Performance Analysis of Triple Junction GaInP/GaAs/Ge Tandem Solar Cells from Numerical Simulation

*Esmeel Hasan T Mohamed **Abdualbast A.Mohmed Hamouda

ABSTRACT: The research aims to analyses the performance of triple junction GaInP/ GaAs/ Ge tandem solar cells. In this study the Analysis of Microelectronic and Photonic Structures (AMPS-1D) simulator has been used to estimate the effect layer thickness on the performance cells. The effect of layer thickness on the performance of triple junction GaInP/GaAs/Ge solar cell has been investigated elaborately. As the layer thickness of GaInP decreases, the efficiency rises. Meanwhile, increasing the n doped GaAs layer thickness slightly enhances the efficiency. The p doped GaAs layer thickness range from 500 nm to 3500 nm gives a variation in efficiency of about 1%. The results clearly indicate that the thickness variation of p-GaInP and n-GaInP significantly change the efficiency of the solar cell. The n doped GaAs layer thickness gives higher effect of the efficiency compared to p doped GaAs layer thickness. Both n and p doped Germanium (Ge) don't show any response when the thickness changed. The optimization achieved here indicates model structure for practical usage to achieve high efficiency GaInP/GaAs/Ge based solar cells.

1. INTRODUCTION

Renewable energy technologies are essential contributors to the energy supply portfolio as they contribute to world energy supply security, reducing dependency of fossil fuel resources, and providing opportunities for reducing emissions of greenhouse gases. One of the key renewable energy technologies is photovoltaic (PV).PV systems are designed specifically to have high efficiency to generate electricity in a cost effective and efficient manner. Properly installed systems require minimal maintenance, have long service lifetimes and are very reliable. This study is focused on discovering and adapting presently available designs and technologies that deal with solar cells development utilizing Gallium Arsenide (GaAs) as the main photovoltaic material. To date, GaAs based solar cells with a maximum theoretical efficiency of 37.9% have been achieved [1, 3]. This level of efficiency is dependent upon the designs of the solar cells. There are several advantages to the use of GaAs in solar cells for both terrestrial and space applications. These allow the creation of more robust and rigid designs for commercial application. GaAs has a band gap of 1.43eV, which is nearly ideal for single-junction solar cells [4, 5]. Temperature fluctuations cause the band gap to range from 1.42eV to 1.5eV [6, 7]. This allows GaAs solar cells to have high absorption characteristics and requires only a cell of a few microns in thickness to absorb sunlight [7, 8]. Hence, it is most suitable for capturing light wavelengths in space when used as a base and when alloyed with other materials [7, 8]. As reductions in the total weight of the solar cell are possible, the launch cost of spacecraft will also be reduced as these are directly dependent upon the total launch weights. Alloys made from GaAs using Aluminum (Al), Phosphorus (P) or Indium (In) possess characteristics complementary to those of GaAs, giving great flexibility in high-efficiency cell design. A cell with a GaAs base can have several layers of slightly different compositions that allow a solar cell designer to control the generation and collection of electrons and holes. This degree of control enables cell designers to generate efficiencies which are closer to theoretical levels. When compared to silicon based solar cells, GaAs cells

* Electrical and Electronics Department, High Institute of Sciences and Technology, Sirte, Libya
Corresponding author: ismaelet@hists.edu.ly
** Renewable Energy Department, Higher Institute of Sciences and Technology, Al jufrah, Libya

