# Fabrication and Characterization of Thin Film Solar Cells Using Liquid Dopant by Spin Coating Method

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***Abstract*—Silicon is still the mostly used element for solar cell production, due to the improvement of physical properties of silicon structures. Thus the aims of the study are to fabricate and the thin film solar cell using phosphorosilicafilm3 x *$10^{20}$*liquid dopant. Phosphorosilicadoped p-type silicon thin films were successfully deposited by spin coating in the range of 2000 - 4000 rpm and by using annealing temperature range of 700°C - 900°C in 30 minutes diffusion.The characterized of the film consist of electrical and physical properties. The properties of thin films solar cell were characterized by using Solar Simulator (Bukoh Keiki CEP-2000) and Field Emission Scanning Electron Microscope (FESEM) to measure current-voltage (I-V),Voc, Isc and fill-factor (FF) to get the efficiency (η) and for structure characterization.**

***Keywords:Phosphorosilicafilm3 x $10^{20}$, P-Type Silicon Solar Cells, Spin Coating Method.***

## I. INTRODUCTION

Silicon solar cells belong to a wide group of semiconductor detector devices and its basic part is p-n junction, which active part is less that 0.2µm thick, so it could be treated as thin film [1]. A large number of methods were developed for their characterization since thin films are very important in many fields of modern science. Spin coating is currently the predominant technique employed to produce materials with uniform thickness in the order of micrometers and nanometers. [2].

In a p-n junction photovoltaic (PV) cell, if the energy of the photon is at least equal to the band gap of the material, a photon of light produces an electron hole pair the p-n junction. The electrons and holes were diffused toward the respective edge of the depletion region. The built-in potential are collected at the electrodes when the electron and holes drift across the junction and the materials with long minority carrier life times and high carrier mobility are desired for high efficiency. A p-type semiconductor is used as light absorbers in a p-n junction solar cell due to the electrons have higher mobility than the holes. [3]

For an ideal homo-junction solar cell, the theoretical efficiency limit calculated by Loferski [4] is 23%, and show that the maximum efficiency falls in the vicinity of the absorbers with band gap energy of 1.5 eV. The predicted efficiency by Shockley and Queisser [5] justifiable as the limit that used atomic processes was put forward a maximum efficiency of 30% for a band gap of 1.1 eV which is possible if exposed to the sunlight of global air mass 1.5.

From the data that was published in Progress in Photovoltaics [6], degradation of the performance over time is a major issue associated with the a-Si solar cells while for thin film technologies, amorphous silicon-hydrogen alloy (a-Si) solar cells are fabricated with low cost technology [7]. Recently, thin film polycrystalline Si-solar cell at relatively low temperature from metal induced crystallization of a-Si is used in an effort to reduce the processing cost [8], but fabrication of these devices is combined with high temperature chemical vapor deposition, which makes it incompatible. [9]

Phosphorosilicafilm3 x $10^{20}$ is the formulation to produce phosphorous diffused layers in Silicon Solar Cells. When applied by spinning, these layers may be produced routinely with sheet resistance profiles over the wafer surface flatter than 1-2% and a film that consists of silica with phosphorous dissolved in it. Phosphorosilicafilm3 x $10^{20}$contains ethyl alcohol as solvent, but methanol or isopropyl alcohol may be used as diluents if it is desired to dilute the "as-received" formulation.

This research is focused on p-type silicon wafer doped with phosphorus by spin coating method. We use spin coating technique to prepare the phosphorosilica layer.

## II. EXPERIMENTAL DETAILS

The p-type silicon thin film solar cell was doped with phosphorosilica film deposited by spin coating method. This spin coating was produced at various spin speed and various deposition temperatures. A fixed of temperature was used for baking but various diffusion temperatures by chemical vapor deposition (CVD) furnace was implemented.

