STRUCTURE THICKNESS ANALYSIS OF SILICON SOLAR CELL USING SILVACO SIMULATOR

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Abstract-Solar cells made from semiconductor materials such as silicon and gallium arsenic. Both materials can produce higher efficiency than other semiconductor materials. The main parameters in solar cell technology are the contact to the cell, the p+ layer, n+ layer and the use of anti-reflective coating (AR coating), which are of capital importance in the improvement of the efficiency of semiconductor solar cells. The focus was given more on the single junction silicon solar cells. Silvaco simulator was introduced for designing and simulating the solar cell. Silvaco Athena tool was used to develop the solar cell structure and Silvaco Atlas tool was used to extract the electrical characteristic of the solar cell. Several samples were created and the effects of the each solar cell were analyzed. By varying the solar cell thickness, the thinner solar cell gives better efficiency because of the reduction of photogeneration rate in deeper area. The rate of carrier generation will be the highest near the incident surface and will decrease exponentially with the distance deeper into the semiconductor.

Keyword: Solar cell, Efficiency, Thickness Effect, Structure Effect

I. INTRODUCTION

Solar cells are made of various semiconducting materials. The direct conversion of sunlight into energy using solar cells is called the photovoltaic effect[4]. The word photovoltaic is a combination of the Greek word for light and the name of the physicist Allesandro Volta. The conversion process is based on discovery by Alexander Bequerel in 1839[4],[12]. The photoelectric effect describes the release of positive and negative charge carriers in a solid state when light strikes its surface.

The absorbed light causes electrons in the material to increase in energy, at the same time making them free to move around in the material. However, the electrons remain at this higher energy for only a short time before returning to their original lower energy position. To collect the carriers before they lose the energy gained from the light, a pn junction is typically used. The pn junction consists of p+ and n+ semiconductor layer[4].

In this project, the different possibilities to improve the efficiency of solar cells will be found and propose to simulate different silicon structured layers thickness to determine the best structured cell that aim at higher efficiency using in a single pn junction. Apply anti-reflective coating (AR coating) to improve their efficiency[2]. The Silvaco simulator is use to design the solar cell structure and simulating the solar cell.

A. Problem statement

One of the factors that determine the economic feasibility of a solar cell is the cost of the semiconductor material. Thus cells made on thin semiconductor films can lower the cost if the energy conversion efficiency is maintained and if other manufacturing costs are not higher in the thin film technology. The photovoltaics industry is dominated by silicon solar cells technology mainly because of the low manufacturing cost. However, these solar cells show an important limiting factor on conversion efficiency due to the inefficient absorption of high energy photons as a consequence of the indirect bandgap structure of bulk silicon.

B. Objectives

- To study about the solar cells characteristics.
- To design the single junction of solar cells using Silvaco Athena simulator.
- To observe the efficiency of different silicon structured layer thickness using Silvaco Atlas simulator.

II. LITERATURE REVIEW

A. Solar cell characteristic.

Solar cells are made from semiconductors and have much in common with other solid-state electronic devices such as diodes.

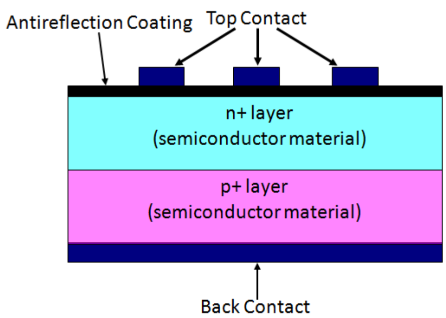

Figure 2.1: Solar cell layers.

The solar cell operation is based on the ability of semiconductors to convert sunlight directly into electricity by exploiting the photovoltaic effect. In the conversion process, the incident energy of light creates mobile charged particles in the semiconductor which are then separated by the device structure and produce electrical current[4].

