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# STRUCTURAL OPTIMIZATION OF HYDROGENATED AMORPHOUS SILICON LAYERS FOR ENHANCED SOLAR CELL EFFICIENCY

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## ABSTRACT

Energy conversion efficiency of *hydrogenated amorphous silicon* (a-Si: H) based solar cells remains a major challenge in the development of renewable energy technologies. One approach to improve this efficiency is through improving the solar cell layer structure. This research aims to maximize the layer structure of a-Si: H solar cells by using OghmaNano software simulation. This simulation allows in-depth analysis of the effect of bandgap variation as well as layer thickness on solar cell performance. The method used in this research is to perform numerical simulations using OghmaNano software. The a-Si: H solar cell model was built by varying relevant parameters such as substrate (*glass*), ITO, p i n layer, and metal contacts. Simulations were performed to obtain the I-V characteristics of the solar cell, which were then used to calculate the energy conversion efficiency. The simulation results were analyzed to identify the layer structure configuration that yielded the highest efficiency. The results hypothesize that determining the layer structure of a- Si: H solar cells can significantly improve the energy conversion efficiency. Variations in intrinsic layer thickness and bandgap have a significant effect on solar cell performance. With variations in layer thickness and bandgap, it is expected to maximize light absorption and increase energy conversion efficiency, which will significantly improve the overall performance of solar cells.

Keywords: a-Si: H; Bandgap; Efficiency; OghmaNano; Thickness

## INTRODUCTION

The global demand for clean and sustainable energy has significantly increased interest in photovoltaic technologies [1]. Among these, *hydrogenated amorphous silicon* (a-Si: H) has attracted attention as a promising material for thin-film solar cells due to its cost-effectiveness, flexibility, and compatibility with large-area deposition [2]. However, a major challenge that persists is the relatively low energy conversion efficiency of a-Si: H based solar cells when compared to their crystalline counterparts [3]. This limitation motivates ongoing research to explore structural and material optimizations that can boost performance without sacrificing the inherent advantages of a-Si: H technology [4].

Despite its commercial potential, a-Si: H solar cells face performance bottlenecks due to suboptimal layer design and light-induced degradation [5]. The key object of this research is the layer structure within the a-Si: H solar cell, including components such as the *transparent conducting oxide* (TCO), p-type, *intrinsic* (i-layer), n-type semiconductor layers, and metallic contacts [6]. Improper thickness ratios and unfavorable electronic band alignments in these layers often lead to poor light absorption and charge carrier recombination, which hinder the overall efficiency [7]. The study focuses on addressing these specific structural limitations that are commonly found in existing solar cell configurations.

Several previous studies have suggested that optimization of the layer thickness and bandgap tuning particularly in the intrinsic layer can significantly enhance device performance [8]. By modifying these parameters, it is possible to increase light trapping, improve charge collection, and reduce defect-related losses [9]. In addition, recent advancements in device simulation have provided new opportunities to investigate these modifications without the cost and complexity of physical prototyping [10]. Simulation-based modeling thus becomes a valuable tool in exploring how changes in structural parameters directly impact solar cell performance, especially in terms of power conversion efficiency [11].

In this research, a numerical simulation approach using the OghmaNano software was employed to model and optimize the structural configuration of a-Si: H solar cells. The simulation involved systematic variation of key parameters such as intrinsic layer thickness and bandgap energy while maintaining realistic representations of the other cell layers (glass substrate, ITO, p/n layers, and metal contacts). The method was chosen due to its ability to provide rapid, accurate analysis of electrical and optical behaviors, including I-V characteristics. The goal is to identify an optimal layer configuration that yields the highest possible energy conversion efficiency, thus offering a theoretical foundation for more efficient solar cell designs in future experimental work.

## METHOD

This study involved several key stages, beginning with a literature review to understand solar cell theory, types, efficiency factors, and prior research as seen in Figure 1. Next, simulation modeling was conducted using OghmaNano software by configuring layer parameters, including variations in thickness and bandgap energy for each layer (*p-layer*, *i-layer*, n-*layer*, *anti-reflection layer*). These parameters influence light absorption, open-circuit voltage (Voc), and overall efficiency. Simulations were performed iteratively to determine the optimal combination for maximum efficiency [12]. The output included *current-voltage* (I-V) curves, from which key performance indicators were derived: $V_{oc}$ (*maximum voltage with no load*), $I_{sc}$ (*maximum current with zero voltage*), *fill factor* (FF), and *efficiency* (η), which is the ratio of electrical power output to light input. These results were then analyzed to assess how parameter variations affect solar cell performance. Finally, findings were compiled into a report, drawing conclusions and offering recommendations for future research. This study uses a quantitative simulation approach to investigate and improve the efficiency of a-Si: H solar cells. By utilizing OghmaNano software, a virtual model of an a-Si: H solar cell will be built, allowing for the tuning of various parameters such as layer thickness and bandgap. Numerical simulations will be run to predict the performance of the solar cell based on these parameters, generating quantitative data such as current, voltage, and efficiency [13]. Through systematic variation of input parameters and analysis of the resulting data, this study aims to identify the best combination that maximizes the efficiency of a-Si: H solar cells.