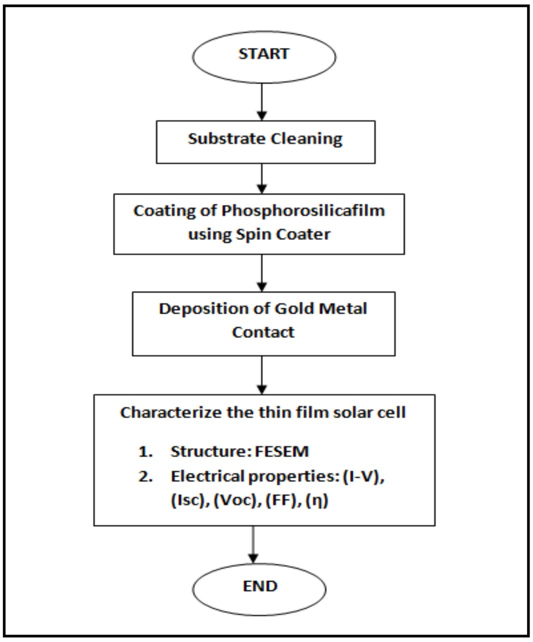



Figure 1: Flowchart for preparation and characterization of thin film solar cell

Refer to figure1, the experiment was started by preparing the p-type silicon wafer in 2cm x 2cm size. The substrates were cleaned with acetone to remove the wafer contamination and followed by cleaning with methanol in Ultrasonic Cleaner (powersonic405) for 10 minutes for both steps. Silicon substrates need to be submerged into solution of hydrofluoric acid and deionized (DI) water with ratio 1ml: 10ml for 1 minutes. The subsrate were cleaned with deionized (DI) water for 10 minutes in Ulrasonic Cleaner and lastly finally was blow dried with Argon (Ar) gas.

The phosphorosilicate liquid dopant was deposited by using spin coating method. Various spin speeds were used that are 2000 rpm, 3000 rpm and 4000 rpm for 30 second. The substrates were baked at 250 $^{o}$C temperature for 3 minutes to increase the adhesion. Then, the substrates were placed in Chemical Vapor Deposition (CVD) furnacefor the diffusion process to form n+ layerfor 30 minutes with various temperatures that are 700 $^{o}$C, 800 $^{o}$C and 900 $^{o}$C. Diffusion process was done in Argon environment by feeding Argon gas to the CVD. The substrates were deposited with pure gold (Au) using Electron Beam Thermal Evaporator for metal contact. At the top of substrate mask was used to the thickness of 8nm and at the bottom of substrate with thickness of 60nm without mask.

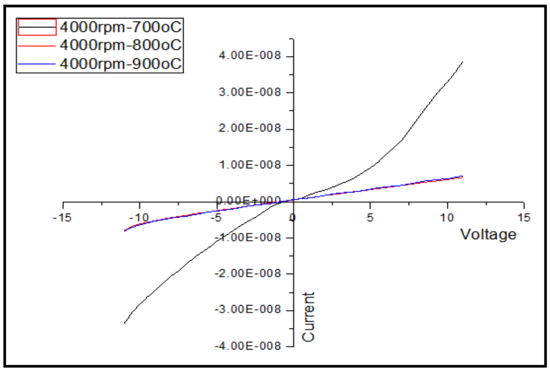
All the samples were characterized by using Solar Simulator (model: Bukoh Keiki CEP 2000) to measure the electrical properties. Field Emission Scanning Electron Microscopy (FESEM, ZEISS Supra 40VP) were use to measure the surface morphology of the substrate.

## III. RESULT AND DISCUSSION

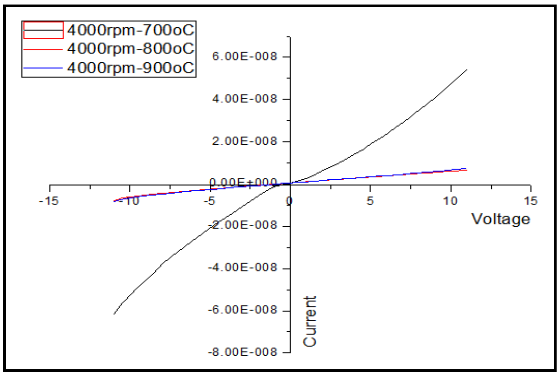
### A. Electrical Properties

#### i) IV Measurement Diffusing

The samples were prepared by diffusing Phosphorosilicafilm on p-type silicon thin film at different temperatures from 700 °C to 900 °C. From the literatures, metal contact such as Ti/Au and Ni/Au used in p-si have high work functions as ohmic contact for annealing temperature below 150 °C, nevertheless when annealing temperature exceed 150 °C, thermal instability occurs and the morphology became rough [10-12]. In this work, annealing temperatures up to 900°C were used gold (Au) as the metal contact. The electrical properties of p-si doped phosphorous thin film were measured by using two point probe solar simulator for voltage output in the range of -11V to 11V at room temperature. The current voltage (i-v) characteristic obtained can be in many form such as linear (ohmic), nonlinear and slightly linear form. [11,13]