The pn-junction is the region in the solar cell where the n-type and p-type silicon layers meet is called the pn-junction. The p-type silicon layer contains more positive charges, called holes, and the n-type silicon layer contains more negative charges, or electrons. When p-type and n-type materials are placed in contact with each other, current will flow readily in one direction (forward biased) but not in the other (reverse biased)[6].

The pn-junction, a one-way road, only allows the electrons to move in one direction. If we provide an external conductive path, electrons will
flow through this path to their original (p-type) side to unite with holes[13].

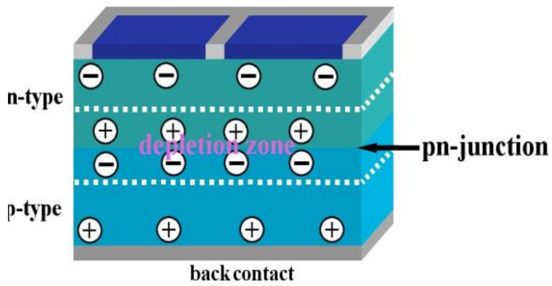

Figure 2.2: pn junction in solar cell.

Pure single crystal silicon is a very poor conductor because all the valence electrons are bonded with their neighbors. To collect the photocurrent, solar cells are constructed like a battery. This is done by taking two semiconductors of opposite charge and putting them together.

To make silicon solar cell, approximately $2x10^{16}/cm^3$ acceptor atoms (atoms with 3 valences electrons such as Boron) or approximately $1x10^{19}/cm^3$ donor atoms (atoms with 5 valence electrons such as Phosphorous) are substituted for the silicon atoms with four valence electrons[6].

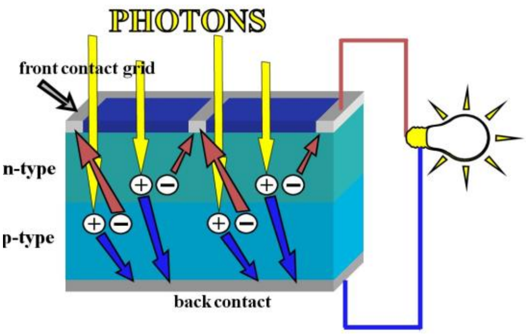

Figure 2.3: how solar cell works.

B. Silvaco simulator

Silvaco simulator has been chosen to simulate the solar cell. Silvaco simulator consists of two parts which are ATHENA and ATLAS.

ATHENA is used to design the solar cell structure and ATLAS is used to simulate the solar cell to produce the result such as the efficiency of the solar cell. ATHENA and ATLAS are device simulator that is developed by Silvaco International was introduced and it is used as a tool in modeling solar cell[11].

ATLAS is capable to simulate the physically-based two (2D) and three-dimensional (3D) simulation of semiconductor devices. ATLAS is best used with other interactive tools including DECKBUILD and TONYPLOT. It also can predict the electrical behavior of specified semiconductor structures and provides insight into the internal physical mechanisms associated with device operation. ATLAS simulator can extracts the electrical characteristics of a solar cell based on virtual fabrication of its physical structure, allowing for direct manipulation of materials, dimensions and dopings[12].

III. Design Methodology

A. Monocrystaline solar cell design

For silicon layer, some impurity must be dope to the silicon to produce the pn junction. To create the p-type region, choosing the Boron impurities to be dope into the silicon layer. The minimum concentration for this p-type region is $2x10^{16}/cm^3$[6]. So, $20x10^{18}/cm^3$ has been choose for designing the p-type region solarcell.

To create the n-type region, choosing the Phosphorous impurities to be dope into the silicon layer. The minimum concentration for this n-type region is $1x10^{19}/cm^3$ [6]. So, $10x10^{19}/cm^3$ has been choose for designing the n-type region solar cell.

Silvaco simulator is tool that used to design and simulate the solar cell. Silvaco simulator consists of two parts which are ATHENA and ATLAS.

