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Improved Performance of Silicon-Germanium Solar Cell Based on Optimization of Layer Thickness

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A B S T R A C T

Electrical energy has become an essential part of our life. Therefore, its supply must be sustainable, economical, and environment-friendly. The conversion of sunlight into electricity is made possible through the solar cell, a semiconductor device, however, the conversion efficiency of these cells is low which can be further improved. This research work presents the design and performance analysis of silicon-germanium (Si-Ge) solar cells. Amorphous silicon / crystalline silicon Heterojunction (a-Si/c-Si HIT) solar, Ge, Si-Ge alloy with 25% Si concentration solar cells are designed in Afors-Het software. An improved conversion efficiency (η) of 25.23%, 5.125%, and 11.53%, respectively is achieved.

1 Introduction

Due to the simplicity in architecture and high efficiency, Si based HIT solar cells have gained a lot of interest from last few years [1,2]. Mostly Si based HIT solar cells have stacked intrinsic (i) and hydrogenated a-Si as a passivation and carrier selective layer [3], which can provide better surface passivation and selectivity [1, 4-6]. The major portion or the absorber layer of Si based HIT has c-Si due to its better temperature coefficient and efficiency [7,8], several groups have achieved more than 22% efficiency [9]. In order to achieve high efficiency at low cost different structures have been examined such as an alloy of Si and Ge (Si-Ge).

Si-Ge alloy solar cell has gained much interest from last few years [10-14]. The reason behind the development of this structure is to make improvement in the conversion efficiency through the additional photocurrent provided by the low band gap material [15]. For this purpose, Ge is considered best because of its low energy photons absorption capability. Additionally, this structure i.e. Si-Ge alloy has high band gap which means that it can easily absorb light of high wavelength then Si and Ge individually which can also improve the efficiency of a solar cell [16,17].

Ge cell is considered best as a bottom cell due to its low band gap which allows it to absorb the low energy photons [18-21], however, temperature effect its different parameters which are examined by V. Baran et al. [22]. By increasing temperature Jsc of the cell increases while the Voc and FF of the cell decreases and as a result the overall conversion efficiency of the cell decreases. The dislocation problems in Si1-xGex is due to the difference in the lattice between Si and Ge [23]. This problem has negative impact on the overall performance of the Si-Ge cell [24,25]. In order to solve this problem different techniques i.e. the composition of grade Ge [26] and Stranski-Kranstanov [27] etc. can be used.

To make improvements in different parameters of a solar cell different structures are examined. The performance analysis of Si-Ge alloy cell with different concentration of Si and Ge i.e. 10% Si and 90% Ge is done using numerical simulation by Ahmad Aizan Zulkefle et al. [28]. Dug Phong Phan et al. proposed Si based tandem which have Si-Ge alloy with Si base heterojunction cell (HIT) and used it as a source of electric power in a water splitting system which provides about 1.54V of Voc [29]. In order to improve the carrier extraction Dug Phon Phan et al. suggested amorphous silicon (a-Si) base a-Si-Ge alloy cell with different buffer layers [30].

In this research work authors made efforts to improve the overall efficiency of Si based HIT, Ge and Si-Ge alloy solar cell by varying different parameters such as thickness and doping different layers.

2 Methodology

2.1 A-Si/c-Si HIT Solar Cell

A-Si/c-Si HIT cell is designed which is shown in Figure 1(a). This structure has silicon material in different forms i.e. amorphous (a-Si) and crystalline (c-Si). The donor layers i.e. N++ and N-type are of a-Si while the absorber layers i.e. P++ and P-type are of c-Si and an intrinsic layer (i-layer) which is sandwiched in between these two layers is also of a-Si. The thickness of these layers are set as 5nm for N++ layer, 10nm for P-type layer, 10nm for i-layer, 200µm for P-type and 5nm for P++ layer.

