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THE CHARACTERIZATION OF DOPING DOSE, ANNEAL TIME AND TEMPERATURE FOR SILICON SOLAR CELL EFFICIENCY

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ABSTRACT

This paper is carry out aiming on produce one design and fabrication of solar cell with various parameters to measure which are concentration of phosphorus, anneals time and temperature that can be the optimum value of silicon solar cell. These parameters are important to definite the optimum depth so that the best efficiency of solar cell can be achieved. The variable parameter for phosphorus doping is 13, 15 and 17, meanwhile the anneal time is 5 min, 10 min and 15 min, and the anneal temperature is 900 ^{o}C, 950 ^{o}C, 1000 ^{o}C and 1050 ^{o}C are considered in this project. This project included the basic principle of operations, creation and fabrication process of solar cell structure, and the electrical characteristics simulated in details. The fabrication process and simulation of solar cell are performing by using '*Virtual Wafer Fabrication*' software produced by SILVACO Inc. TCAD tools. There are two sub aid module which are modelling a solar cell device and simulated the electrical characteristic were computed by Athena and Atlas simulator, respectively. Spectral response and *I-V* characteristic graphs are important output that produce a short circuit current density, J_{sc} and open circuit voltage, V_{oc} were changed due to various parameters on silicon solar cell. As a conclusion, the result outcome shows that solar cell operated according to the optimum efficiency when phosphorus doping is 8×10^{15} atom/cm^2 during 5 min at 900^{o}C in annealing process and each has 13.08%, 13.47%, 13.89%, respectively.

INTRODUCTION

Solar cell also known as photovoltaic cell is a device that converts light energy from sun into electrical energy. The basic material of solar cell is semiconductor. Earth can received the maximum power from sun is about 1000 W/m^2 [1]. This energy will build a charged particle moving in semiconductor material. Electrons or negative charged are knocked loose from their atoms, allowing them to flow through the material to produce electricity. The complementary positive charges that are also created (like bubbles) are called holes and flow in the direction opposite of the electrons in a semiconductor solar panel. An array of solar panels converts solar energy into a usable amount of direct current (DC) electricity.

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Several parameters are required in semiconductor material selection to obtain the optimum result. Fabrication cost, material source, toxicity and efficiency are the most selection factors. In this case, the solar cell will be studied the efficiency with variable of phosphorus concentration in silicon substrate as a thin film, and also changing of temperature and annealing time. These parameters are to control the optimum junction depth for the maximum performance solar cell.

The most semiconductor material in earth is silicon and it is exist from silicon dioxide. On Earth, silicon is the second most abundant element (after oxygen) in the crust, making up 25.7% of the crust by mass. So, it is easily found and the toxicity is less. The solar cell classification is based on cell designing and cell fabrication process. These are the most classification required such as cell poles, junction depth, multilayer surface and antireflective coating. Other classifications are efficiency of cell, cell size, type of cell and configuration of cell absorbtion and thickness.

A solar cell is a pn junction device with no voltage directly applied across the junction. The solar cell converts photon power into electrical power and delivers this power to a load. The devices have long been used for the power supply of satellites and space vehicles, and also as the power supply to some calculators. Consider the pn junction shown in Figure 1 with a resistive load. Even with zero bias applied to the junction, an electric field exists in the space charge region, as shown in figure. Incident photon illumination can create electron-hole pairs in the space charge region that will be swept out producing I_L in the reverse-bias direction as shown.