are also more resilient to heat damage [4]. A more important property is its high immunity to radiation damage. This is important as solar cells in space experience degradation due to bombardment of cell by constituents of naturally occurring charged particles in a radiation environment. Radiation damage causes the reduction of the efficiency due to material degradation. The degree of radiation damage depends on material, device structure [4, 5]. This makes GaAs solar cells very suitable for high performance and high efficiency applications. Due to continuous research, the efficiency of GaAs based solar cells has constantly increased. GaAs is now used in single and multi-junction solar cells, thin film solar cells as well as in concentrator systems [2, 6]. Briefly, thin film solar cells are layers of ultra-thin material combined together and is designed to be used in areas where space is at a premium. Concentrator systems are now being employed in conjunction with solar cell arrays to economically generate large amounts of energy. GaAs is used for the manufacture of space based solar cells due to two reasons. Firstly, GaAs is a very flexible material, it very useful when used in the design of multi-junction solar cells [2]. Secondly, these multi-junction cells that are a combination of various types of semiconductor materials are able to absorb light of various wavelengths thus contributing to a higher conversion capability [2]. In this capacity, the output power can be approximately 30% higher for the same amount of sunlight exposure when compared with silicon based solar cells. This results in a lesser surface area being required to generate an equal amount of energy, thus reducing the total weight of the solar cell. This has the effect of reducing the total launch cost of a satellite which may result in savings worth millions of dollars. GaAs based solar cells also possess higher radiation reliability which means it has high radiative stability. This may be as much as a 20% improvement depending upon the environmental conditions in which the cells' operate. GaAs based solar cells are also known to have better temperature characteristics as the temperature coefficient has been proven to be as much as two times lower when experiencing temperature fluctuations [3, 7]. The simulation using an Analysis of Microelectronic and Photonic Structures one dimensional (AMPS-1D) simulator for the performance test of GaAs-based solar cell with double junction solar cell incorporated with Gallium Indium Phosphide (GaInP). They demonstrated that the decrease in the thickness of GaInP and increase in the n-doped GaAs layer increased the efficiency of the cells. Radiation damage and degradation of GaAs absorber layer are big issues in the solar cells [9, 10]. In space, the ability to withstand the extremes of temperature is vital as the change in temperature may range from below freezing to tens of degrees above the melting point or higher. GaAs based solar cells have been known to have a service lifetime of about 20-30 years which ensures minimal maintenance requirement. As stated earlier, GaAs is also a direct bandgap semiconductor, when coupled with is radiation resistive and relative temperature insensitivity, the conversion efficiency of the GaAs based solar is also known to be 20%-25% higher, thus enabling higher outputs to be achieved using less material. In this work triple junction solar cell will be discussed in depth based on the obtained simulation results.

2. NUMERICAL SIMULATION

The main target of this research is to develop GaAs based solar cell with improved cell efficiency by using AMPS-1D. As there are many parameters in the study such as doping concentration, the effect of temperature and sunlight concentration, most of the parameters are treated as constant value to avoid confusion and to make the solar cell design simpler. Generally, AMPS-1D is a general software used to analyse and design transport microelectronic structures. AMPS-1D solves the three governing semiconductor device equations including the Poisson equation, the electron and hole continuity equation. It can be used to examine the variety of devices that includes homo-junction and hetero-junction p-n or p-i-n solar cells, detectors, microelectronic structures or multi-junction solar cell structure. Using AMPS-1D, many output characterizations can be obtained. Among them are current and voltage characteristics, in dark or illuminated condition, spectral response, conduction band, valence band, efficiency, open-circuit voltage Voc, short circuit current density Jsc and fill factor FF. Prior to simulating any solar cell model when using AMPS-1D, various parameters are required to be keyed in before a simulation can begin. In this analysis, the thickness has been varied for different layers in different junctions. All the other parameters are kept constant in order to accurately study the effects of this process.Fig.1 illustrates the triple junction GaAs based solar cell structure.