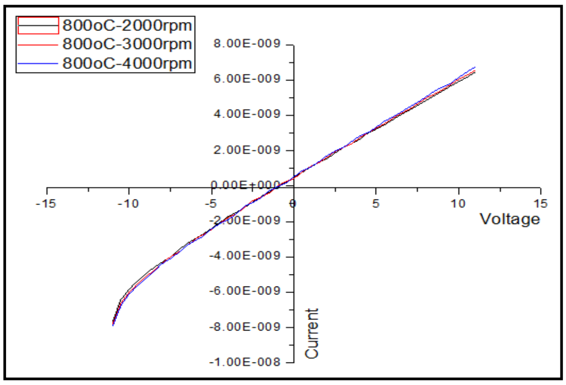

(a)



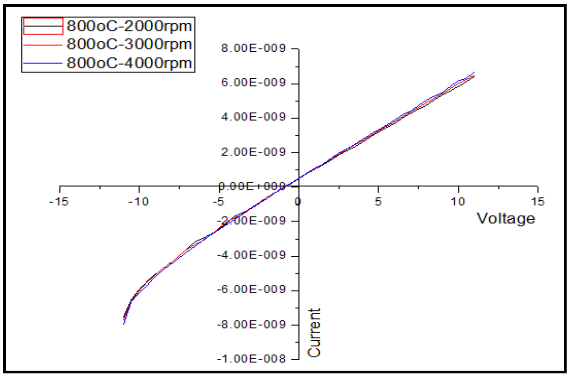

(b)

Figure 2: I-V measurement of Phosphorosilicafilm at 4000 rpm in the (a) dark and (b) illumination

From the figure 2, the slopes of i-v characteristic at 800 °C and 900 °C was linear (ohmic) for both in the dark and under illumination. The slopes at 700 °C show that the i-v characteristic is not linear (non-ohmic) which means the current does not increase linearly with applied voltage. The value of resistance can be determine by the value of current (I) and voltage (v) at point for one value because the resistance is not same as Ohm's law said. The nonlinear curve sometimes static but the resistance value depending on the point at nonlinear curve as seen in figure 2 above. [14, 15]



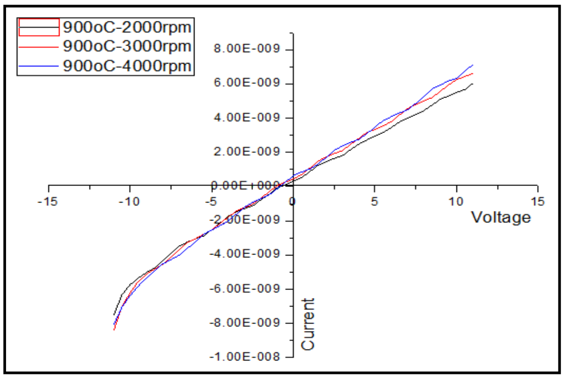

(a)



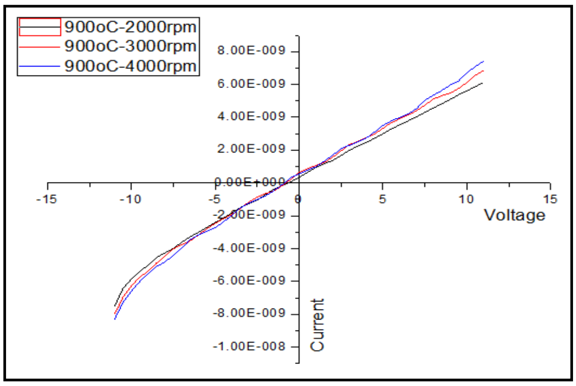

(b)

Figure 3: I-V measurement of Phosphorosilicafilm at 800°C in the (a) dark and (b) illumination

At the diffused temperature of 800 °C, the entire sample was linear (ohmic) in different spin speed for both situation of under illumination and in the dark behavior which means they produce the same value of resistance (R=V/I) [16,17]. Its mean that 800 °C is the good temperature for phosphorosilicafilm to diffuse due to the i-v characteristics is same for all sample.




