

Metal Surface Treatment Effects on Screen Printed Silicon Solar Cells

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High series resistance due to the presence of glass frit is one of the major problems for screen printed silicon solar cells. Cells having electrical parameters below the prescribed values are usually rejected during solar module fabrication. Therefore, it is highly desirable to improve the electrical parameters of the silicon solar cells and thereby to increase the overall production yield. It was observed that, the performance of low quality mono-crystalline silicon solar cells made by standard screen printing technology could be improved remarkably by novel surface treatment. We have chemically treated the surface using sodium hydroxide (NaOH) and silver nitrate (AgNO_3) solutions. NaOH treatment helps to reduce the series resistance by decreasing the presence of excess glass frit on the top silver grid contact. The AgNO_3 treatment is used to reduce the series resistance comes from the deposition of silver on the grids by filling the holes present (if any) within the grid pattern.

Keywords : Solar cell, Chemical treatment, AgNO_3 treatment, I-V characteristics

1. INTRODUCTION

CZ wafers of equal to or more than 100 mm diameter are used to fabricate large area single crystal silicon solar cells and these cells have screen-printed front and back contacts [1]. The front surface of the solar cells generally has a texture and the front contact has a grid pattern that typically covers $\approx 10\%$ of the cell area. The processing of the cells is carried out in batches, with a large number of cells in each batch. In a given batch, however, the cell performance parameters, namely the open circuit voltage (V_{oc}), short circuit current (I_{sc}), curve factor (C.F.) and efficiency (η) generally show a broad distribution

[2,3]. Cells below a particular set of values of parameters are usually rejected during paneling. In many cases, the inferior I-V characteristics of the cells result not from their inherent drawbacks but due to the contamination of the exposed surface of the cell [4]. Therefore, it is highly desirable to improve the performance parameters of such cells by some procedure so that the number of discarded cells in a batch may be minimized as much as possible.

During the course of present work it was discovered that the I-V characteristics of bare silicon solar cells with screen-printed contact could be improved remarkably by surface treatment of the cells using NaOH followed by AgNO_3 . The study of this

treatment and on the I-V characteristics of cells is described in the following section

2. EXPERIMENTAL

A batch of 20 cells of dimension $10 \times 10 \text{ cm}^2$ was processed using (100) oriented CZ grown p-silicon wafers of pseudo square shape (area = 94 cm^2) and $1.2 \text{ } \Omega\text{-cm}$ resistivity. Prior to diffusion the wafers were textured to reduce reflectivity. The n^+ emitter was formed by conventional phosphorous diffusion using a POCl_3 source [5.6]. Both silver (Ag) and silver-aluminium contacts (Ag/Al) at the front (F) and back (B) surfaces of the cell were made by screen-printing followed by sintering at $650\text{-}750^\circ\text{C}$ for a few minutes. For sintering, the screen printed wafers were placed vertically in a fused silica boat in the FFBBFFBB configuration. This boat was then placed in hot zone of the sintering furnace for a few minutes to carryout the sintering in a zero air or equivalent N_2/O_2 ambient. I-V characteristics of the cells were measured at 25°C under dark and under simulated AM 1.5 conditions at 100 mW/cm^2 intensity.

The shunt resistance (R_{sh}) of the cells was calculated from the dark reverse I-V characteristics, whereas, the reverse saturation current (I_0), and n factor were determined from V_{oc} - I_{sc} characteristics of the fully illuminated cell [7]. The value of series resistance (R_s) was estimated by comparing the dark and illuminated I-V curves and by transposing the later from the 4th quadrant to 1st quadrant. The difference ΔV in the voltages for the dark and the transferred illuminated I-V curves, corresponding to $I=I_{sc}$, yields the value of R_s . This R_s value is related the point $V = V_{oc}$ and $I=0$ on the illuminated I-V curve of the cell.

The cells were treated first with a solution of sodium hydroxide (NaOH) and washed thoroughly in deionised water. This was followed by the current voltage measurement and the determination of other parameters. Subsequently the cells were dipped in an AgNO_3 solution which was kept in a Petri dish and illuminated with white light. After cleaning the surface, I-V measurements were repeated and the parameters like R_s , R_{sh} , I_0 and n were calculated. PECVD silicon nitride anti-reflection coating was also given on the front surface of some of the cells.

3. RESULTS AND DISCUSSION

Figure 1 shows the I-V characteristics of a typical cell before and after the NaOH and AgNO_3 treatments. The various device parameters determined for three different cells are listed in Table 1 in which A, B and C refer to untreated cells, NaOH treated cells and AgNO_3 treated cells after NaOH treatment respectively. It can be noted that the I-V characteristics got improved substantially after subjecting the cells to NaOH treatment. The improvement was remarkable for the curve factor (fill factor). It increased from 0.324 to 0.505 for cell #1, from 0.53 to 0.617 for cell #2, and from 0.477 to 0.603 for cell #3. In all the cells there was some improvement in V_{oc} as well. A careful examination of the data in Table 1 shows that NaOH treatment led to a large decrease in R_s and a very significant improvement in R_{sh} for all the cells. For cell #1, the initial value of R_s was so large that it had limited its I_{sc} value. The decrease in R_s from $141 \text{ m}\Omega$ to $\sim 78 \text{ m}\Omega$ has been so significant for Cell #1 that I_{sc} improved from 1704 to 1990 mA. Improvement of R_{sh} may be attributed to removal of metallic contaminants from the edges. Table 1 shows that NaOH treatment followed by AgNO_3 treatment under illumination further improved the curve factor (C.F); but did not significantly affect any other parameters. From the figure 1 and Table 1 it is evident that the improvement in R_s has led to betterment of C.F. and η .