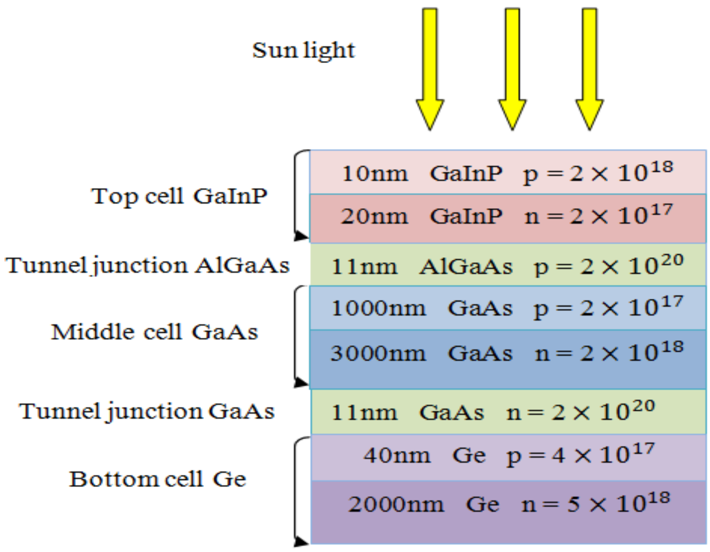
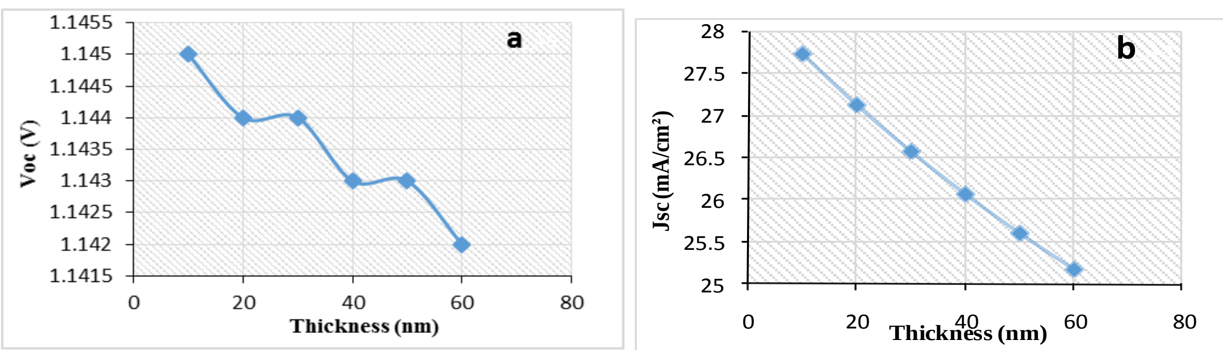


FIGURE 1. Schematic diagram of Triple Junction GaInP/GaAs/Ge Tandem Solar Cells structure used in AMPS-1D.

3. RESULT AND DISCUSSIONS

3.1.1 Effect of p-GaInP layer thickness

Triple junction solar cell structure consists of GaInP top cell, AlGaAs tunnel diode, GaAs middle cell, GaAs tunnel junction and Ge bottom cell. The GaInP top cell with a wideband gap of 1.88 eV absorbs mostly the short-wavelength part of the solar spectrum whereas remaining longer wavelength are absorbed more effectually by the GaAs 1.42 eV middle cell. The longest wavelength photons are absorbed by Ge bottom cell comprising band gap 0.66eV.The thickness of n doped GaInP, GaAs and Ge layers are kept constant while the thickness of p doped GaInP layer was varied. The impacts are shown in figure2. The highest efficiency value is attained by using a thickness of 10nm. When the efficiency decreases, Jsc also declines with the fill factor and Voc remain persistent.



