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NON-DESTRUCTIVE EVALUATION OF BIFACIAL SOLAR CELL THROUGH SEM CHARACTERIZATION

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ABSTRACT

Bifacial solar cell is a specially designed solar cell for the production of electricity from both sides of solar cell. Bifacial solar cell is an active field of research since its advantages on making photovoltaic (PV) more competitive together with current efforts to increase efficiency and to lower material costs. This paper reports on the fabrication of bifacial solar cells with a structure of n+pp+. This fabrication used phosphorus-oxy-trichloride ($POCl_3$) diffusion as emitter source, and aluminium (Al) diffusion using screen-printing process as back surface filed (BSF). This n+pp+ bifacial structure was sandwiched by silicon nitride (SiN) as anti reflective coating, silver (Ag) as a front contact and silver/aluminum (Ag/Al) as a back contact. The n+ and p+ layer was analyzed using Scanning Electron Microscope (SEM). The open circuit voltage (V_{OC}) obtained by this bifacial solar cell was 580 mV for the front surface and 560 mV for the back surface, while the short circuit current (I_{sc}) achieved were 0.47 A and 0.23 A for a front and back surface, respectively.

Keywords: Bifacial solar cell; $POCl_3$ diffusion; Al-alloyed back surface field; surface combination

INTRODUCTION

Crystalline silicon solar cells are the dominant players in commercial applications of the photovoltaic (PV) technology. This is due to several factors including high conversion efficiency, long term stability, low cost and technological basis in integrated circuit manufacturing. However, transition to universal PV application faces serious challenges in higher cost of energy conversion and limitations in performance. For example, in crystalline silicon PV, the cost of the wafer accounts for almost 50 % of the energy conversion cost [1]. Similarly, the process of manufacturing solar cells is inherently energy and water intensive; therefore, semiconductor processes requiring less energy and water usage are highly desirable. Bifacial solar cells appear to be the most desirable candidates for overcoming limitations discussed above. By developing a thin, bifacial solar cell, the expensive semiconductor material use is significantly reduced. Thinner wafers are also better processed in water-less environment.

H. Mori reported the first approach on bifacial solar cell by introducing a collecting p-n junction on both sides of a silicon wafer. In order to compensate for the short minority carrier lifetime in wafer, Mori proposed to place a second pn-junction at the rear surface to improve the collection efficiency for long-wavelength photons [2]. However, need for a third metal contact makes such devices impractical. The research on bifacial solar cell has since extended by the other researchers through wide range of of device configurations in order to achieve high efficiency including triode and Rear-Floating Emitter (RFE)[3], passivated emitter rear type (PERT) [4], and ALU+ structure [5]. Some of the methods that have been used in fabrication of bifacial solar cells include lithography [6], plasma enhanced chemical vapor deposition (PECVD) [7], double sided buried contact [8], screen printed boron and phosphorus pastes [9] and spin on emitter [10].

Some of the advantages of bifacial solar cells include applicability to thinner wafers, superior high temperature performance, lower metal usage, enhanced power generation; bifacial solar cell is an active field of research. A large number of bifacial solar cell improvements have been reported through buried contact [11], laser grooving [12] and electroplating [13]. In this study, we designed a bifacial solar cell with a simple fabrication process that could be realized in commercial industrialization.

METHODS

Bifacial solar cells with a configuration of n^+pp^+ with Aluminium Back Surface Field (Al-BSF) were designed. Front surface Ag and back surface Ag/Al screen-printed solar cells were fabricated. Basic bifacial solar cell structure is schematically described in Figure 1.

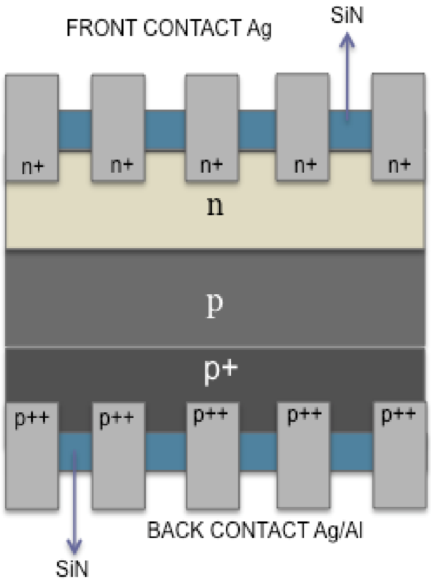


Figure 1: The structure of bifacial Si solar cell.

