

INVESTIGATION OF CELL PERFORMANCE WITH DIFFERENT FIRING TECHNIQUE ON BIFACIAL SOLAR CELL

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ABSTRACT

Fire-through metallization is the most common method for forming front and back contact on screen-printed silicon solar cells. Screen printing technique typically used in industrial metallization due to its cost-effectiveness, rapid and simple production, compared to the photolithography and buried-contact techniques which is time-consuming and expensive. Another problem occurred during firing is Ag shunting junction. In this study, an alternative way of firing process, namely Quartz Tube Furnace (QTF) was investigated. QTF is a non conveyor belt furnace that can be heated until 1200°C. Two different temperature were used which is 700 and 750°C. As temperature increased, the electrical properties of bifacial solar cell also increased. Preliminary results shows that the QTF can be used as the alternative way for firing process in Si solar cell fabrication.

Keywords: Bifacial Solar Cell; Rapid Thermal Annealing; Quartz Tube Furnace; Light Current-Voltage (LIV); Quantum Efficiency;

INTRODUCTION

Contact firing and metallization application is used in the manufacturing of silicon solar cells. Screen-printing technique is standard metallization for Si solar cell manufacturing due to its cost-effectiveness, high throughput, time-saving, it reduces chemical wastes with little or no environment impact and simplicity if compare with other technique such as photolithography which is time-consuming and expensive [1], [2]. Firing condition and screen printing process are the parameters need to control in order to produce high efficiency of solar cells. The metallization process strongly affects various properties of the solar cell, such as the short circuit current (I_{SC}), the open circuit voltage (V_{OC}), the series resistance (R_S), the shunt resistance (R_{SH}) and the fill factor (FF) [2]. The various properties can be control by keeping the Al-Si alloy properly of the back side of the silicon wafer as a back surface field (BSF).

Rapid heating required to ensure proper fire-through to deliver excellent contact and also to improve the Al back surface field (BSF). Rapid firing at a high temperature is required in order to avoid degradation of the electrical quality of the Aluminum (Al) and Silver (Ag) metal contacts [3]. Fast cooling is required to prevent the diffusion of silver into the junction. Kim et al [5] shows that sufficient temperature difference is required during co-firing to prevent junction leakage for both front and back side surface. A novel approach to control the temperature has been investigated by Kim et al. [4]. The actual peak temperature for Ag-printed surface and Al-printed surface were found which are 605°C (Ag) and 743°C (Al). This actual peak temperature is appropriate for the high quality metal contact formation in screen-printed cells, without any degradation in minority carrier lifetime [4]. Si solar cell with FF = 0.79, V_{OC} = 617.8 mV, I_{SC} = 4.81 A, and conversion efficiency 15.02% was obtained by this approach.

Another investigation to enhance the silicon solar cell performance by rapid thermal firing of screen-printed metals was done by Jeong et al. [5]. Two-step firing was found to form more effective back surface field than co-firing which are rapid thermal processing (RTP) and beltline processing (BLP). However, RTP was found to be more effective than BLP [5]. Jeong shows that the enhancement in Al-BSF quality due to the BLP and RTP process (16.5%) which is done in separately process resulted in a ~0.6% increase in conversion efficiency compared to BLP and BLP process (15.9%) in separate processing. The stability of surface passivation layers during metallization process at high temperature is major challenges that contribute to a serious shunting problem due to the firing process. Moreover, the high temperature causes a breakage and changes the physical properties of the thinner wafer.

In this study, the electrical properties of the fire-through metal contacts on p-type silicon surface have been investigated. Two different temperatures which is 700 and 750°C was used. A high temperature needed in order to form low resistance ohmic contacts between metal and silicon surface [6]. Quartz tube furnace was used to enhance the efficiency of device. The aim of this research is to enhance the bifacial silicon solar cell performance and also to find an alternative technique to fire-through the metals and silicon surface.