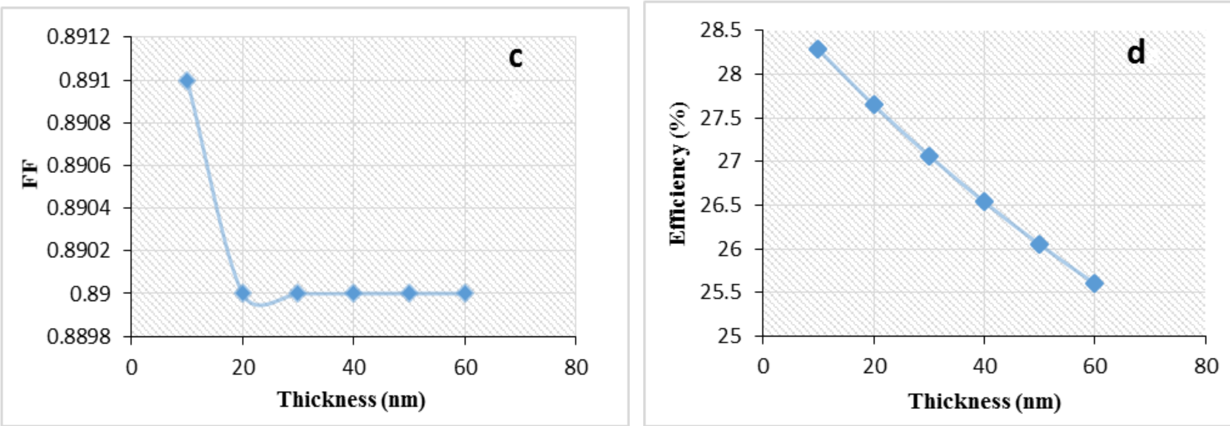


FIGURE 2.Effect of p-GaInP thickness variation on triple junction solar cell performance (a) open-circuit voltage (b) current density (c) fill factor (d) efficiency.

3.1.2 Effect of n-GaInP layer thickness

Then the thickness of n doped GaInP layer is varied. In this case, the thickness of p doped GaInP,GaAs and Ge layers are kept unchanged. The effects are represented in figure3where the highest efficiency value is obtained by using a thickness of 20nm. When the efficiency reduces, Jsc, Voc and FF also decline proportionally.

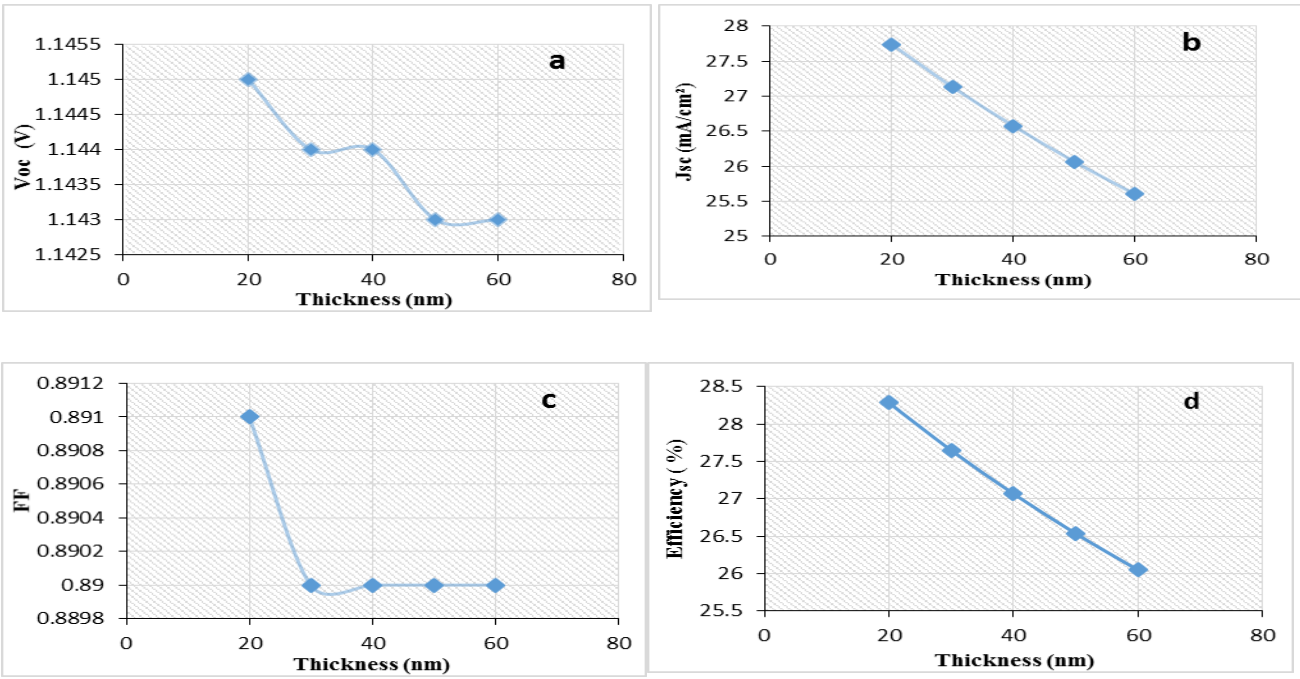


FIGURE 3. Effect of n-GaInP thickness variation on triple junction solar cell performance (a) open-circuit voltage (b) current density (c) fill factor (d) efficiency.