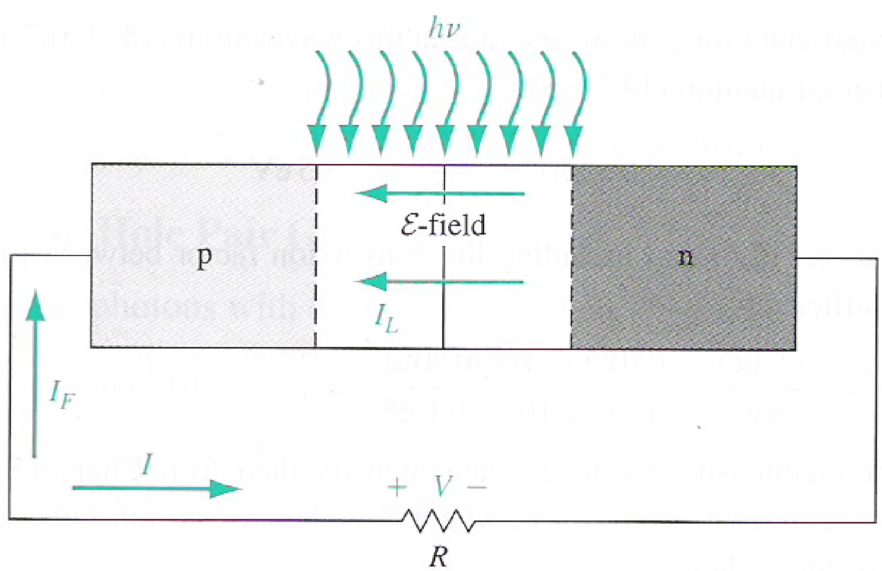

Figure 1. A pn junction solar cell with resistive load.

The photocurrent I_L produces a voltage drop across the resistive load, which forward bias the pn junction. The forward bias produces a forward-bias current I_F, as indicated in the figure. The net pn junction current, in the reverse-bias direction, is

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$$I = I_L - I_F = I_L - I_S\left[\exp\left(\frac{eV}{kT}\right) - 1\right] \quad (1)$$

Where the ideal diode equation has been used. The are two limiting cases for interest. The short-circuit condition occurs when R = 0 so that V = 0. The current in this cases is referred to as the short-circuit current, or

$$I = I_{sc} = I_L \qquad (2)$$

The second limitiing case is the open-circuit condition and occurs when R→∞. The net current is zero and the voltage produced is the open-circuit voltage. The photocurrent is just balanced by the forward-biased junction current, so

$$I = 0 = I_L - I_S\left[\exp\left(\frac{eV_{oc}}{kT}\right) - 1\right] \qquad (3)$$

And find the open circuit voltage V_{oc} as

$$V_{oc} = V_t \ln\left(1 + \frac{I_L}{I_S}\right) \qquad (4)$$

A plot of the diode current *I* as a function of the diode voltage *V* from Eq. 1 is shown in Figure 2. The current and voltage which will deliver the maximum power to the load by setting the derivative equal to zero, or $dP/dV = 0$. Using Eq. 4, can find

$$\frac{dP}{dV} = 0 = I_L - I_S\left[\exp\left(\frac{eV_m}{kT}\right) - 1\right] - I_S V_m\left(\frac{e}{kT}\right)\exp\left(\frac{eV_m}{kT}\right) \qquad (5)$$

where V_m is the voltage which produces the maximum power. The value of V_m can be determined by the trial and error. The maximum power rectangle where I_m is the current when $V = V_m$ as shown in Fig. 2.

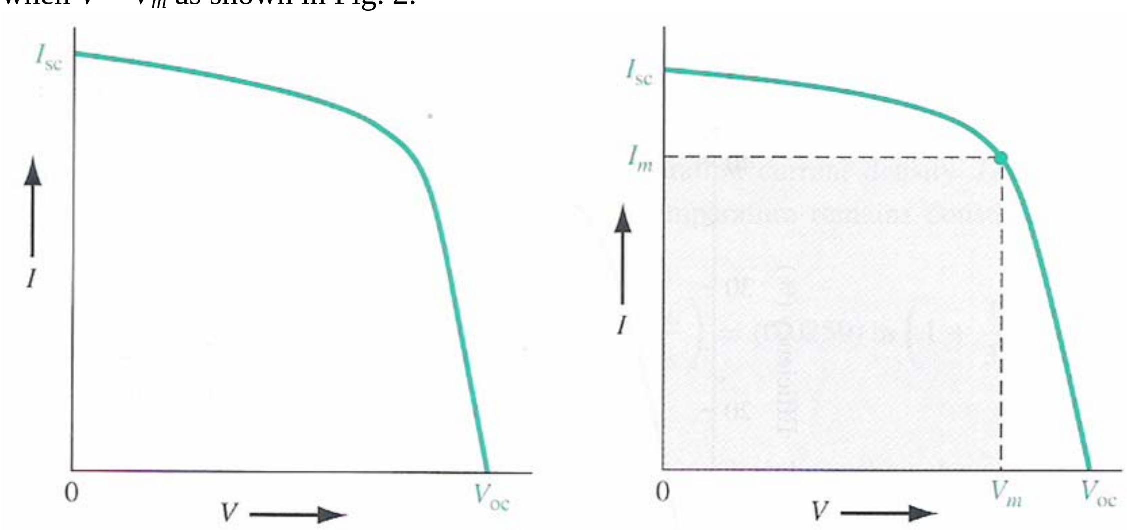

Figure 2. *I-V* characteristic of a pn junction solar cell and maximum power rectangle of the solar cell *I-V* characteristics