Both tools are used to design the structure of the solar cell. Firstly, the first layer of silicon was constructed and dopes it with Boron to form the p-type (p+) region. Boron is group III material in periodic table. Group III materials have 3 electrons valance. Secondly, the second layer of silicon was constructed and dopes it with Phosphorous to form the n-type (n+) region. Phosphorous is group V material in periodic table. It has 5 electrons valance.

After that, the AR coating layer was created using the silicon dioxide material[9]. AR coating material must be a material that very goods in light absorbing. This layer is very important so that the solar cell can absorb the light energy as much as they can. A lot of light energy can be absorb will produce the great efficiency for the solar cell. So, silicon dioxide (SiO_2) was chosen as an AR coating layer.

The last process is to create the back contact and the top contact of the solar cell. Aluminum was chose as a material for top contact in the designing the structure of solar cell[10].

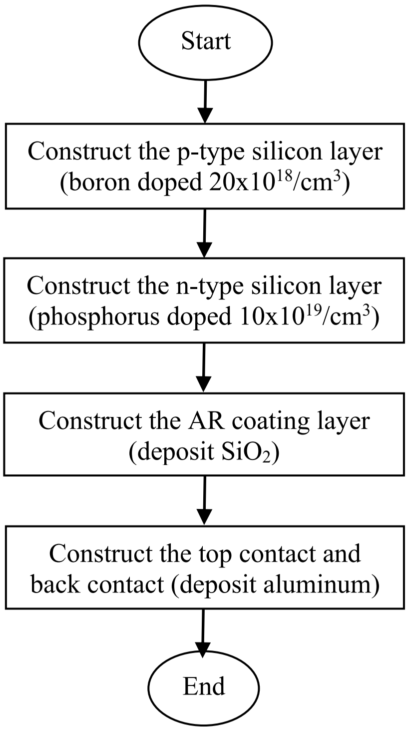

Figure 3.1: Solar cell design flow chart.

B. Solar cell analysis

The first Atlas simulation is to analyze the photogeneration rate of the solar cell. The imaginary refractive index for aluminum is set to 1000. It's defined to a high value to ensure it is opaque to the incident radiation. The beam statement represents the illumination by solar spectrum. Both origin and angle of incidence are set to be x.origin=60µm y.origin is varies with the thickness of the solar cell structure and the angle=90° that is the normal light incident from the top. The TONYPLOT show different contours of photogeneration rate means that the effect of the opaque cathode current.

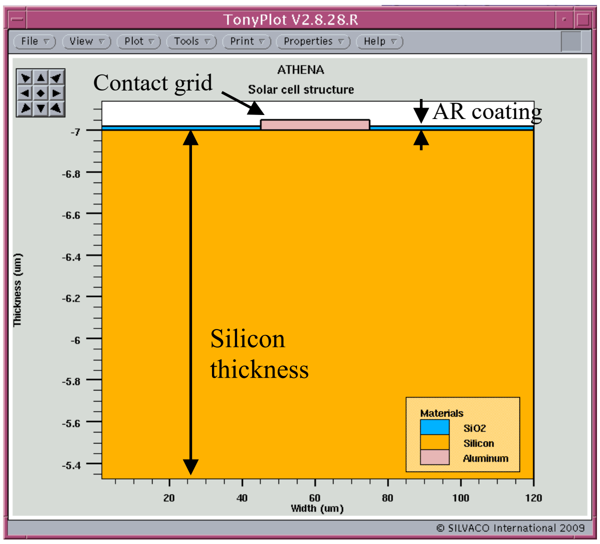

Figure 3.2: Solar cell structure

The second ATLAS simulation is to analyze the spectral response of the solar cell. A different light beam is required and the various wavelengths are used. The range of wavelength is 0.3µm to 1µm. The plot of source photocurrent (current available in the light beam), available photocurrent (current available for collection) and actual cathode current versus wavelength shows how the device behaves.