The doping level of these cells are set as 5E19 for N++ layer, 5E18 for N-type, 200µm for P-type and 5E19, P++ layer and for i-layer the doping levels of both n-type and p-type are kept same in order to get an optimized Si based HIT solar cell. As high energy photons have low wavelength, when the above structure is exposed to the sun, the photons of higher energy will be absorbed in the top layer i.e. N++ which is of a-Si and comparatively low energy photons will be absorbed in N-type while the lowest energy photons will be absorbed in P-type. For the absorption of photons, the band gap of material must be lower than its energy. The structure shown in figure 1(a) is designed in Afors-Het and its results are comparatively good (values of Jsc, Voc, FF, and η) than some of the previous works. For a good solar cell, the percentage of FF must be greater than or close to 80%, therefore, this cell is acceptable, and however, further improvements are still required.

2.2 Ge Solar Cell

A single junction Ge solar cell is designed in Afors-Het. This structure is of a crystalline form of Ge. The thickness and doping level of the donor and absorber layers are 10 nm and 180 micrometres, 1E20 and 1E17 respectively. The proposed structure of Ge solar cell is shown in figure 1(b). As the band gap of a Ge material is very low as compare to the other semiconductor materials such as silicon etc. Ge solar cell offers high value of shirt circuit current as compare to the other materials. Due to the low band gap, less number of photons will be absorbed in this type of solar cell which results in lower η as compare to the cells of such materials who have higher band gap. Ge solar cell can be used in a tandem solar cell as a bottom layer to absorb the low energy photons and enhance the overall η of a cell. An effort is made to get an efficient Ge solar cell.

2.3 Si-Ge Alloy Solar Cell

The bandgap of Si-Ge cell is higher than that of Si and Ge which means that it can easily absorb the sun light of high wavelength. Here, Fig 1(c) shows the basic structure of the suggested Si-Ge alloy solar cell with different level of concentration of Si and Ge. In this research work the Si-Ge cell with 25% of Si and 75% of Ge is designed in Afor-Het. The thickness of these layers are set as 5nm for N++ layer, 10nm for P-type layer, 10nm for i-layer, 200µm for P-type and 5nm for P++ layer. The doping level of these cells are set as 5E19 for N++ layer, 5E18 for N-type, 200µm for P-type and 5E19, P++ layer and for i-layer the doping levels of both n-type and p-type are kept same in order to get an optimized solar cell.

As the absorption of photons depends on the bandgap of a material, the Si can absorb high energy photos as its bandgap is higher than the Ge and Ge can absorb low energy photons because of its low energy bandgap. High energy photons have low wavelength, when the above structure is exposed to the sun, the photons of higher energy will be absorbed in the top layer i.e. N++ and comparatively low energy photons will be absorbed in N-type while the lowest energy photons will be absorbed in P-type. For the absorption of photons, the bandgap of material must be lower than its energy. Higher the number of absorbed photons higher will be the overall η of a cell. To get a higher number of absorbed photons different percentages of these two materials can be tested together i.e. 28% of Si material and 72% of Ge material, 50% of Si and 50% of Ge, 75% of Si and 25% of Ge and 98% of Si and 2% of Ge, etc. This thesis presents an effort for the 25% of Si and 75% of Ge to get an efficient solar cell.