The conversion efficiency of a solar cell is defined as the ratio of output electrical power to incident optical power. For the maximum power output, can write

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$$\eta = \frac{P_m}{P_{in}} \times 100\% = \frac{I_m V_m}{P_{in}} \times 100\% \qquad (6)$$

The maximum posible current and the maximum posibble voltage in the solar cell are I_{sc} and V_{oc}, respectively. The ratio $I_m V_m / I_{sc} V_{oc}$ is called the fill factor and is a measure of the realizable power from a solar cell. Typically, the fill factor is between 0.7 and 0.8 [2].

METHODOLOGY

The fabrication process of solar cell started from the silicon substrate grid selection on silicon wafer p type with the boron concentration is 3.0×10^{14} atom/cm^2 and the orientation is <111>. Then the oxide is doped for 0.5 μm to produce SiO_2 layer on a top surface of substrate. It is used as a dope mask while doping process is running and prevented while the etching process is on. After the SiO_2 has been deposited, the etching process is applied to discard the unused SiO_2 layer. When the etching process is done, the ion implant technique is applied on silicon substrate with phosphorus atom doping 8.0×10^{13} atom/cm^2 concentrations. The doped atom is absorbed through annealing process in 10 min with 1000 °C temperatures. This process is used to develop a border region for n^+-p junction. The next step is applying the etching method with different thickness from before. This method is to have a gap between substrate and aluminum electrode. After the aluminum electrode is placed on substrate, the incident light is applying on solar cell surface to obtain the complete solar cell structure. Last but not least is to place the cathode electrode on the top of left and right side structure, and anode electrode on the bottom structure to connect to other circuit. This complete modeling process also applying onto variables phosphorus concentrations, annealing time and annealing temperature to compute the efficiency of solar cell. Finally, the model structure needs to apply voltage to analysis the current density output and open circuit voltage of solar cell.

RESULTS AND DISCUSSION

The solar cell structure has been done modeling by using SILVACO software package. In this project, the variable parameters for concentration of phosphorus are 8×10^{13} atom/cm^2, 8×10^{15} atom/cm^2 and 8×10^{17} atom/cm^2 has been choosen. Figure 3 shows the solar cell structure and the graph of photogeneration rate (red line) and total current density (green line) for variable phosphorus doping. This figure shown that the total current density from 8×10^{13} atom/cm^2 is higher than others phosphorus doping. At 8×10^{13} atom/cm^2 start from 0.018 A/cm^2 at surface structure, meanwhile 8×10^{15} atom/cm^2 and 8×10^{17} atom /cm^2 start from 0.01 A/cm^2 and 0.0055 A/cm^2, respectively.

