a solar cell. The fill factor is a key metric that, along with the open-circuit voltage (Voc) and the short-circuit current (Isc), determines the maximum power output of the cell. **The fill factor** is defined as the ratio of the maximum power point (Pmax) to the product of Voc and Isc, and is expressed as [8].(1):

$$FF = \frac{P_{max}}{V_{oc} \cdot I_{sc}} \quad (1)$$

A higher fill factor indicates a more efficient solar cell, as it reflects lower internal resistive losses and better overall device performance.

Efficiency is another crucial parameter used to assess the performance of a solar cell. It is defined as the ratio of the electrical power output to the incident solar power input under standard test conditions. In other words, efficiency measures how effectively the solar cell converts sunlight into usable electrical energy. It is typically expressed as a percentage and can be calculated using the following formula [9].(2) :

$$\eta = \frac{V_{oc} \cdot I_{sc} \cdot FF}{P_{in}} \cdot 100 \quad (2)$$

The P_{in} is the incident solar power, usually standardized at 1000 W/m².

A higher efficiency indicates a better-performing solar cell, capable of converting more sunlight into electricity under the same conditions.

III. 1 - The thickness of the area influences the (I-V),(P-V) characteristic:

We used the same parameters as the basic cell and modified the thickness of region n, i.e. region 1. In this section, the solar cell's performance was evaluated by modifying the thickness layer in 50 μm to 250 μm . Table.2 presents the impact of varying thicknesses on the device's overall performance. As illustrated in Fig. 2, the layer thickness significantly influences key electrical parameters, including the open-circuit voltage (Voc), short-circuit current (Isc), Max Power (Pmax) and the overall efficiency.

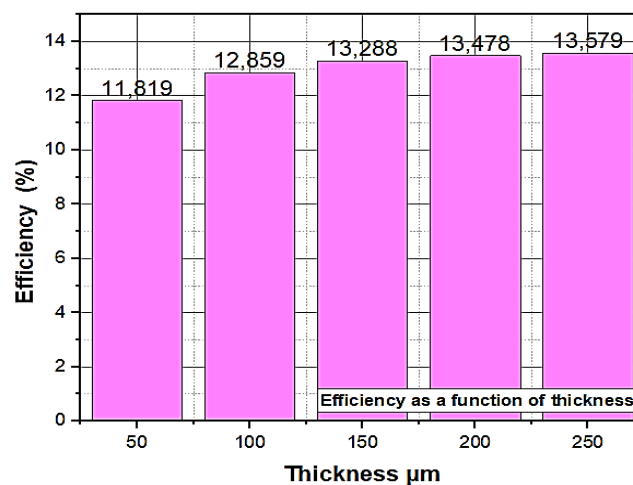


Figure.2: Efficiency as a function of thickness.

Table.2 : shows the general testing (thickness) conditions parameters.

Thickness μm	Short-circuit current (Isc), A	Maximum power (Pmax), W	Open-circuit voltage (Voc), V	Fill Factor (FF)	Efficiency (%)
50	-2.860	1.182	0.5727	72.16	11.819
100	-3.039	1.286	0.5842	72.43	12.859
150	-3.116	1.329	0.5887	72.44	13.288
200	-3.154	1.348	0.5906	72.36	13.478
250	-3.174	1.358	0.5916	72.32	13.579

To further understand the influence of the absorber layer thickness on solar cell performance, simulations were conducted using PC1d by varying the thickness from 50 μm to 250 μm . The results demonstrated a clear trend: as the thickness increased, the overall efficiency of the solar cell improved Fig.3. This enhancement can be attributed to the greater absorption of incident photons in thicker silicon layers, which leads to higher generation of charge carriers. Consequently, key performance parameters such as the short-circuit current (Isc) and conversion efficiency showed significant improvements. These findings highlight the importance of optimizing the absorber thickness to achieve better energy conversion in silicon-based solar cells [10].