EXPERIMENTAL

Bifacial solar cell with n^+pp^+ was fabricated. The structure is shown in Figure 1. Samples of p-type Si (100) wafers with 200 μm thickness were used in this experiment. The resistivity of the wafer was in the range of 3.0 ~ 6.0 $\Omega\text{ cm}$ and each sample was cut to 10 x 10 cm. The Si wafer was initially cleaned by immersed in 10% potassium hydroxide (KOH) at a temperature of 70°C for 10 minutes for saw damage removal. After rising with deionized water, the wafer was then dipped into hydrofluoric acid (HF) and water (H_2O) in a ratio of 1:50 for 1 minute. The texturing process was undertaken after the saw damage removal procedure. The wafers were textured using a

solution of KOH, 2 propanol (IPA) and H₂O in the ratio of 1:2:125 for 30 minutes. The wafer was repeatedly clean in HF:H₂O after rinsing with deionized water. The cleaning process was take place after the saw damage and texturing processes. The textured wafer was then dipped into solution of HF and nitric acid (HNO₃) in a ratio of 1:100 for 10 minutes. After rinsing with deionized water, it was then repeatedly cleaned in HF:H₂O for 1 minute.

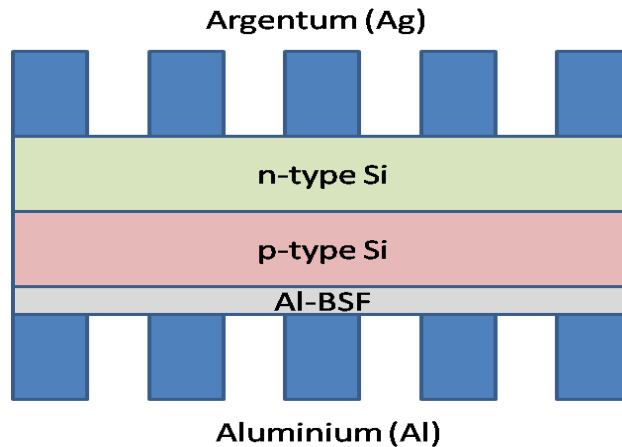


Figure 1 The structure of bifacial solar cell

After the texturing process, the wafers were subjected to the n-type diffusion procedure. The heavily doped n⁺ region was formed on the Si wafer surface by using phosphorus oxychloride (POCl₃) as diffusion source at 875°C for 30 minutes. The backside POCl₃ oxide was then removed through vapour etching (HF) for 90 seconds.

For bifacial solar cells with Al-BSF, Al pastes were screen-printed onto the back side of the Si wafer. Aluminium (Al) paste used was FERRO purchased from Electronic Material. After that, the wafers were annealed at 100°C for 10 minutes. After oven drying, the wafers were fired in quartz tube furnace at different temperature (700 and 750°C) to form Al-diffused p⁺ layer. The excess of Al was then removed by soaking in a solution of hydrochloric acid (HCl) and hydrogen peroxide (H₂O₂) at 30°C. In this way the n⁺pp⁺ structure was successfully fabricated.

The wafers were then ready for the metallization process. The Ag and Al pastes were screen-printed on both Si wafers forming front and back contacts. After that, the wafers were annealed at 100°C for 10 minutes. After oven drying, the wafers were fired in quartz tube furnace with different temperature (700 and 750°C). The cross section images of solar cells of Ag and Al paste have been characterized by Scanning Electron Microscope (SEM). The finished solar cells were cut into 3 x 3cm and analysed using light Current-Voltage (LIV) Measurement System. The cell performance also characterized on Quantum Efficiency measurements using Photovoltaic SR-EQE-IQE mapping system.

RESULTS AND DISCUSSIONS

Figure 2 shows the Ag grain size images of un-fired cell that characterized using SEM. The grain size of Ag before firing process is 416.44 nm. There is an increase in the particle size because the adjoining particles fuse together [7]. As the temperature increased, many Ag particles agglomerate and fuse together into bunches and react with Si to form n⁺ layer. The n⁺ layer provides the tunnel for electron and can easily move to the electrode and thus enhance the open circuit voltage (V_{oc}) [7].