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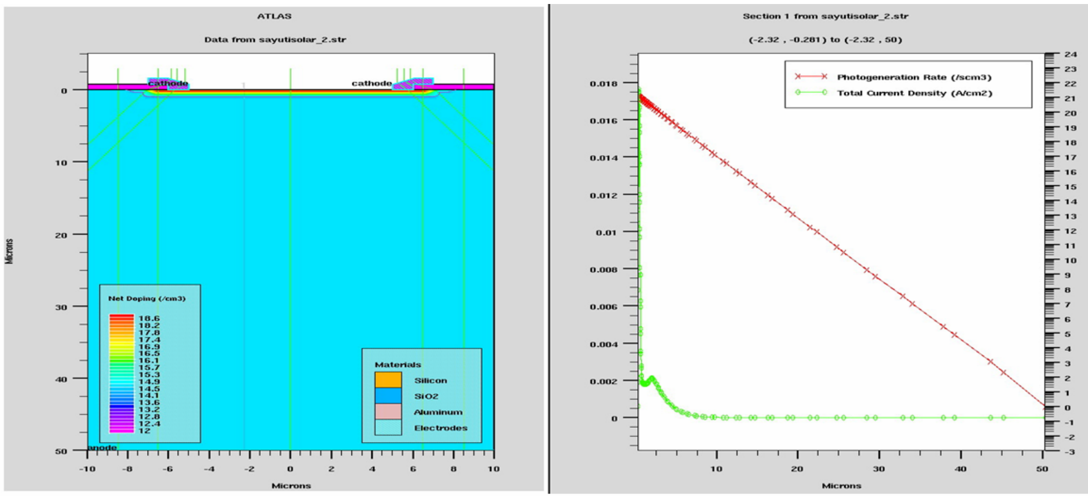
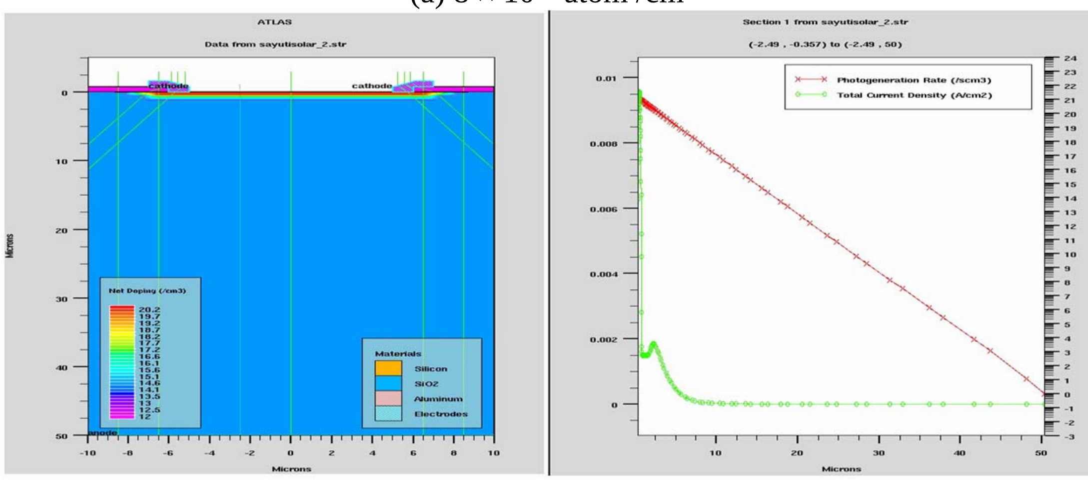
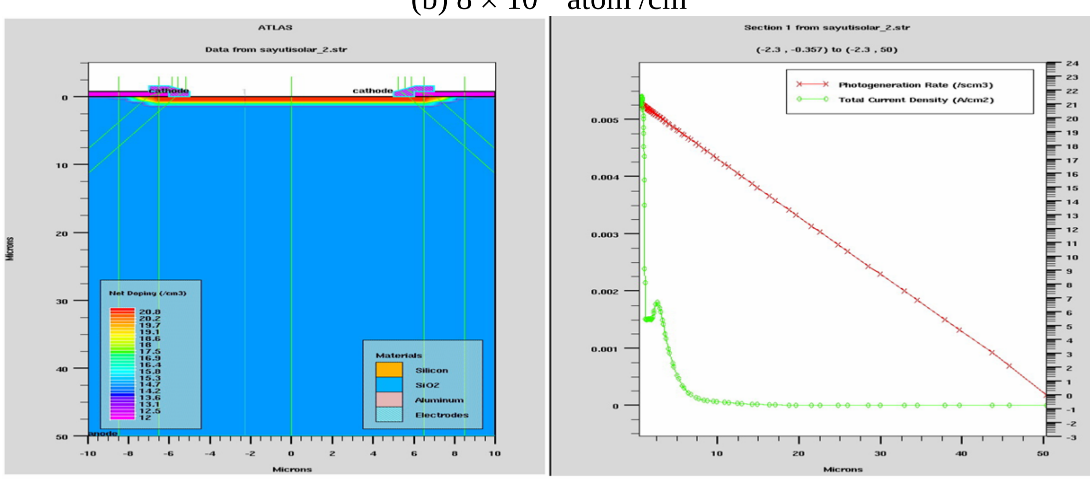


(a) 8×10^{13} atom /cm^2



(b) 8×10^{15} atom /cm^2



(c) 8×10^{17} atom /cm^2

Figure 3: Solar cell structure and graph of photogeneration rate and total current density vs. structure depth for variable phosphorus doping