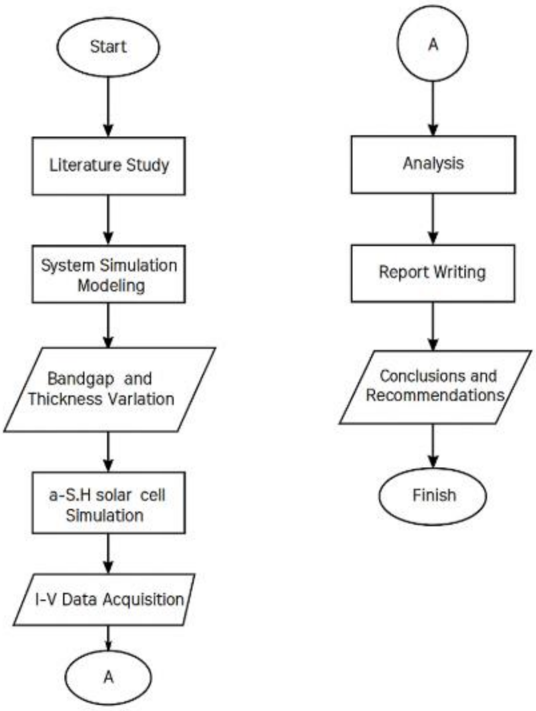


**Figure 1.** Research Flow Chart

The simulation parameters of the a-Si:H solar cell, as illustrated in Figure 2, were modeled using OghmaNano software. The simulated solar cell structure consisted of ITO (80 nm)/p layer (10 nm)/i layer (200 nm)/n layer (30 nm)/Ag (80 nm). The simulation focused on varying the bandgap and thickness of the n layer (Layer 2), intrinsic i layer (Layer 3), and p layer (Layer 4). For configurations without enhancement, the bandgap was kept constant at 1.7 eV and the thicknesses at 10 nm (n layer), 300 nm (i layer), and 30 nm (p layer). Bandgap determination, ranging from 1.6 eV to 1.95 eV, was conducted to identify optimal values for the p, i, and n layers to improve solar cell performance. This process helps maximize the energy conversion efficiency of a-Si:H-based solar cells by selecting suitable semiconductor energy levels. Additionally, the simulation varied the thickness of the i layer from 100 nm to 600 nm in steps of 100 nm, while the p and n layers remained fixed at 10 nm and 30 nm, respectively. These variations were aimed at evaluating the impact of structural parameters on device efficiency, guiding the identification of optimal configurations for improved performance.

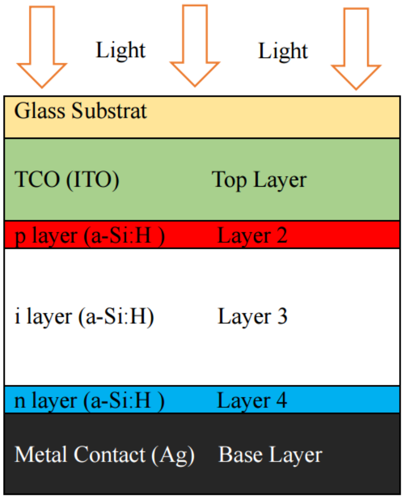
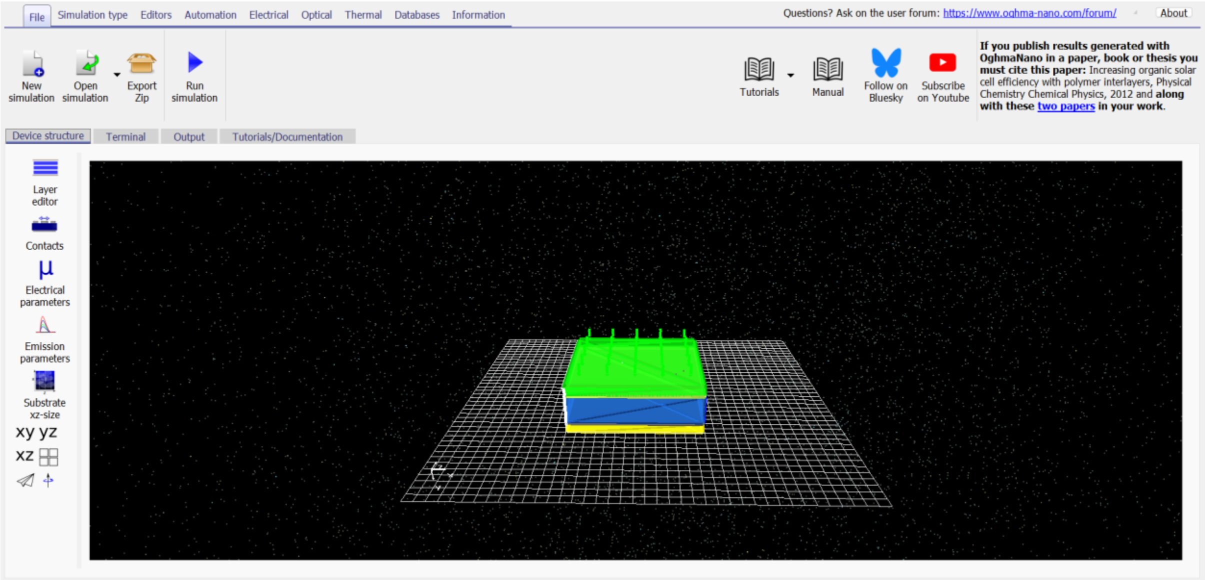