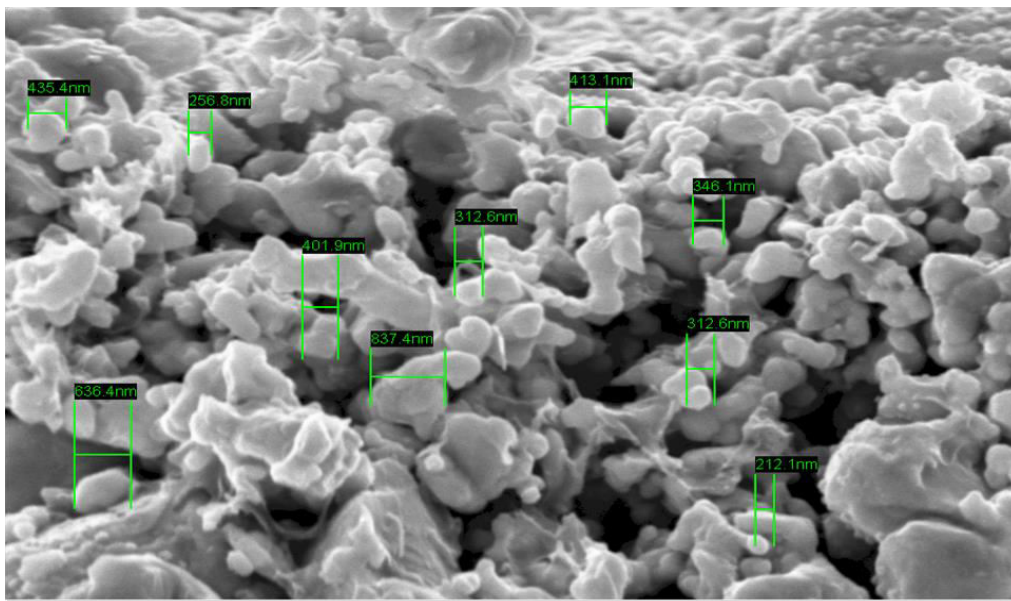


Figure 2: The grain size image of Argentum paste before firing process

Figure 3 and Figure 4 show cross section images of firing temperature at 700 and 750 °C, respectively. The thickness of cell fired at 700°C is 16.72 µm, while the thickness of cell fired at 750°C is 14.74 µm. From this figures, it is clearly shown that the Ag paste diffuse in the p-type Si layer and proved that the n⁺ layer has been form. This situation is similar with Aluminium (Al) paste. The Al particles were agglomerate and fuse together into bunches as the temperature increase and react with Si to form p⁺ layer.