A p-type <100> Si wafer with a sheet resistivity in a range of 1-10 ohm/cm was used. The Si wafer was initially cleaned by dipping into solution of hydrofluoric acid (HF) and nitric acid (HNO_3) in a ratio of 1:100 for 10 minutes. After rinsing with deionized water, it was then dipped into HF and water (H_2O) in a ratio of 1:50 for 1 minute. The wafer was then immersed in 10% potassium hydroxide (KOH) at a temperature of 70˚C for 5 minute. Subsequently, the wafer was repeatedly cleaned in HF:H_2O. The texturing process was undertaken after the cleaning procedure. The wafers were textured using a solution of KOH, iso-propil alcohol (IPA) and H_2O. After the texturing process, the wafers were subjected to the n-type diffusion procedure using gas-source phosphorous oxychloride ($POCl_3$) as the diffusion source. The edges of Si wafers were then mechanically diced to achieve edge isolation.

For bifacial solar cells with Al-BSF, the following procedure was applied. Al pastes were screen-printed on back side of Si wafer. Screen-printed Al paste was annealed at 150˚C for 10 minutes prior to firing at temperature of 830˚C in a rapid thermal annealing (RTA) furnace to form Al-diffused p+ layer. Excess Al was removed by soaking in 100% hydrochloric acid (HCl) solution. Using plasma enhanced chemical vapor deposition (PECVD) system, Silicon nitride (SiN) films were subsequently deposited on both sides of the Si wafer to serve as passivation and anti-reflecting coating (ARC). Finally, the metallization processes were continued through screen printing of Ag and Ag/Al pastes using identical grid masks on a front and back surfaces respectively. Screen-printed contacts were fired at ~ 830˚C to form ohmic front and back contacts. The cross section images was analyzed using Scanning Electron Microscope (SEM) model LEO 1450VP 2001, with an operating voltage at 20.0 kV. The finished solar cells were evaluated using light Current-Voltage (LIV) Measurement System.

RESULTS AND DISCUSSIONS

We had performed the characterization studies on each processes before proceed to device fabrication. Figure 2 shows the Scanning Electron Microscope (SEM) image of pyramid texture created through KOH/IPA texturing process. The pyramid size is in a range of 550-730 nm. We first focused on nanotextured surfaces since the geometry of the texture determines how the photons are absorbed in solar cell, thus influencing the reflectance, optical losses and efficiency of the solar cell.

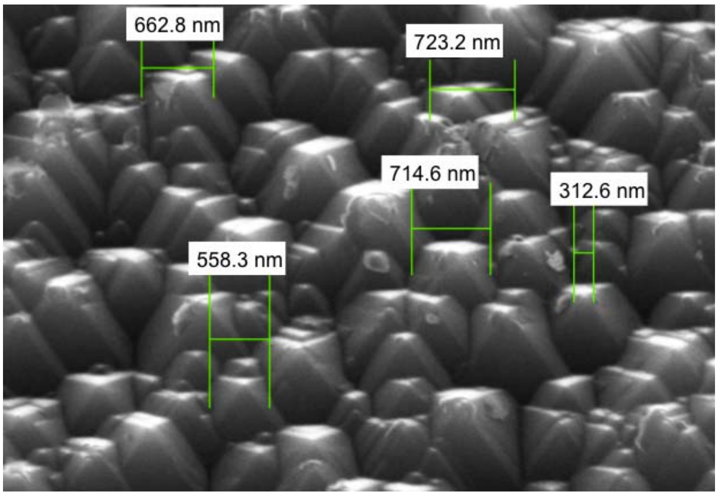


Figure 2: SEM image of pyramid texture with a magnification of 1000x

According to our device structure (Figure 1), we had to form n+ and p+ layer as its contribution in keep minority carriers away from high recombination at the front and rear contact, respectively. Figure 3 shows the cross section images of Ag on n type Si layer before firing process. It is clearly shown that the Ag particles have not fuse yet and the thin film of Ag is on the pyramid textured Si wafer. Figure 4 (a) and (b) shows cross section images of firing temperature at 650 and 742°C, respectively. The thickness of cell fired at 650°C is 16.72 µm, while the thickness of cell fired at 742°C is 14.74 µm. From these figures, it is clearly shown that the Ag paste diffuse in the n-type Si layer after firing process. As the temperature is increased, many Ag particles agglomerate and fuse together into bunches. At the peak temperature, some of the agglomerates close to the surface react with Si to form n+ layer. The n+ layer provides the tunnel for electron. The electron can move easily to the electrode and this enhances the open circuit voltage (V_{oc}).