The main objective is to observe the effect of the thickness on solar cell efficiency. So, plot of efficiency versus light energy was needed and gives more focus. By using TONYPLOT function, the x-axis was set to be light energy as[14]:

$$\text{Light Energy (eV)} = hc/q \qquad (3.1)$$

Where h=Planck's constant, c=speed of light and q=electronic charge. In TONYPLOT the function needed was:

6.6e-34*3.0e+8/ (1.6e-19*Optical Wavelength)

On the y-axis, the efficiency was needed. Basically, the efficiency is defined as power output/power input. In TONYPLOT the function needed was:

Cathode Current/Source photo current

IV. Result And Discussion

This project focuses on observing the effect of structure thickness on the efficiency of single junction solar cell. Several samples with differences thickness of solar cell were designed.

All the characteristic of the solar cell were extracted. Analysis about the efficiency was done and compare with the theoretical. Generally the efficiency of the single junction silicon solar cell is about 16% – 24% with total radiance in 1000 Wm^{-2}[3].

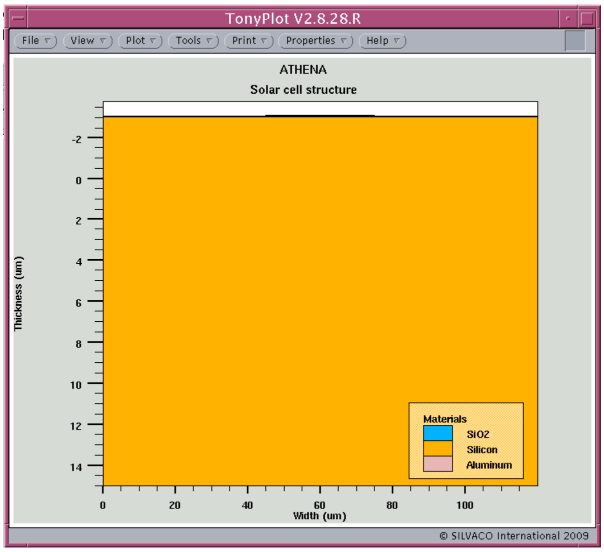

Figure 4.1: Solar cell structure for thickness of n-type=3µm and p-type=15µm.

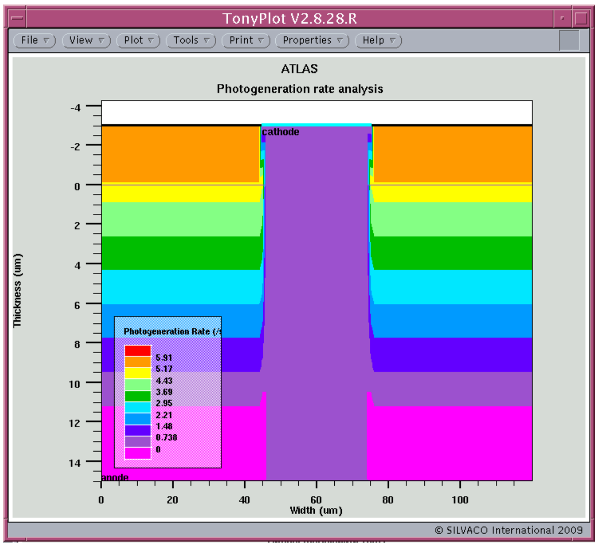

Figure 4.2: Photogeneration rate of solar cell for thickness of n-type=3μm and p-type=15μm.

Figure 4.1 was design with thickness of n-type=3μm and p-type=15μm. Figure 4.2 shows that the photogeneration rate of this solar cell. About 77.8% of the area of cell absorb the photon energy and generate it to current density except the area under the contact grid. The contact grid was blocked the light energy from the top. Figure 4.3 shows the graph of source photocurrent (current available in the light beam), available photocurrent (current available for collection) and actual cathode current versus wavelength.