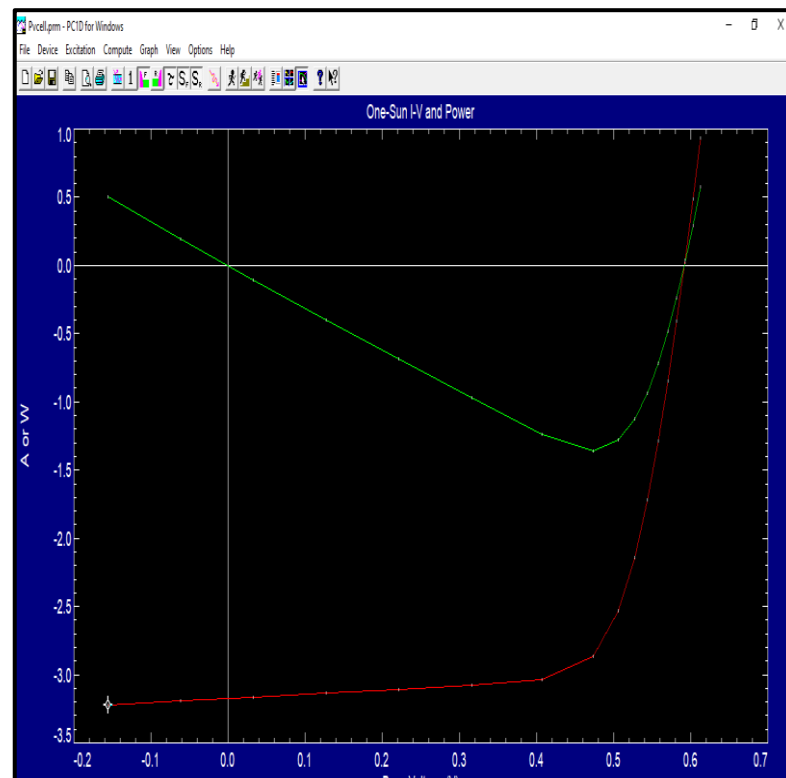


Figure.3: (I-V) and (P-V) characteristic for 250 μm thickness.

III. 2 - Temperature influence on (I-V),(P-V) characteristics:

As the previous findings indicated that 250 μm yields optimal performance, this thickness was selected for further analysis. The next phase involves varying the temperature parameters to examine their influence on cell solar performance.

In this part, different operating temperatures were applied to examine their impact on the (I-V) and (P-V) characteristics of the solar cell, as illustrated in Tab.3. The temperature range considered was from 15°C to 35°C.

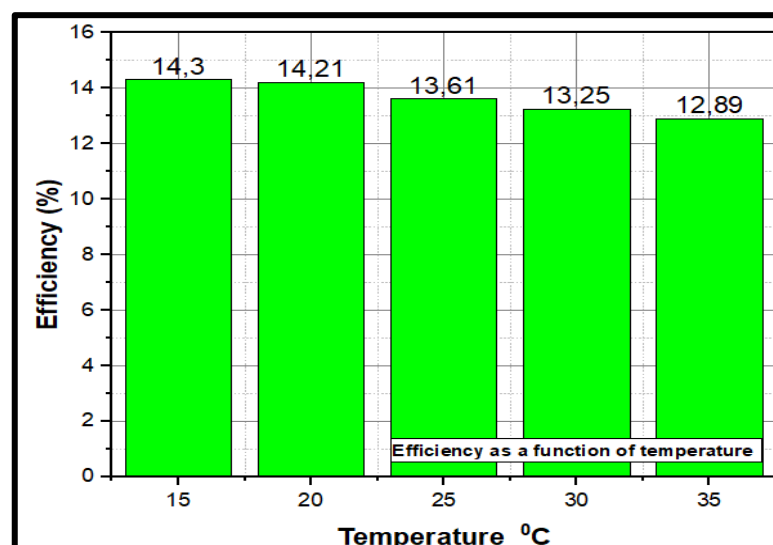


Figure.4: Efficiency as a function of thickness.

Table.3 : shows the general testing (temperatures) conditions parameters.

Temperature °C	Short-circuit current (Isc), A	Maximum power (Pmax), W	Open-circuit voltage (Voc), V	Fill Factor (FF)	Efficiency (%)
15	-3.178	1.430	0.6138	73.30	14.30
20	-3.179	1.396	0.6029	72.83	14.21
25	-3.180	1.361	0.5918	72.31	13.61
30	-3.181	1.325	0.5808	71.71	13.25
35	-3.181	1.289	0.5697	71.12	12.89

The simulation results clearly demonstrate that temperature has a significant impact on the electrical performance of the solar cell, particularly on both the short-circuit current and the open-circuit voltage. As the temperature increases, tends to rise slightly due to enhanced thermal energy that facilitates the generation of electron-hole pairs. However, this increase is often overshadowed by a more substantial decrease in I-V, which results from the heightened intrinsic carrier concentration and increased recombination rates at elevated temperatures. Consequently, these variations directly influence key performance indicators such as the fill factor (FF) and the overall conversion efficiency (η), as illustrated in Fig. 4. Specifically, the reduction in I-V leads to a decrease in both FF and η , despite the marginal gain in current. These temperature-induced changes reflect altered carrier dynamics within the device, including reduced carrier lifetime and mobility, which collectively degrade the photovoltaic performance [11].

