

Understanding the role of impurity level in the screen-printed front silver paste for high sheet resistance emitter silicon solar cells

A. Ebong, A. Rohatgi and W. Zhang¹

University Center of Excellence for Photovoltaic Research and Education, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

¹Heraeus Inc., Thick Film Materials Division, 24 Union Hill Road, W. Conshohocken, PA 19428

ABSTRACT

The front silver screen-printed paste plays a major role in forming a high quality contact to high sheet resistance emitters. The glass frit is important for adhesion and etching of antireflection coating to allow the silver and silicon to interact and form silver crystallites. The silver crystallites are essential for carrier transfer into front metal grid. In this mixture of silver powder, organics and glass frit, the purity of the front silver paste is critical, especially for emitters with $<0.3 \mu\text{m}$ junction depth. In this paper we report on use of three front silver pastes with varying impurity levels low (paste A), medium (paste B) and high (paste C)) to form high quality contacts to high sheet resistance emitters. We used the float zone to remove any variable other than the level of impurities in the front silver pastes. We achieved 17.6%, 17.5% and 17.3% efficiencies, respectively, for cells using the front silver paste A, B and C. Cells made with paste A showed excellent ideality factor of 1.03 and the dark saturation current density (J_{02}) of 7.3 nA/cm^2 . However, high ideality factor of 1.24 and J_{02} of 41.8 nA/cm^2 were shown for cells using paste C. This study shows the impurity level in the front silver paste is critical in achieving low junction leakage current for solar cells fabricated with high sheet resistance emitters and shallow junction.

Keywords: Impurity, shallow emitters, solar cells, screen-printing, high sheet emitters, silver paste

Introduction

Making solar electricity affordable, attractive and grid parity relies on reducing the module manufacturing cost. Cell efficiency is one of the key drivers for cost reduction because it reduces the number of wafers, cells and modules needed for a given power output. Cell efficiency also lowers the balance of system (BOS) and installation costs. Computer modeling shows the efficiency of a screen-printed cell can be increased by $\sim 0.7\%$ by using high sheet resistance emitters ($100 \Omega/\text{sq}$). We have achieved small area (4-cm^2) 19%-efficient cells on mono Si with screen-printed contacts to $100 \Omega/\text{sq}$ homogeneous emitters [1]. However, all the nine cells on the 4-inch wafer did not give 19% because the emitter was nonuniform. Large area cells with high emitter sheet resistance and shallow front junction are more susceptible to nonuniformity in the emitters [2]. The nonuniformity in the emitter results in shunting, even with a front silver paste that is compatible with the shallow junctions. This normally results in low fill factor and open circuit voltage. Figure 1 illustrates the effect of shunt resistance and reverse saturation current density on the fill factor of a solar cell.

In general the front silver paste need to form high quality contacts to the n^+ in a solar cell must not result in high leakage current, high ideality factor and high contact resistance. However, for the high sheet

resistance emitters with shallow junction, the silver particle size, the nature and glass frit content (percentage by weight) and the modifiers are critical. Large silver particles can lead to shunting of the shallow junction by the silver crystallites. High glass frit content can lead to thick glass layer at the silicon and front finger grid interface. This will lead to high contact resistance and low fill factor.

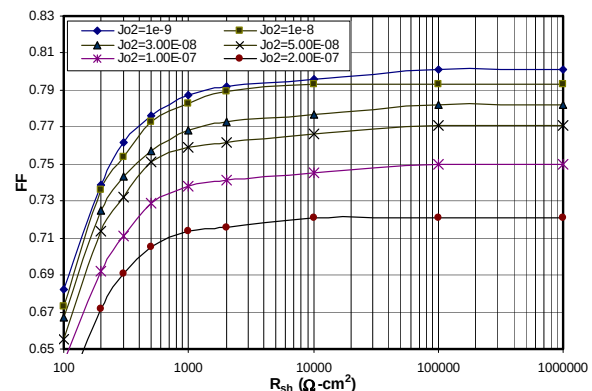


Figure 1: Effect of shunt resistance and reverse saturation current on the fill factor of a solar cell

Also, aggressive glass frit will cause excessive etching of silicon and result in shunting of the junction. Therefore, the glass frit, silver powder, organics and the additives must be in the right proportion to achieve excellent adhesion, low contact resistance, low ideality

factor (low leakage current) and high fill factor. In this paper we will study the role of impurity level in the front silver paste. This will be an added requirement for front silver paste that will result in high quality contact to high sheet resistance emitters. We examined three front silver pastes A, B, and C, respectively, with low, medium and high impurity levels. The formulation for these three pastes was based on Heraeus paste CL80-8897 [3].