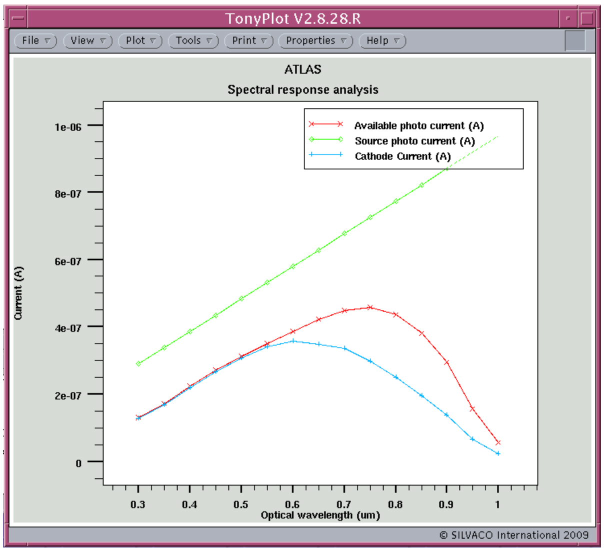

Figure 4.3: Spectral response of solar cell for thickness of n-type=3μm and p-type=15μm.

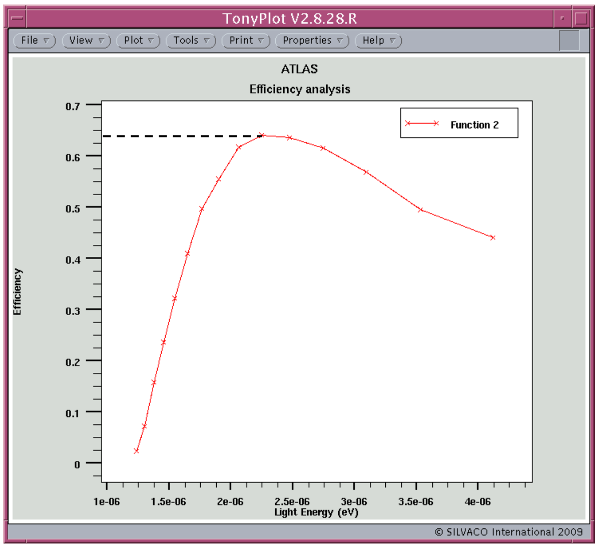

Figure 4.4: Efficiency of solar cell for thickness of n-type=3μm and p-type=15μm.

However, the decreasing of cathode current is cause by the solar cell reaches absorption limits[4] (Silicon visible wavelength 0.2μm ~ 1.2μm[13]). Figure 4.4 shows the maximum efficiency of this sample is 64.5%(see Figure 4.4).

Figure 4.5 was design with thickness of n-type=7μm and p-type=35μm. It shows that there are only about 34.5% of the total area of cell absorb the photon energy and generate it to current density. The maximum efficiency for this sample is 62.6% (see Figure 4.6).

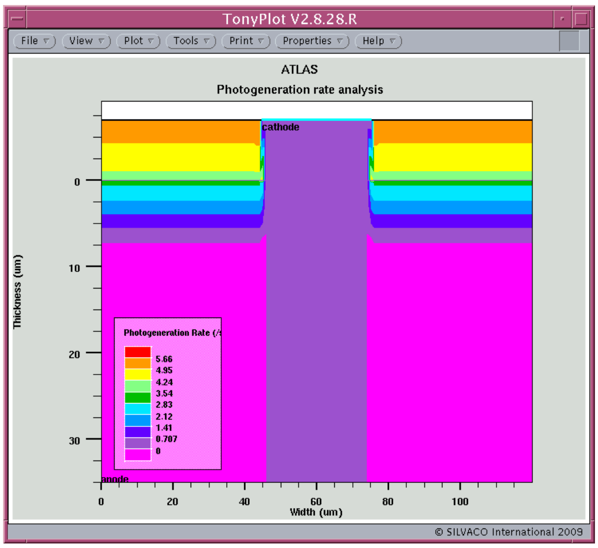

Figure 4.5: Photogeneration rate of solar cell for thickness of n-type=7μm and p-type=35μm.