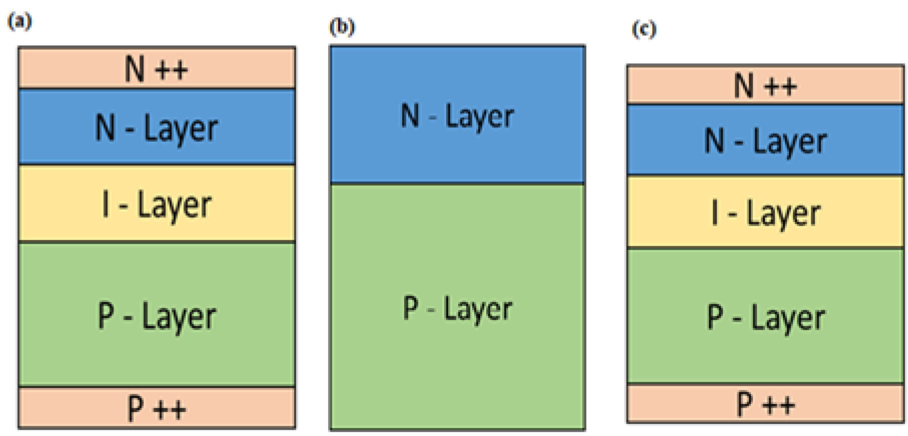

Fig. 1. A, B and C Show Si based HIT Solar Cell Architecture, Ge Solar Cell Architecture and Si-Ge Alloy Solar Cell Architecture

3 Results and Discussion

Si base HIT solar cell is designed in Afors-Het whose results are shown from figure 2 to 4. These figures show effect of thickness of different layer on the cell's results i.e. varying the thickness of N++ layer while keeping the thickness of other layers constant. This process is repeated for all layers to find their effect on the cell's results and get an optimized solar cell. Figures show the Si base HIT solar cell output results. The values for Voc, Jsc, FF and η that are achieved from this cell are 712 mV, 42.06 mA, 84.26% and 25.23% respectively. These results can further be improved; however, it is an improved result of this type of HIT solar cell compared to the work done by the few groups. In this structure, the a-Si which has a high band gap as compared to the c-Si is placed at the top of a cell. The top layer, a-si due to its high band gap will absorb the photons of higher energy as compared to the c-Si having a low band gap. For a better solar cell, the FF must be greater or closer to 80%, as the value of FF obtained from this cell is greater than 80% so this cell can be used for further applications i.e. to form a tandem solar cell with other cells.

Several groups working on a-Si/c-Si HIT solar cell an η of about 22%, however, further improvements are made by Reza Asadpour et al [7]. The authors in [7] achieved 24% η in a-Si/c-Si cell to stack with other materials, here we made further improvements in its η pushing it to 25.23% which can be considered best for the same purpose.