**Figure 2.** Schematic of a-Si: H Based P-I-N Structure Solar Cell

## RESULTS AND DISCUSSION

### Hydrogenated Amorphous Silicon Solar Cell Layer Stack Design

The Layer Arrangement Design of Hydrogenated Amorphous Silicon Solar Cells is an important aspect in increasing energy conversion efficiency. Hydrogenated amorphous silicon (a-Si:H) based solar cells are designed with a layered structure consisting of several main components, namely the Front Layer which functions as an antireflection and transparent conductor. Usually using materials such as indium tin oxide (ITO) or fluorine-doped tin oxide (FTO) as seen in Figure 3. This layer maximizes light absorption by reducing reflection on the surface of the solar cell. Then the Active Layer consisting of hydrogenated amorphous silicon which functions as a light absorbing material. This layer is often divided into sublayers, namely the P (P-Type) layer which uses hydrogenated amorphous silicon with boron doping to create a positive charge. The Intrinsic Layer which is the main layer for light absorption and electron-hole pair generation. This layer must be thick enough to absorb light optimally, but still thin to avoid charge recombination. And the N layer (N-Type) which uses hydrogenated amorphous silicon with phosphorus doping to create a negative charge. Next is the back layer (back bayer) which functions as a light reflector to increase absorption in the active layer and as a rear electrode. Usually using metal materials such as aluminum or silver. And the last layer is the substrate layer which is a mechanical support that can be glass, flexible plastic, or metal, depending on the desired application where this layer is on the outermost layer of the hydrogenated amorphous silicon solar cell [14]. Determining the design of this layer arrangement aims to maximize light absorption, minimize charge recombination, and increase the efficiency of electron-hole transport. Adjusting the thickness of each layer, and the reflector material are key in the process of increasing efficiency.



Questions? Ask on the user forum: https://www.oghma-nano.com/forum/

**If you publish results generated with OghmaNano in a paper, book or thesis you must cite this paper:** Increasing organic solar cell efficiency with polymer interlayers, Physical Chemistry Chemical Physics, 2012 and **along with these two papers in your work.**