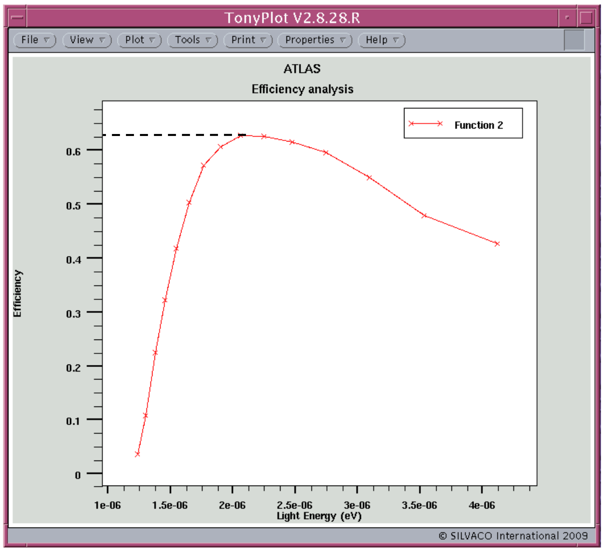

Figure 4.6: Efficiency of solar cell for thickness of n-type=7µm and p-type=35µm.

Figure 4.7 was design with thickness of n-type=11µm and p-type=55µm. It shows that there are only about 21.7% of the total area of cell absorb the photon energy and generate it to current density. The maximum efficiency for this sample is 59.1%(see Figure 4.8).

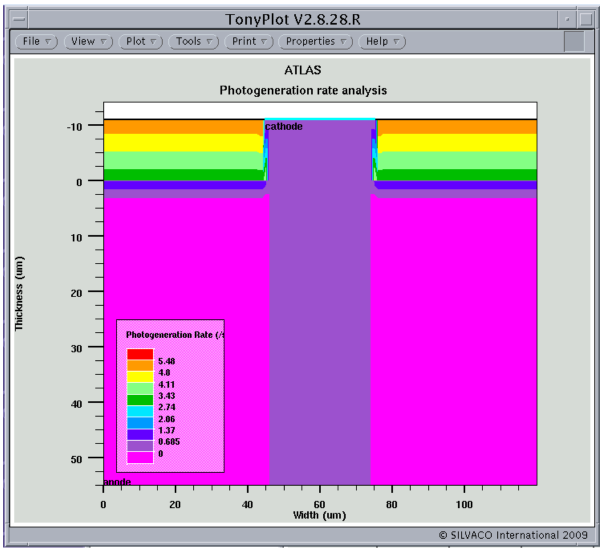

Figure 4.7: Photogeneration rate of solar cell for thickness of n-type=11µm and p-type=55µm.

Table 4.1 show the various sample of solar cell with different thickness. The maximum efficiency of each sample was taken. Based on the Table 4.1, it shows that the thickness of the solar cell gives an effect on solar cell efficiency. The thinner solar cell the higher efficiency produced. This is because in actual case the photon absorption and carrier generation will not be uniform everywhere. So, the rate of photogeneration will be the highest near the incident surface and will decrease exponentially with distance[13].