3.2.1 Effect of p-GaAs layer thickness

In this analysis, the thickness of the GaInP, n doped GaAs and Ge layers are kept constant and the thickness of the p doped GaAs layer is varied. All the other parameters are also kept constant in order to accurately study the effects of this process. From figure4, it is observed that the J_{sc} changes proportionally with the efficiency while the V_{oc} remains constant until thickness reaches 800nm then it decrease slightly. FF increases slightly until thickness exceeds 300 nm then it remains constant. However the change in p doped GaAs thickness As shown in figure 4 d, when the thickness changed from 500nm to 1000 nm the efficiency value increased about 0.01%. The efficiency increase considered useless in terms of cost and Weight. It is also noted that the efficiency values stay within 28 % throughout the process thus enabling the layer thickness to be reduced and maintained at 500 nm in this optimization models.

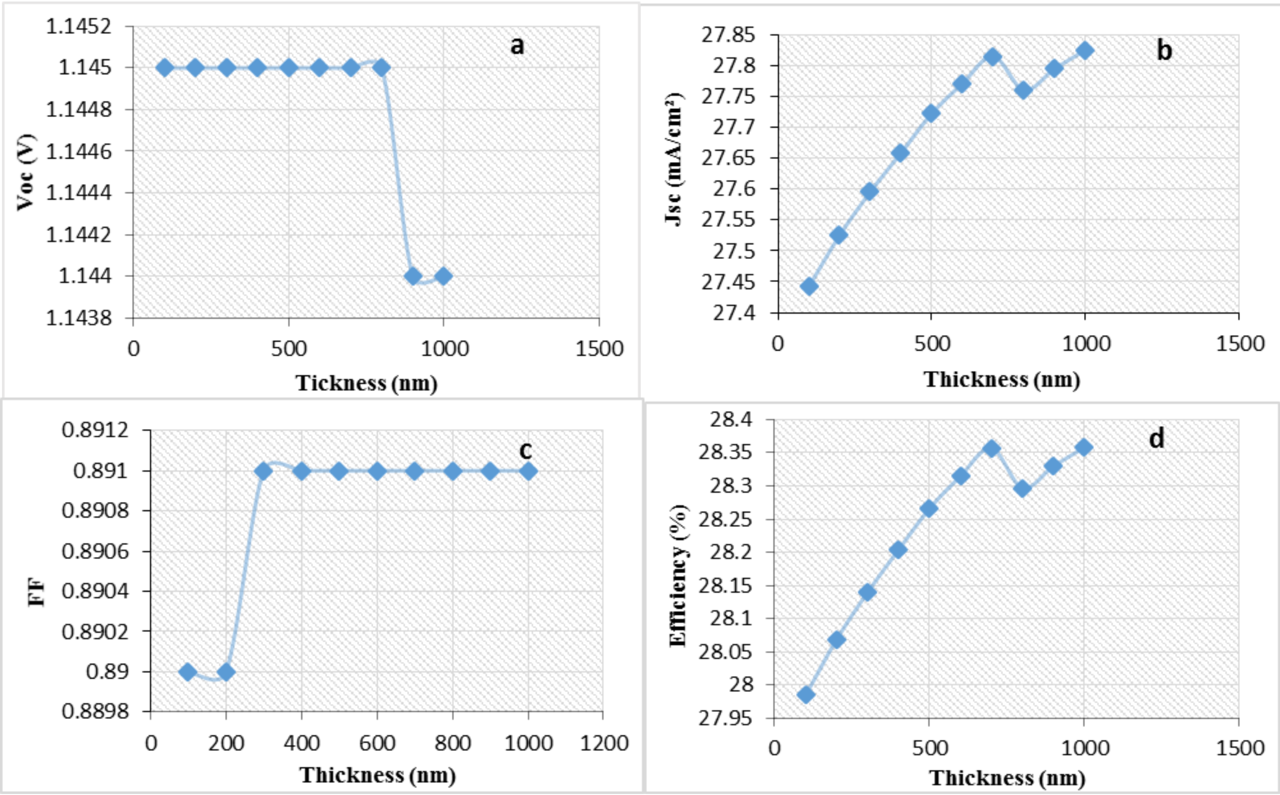
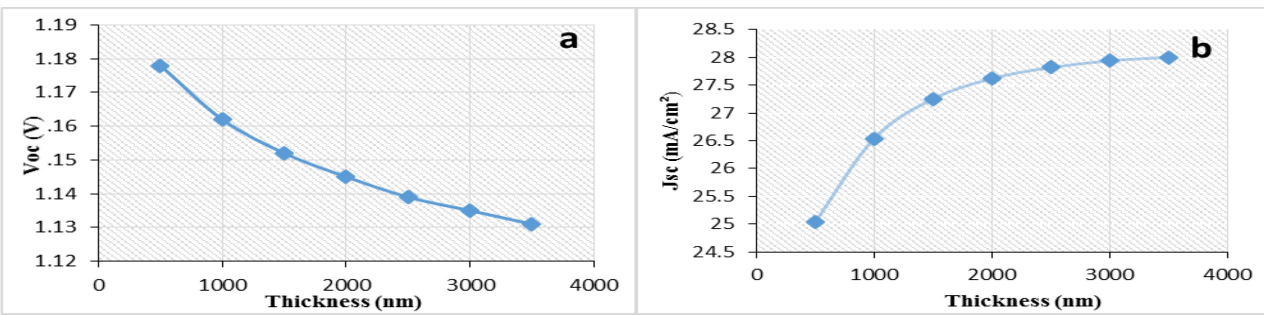