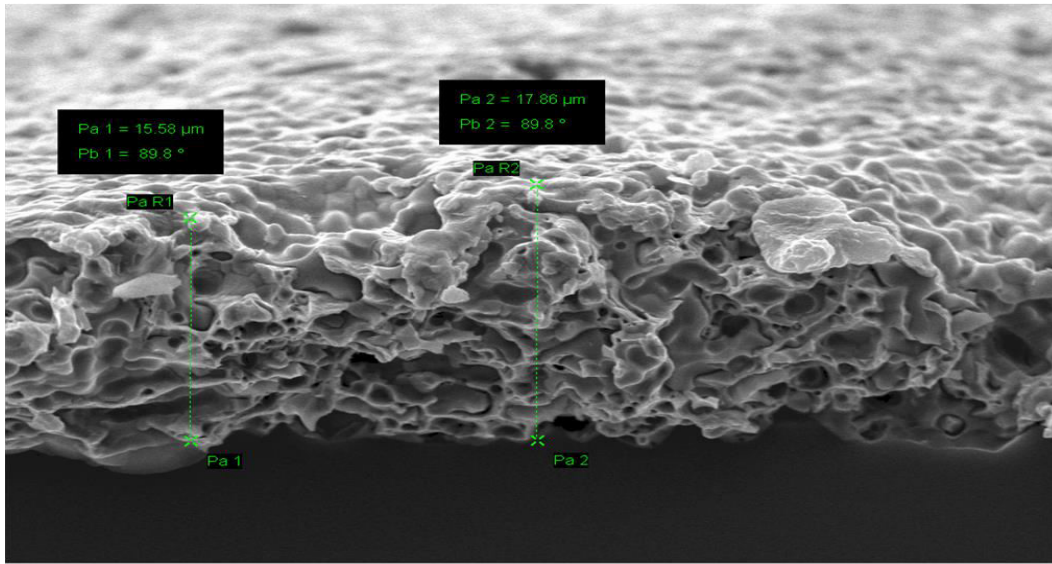


Figure 3: The cross section images of Argentum for a firing temperature at 700°C

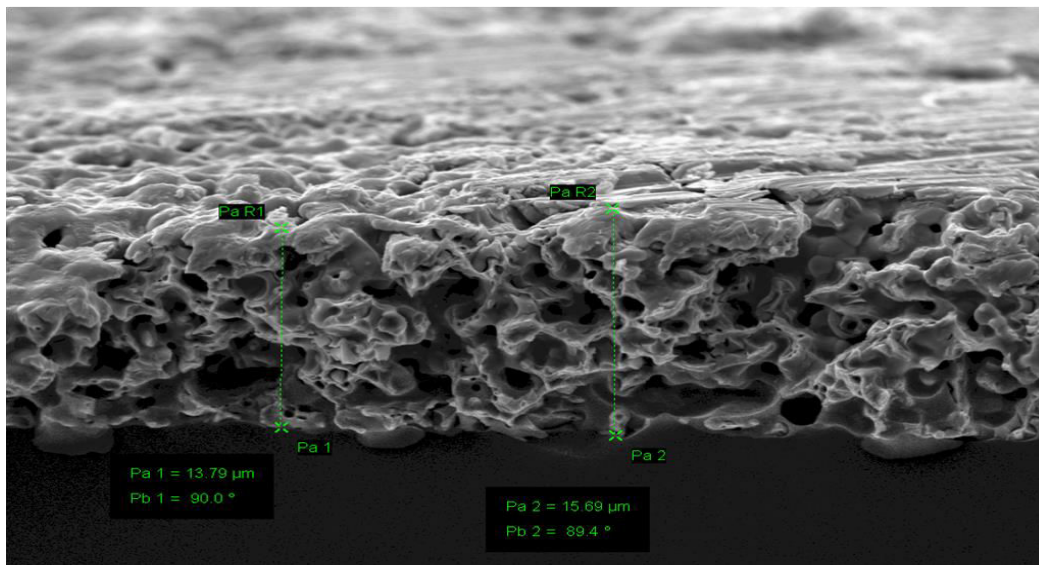


Figure 4: The cross section images of Argentum for a firing temperature at 750°C

After firing process, the bifacial solar cell are ready for LIV test to measured the electrical properties. Figure 5 shows the current-voltage (I-V) curve of bifacial silicon solar cell for front and back side surface. Preliminary results shows the open circuit voltage (V_{oc}) increased for both side with the increasing of firing temperature from 700 to 750 °C. The short circuit current density (J_{sc}), fill factor (FF) and efficiency also increase when V_{oc} is increased. The summarized result of I-V curve shown in Table 1.

The increasing of V_{oc} is because of the thickness of the thin film that closely related to the carrier diffusivity in the device [7]. It is observed that the fill factor (FF) and short circuit current density for both side increased about 10% and 25%, respectively. Effective firing with QTF contributed to increasing of electrical properties and enhanced the efficiency of bifacial silicon solar cell.