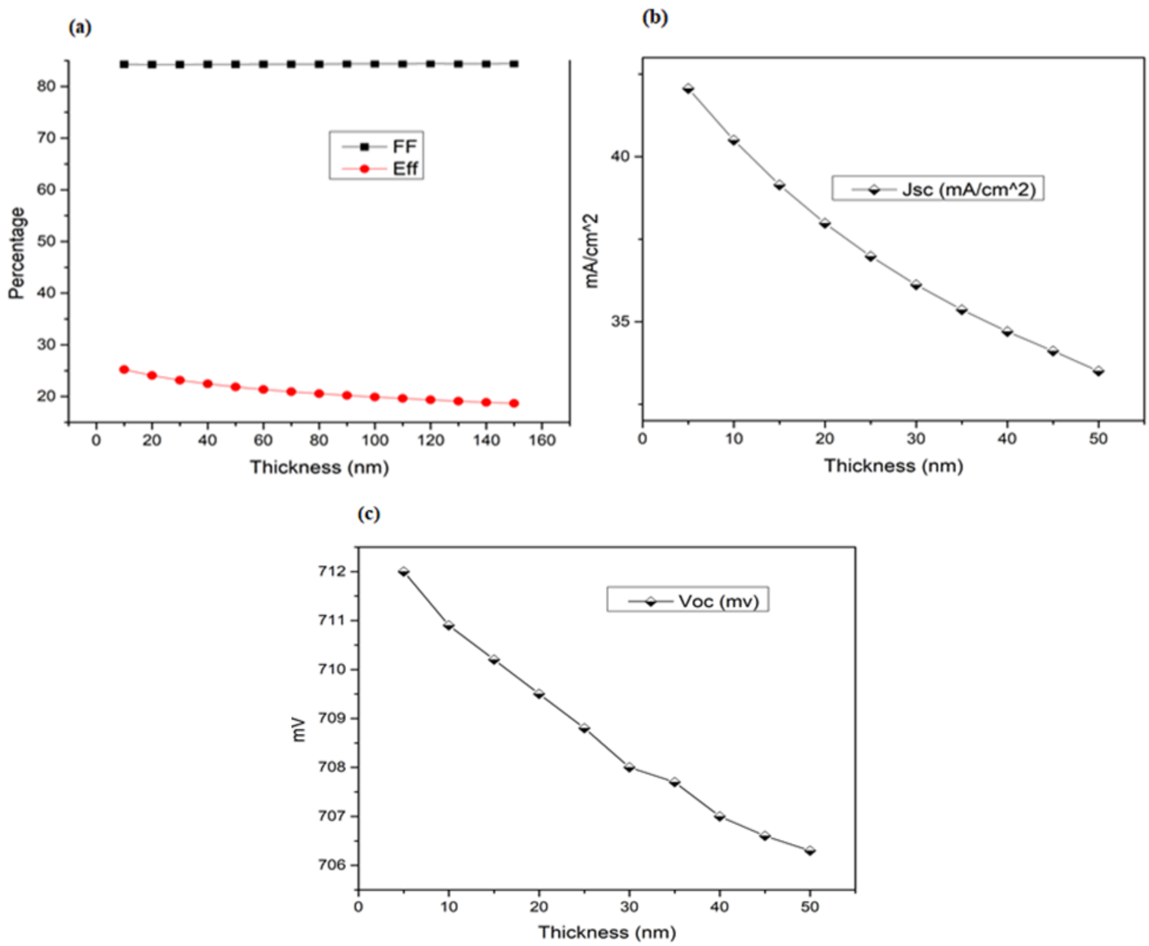

Fig. 2. a, b and c Show Si based HIT Solar Cell Architecture, Ge Solar Cell Architecture and Si-Ge Alloy Solar Cell Architecture

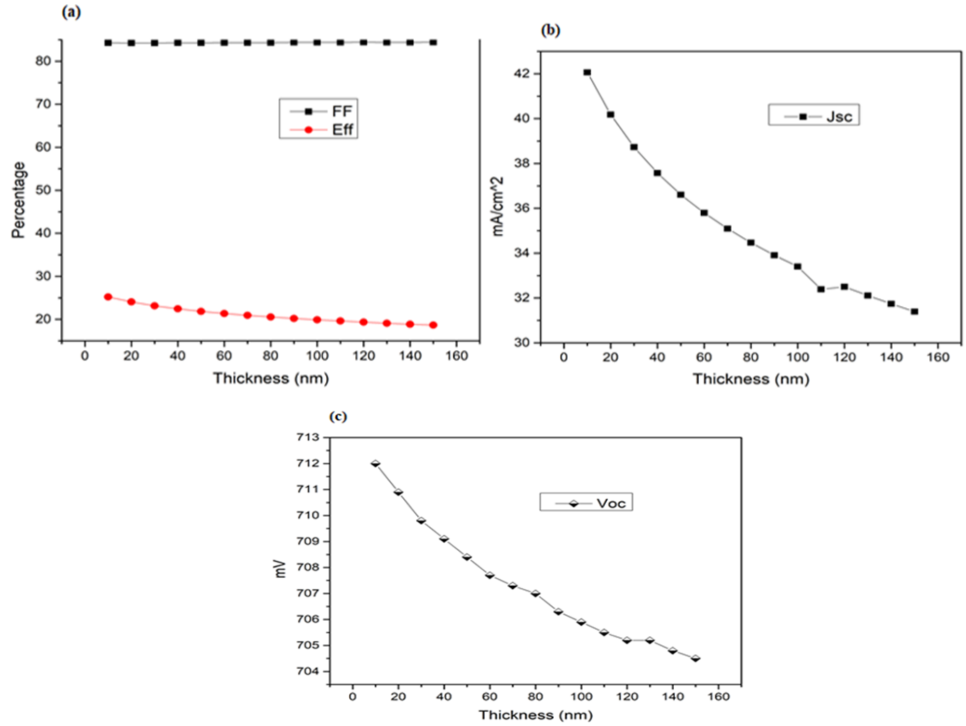

Fig. 3 (a), (b), and (c) show the effect of N layer thickness on the results (FF, Eff, Voc and Jsc) of Si based HIT Solar Cell.