Figure.4Effect of p-GaAs thickness variation on triple junction solar cell performance (a) open-circuit voltage (b) current density (c) fill factor (d) efficiency.

3.2.2 Effect of n-GaAs layer thickness

For the n-GaAs layer in figure5 any increase in thickness of the n doped GaAs layer will result in a slight increase of the efficiency performance of the solar cell until thickness reaches 2000 nm, in this study, the efficiency remains constant even the thickness increased . N doped GaAs layer thickness shows that it gives higher effect to efficiency compared to p doped GaAs layer thickness. Hence it can be concluded that using 2000 nm thickness for n doped GaAs will provide the highest efficiency which is 28.159% in this case.



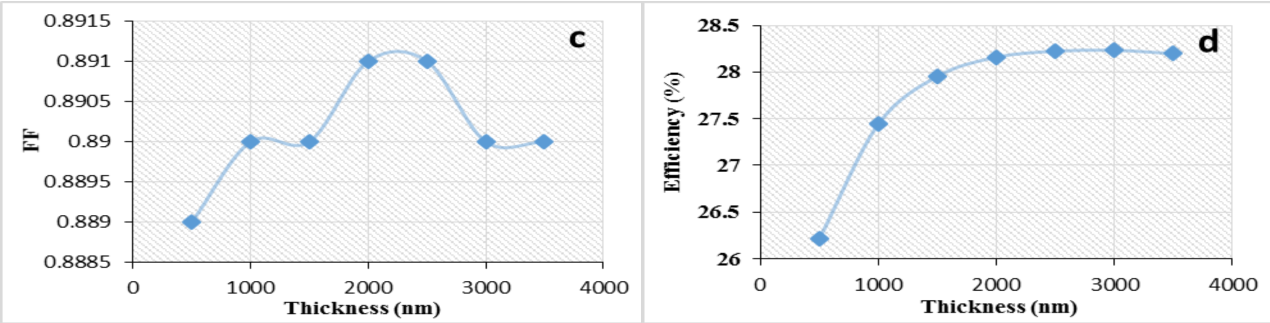


Figure.5 Effect of n-GaAs thickness variation on triple junction solar cell performance (a) open-circuit voltage (b) current density (c) fill factor (d) efficiency

3.3.1 Effect of p-Ge layer thickness

In this analysis, the thickness of the GaInP, GaAs and n doped Ge layers are kept constant and the thickness of the p doped Ge layer is varied. All the other parameters are also kept constant in order to accurately study the effects of this process. From figure6, it is observed that the J_{sc} and efficiency decrease when the layer thickness exceeds from 30nm until 40nm, then it remains constant, while the Voc and FF remain constant.