(a)




(b)

Figure 4: I-V measurement of Phosphorosilicafilm at 900°C in the (a) dark and (b) illumination

The i-v characteristic for phosphorosilica at 900°C is higher at spin speed of 2000rpm and 3000rpm respectively for both situations. At 2000rpm is the lower curve but still linear (ohmic). Its mean that the diffused of phosphorosilica is also suitable at this temperature.

The resistivity ( $\rho$ ) and conductivity (σ) of phosphorosilicafilm thin films was calculated from the I-V curves by using the following equation:

$$\rho = \frac{RA}{L} = R\frac{wt}{L} \qquad (1)$$

$$\sigma = \frac{1}{\rho} \qquad (2)$$

The resistivity ( $\rho$ ) between two measured metal contacts can be calculated using equation (1) above where R is resistance measured from -11V to 11V, w is width of metal contact, t is the junction depth that diffused in silicon solar cell and L is distance between two metal contacts. From equation (1), the conductivity can be calculated using equation (2). [18]

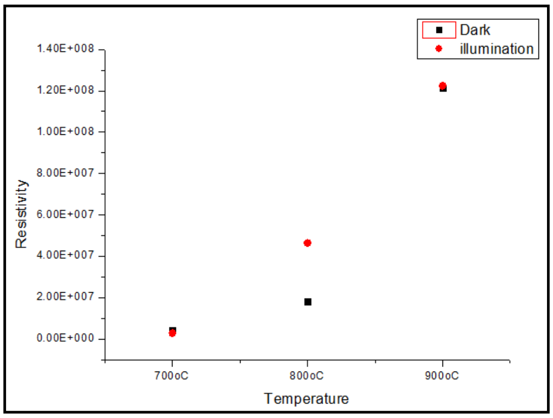



Figure 5: Resistivity curves of phosphorosilicafilm deposited at 4000rpm in the dark and illumination

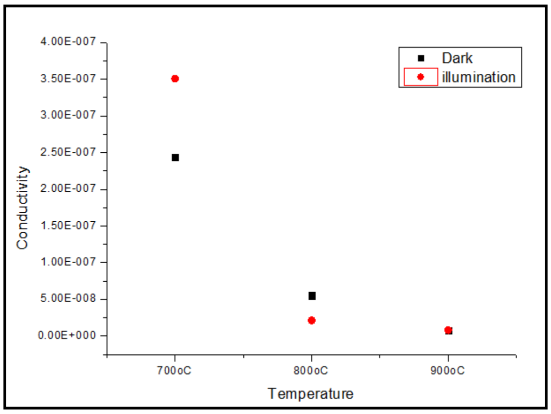



Figure 6: Conductivity curves of phosphorosilicafilm deposited at 4000rpm in the dark and illumination

The resistivity and conductivity was plotted as shown in figure 5 and figure 6 respectively. The resistivity and conductivity were calculated for both in dark and under illumination conditions. From figure 5, the resistivity of phosphorosilica film decreased for annealing temperature of 700$^{o}$C to 800$^{o}$C and increased at temperature 900$^{o}$C for both spin speed 2000rpm and 3000rpm. At spin speed 4000rpm, the resistivity increased with annealing temperature. The resistivity is very low at 4000rpm-700$^{o}$C at value 4.0992 x10$^{6}$(Ωcm) in dark and 2.8512 x10$^{6}$ (Ωcm) under illumination