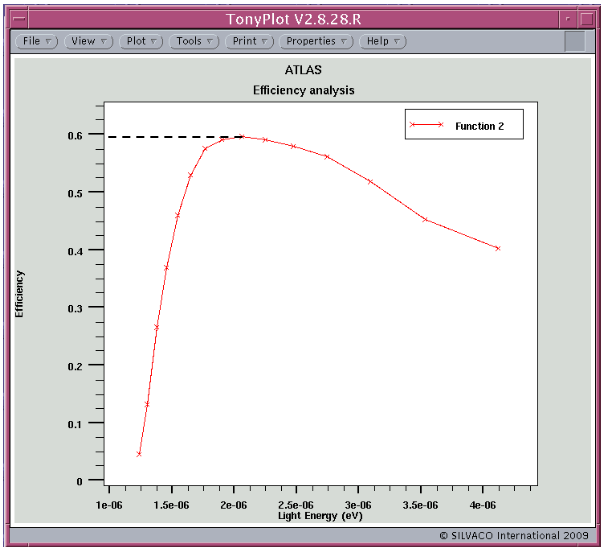

Figure 4.8: Efficiency of solar cell for thickness of n-type=11µm and p-type=55µm.

Table 4.1: Maximum efficiency for silicon solar cell with different thickness

Thickness (µm)		***Efficiency (%)***
p-type	n-type	
15	3	64.5
20	4	64.5
25	5	63.8
30	6	63.0
35	7	62.6
40	8	62.1
45	9	61.7
50	10	60.8
55	11	59.1

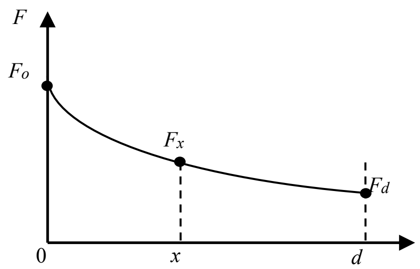

Figure 4.9: Photon flux inside the semiconductor as a function of distance.

Figure 4.9 show that the emerging photon flux F_d will be much less than the incident flux Fo. The higher photon energy the higher will be chance of ionizing a covalent bond and the higher will be the rate of absorption rate of the photons. Photon absorption is measured in term of absorption coefficient, α in the semiconductor[13].

$$F_{(x)} - F_{(x-\Delta x)} = \alpha F_x \Delta x \quad (4.1)$$

$$\Delta F_x = -\alpha F_x \Delta x \quad (4.2)$$

$$\frac{dFx}{dx} = -\alpha F_x \quad (4.3)$$

Solving eqn (4.3) subject to boundary condition that

$$F_x = F_0 \quad at\ x = 0 \qquad (4.4)$$

$$F_x = F_0 e^{-\alpha x} \qquad (4.5)$$

Where x is the thickness of semiconductor.

That mean the deeper into the bulk the less photogeneration occur cause by the decreases of light energy. Its mean the thinner of the solar cell gives better photogeneration rate and will increase the efficiency.

V. CONCLUSION

In conclusion, the solar cells consist of several layers which are top contact, anti-reflecting coating, semiconductor layer (n+ and p+) and back contact. All of this layers have their own function and very important in design the solar cells. Single junction is the best technology of silicon solar cells because it gives the best energy conversion than other technologies. Silvaco simulator is used to design the solar cells and simulate it to extract the characteristics of the solar cells. The thickness of the solar cell gives an effect to the solar cell efficiency. By varying the thickness, the thinner solar cell gives better efficiency because of the photogeneration rate is reduced in deeper area. Furthermore, varying the thickness also give an impact on the construction cost. Thin solar cell used fewer raw materials and reduces operational cost.

VI. FUTURE DEVELOPMENT

Solar cells become popular nowadays because of their ability to provide nearly permanent, uninterrupted power. However in providing the power, they have low power per unit area of sunlight which causes the low efficiencies. Its performance is dependent upon the intensity of the sunlight and also the material used for the solar cell device.

There are several methods in designing solar cell. Different method will give an effect on the solar cell efficiency. Likes using different bulk structure such as V-groove and corrugated solar cell. In addition, the fabrication steps also give an effect on the solar cell such as varying temperature, diffusion method, implantation method and etching. In fact, in the previous research it had been proven that smaller contact area has given the higher efficiency of solar cell. So, by combining this analysis and previous analysis will improve the efficiency of solar cell.

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