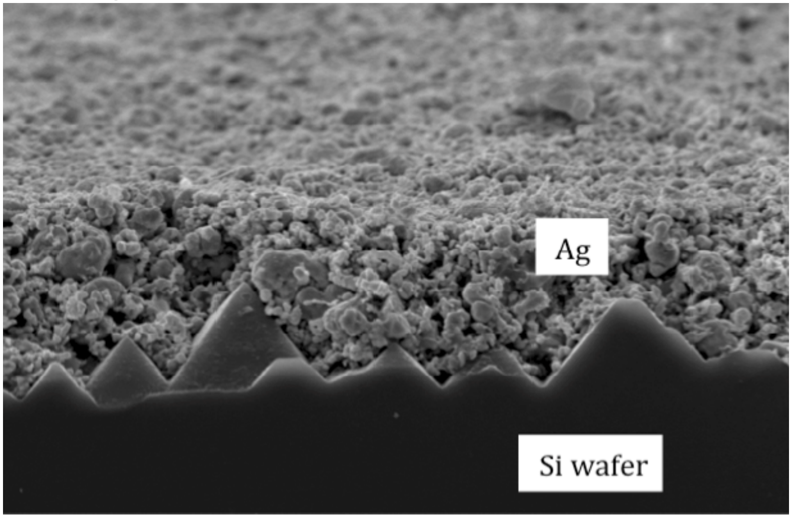


Figure 3: Cross section image of un-fired Ag on Si wafer

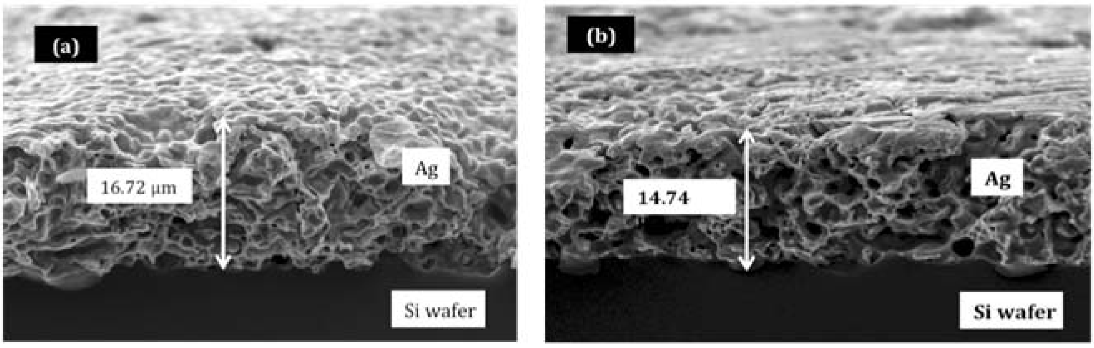


Figure 4: Cross section images of Ag fired at (a) 650°C and (b) 742°C

Besides that, we also had to verify that the p+ layer exists through our technique. We investigate the Energy Dispersive X-Ray (EDX) study in cross section image (Figure 5(a)) to validate that there are Al diffusion in Si wafer, thus prove that p+ layer had been formed. From EDX profile (Table 1) and Figure 5(a), it is clearly seen that the Al exists until Spectrum 4 profile. The deeper the EDX spectrum analysis, the less Al existed. We then measure the height of Spectrum 4 in a cross section image in Figure 5(b). It was found that the p+ have a thickness of 3.351 µm.