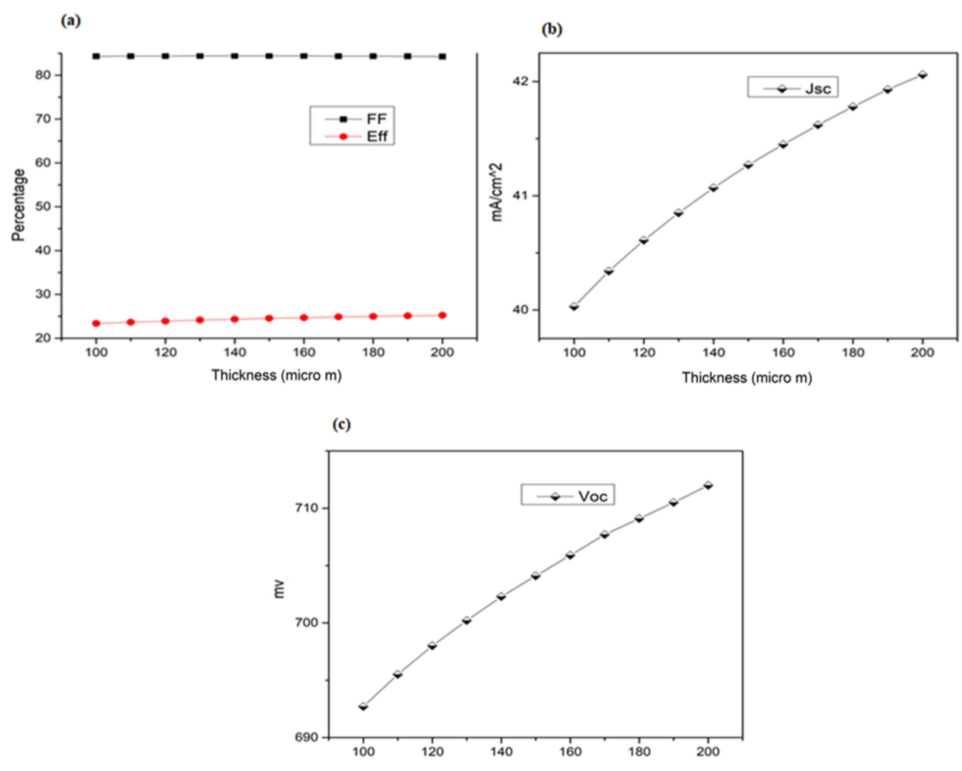

Fig. 4 (a), (b), and (c) show the effect of P layer thickness on the results (FF, Eff, Voc and Jsc) of Si based HIT Solar Cell.

Similarly, Ge solar cell is designed in Afors-Het whose results are shown from figure 5 and 6. These figures show effect of thickness of different layer on the cell's results i.e. varying the thickness of N++ layer while keeping the thickness of other layers constant. This process is repeated for all layers to find their effect on the cell's results and get an optimized solar cell. The figure shown below shows the output results of a cell. The below figures show the output results of a Ge solar cell. As can be seen in the figure the values for Voc, Jsc, FF, and η achieved from this cell are 209.5 mV, 37.56 mA, 65.13% and 5.125% respectively. The band gap of a Ge cell is low, 0.67 due to which it absorbs less number of photons and results in lower η of Ge cell. Due to low band gap Ge is considered best as a bottom layer for tandem solar cell where it will be responsible to absorb the low energy photons and contribute in the overall results of a solar cell.

The authors in [31] have done a comparative study between Ge and Si-Ge alloy. The authors achieved 2.73% and 9.74% efficiencies for Ge and Si-Ge alloy respectively. In comparison with individual Ge solar cells, this research work achieved an efficient Ge solar cell with 5.125% η.