ii) Solar Cell Characterization

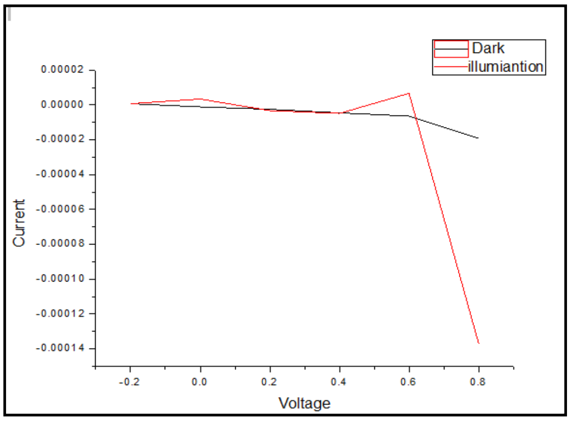



Figure 7: Solar cells measurement of Phosphorosilicafilm at 2000rpm-900$^{o}$C in the dark and illumination

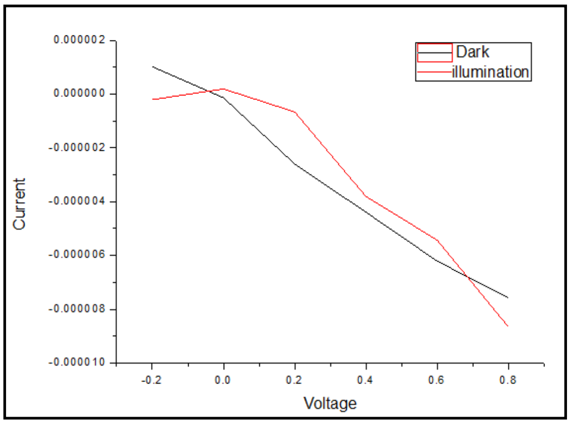



Figure 8: Solar cells measurement of Phosphorosilicafilm at 4000rpm-800$^{o}$C in the dark and illumination

Figure 7 and figure 8 shows the best I–V characteristic of the phosphorosilicafilm for solar measurements. The best samples were prepared at 2000rpm-900 oC and 4000rpm-800 oC. The fill factor (FF) and efficiency ( η) of phosphorosilica thin films were calculated from the I-V curves by using the following equation :

$$\mathrm{FF} = \frac{(VmppxImpp\ )}{(VocxIsc\ )}(1)$$

$$\mathrm{n} = \frac{(VocxIscxFF\ )}{(Pin)}\ \mathrm{x}\ 100\%(2)$$

The fill factor (FF) of solar cells can be calculate using equation (1) above where Vmpp is maximum power point voltage, Impp is maximum power point current, Voc is voltage at open circuits and Isc is current at short circuits. From equation (1), the efficiencies of solar cell can be calculated using equation (2) where Pin is light input power used in this work.

From the figure 7, the fill factor that obtained for sample that was prepared at 2000rpm-900 $^{o}$C is 11.73242 and 0.000004% for efficiencies. From figure 8 that is for sample that was prepared at 4000rpm-800 °C, the fill factor that obtained is -369.82 and its efficiencies are 0.000006%. From the result that obtained shows that the efficiencies and fill factors of this thin film were very small.

From the result, some factors could cause the low fill factor and efficiencies. Fill factor of a solar cell primarily depends on parasitic losses, such as recombination losses at the wafer surface and doped layers [22]. D. L. Meier et.Al [23] said that the response at longer wavelengths is also noteworthy, since it indicates a minority carrier diffusion length that is several times the silicon thickness. This means that the solar cell is consistent with relatively high diffusion length (junction depth) in the finished cell. The higher temperature increased the junction depth as has been discussed by ZeynepDenizEygiet.Al [24]. High temperature steps occurring during solar cell processing particularly the gettering effect of the diffusion are known to change the electrical properties of Si wafers. So, the low fill factor and efficiencies of this experiment is due to the thin of junction depth that means the diffused temperature must be higher to increase the junction depth.