**Figure 3.** Hydrogenated Amorphous Silicon Solar Cell Layer View Using OghmaNano Simulation

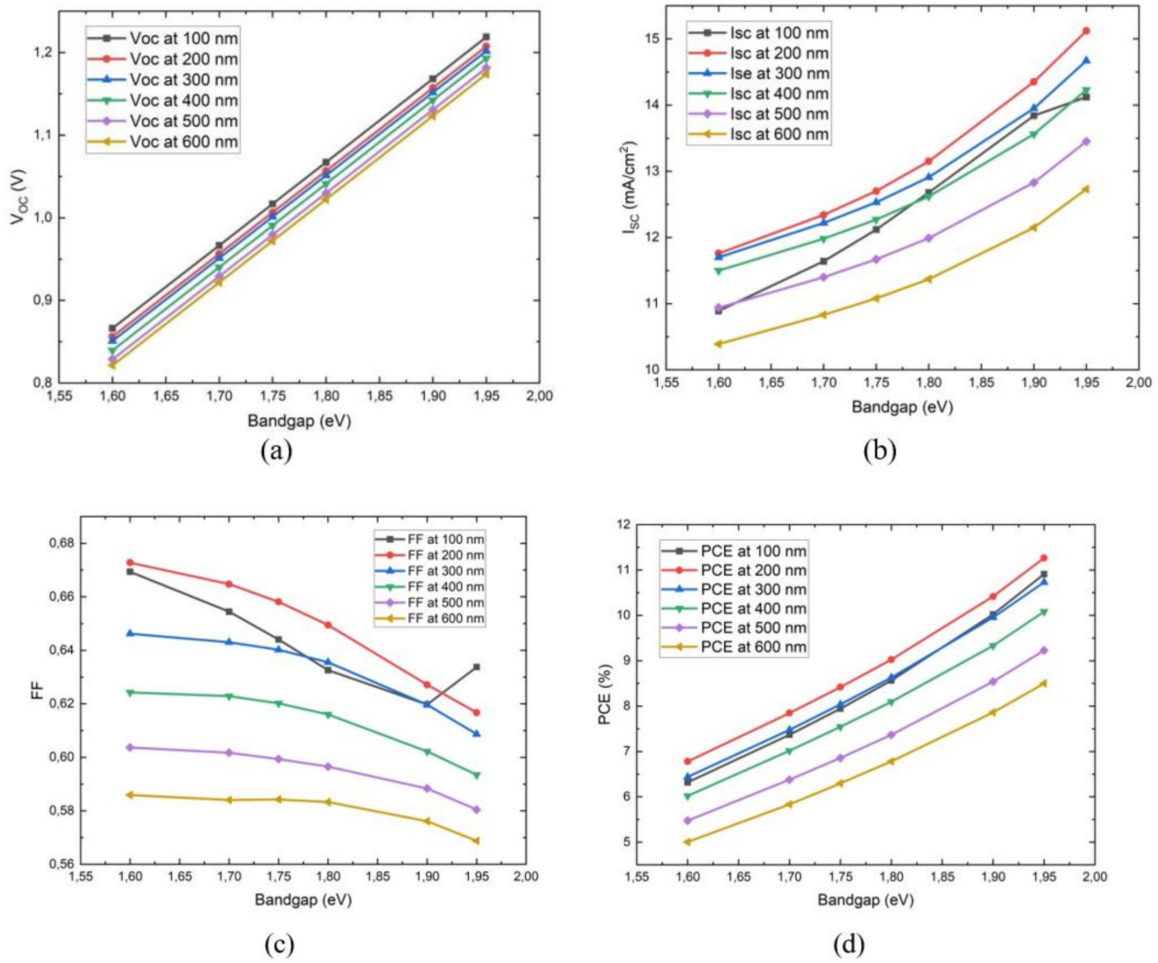
The simulation parameters play a crucial role in determining the electrical and optical behavior of a-Si: H solar cells as shown in Table 1. Key among these is the intrinsic (i) layer thickness, varied between 100–600 nm, while the p and n layers are fixed at 10 nm and 30 nm respectively. The i-layer serves as the primary light-absorbing region and the site of electron-hole separation. Too thin an i-layer reduces photon absorption and short-circuit current (Isc), while too thick increases recombination, $V_{oc}$ and efficiency. The bandgap, varied from 1.6 to 1.95 eV, affects light absorption and energy conversion. A smaller bandgap improves $I_{sc}$ but lowers $V_{oc}$, while a larger bandgap raises $V_{oc}$ but reduces Isc. The dielectric constant, though material-dependent, influences the electric field strength that aids charge separation. Low carrier mobility (electrons: 5 cm²/V·s, holes: 1 cm²/V·s) in a-Si: H increases recombination risks, reducing the FF. The Effective Density of States impacts transition probabilities, and improper balance may raise recombination. Doping levels are set at $1\times10^{18}$ $cm^{-3}$ (p-layer) and $1\times10^{20}$ $cm^{-3}$ (n-layer) to ensure a strong internal field. Lastly, electron affinity at 3.9 eV influences band alignment and charge separation efficiency.

**Table 1.** Layer Settings and a-Si: H Simulation Ogmanano Parameters

| **Parameter** | **(p) a-Si:H** | **(i) a-Si:H** | **(n) a-Si:H** |
|---|---|---|---|
| Layer (nm) | 10 | 400 | 30 |
| Dielectric constant | 11.9 | 11.9 | 11.9 |
| Bandgap (eV) | 2.1 | 1.6 – 1.95 | 1.95 |
| Electron mobility ($cm^2V^{-1}s^{-1}$) | 5 | 5 | 5 |
| Hole mobility ($cm^2V^{-1}s^{-1}$) | 1 | 1 | 1 |
| Effective conduction band density ($cm^{-3}$) | $1\times10^{20}$ | $1\times10^{20}$ | $1\times10^{20}$ |
| Effective valence band density ($cm^{-3}$) | $1\times10^{20}$ | $1\times10^{20}$ | $1\times10^{20}$ |
| Doping concentration of acceptors ($cm^{-3}$) | $1\times10^{18}$ | 0 | 0 |
| Doping concentration of donators ($cm^{-3}$) | 0 | 0 | $1\times10^{20}$ |
| Electron Afinity | 3.9 | 3.9 | 3.9 |