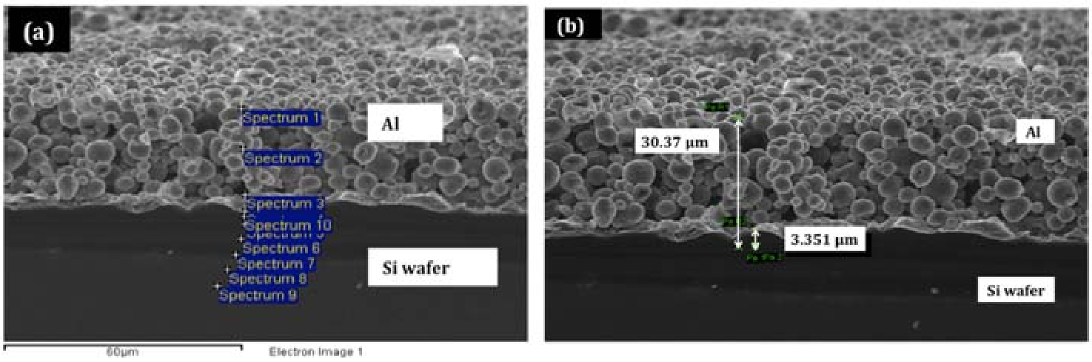
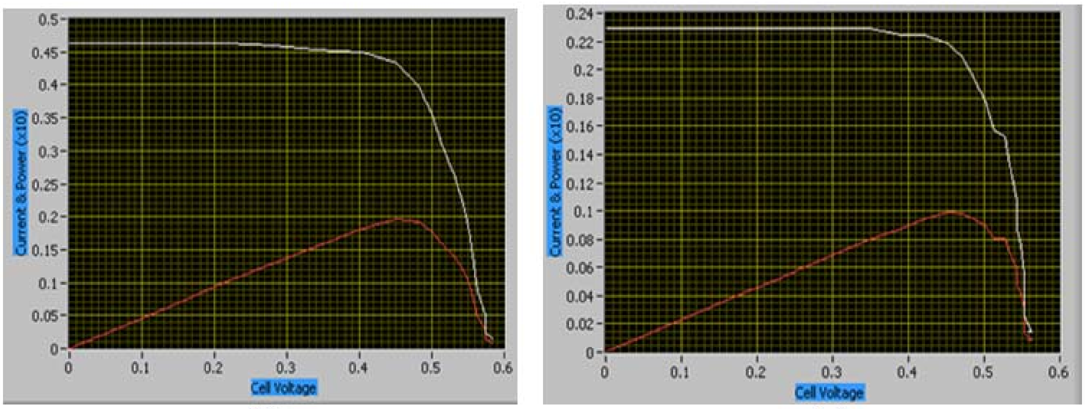


Figure 5: (a) EDX profile, (b) cross section image of Al fired on the Si wafer

Figure 6 shows the I-V curve of bifacial solar cell for front (a) and back (b) surfaces. Based on these measurements, it can be seen that the V_{oc} values measured are 580 mV and 560 mV for front and back surfaces, respectively. While, the short circuit current (I_{sc}) achieved were 0.47 A and 0.23 A for a front and rear sides, respectively. This large performance degradation for back surface may be attributed to lack of back surface field (BSF), high surface recombination, poor minority carrier lifetime and large (~ 600 µm) wafer thickness.

Table 1: EDX profile of fired Al on the Si wafer

Spectrum	Al	Si	Total
1	89.96	10.04	100
2	88.35	15.45	100
3	84.55	11.65	100
4	57.24	42.76	100
5	0	100	100
6	0	100	100
7	0	100	100
8	0	100	100
9	0	100	100
10	0	100	100



(a) (b)

Figure 6 : I-V curve of bifacial solar cell for (a) front (a) and back (b) surfaces

CONCLUSION

Bifacial solar cells performance with a structure of n+pp+ had been fabricated. Open circuit voltage (V_{oc}) obtained from the device was 580 mV and 560 mV for front and back surfaces, respectively. While, the short circuit current (I_{sc}) of 0.47 A and 0.23 A for a front and rear sides; respectively are achieved. The poor performance of back side in bifacial solar cell is due to the low minority carrier lifetime of Si wafer, large wafer thickness, and also the method on removing the fired Al to form BSF. For our future research, we will develop a dry process using boron solid source to enhance the quality of BSF.

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