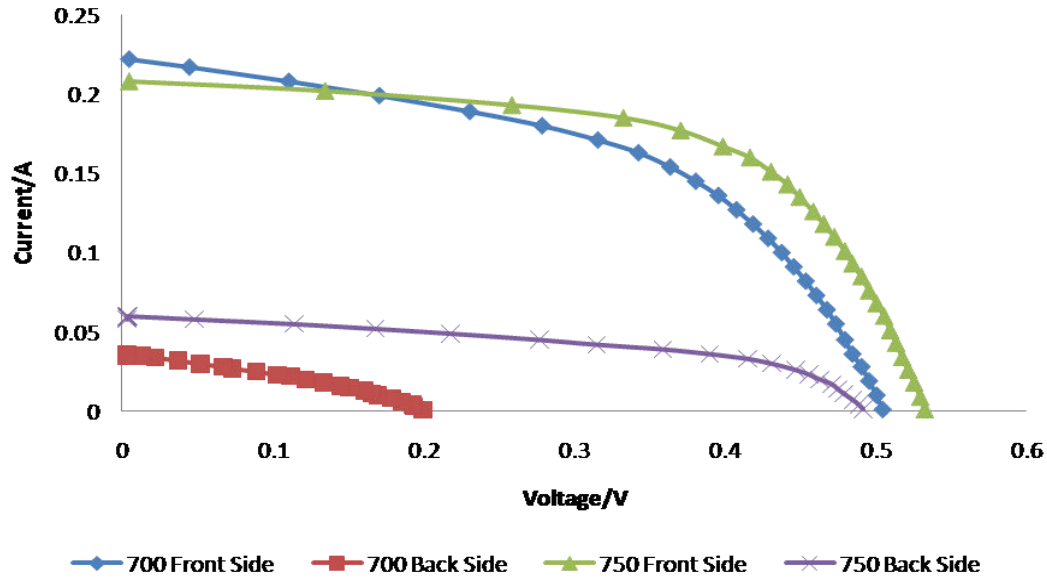


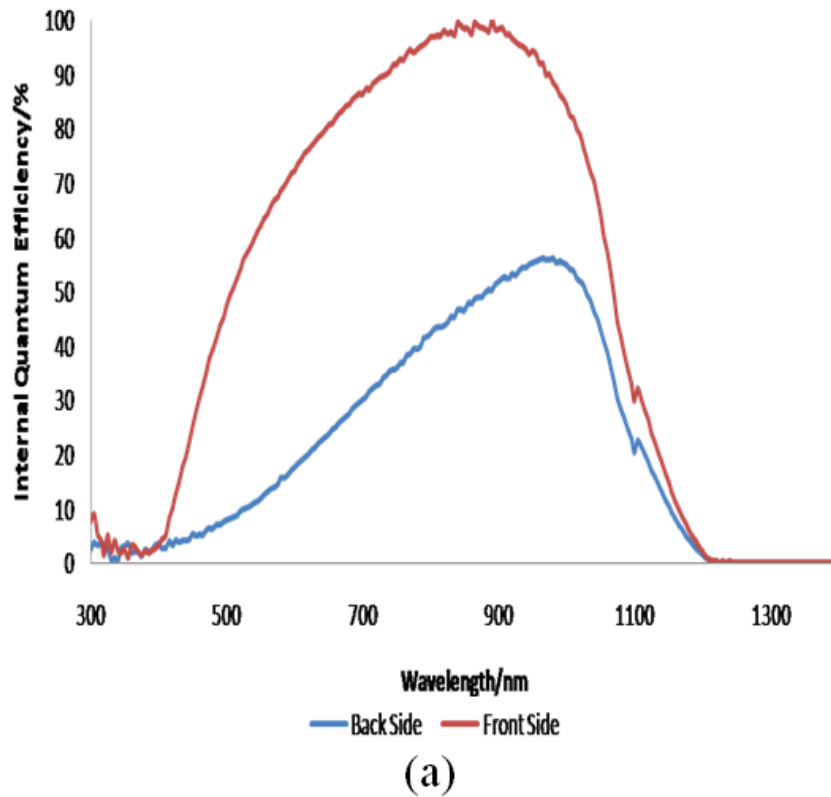
Figure 5: I-V curve of bifacial solar cell for front and back side surface

Table 1 Summarized result from I-V curve

Temperature (°C)	Surface Side	V_{oc}	J_{sc}	FF	Efficiency (%)
700	Front side	0.505	4.000	0.490	6.103
	Back side	0.200	24.667	0.280	0.224
750	Front side	0.533	6.667	0.600	7.391
	Back side	0.492	23.111	0.470	1.542