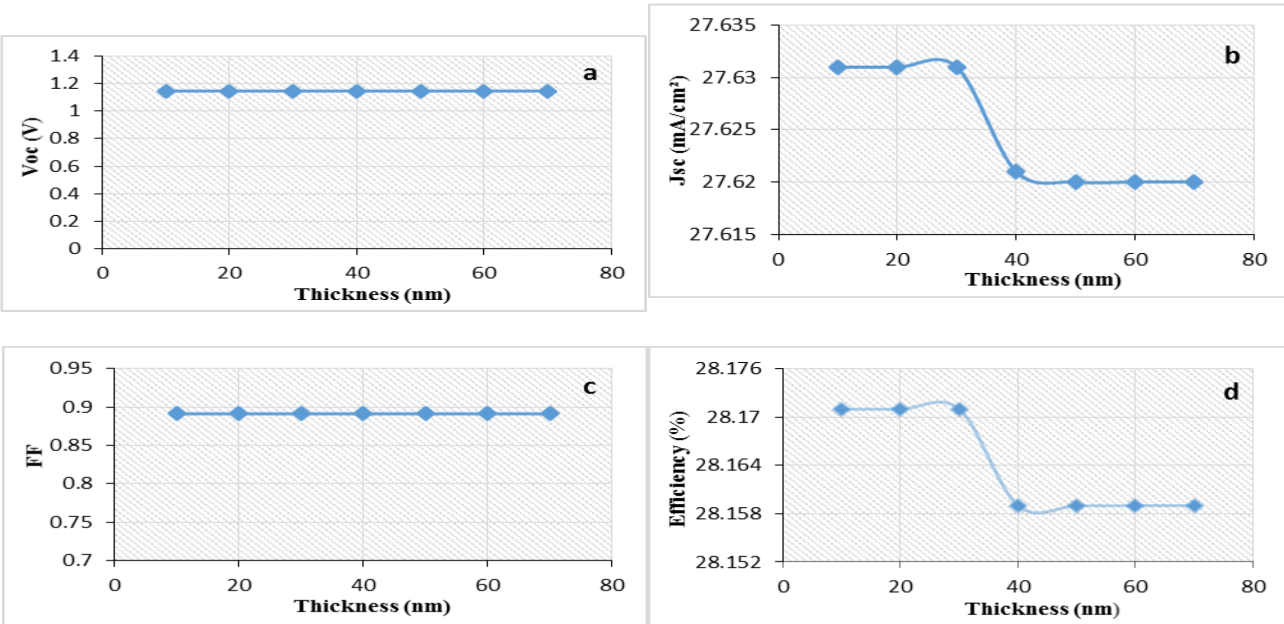
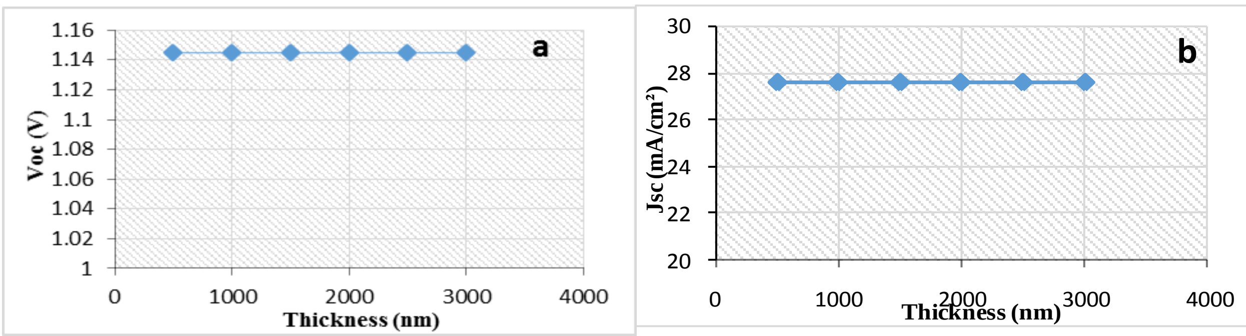


Figure.6 Effect of p-Ge thickness variation on triple junction solar cell performance (a) open-circuit voltage (b) current density (c) fill factor (d) efficiency.