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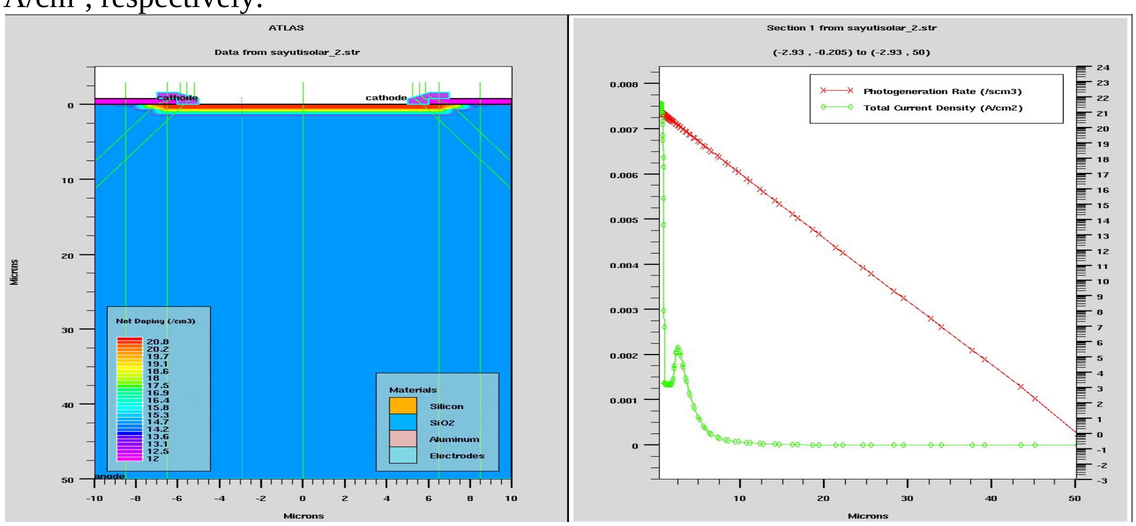
The *I-V* result increased some current density at 8×10^{15} atom/cm^2 and decreased at 8×10^{17} atom/cm^2. In this case, the parameter of annealing time and temperature are fixed to 10 min and 1000 °C, respectively. After all simulation has done running, the value of junction depth, short circuit current and open circuit voltage have been recorded and calculated in Table 1. This result can be concluded the efficiency of 8×10^{15} is higher than others doping which is η is 13.08%.

Table 1: Final result for variable phosphorus doping

Phosphorus Doping (atom/cm^2)	**8×10^{13}**	**8×10^{15}**	**8×10^{17}**
Junction Depth (μm)	0.98206	1.14738	1.39267
J_{sc} (nA)	3.99337	4.06532	4.06312
V_{oc} (mV)	433.96	434.35	434.23
η (%)	12.43	13.08	12.31

The research continues to the next parameter that has been chosen is annealing time, which are 5 min, 10 min and 15 min. The fixed parameters are phosphorus doping 8×10^{17} atom/cm^2 and temperature at 1000 °C. Figure 4 shows the solar cell structure and the graph of photogeneration rate (red line) and total current density (green line) for variable annealing time of solar cell. This figure shown that the total current density from 5 min is higher than others annealing time. At 5 min start from 0.0076 A/cm^2 at suface structure, meanwhile 10 min and 15 min start from 0.0065 A/cm^2 and 0.0050 A/cm^2, respectively.