Paste formulation

In general, the thick film conducting paste for solar cells and printed circuit boards (PCB) constitutes three components including (a) metal powder, which provide the conductive phase, (b) glasses (lead containing) or oxides which promote sintering of the metal powder during contact firing and enable binding of the metal contact to the substrate; and (c) organic phases, which disperse the metal and binder components to impart the desired rheological characteristics to the paste [4, 5]. It is not uncommon to add some elemental metals such as Ge, Bi, Pb, Li, Cd, In, Zn etc, as modifiers to the paste. The quantity and type of modifier is proprietary to the paste manufacturer. Also, there is addition of phosphorus dopant to improve contact resistance between silver finger and silicon. In this study the proper level of the modifier was used in and the level of metal impurity was introduced as variable. Three front silver pastes with different impurity levels were made by Heraeus, Inc. This formulation was based on CL80-8897 silver paste [3] as the control paste. Table I shows the impurity level for each paste.

Table I: Impurity levels for the three pastes

Paste	Impurity level (ppm)	Difference in Ag powder from control paste
A	low	Diff. Ag powder morphology
B	medium	Same as control
C	high	Same as control

Device fabrication

In this study we used large area (149-cm²) float zoned silicon wafers of 2-3 Ω -cm resistivities to avoid any variable in silicon material. These wafers were textured both sides, rinsed in dilute HCl before cleaning in H₂SO₄:H₂O₂:H₂O for 5 minutes, followed by a 3 min rinse in deionized (DI) water. A final dip in 10% HF for 2 minutes was performed, followed by a 30-second rinse in DI water. After the cleaning, the emitters were formed in conventional tube furnace using POCl₃ at a set temperature of 855°C, which resulted in a 65 Ω /square emitters. Next, edge isolation was performed. After the phosphorus glass removal and DI water rinse, a single layer low frequency PECVD SiN antireflection coating was

deposited on the front at 400°C. Next, an Ag/Al stripes were printed on the back and dried at 200°C followed by a screen-printed Al and dry at 200°C. This was followed by front Ag grid printing (4-cells for each pastes A, B, and C) and dried at 200°C. Next, the samples were co-fired in the IR belt furnace after a controlled profile to ascertain the peak firing temperature, which ranged from 740-800°C. This was followed by I-V characterization and analysis.

Results and Discussion

Table II: Electrical parameters of silicon solar cells fabricated with the three front silver pastes A (low), B (medium), and C (high)

Cell ID	V _{oc} mV	J _{sc} mA/cm ²	FF	Eff (%)	n	R _s (Ω cm ²)	R _{sh} (Ω cm ²)
A	628	35.8	0.782	17.6	1.03	0.889	2526
B	628	35.9	0.777	17.5	1.09	0.823	2076
C	627	36.0	0.764	17.3	1.24	0.791	1379

Table II shows the results of the solar cells fabricated with the three front silver pastes with varying impurity levels. Cells fabricated with pastes A and B (low and medium impurity levels) gave average efficiency of 17.6% with excellent fill factors and ideality factors. The ideality factor of 1.03 - 1.09 coupled with low dark saturation current density of 7.3 nA/cm² suggests excellent junction quality. Therefore, the low and medium impurity levels paste produced excellent shunt resistance, which supports the model calculation shown in Figure 1.

On the other hand, the cells which were fabricated with paste C (high impurity level) showed efficiency of only 17.3%. An efficiency loss of ~0.3% depicts the impact of high ideality factor on the fill factor, which also caused a 1 mV drop in open circuit voltage. An ideality factor of 1.24 and dark saturation current density of 41.8 nA/cm² suggests high recombination in the depletion region. It is apparent that such junction parameters will reduce fill factor and hence the open circuit voltage. Therefore a paste such as paste C, with high impurity level cannot produce acceptable junction quality needed for high efficiency solar cells.

Conclusions

The impurity level in a front silver paste is critical to producing solar cells with high junction quality. The junction quality of a solar cell dictates the leakage current, which impacts the open circuit voltage, fill factor and efficiency. This junction quality can be compromised if there is diffusion of impurities into the depletion region or physical shunting of the junction by

the silver crystallites. We have explored three front silver pastes with low, medium and high impurity levels. The cells fabricated with paste A and B produced efficiencies of 17.6% and 17.5%, respectively, with excellent fill factors and ideality factors. The 1.03-1.09 ideality factor suggests very little or no recombination in the depletion region and therefore low dark saturation current density of 7.3 nA/cm². However, cells with paste C gave 17.3% efficiency with fill factor of 76.4% and high ideality factor. The high ideality factor suggests recombination in the depletion region of the cell, which corresponded to high dark saturation current density of 41.8 nA/cm². The results show the impurity level in the front silver paste is critical to making reliable silicon solar cells with low junction leakage current.

Reference

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