### The Effect of Bandgap on the I - V Curve Output

The variation of intrinsic layer (i-layer) bandgap greatly affects the performance parameters of hydrogenated amorphous silicon (a-Si:H)-based solar cells, including open circuit voltage (Voc), short circuit current (Isc), fill factor (FF), and power conversion efficiency (PCE). In the simulations conducted, the bandgaps in the p and n layers were fixed at 2.1 eV for the p layer and 1.95 eV for the n layer, respectively, while the bandgap in the intrinsic layer was varied. Based on the simulation data of a-Si:H solar cells shown in Figure 4, obtained using OghmaNano software, the bandgap variations used in the simulation were 1.6 eV, 1.7 eV, 1.75 eV, 1.8 eV, 1.9 eV, and 1.95 eV. The simulation results show that increasing the bandgap value affects the power conversion efficiency (PCE), open circuit voltage (Voc), short circuit current (Isc), and fill factor (FF). In general, the larger the bandgap value, the higher the Voc because the energy required for electron excitation is higher. In addition, increasing the bandgap also causes an increase in Isc because increasing the bandgap reduces recombination and increases the number of charge carriers generated and collected by the electrode [15]. However, at too high a bandgap value, light absorption decreases, which ultimately limits the increase in Isc and decreases the power conversion efficiency (PCE).



(a) (b)

(c) (d)

**Figure 4.** Bandgap Variation Graph (a) Voc, (b) Isc, (c) FF, and (d) PCE Against I-V Curve Characteristics

Figure 4 shows that a larger bandgap means that the photons that can be absorbed must have higher energy. As a result, only photons with energy greater than the bandgap can create electron-hole pairs. This reduces the possibility of charge carrier recombination, since only a few electrons have enough energy to recombine with holes before reaching the electrodes. With a larger bandgap, the solar cell has a higher energy difference between the valence band and the conduction band. This results in a stronger internal electric field in the intrinsic layer (i-layer), which helps to drive electrons and holes towards their respective electrodes more efficiently, thereby increasing Voc.

In addition, there is an Isc graph that increases with increasing bandgap. This shows that in the simulation, the larger the bandgap of the material, the more charge carriers are produced and successfully collected. One possible reason is that a larger bandgap can reduce charge carrier recombination because higher energy can help maintain electron-hole separation longer before recombination occurs. In addition, changes in the optical properties of the material with increasing bandgap can affect the number of photons absorbed and the conversion of light energy into electric current more efficiently [16]. However, increasing the bandgap above a certain value usually causes a decrease in Isc because materials with larger bandgaps can only absorb photons with higher energy, so the spectrum of light that can be converted into electric current becomes narrower.

The larger the bandgap, the lower the mobility of charge carriers. Lower mobility causes an increase in series resistance, which worsens the current distribution in the cell and reduces the fill factor and also with increasing bandgap, the resistance effect becomes more dominant, causing the curve to be more curved and reducing the fill factor value. When photons hit the solar cell material, only photons with energy greater than or equal to the bandgap can create electron-hole pairs. When photons hit the solar cell material, only photons with energy greater than or equal to the bandgap can create electron-hole pairs [17]. With a larger bandgap, the energy required for the transition of electrons from the valence band to the conduction band is also higher, which directly increases the Voc. Then isc continues to increase, probably due to increased charge transport and decreased recombination. A larger bandgap reduces thermal recombination, because electrons have more energy to move to the electrode before recombining back to the valence band. Therefore, increasing Voc and Isc significantly increases the output power, although the FF decreases slightly which causes the PCE to increase with increasing bandgap.

## The Effect of Intrinsic Layer Thickness Variation on I - V Curve Output

The variation of the intrinsic layer thickness can affect the short-circuit current (Isc), open-circuit voltage (Voc), and fill factor (FF), which ultimately impacts the energy conversion efficiency of the solar cell. The simulation of a-S:H solar cells will be run with variations in the thickness of the a-Si:H solar cells. Furthermore, the simulation with variations in the thickness of the hydrogenated amorphous silicon solar cell layers used is a fixed p layer thickness of 10 nm, a fixed n of 30 nm, and variations in the i layer thickness of 100 - 600 nm with a bandgap of 1.6 eV - 1.95 eV. Based on the simulation data of the a-Si:H solar cells shown in Figure 5, which was obtained using the OghmaNano software, the variation in the thickness of the intrinsic layer (i-layer) used in the simulation ranges from 100 nm to 600 nm. The thickness of the intrinsic layer plays an important role in the performance of solar cells because this layer is responsible for the process of light absorption and charge carrier transport.