(a) 5 min

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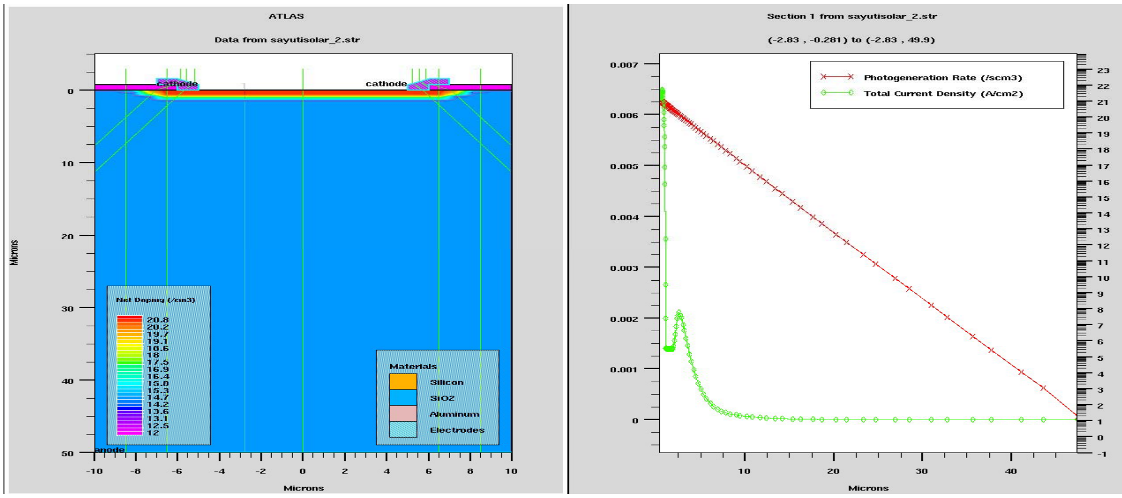
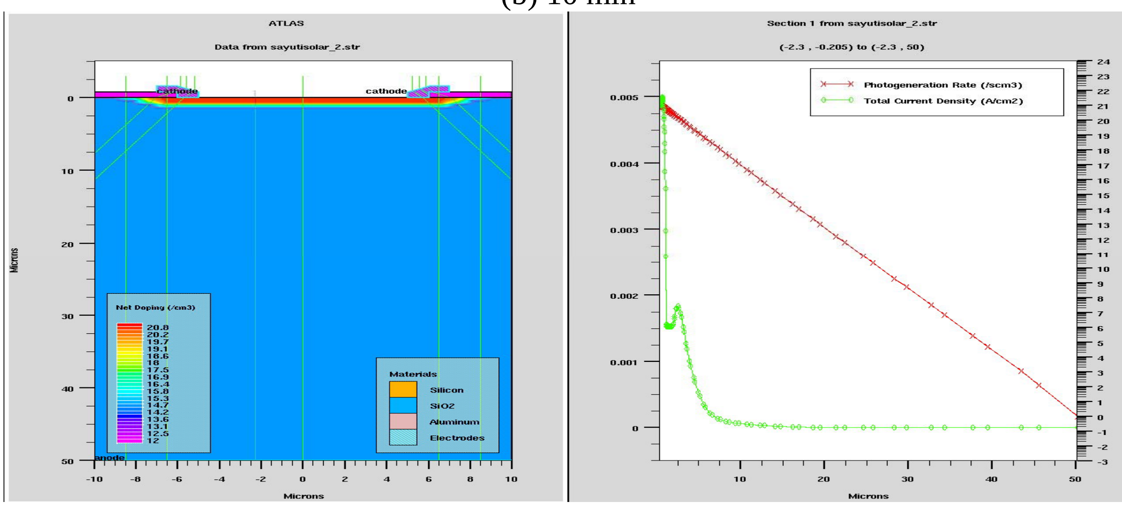


(b) 10 min



(c) 15 min

Figure 4: Solar cell structure and graph of photogeneration rate and total current density vs. structure depth for variable annealing time

After all simulation have done running, the value of junction depth, short circuit current and open circuit voltage have been recorded and calculated in Table 2. This result can be concluded the efficiency of 5 min is higher than others annealing time which is η is 13.47%.

Table 2: Final result for variable annealing time

Anneals Time (min)	**5**	**10**	**15**
Junction Depth (μm)	1.3857	1.3927	1.3997
J_{sc} (nA)	4.0678	4.0631	4.0591
V_{oc} (mV)	434.3	434.2	434.2
η (%)	13.47	12.75	12.34