3.3.2 Effect of n-Ge Layer Thickness

In this case, the thickness of the GaInP, GaAs and p doped Ge layers are kept constant and the thickness of n-doped Ge layer is varied. All the other parameters are also kept constant in order to accurately study the effects of this process. From figure7, it is observed that all the parameters remain constant and they do not show any response when the thickness changed. It can be concluded that any change in n doped Ge thickness does not affect the efficiency.



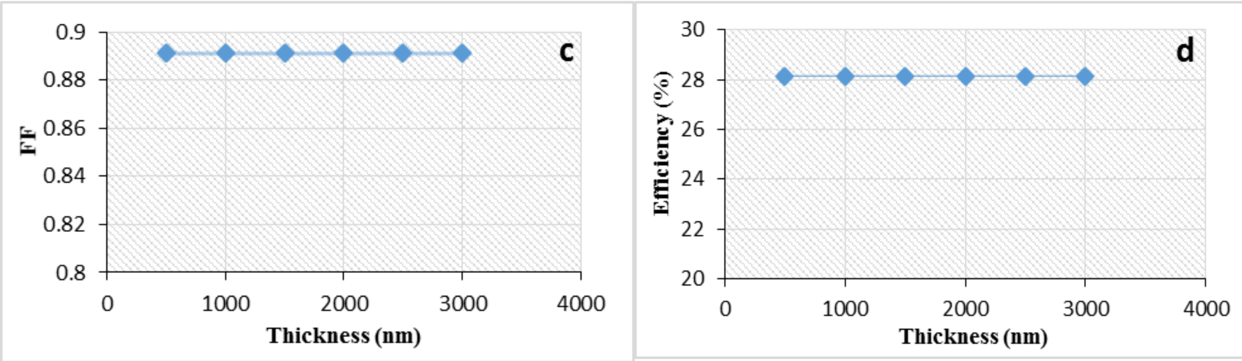


Figure.7 Effect of n-Ge thickness variation on triple junction solar cell performance (a) open-circuit voltage (b) current density (c) fill factor (d) efficiency.

4. CONCLUSION

The objective of this study was to analyses the performance of triple junction GaInP/ GaAs/Ge tandem solar cells. This numerical simulation focuses on creating an optimum solar cell model for triple junction solar cell. Based on simulation results, p and n doped GaAs and Ge do not show substantial change in overall efficiency. As the layer thickness of GaInP in triple junction solar cell is improved, the degree of efficiency highly declines. It can be concluded that GaInP layers significantly affects triple junction cells. The efficiency for triple junction has been achieved is 28.159%.

تحليل أداء الخلايا الشمسية ثلاثية الطبقات GaInP/GaAs/Ge من خلال المحاكاة العددية

المستخلص: في هذه الدراسة تم تحليل أداء خلية شمسية تتكون من ثلاث طبقات GaInp/GaAs/Ge باستخدام برنامج تحليل محاكاة الهياكل الالكترونية الدقيقة و الفوتونية (AMPS-1D). تم دراسة تأثير سماكة الطبقة على أداء الخلية الشمسية ثلاثية الوصلات بشكل معمق. مع انخفاض سمك طبقة GaInP تزداد الكفاءه، وعند زيادة سماكة طبقة n-GaAs تزداد الكفاءه بشكل طفيف . p-GaAs يعطي مدى السماكة من 500 نانومتر إلى 3500 نانومتر تباينًا في الكفاءة يبلغ حوالي 1 ٪. تغيير سماكة p-GaInP و n-GaInP يؤثربشكل كبير في كفاءة الخلية الشمسية بينما لا يظهر الجرمانيوم (Ge) أي استجابة عند تغير السُمك. يشير التحسين الذي تم تحقيقه في هذه الدراسة إلى بنية نموذج عملي للحصول على خلايا شمسية عالية الكفاءه قائمة على GaInP / GaAs / Ge .

5. REFERENCES

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