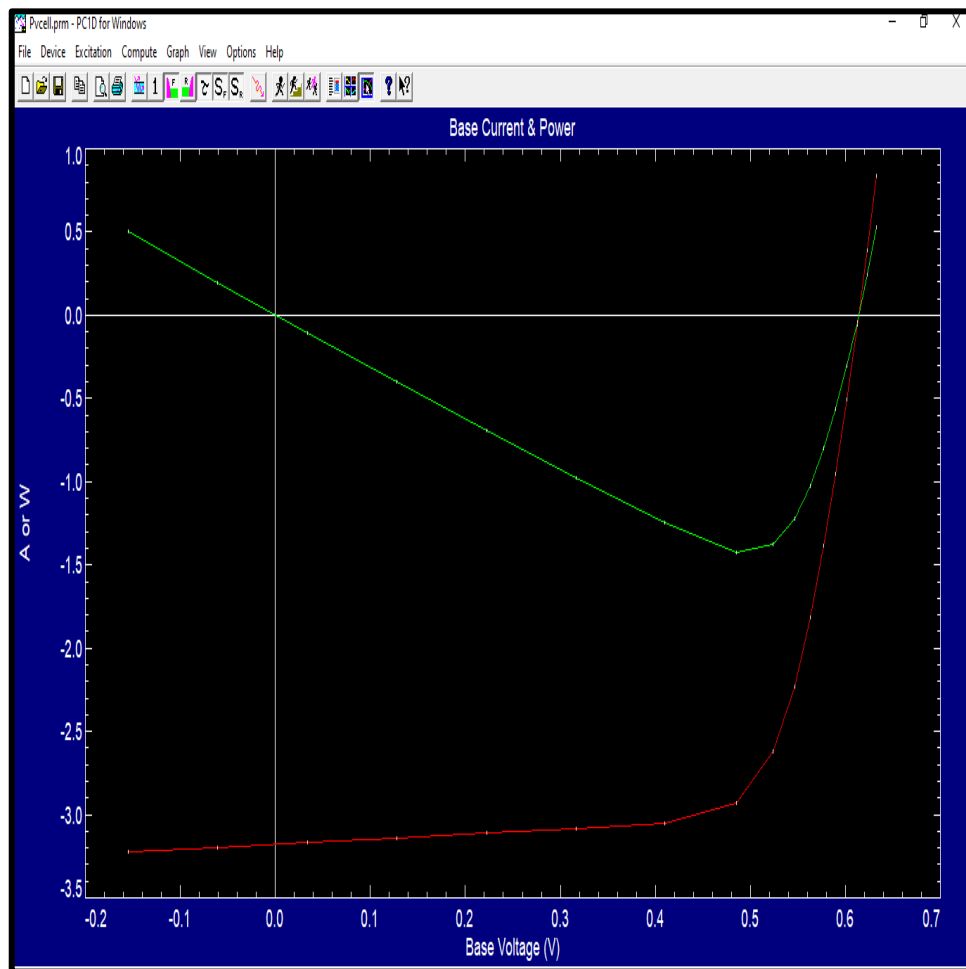


Figure.5: (I-V) and (P-V) characteristic for 15 °C temperature.

IV. Conclusion

The simulation results clearly indicate that both absorber thickness and operating temperature have a substantial impact on solar cell performance. Increasing the thickness of the absorber layer enhances light absorption and carrier generation, leading to improved efficiency. Meanwhile, reducing the operating temperature helps maintain higher efficiency and FF, resulting in superior device performance. Conversely, higher temperatures negatively affect these parameters due to increased carrier recombination and thermal losses. Therefore, optimal performance is achieved under conditions of greater thickness and lower temperature, highlighting the importance of carefully balancing structural and thermal factors in photovoltaic device design. In conclusion, this modest work has allowed us to identify the ideal characteristics needed to modify the basic cell in order to achieve optimal efficiency.

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