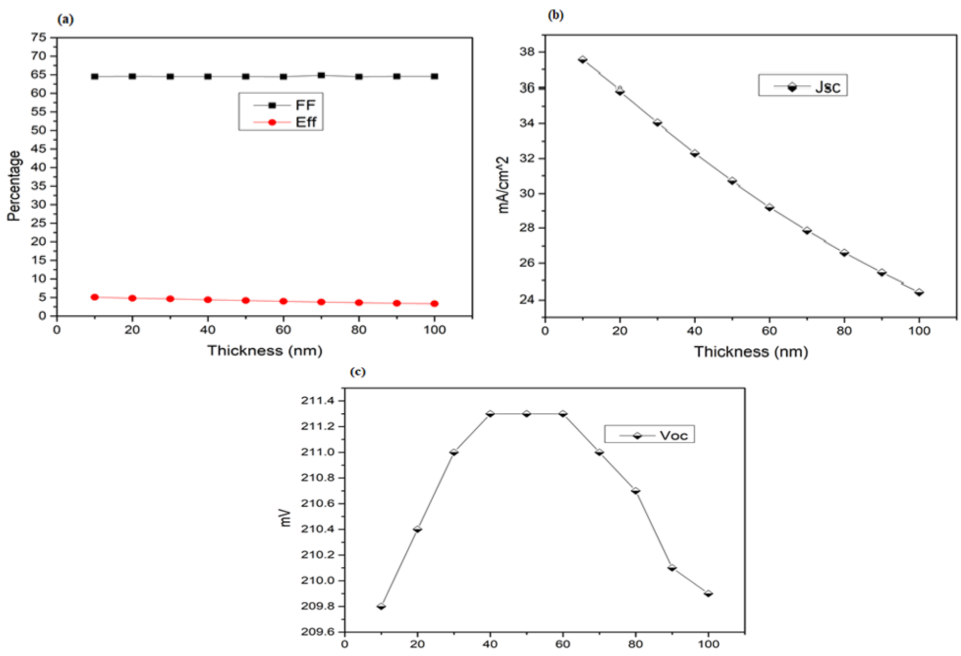

Fig 5. (a), (b), and (c) show the effect of N layer thickness on the results (FF, Eff, Voc and Jsc) of Ge Solar Cell.

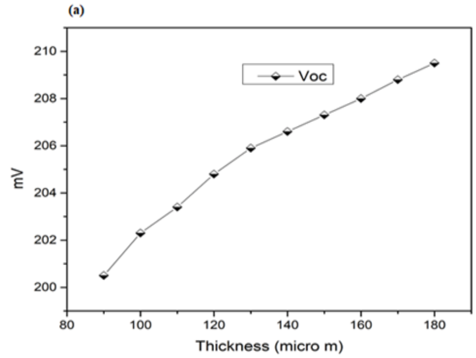

Fig. 6 (a) shows the effect of N layer thickness on the results (FF, Eff, Voc and Jsc) of Ge Solar cell.

Furthermore, Si-Ge alloy solar cell is designed in Afors-Het whose results are shown from figure 7 to 9. These figures show effect of thickness of different layer on the cell's results i.e. varying the thickness of N++ layer while keeping the thickness of other layers constant. This process is repeated for all layers to find their effect on the cell's results and get an optimized solar cell. The Si-Ge alloy with 25% Si and 75% Ge as discussed in chapter 3 achieved 11.53% η. The values of other parameters like Voc, Jsc, FF, and η are 360.2 mV, 42.5 mA/cm2, 75.3% and 11.53% respectively. Up to the author's best knowledge, this is the best η achieved so far.

The authors in [31] have done a comparative study between Ge and Si-Ge alloy. The authors achieved 2.73% and 9.74% efficiencies for Ge and Si-Ge alloy respectively. In comparison with individual Si-Ge solar cells, this research work achieved an efficient Si-Ge solar cell with 11.53% η.