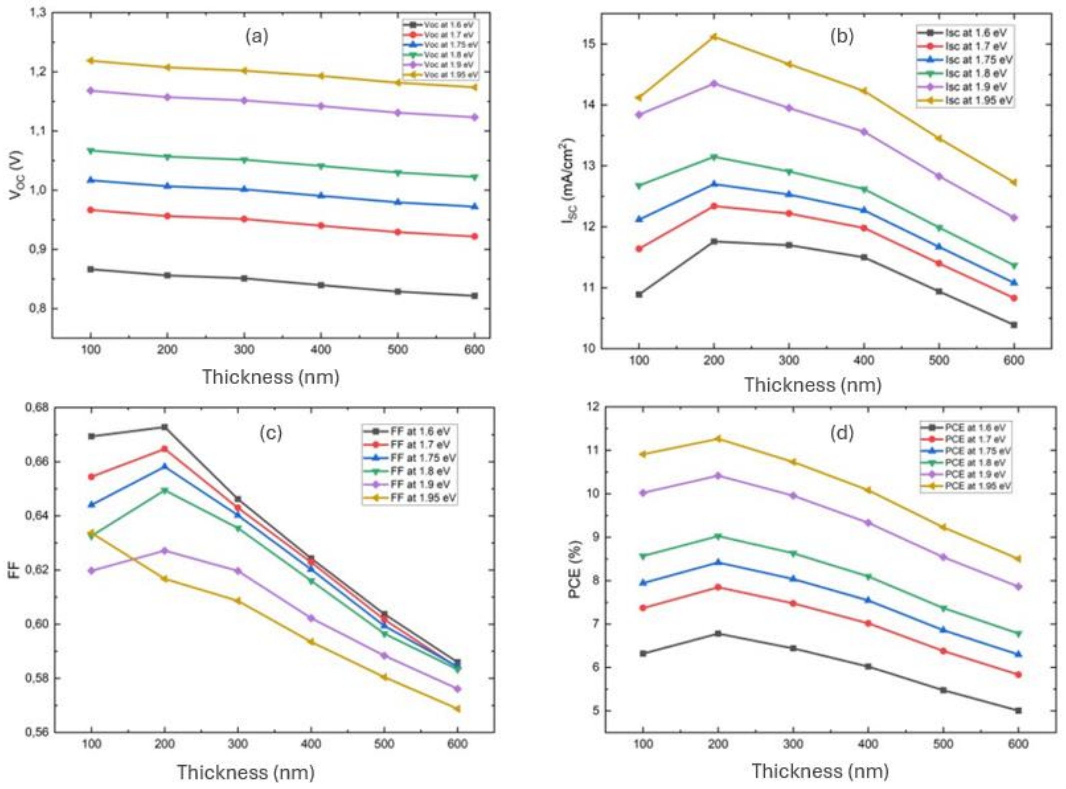


**Figure 5.** Relationship between Layer Thickness Variation with (a) Voc, (b) Isc, (c) FF, and (d) PCE

Figure 5 shows that the layer thickness greatly affects the output results obtained. At smaller thicknesses (around 100 nm), the power conversion efficiency (PCE) tends to be low because the number of photons absorbed is smaller, resulting in a smaller short-circuit current (Isc). However, the open-circuit voltage (Voc) is relatively higher at small thicknesses due to reduced charge carrier recombination. From the simulation results of the open-circuit voltage (Voc) on a-Si:H-based solar cells with bandgap variations of 1.6 eV to 1.95 eV and intrinsic layer thickness (i-layer) from 100 nm to 600 nm. Based on the graph, it can be seen that the greater the thickness of the intrinsic layer, Figure 5 (a) shows Voc value decreases slightly for each bandgap variation. This occurs because charge carrier recombination increases in thicker layers. As the thickness of the intrinsic layer increases, electrons and holes must travel a greater distance before reaching the electrode. As a result, the chance of recombination increases, which causes a decrease in the number of charge carriers that can contribute to the solar cell voltage [18]. Higher recombination reduces the concentration of free charge carriers in the intrinsic layer, thus decreasing Voc. There are 6 bandgap values used also in the simulation of layer thickness variation, the higher the material bandgap (from 1.6 eV to 1.95 eV), the Voc value also increases.

Figure 5 (b) shows that Isc increases as the layer thickness increases, Isc will also increase until it reaches a maximum point at a thickness of 200 nm and then decreases. This occurs because of the balance between light absorption and charge carrier recombination. As the intrinsic layer thickness increases, more photons can be absorbed, producing more electron-hole pairs. Therefore, Isc increases until it reaches an optimal thickness of 200 nm, where light absorption is most effective. After passing the optimal thickness, charge carriers (electrons and holes) must travel further to reach the electrode [19]. This increases the possibility of recombination before reaching the contact, which causes a decrease in Isc at thicknesses above 200 nm. The maximum Isc value is also at a bandgap of 1.95 eV because the larger the bandgap (from 1.6 eV to 1.95 eV), Isc tends to increase because materials with higher bandgaps can produce more electron-hole pairs. However, if the bandgap is too large, the absorption of the visible light spectrum decreases, which causes Isc to decrease after the optimal point.