The electrical sensitivity of the bifacial solar cell at 700 °C firing was measured using quantum efficiency (QE). Figure 6 (a) shows internal quantum efficiency (IQE) for

front and back side, while Figure 6 (b) shows external quantum efficiency (EQE) for front and back side of bifacial solar cell. The IQE of the cell is 98% (front side) and 56% (back side). The EQE for front side and back side is 79% and 51%, respectively. Based on the figure, it shows that the percentage of IQE is much higher than percentage of EQE for both front and backside. The low QE in a region of 300 to 400 nm is due to surface recombination. For backside for both QE, the collection probability is quite lower mainly due to low of minority carriers diffusion length and ineffective of back surface field. With this situation, the photo-generated of minority carriers need to travel large lateral distances before being collected. Other factors that contribute to degradation of the quantum efficiency in solar cells are due to low absorption, low field factor, high saturation current density, and high bulk recombination [8].



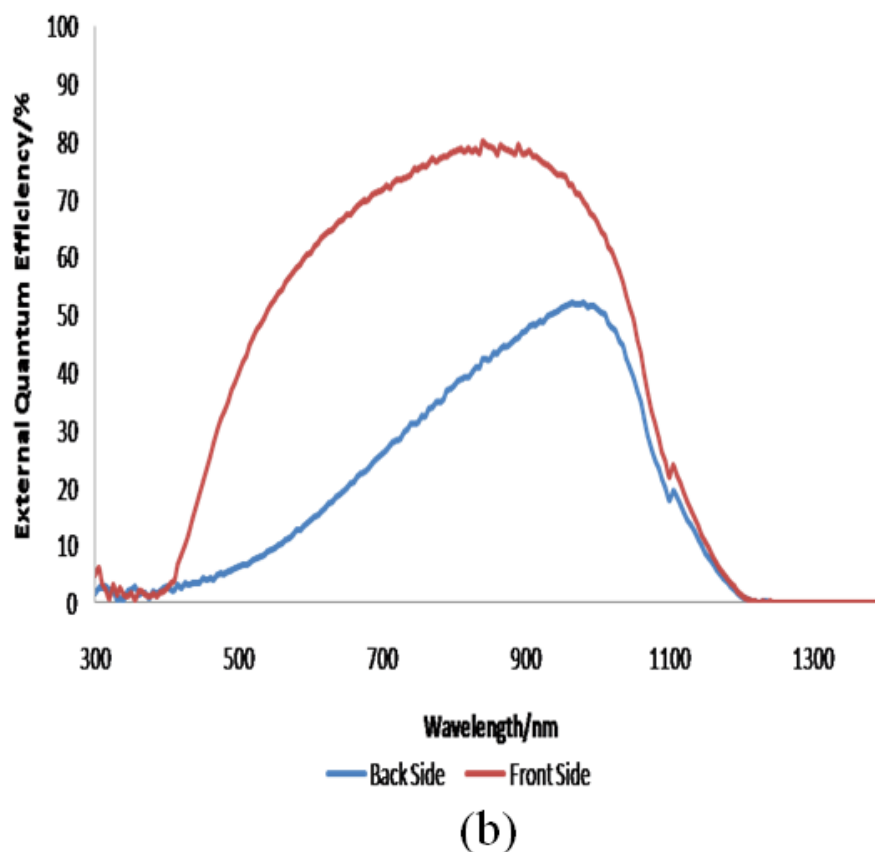


Figure 6 QE analysis (a) Internal Quantum Efficiency (b) External Quantum Efficiency for firing temperature of 700 °C of bifacial solar cell.

CONCLUSION

In conclusion, the use of Quatrz Tube Furnace (QTF) for firing process in Si solar cell fabrication have been investigated. The premilinary results of IV shows that the open circuit voltage (V_{oc}) increased for both side with the increasing of firing temperature from 700 to 750 °C. Higher temperature are needed in firing process to ensure that the Ag and Al particles agglomerate and diffuse on Si surface.

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