## B. Physical Properties

Table 1: Thickness of Phosphorosilica thin film

| **Spin speed (RPM)** | **Annealing Temperature (°C)** | **Thickness(nm)** |
|---|---|---|
| 2000 | 700 | 276.86 |
| 2000 | 800 | 253.26 |
| 2000 | 900 | 229.16 |
| 3000 | 700 | 272.09 |
| 3000 | 800 | 249.66 |
| 3000 | 900 | 227.94 |
| 4000 | 700 | 192.61 |
| 4000 | 800 | 175.81 |
| 4000 | 900 | 155.31 |

The film thickness can be affected by six factor which is viscosity of the fluid, concentration of the fluid, spin speed, spin time, softbake time and softbake temperature [19]. Table 1 shows the thickness of phosphorosilicaaffected by spin speed and annealing temperature. These film thicknesses were measured by using surface profiler (VEECO - D 150). From the table 1, the film thickness decreased as the annealing temperature increased. The film thickness also decreased when the spin speed increased. Mohajeraniet. Al [20] and Musa Mohamed Zahidiet.Al [21] said that the film becomes thinner for various annealing temperatures and spin speed which is similar with that recommended as seen in table1 above.

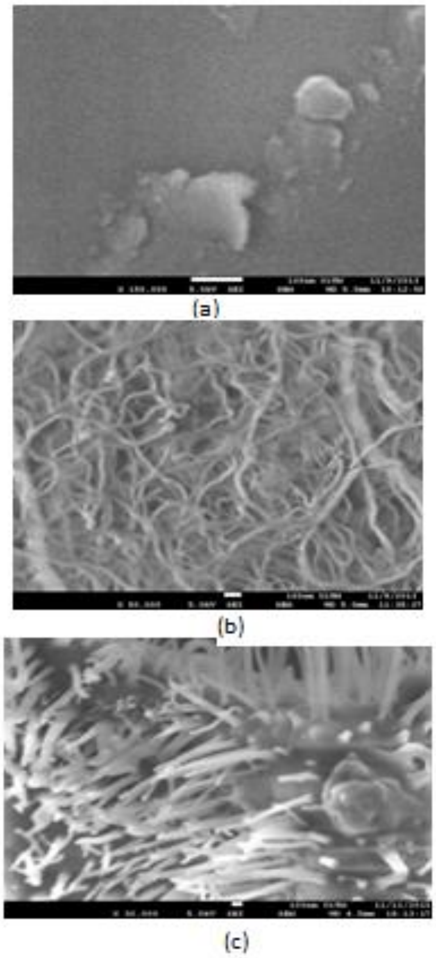


Figure 9: FESEM images of Phosphorosilica thin film at (a) 2000rpm-800°C, (b) 3000rpm-800°C, (c)4000rpm-800°C

Field Emission Scanning Electron Microscope (FESEM) is used to observe the surface morphologies of the phosphorosilica thin film. Figure 9 show the image of phosphorosilica thin films prepared with different spin speed and diffusion temperatures.When the diffused temperature 800°C but the spin speed is 2000rpm as shown in figure 9(a), the images showed that combination of smallcircle produced. At 3000rpm-800 °C figure 9(b), the phosphorosilica showed the carbon nanotube (CNT) with more layer and when spin speed increased for 4000rpm, the images shown the CNT with larger size as show in figure 9(c).From figure 9, it can be said that the characteristic of phosphorosilica thin film increase when the spin speed increase . It means that at 800°C is the best temperature for phosphorosilica thin film when its showed the ohmic contact, fill factor and good efficiencies.

## IV. CONCLUSION

In this research work, the fabrication, characterization, and analysis are presented for phosphorosilicafilm solar cell. Phosphorous doped silica samples were analyzed mainly according to the measurements made at same duration time. The difference between the samples arises from the different annealing temperature and spin speed. With the different spin speed and annealing temperature, the PSG layer and junction depth thickness also different that influenced the characterization of solar cells.With the same temperature but different spin speed can increased the junction depth as well as the same spin speed but different annealing temperature. Increased the junction depth can increase the fill factor (FF) and also can increase the solar cell efficiencies. The result confirmed that higher deposition temperatures can increased the junction depth with higher FF due to improved contact properties between silicon thin film and n layer that can increase the solar cell efficiencies. For future work, the higher diffusion temperature with long duration time will be suggesting to increase the junction depth as well as the fill factor and efficiency of the film will increase.

## V. ACKNOWLEDGEMENT

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