Figure 5 (c) shows that FF increases at small thicknesses from 100 nm to 200 nm, then decreases significantly as the layer thickness increases above 200 nm. This is because at smaller thicknesses, the series resistance is lower, so the FF is higher. However, as the thickness increases, the series resistance increases due to the longer charge transport path, causing the FF to decrease. In addition, the parallel resistance decreases due to increased recombination in the material, which also has an impact on decreasing FF. Another factor that causes FF to decrease is charge carrier recombination, which when the thickness increases, the travel time of charge carriers from the generation zone to the electrode becomes longer. This increases the possibility of recombination before the charge carrier reaches the electrode, which reduces the maximum voltage and current, so that FF decreases [20]. Then for the bandgap level in this FF, FF tends to be higher at lower bandgaps (1.6 eV) and decreases at higher bandgaps (1.95 eV). This is due to the relationship between bandgap and Voc. A higher bandgap increases Voc, but also increases the material resistance, which contributes to a decrease in FF.

Figure 5 (d) shows the PCE, the higher the intrinsic layer thickness, the higher the charge carrier recombination will be. In a-Si:H solar cells, the intrinsic layer functions to absorb light and produce charge carriers, but if it is too thick, many charges are lost due to recombination before they can be used to generate electricity. As a result, the efficiency of the solar cell decreases even though more light is absorbed [21]. Based on the graph above, the maximum Voc value obtained is at 100 nm with a bandgap of 1.95 eV, which is 1.22 V, the maximum Isc value obtained is at a layer thickness of 200 nm with a bandgap of 1.95 eV, which is 15.12 mA/cm2.

The highest FF value is at a layer thickness of 100 nm with a bandgap of 1.6 eV, which is 67% and the highest PCE value is at a layer thickness of 200 nm with a bandgap of 1.95 eV, which is 11.27%.

## Bandgap and Intrinsic Layer Thickness on Optimum Efficiency

Based on the simulation results visualized in the 3D graph in Figure 6, it can be seen that the efficiency of a-Si solar cells is influenced by two main parameters, namely the bandgap and the thickness of the active layer. The graph shows that the efficiency increases with increasing bandgap until it reaches a maximum value at a bandgap of 1.95 eV and a thickness of 200 nm, with an energy conversion efficiency of 11.27%. However, after this point, the efficiency begins to decrease, indicating an optimal limit in the design of a-Si:H-based solar cells.

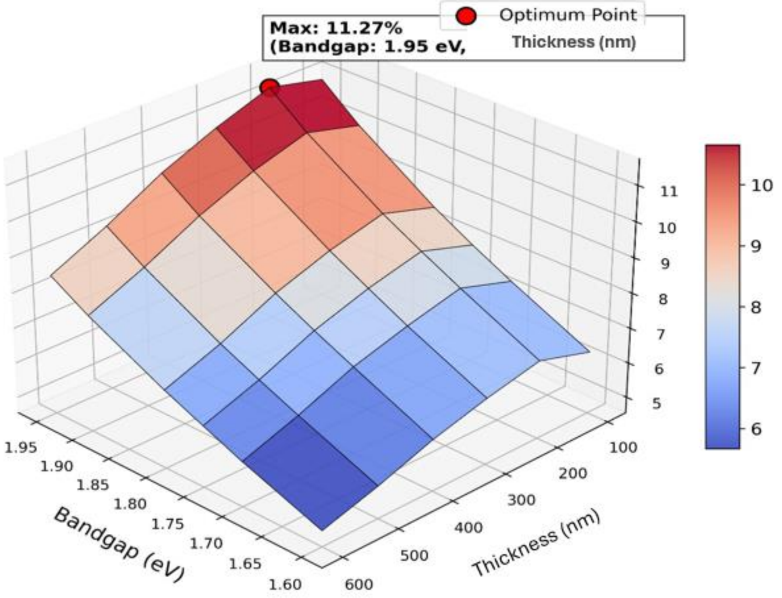


**Figure 6.** Bandgap Optimization and Layer Thickness on Efficiency

The relationship between bandgap and efficiency shows that the larger the bandgap value, the higher the produced by the solar cell. This is because a larger bandgap requires higher photon energy to excite electrons from the valence band to the conduction band, thereby increasing the potential output voltage. However, increasing the bandgap also has an effect on the Isc value, the Isc value will increase as the bandgap increases but will decrease at a certain bandgap value that is large enough, namely a decrease in the short-circuit current (Isc) due to the reduced number of photons that can be absorbed. If the bandgap is too large, then many photons from the sunlight spectrum that have lower energy than the bandgap will not contribute to the generation of electron-hole pairs, so that the total current produced by the solar cell will decrease [22]. Therefore, there is an optimal bandgap value around 1.95 eV, where there is a balance between increasing Voc and decreasing Isc, which results in the highest energy conversion efficiency.