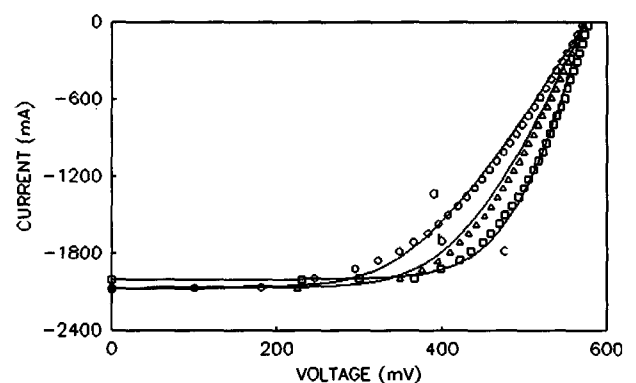
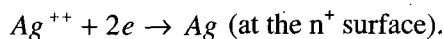


Fig. 1. I-V Characteristics of a typical cell. The curve marked with "o" is for untreated cell and those marked with "Δ" and "□" are after NaOH and AgNO_3 treatments.

Solar cell generates a negative potential at n^+ surface. When this surface is dipped in $AgNO_3$ solution, Ag deposits over it. However, the rate of Ag plating is very small as the $AgNO_3$ solution is highly conducting and keeping the cell very close to the short-circuit condition. The availability of photo-generated excess electron at n^+ surface allows Ag plating to take place by permitting the electron transfer according to the relation,



silicon nitride antireflection coating.

4. CONCLUSION

A very significant improvement in the performance of large area silicon solar cells on a novel surface treatment with NaOH and $AgNO_3$ solutions has been observed. The $AgNO_3$ treatment after the NaOH reduced R_s and improved C.F. This could be attributed to the Ag plating, which would have increased the thickness of the Ag grids and the

Table 1. Performance parameters (V_{oc} , I_{sc} , C.F., η) and diode parameters (I_0 , n , R_s , and R_{sh}) for three cells without any treatment (A), after NaOH (B) treatment and $AgNO_3$ (C) treatment after the NaOH treatment.

Cell	Treatment	V_{oc} (mV)	I_{sc} (mA)	I_0 (A)	n	R_{sh} (Ω)	R_s ($m\Omega$)	C.F.	η %
#1	A	572	1704	5×10^{-7}	1.5	0.2	141	0.324	3.36
	B	577	1990	7×10^{-8}	1.3	3.5	78	0.505	6.17
	C	578	1990	7×10^{-8}	1.3	3.5	59	0.571	6.99
#2	A	572	2071	1×10^{-9}	1.1	12.4	83	0.530	.68
	B	573	2073	1×10^{-9}	1.1	25.3	58	0.617	7.80
	C	577	2007	1×10^{-9}	1.1	25.3	28	0.674	8.30
#3	A	576	2213	1.7×10^{-8}	1.2	10.5	93	0.477	6.47
	B	581	2209	1.2×10^{-8}	1.2	17.4	51	0.603	8.23
	C	581	2157	1.2×10^{-8}	1.2	7.4	36	0.628	8.37

Table 1 shows that $AgNO_3$ treatment after the NaOH treatment reduced R_s and improved C.F. This can be clearly attributed to Ag plating, which would have increased the thickness of the Ag grids and busbar of the front contact and consequently decreased its electrical resistance. The data show that Ag plating did not affect I_{sc} adversely, which meant that the Ag plating on the uncovered n^+ front surface of the cells, if any, was too small to affect the reflectivity significantly. The substantial reduction in R_s due to the NaOH treatment shows the possibility of decrease in the series resistance contribution of the n^+ region. It is presumably due to the etching of glass by NaOH from within and beneath the metal grid contacts. It is very interesting and important to note that the NaOH and subsequent $AgNO_3$ treatment described above have not shown any degradation effect on the I-V characteristics, over a period of many months, of the cells covered with PECVD

busbar of the front contact and consequently decreased its electrical resistance. The silver (Ag) plating did not affect I_{sc} adversely and NaOH treatment has decreased R_s substantially. This is due to the etching of glass by NaOH from within and beneath the metal grid contacts. Cells covered with PECVD silicon nitride antireflection coating are not affected by the surface treatment with NaOH and $AgNO_3$. So it can be concluded that these types of chemical treatments are very much helpful to improve the yield of good quality large area commercial solar cells.

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