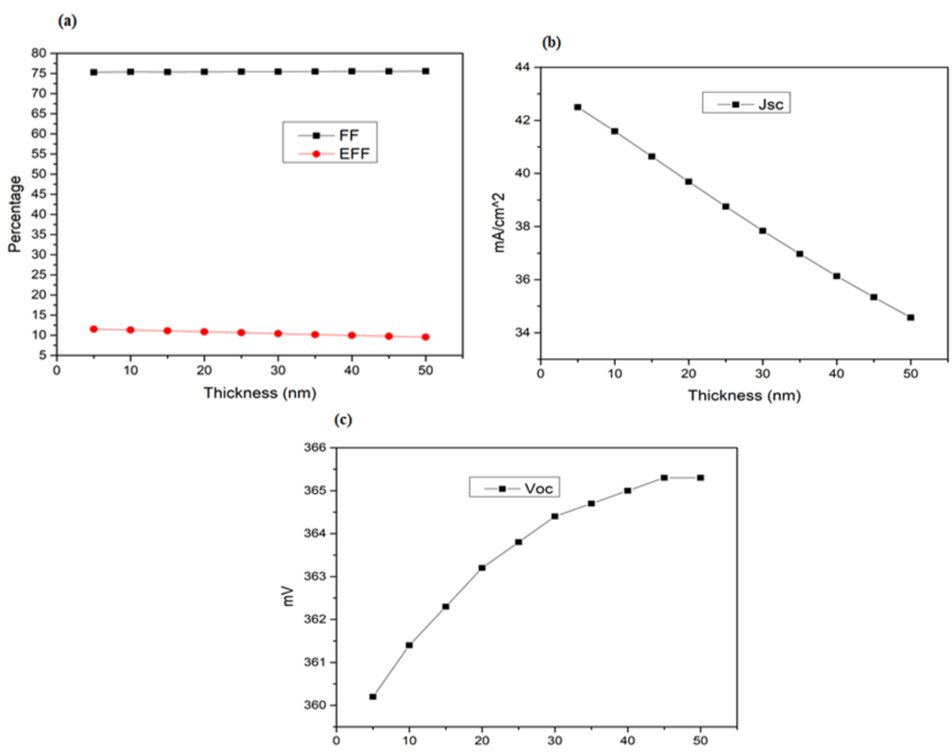

Fig.7 (a), (b), and (c) show the effect of N++ layer thickness on the results of Si-Ge alloy Solar Cell.