In addition to the bandgap, the thickness of the active layer also plays a very significant role in determining the efficiency of a-Si solar cells. From the simulation results, it can be seen that the highest efficiency is achieved at a thickness of about 200 nm, while at thicknesses greater or smaller than this value, the efficiency tends to decrease. When the layer thickness is too thin (<200 nm), the amount of light that can be absorbed by the material becomes less, so that not enough electron-hole pairs are generated to produce significant electric current. Conversely, if the layer thickness is too large (>400 nm), then the generated charge carriers must travel a longer distance before reaching the electrode, which increases the possibility of recombination before they can be extracted into electric current [23]. Therefore, a thickness of about 200 nm provides an optimal balance between light absorption and charge carrier transport, which ultimately results in the highest efficiency. In terms of the operating principle of a-Si: H solar cells, these simulation results can be explained based on the mechanisms of light absorption, electron-hole pair generation, charge carrier transport, and recombination. a-Si: H based solar cells have a very high absorption coefficient, which allows light absorption in a much smaller thickness compared to crystalline silicon (c-Si) based solar cells. In other words, even though the a-Si:H layer is thinner, it can still capture most of the photons with higher energy. Therefore, optimal thickness design is very important to maximize energy conversion efficiency.

Overall, the analysis of these simulation results shows that the selection of optimal bandgap parameters and layer thickness is very important in the design of efficient a-Si: H solar cells. The optimal bandgap of about 1.95 eV provides the best balance between the output voltage and the number of photons that can be absorbed, while the layer thickness of about 200 nm allows sufficient light absorption without increasing the recombination of charge carriers [24]. Therefore, in the development of a-Si: H-based solar cells, further optimization is needed through layer structure engineering, utilization of reflective layers to increase light absorption, and material processing techniques that can reduce the density of recombination defects.

## Correlation Between Simulation and Experiment

In this study, the highest efficiency results obtained were at a layer thickness of 200 nm with a bandgap of 1.95 eV, although this value is the most optimum, but when correlated with previous studies, the highest efficiency value was used with a bandgap of 1.75 eV, where the size of this bandgap is the average optimum efficiency used in previous studies compared to 1.95 eV. Therefore, at a bandgap of 1.75 eV, the highest efficiency that can be achieved is 8.42% in this simulation with an a-Si: H p-i-n solar cell structure. Based on the available simulation data and previous studies, previous studies in the form of experiments with a-Si: H p-i-n layer structures by [25] obtained an efficiency of 5.37%. Therefore, the correlation of simulation results with experiments by Benigno, namely simulations show higher efficiency due to the use of ideal parameters but experiments are lower due to material defects, high charge carrier recombination and large series resistance, experimental results are limited by the quality of PECVD deposition which results in structural defects and uneven electric field distribution but simulations are free from these conditions. Then another study with AFORS-HET simulations [5], the maximum efficiency achieved was 10,765 with a p-i-i-n structure. The correlation of previous simulation results by Hamdani et al, namely several factors that affect the results such as the thickness of the double intrinsic layer, variations in single and double bandgaps so that the double intrinsic layer structure overcomes carrier recombination and increases light absorption more effectively. With a simulated PCE of 8.42%, the experimental efficiency is estimated to be below the simulated efficiency, depending on the quality of the material, deposition technique, and process parameter control during the experiment.

## CONCLUSION

In conclusion, the structure of the a-Si: H solar cell layer used to maximize absorption consists of 6 layers including substrate (glass), ITO, p layer, i layer, n layer, and metal contact where the size of each layer is on ITO (80 nm), p layer (10 nm), i layer varies (100 - 600 nm), n layer (30 nm) and metal/Ag contact layer (30 nm). Bandgap greatly affects the efficiency of hydrogenated amorphous silicon solar cells where the results obtained show that in the p layer with a bandgap of 2.1 eV, n bandgap 1.95 eV and i bandgap variation of 1.6 eV– 1.95 eV, the results show that the higher the bandgap, the higher the efficiency obtained. The thickness of the layer also greatly affects the efficiency obtained where the higher the thickness of the layer causes the recombination of charge carriers to increase in the intrinsic layer of the a-Si:H solar cell, so that many electron-hole pairs are lost before contributing to the electric current. The characteristics of the I-V curve in hydrogenated amorphous silicon solar cells against the Voc value are that the thicker the intrinsic layer, the lower the Voc value obtained, as well as Isc. The FF and efficiency values increase at a thickness of 200 nm then decrease again above a thickness of 200 nm. Then the maximum value of each normal parameter obtained is at an optimum layer thickness of 200 nm with a bandgap of 1.95 eV where the Voc value obtained is 1.21 V, Isc is 15.12 mA/cm2, FF is 0.62% and PCE is 11.27%.

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