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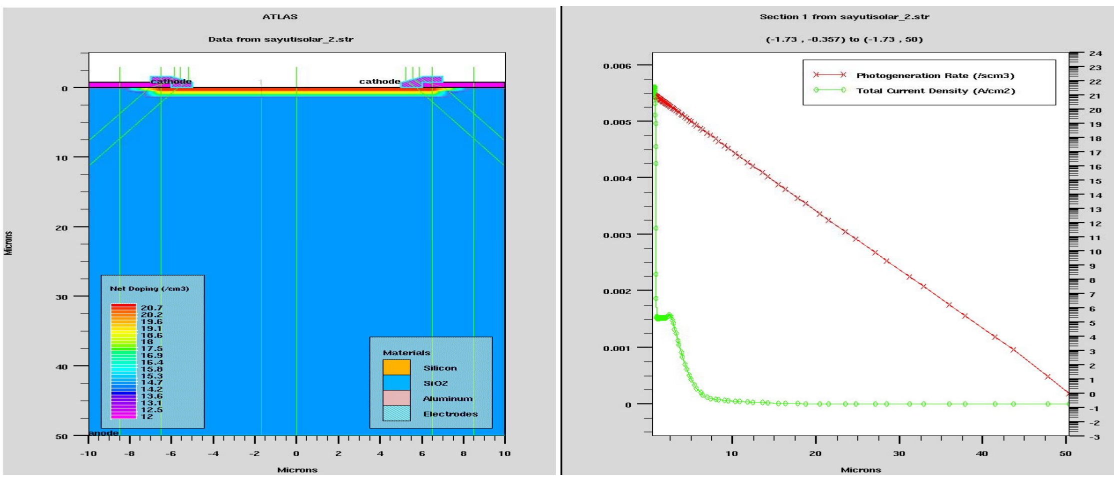
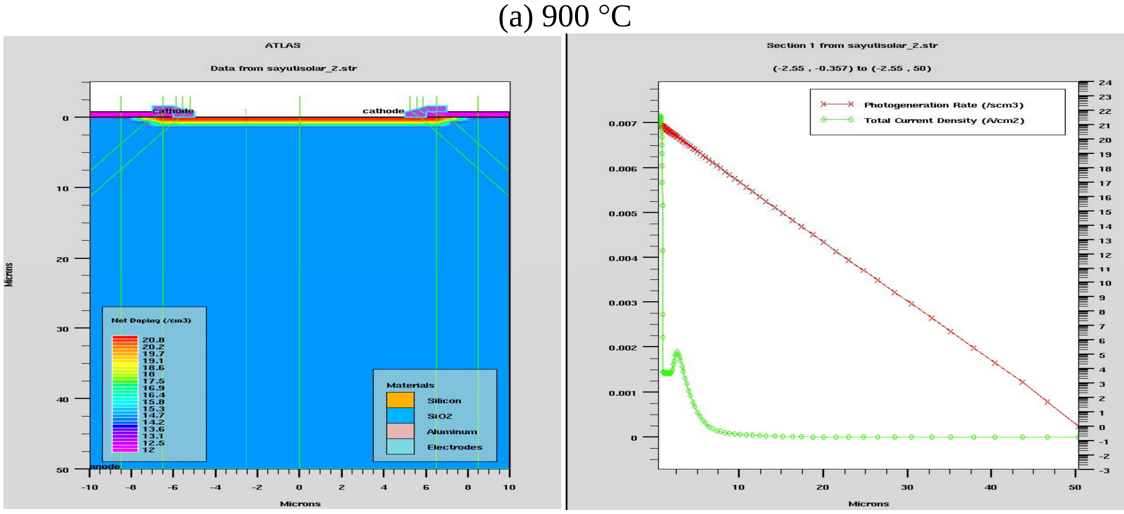
For the final parameter that has been concerned in this case is annealing temperature. The variable annealing temperature is 900 °C, 950 °C, 1000 °C and 1050 °C has been chosen. Figure 5 shows the solar cell structure and the graph of photogeneration rate (red line) and total current density (green line) for variable annealing temperature of solar cell. This figure shown that the total current density from 950 °C is higher than others annealing temperature. At 950 °C start from 0.0072 A/cm^2 at suface structure, meanwhile 900 °C, 1000 °C and 1050 °C start from 0.0057 A/cm^2, 0.0059 A/cm^2 and 0.0042 A/cm^2, respectively.