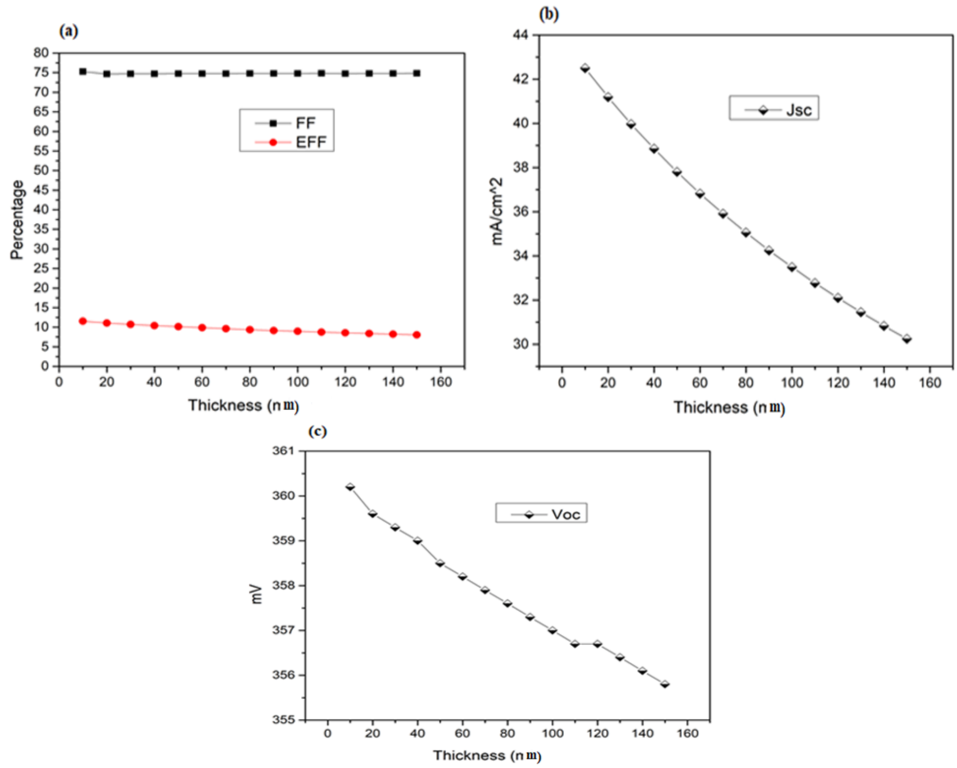

Fig 8. (a), (b), and (c) show the effect of N layer thickness on the results of Si-Ge alloy Solar Cell.

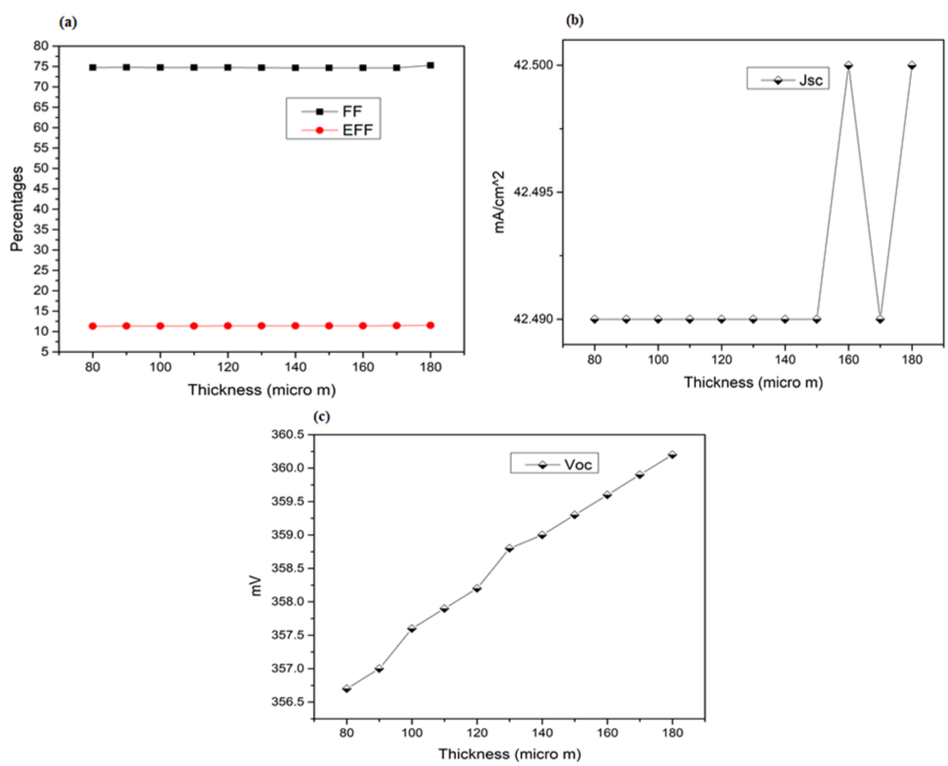

Fig 9. (a), (b), and (c) show the effect of P layer thickness on the results of Si-Ge alloy Solar Cell.

4 Conclusion

In this paper, an efficient a-Si/c-Si HIT solar cell with 25.23% conversion efficiency, 712 mV Voc, 42.06 mA/cm2 Jsc, and 84.26% FF is designed. Moreover, an efficient Si-Ge alloy and Ge solar cell with a conversion efficiency of 11.53% and 5.125% are designed respectively. These solar cells can perform best for making tandem cells with other materials as well as these cells can be stacked with each other to form a very new tandem structure.

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