(a) 900 °C



(b) 950 °C

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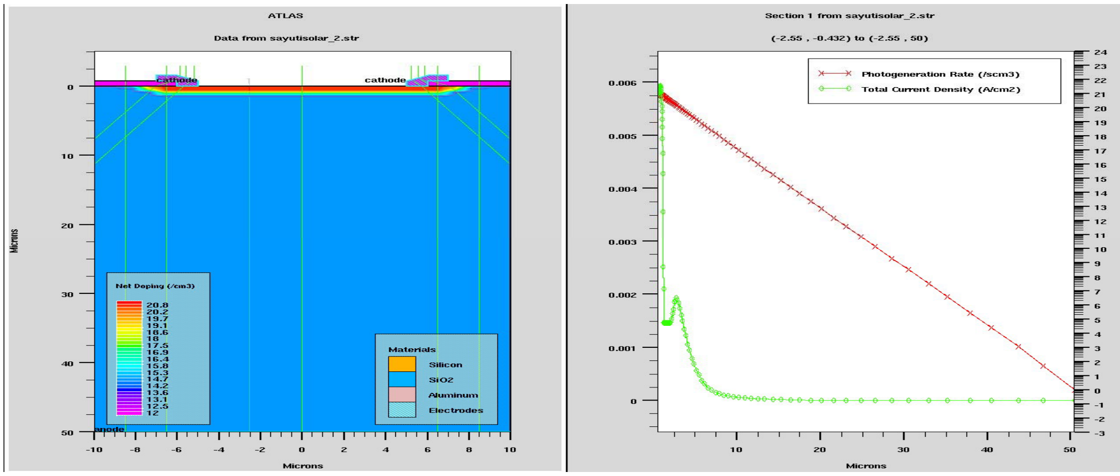
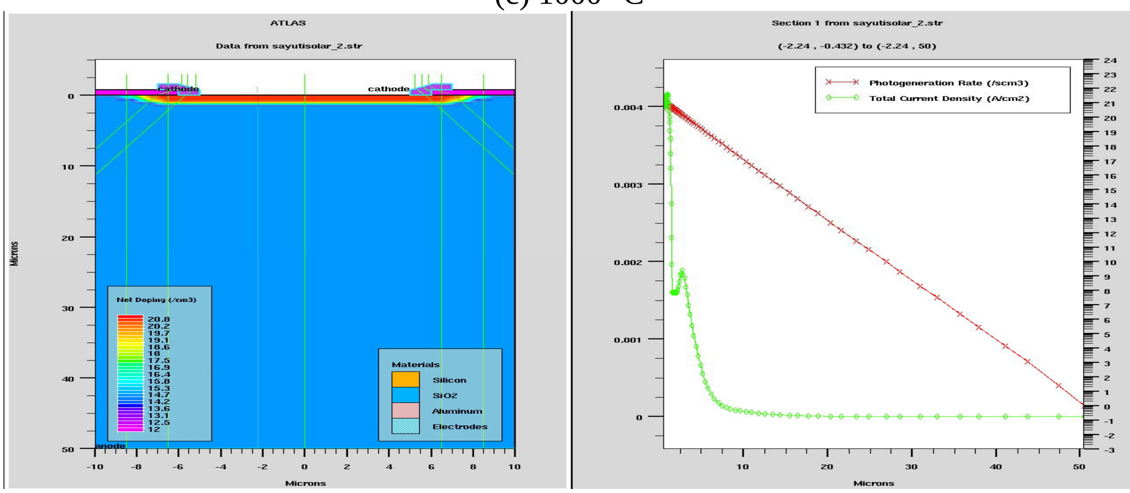


(c) 1000 °C



(d) 1050 °C

Figure 5: Solar cell structure and graph of photogeneration rate and total current density vs. structure depth for variable annealing temperature

After all simulations have done running, the value of junction depth, short circuit current and open circuit voltage have been recorded and calculated in Table 3. This result can be concluded the efficiency of 900 °C is higher than others annealing temperature which is η is 13.89%.

Table 3: Final result for variable annealing temperature

Anneals Temperature (°C)	**900**	**950**	**1000**	**1050**
Junction Depth (μm)	1.3796	1.3823	1.3927	1.4294
J_{sc} (nA)	4.0725	4.0694	4.0631	4.0498
V_{oc} (mV)	434.29	434.3	434.2	434.1
η (%)	13.89	13.42	13.02	12.27

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CONCLUSION

There are several parameters are needed to obtain the optimum depth, and have been stimulated in this project. The optimum concentration for phosphorus is 8×10^{15} atom/cm^2. This phosphorus concentration computed the short circuit current density, J_{sc} and open circuit voltage, V_{oc} better than the others. The suitable annealing time to get optimum depth is 5 min compared to other anneals time which are 10 min and 15 min. Meanwhile the optimum annealing temperature is 900 °C. These parameters resulted the optimum junction depth can be stimulated and the value of J_{sc} and V_{oc} is higher that other temperature. Through all the simulation have been done calculated, it can be concluded that there are some changes of energy conversion efficiency when the variable parameters of phosphorus doping, anneal time and anneal temperature are differently setting out. The optimum efficiency of silicon solar cell for phosphorus doping 8×10^{15} atom/cm^2, annealing time 5 min and temperature 900 ^{o}C is 13.08%, 13.47%, 13.89%, respectively.

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