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ALUMINUM PASTES FOR THIN WAFERS

S. Kim[1], A. Shaikh[1]*, S. Sridharan[2], C. Khadilkar[2], * T. Pham[1],
1. Ferro Corporation, Electronic Materials System,
1395 Aspen Way, Vista, CA 92083, USA
Phone: (1)- 760-305-1009, Fax: (1)-760-305-1100
2. Ferro Corporation Technical Center, 7500 East Pleasant Valley Road, Independence, Ohio 44131
*Corresponding author: shaikha@ferro.com

ABSTRACT

Presently, a typical thickness of the silicon wafer used by the solar cell industries is about 330 um. The industry trend is to use thinner wafers to reduce the cost of solar cells. The wafer cost is about 60 % of the cell fabrication cost. Going-forward industry is targeting thickness of 280, 250, 230 and finally 200 um. As the wafer thickness decreases, the bowing of the cell due to the sintering stress generated by aluminum increases. Also, the industries are trying to make cells with metal pastes which do not contain lead due to the environment concern. Present aluminum pastes contain lead-based glass and make finished cells bow after firing. This paper deals with a development of lead-free aluminum paste for thin wafers.

A typical aluminum paste contain metal powders, glasses, and additives mixed in an organic medium. The effect of paste variables such as metal powder, glass chemistry and additives on electrical performance and bowing was investigated. Also the effect of aluminum paste deposit amount on bending and BSF layer was studied. Based on this study new lead-free/ low-bow aluminum paste (CN53-100) is developed.

Newly developed lead-free low-bow aluminum paste (CN53-100) showed only 0.5 mm of bowing on 260 um thick X 5” X 5” single crystal wafer when the wet deposition amount is 1.14 gram per wafer.

Key words: aluminum, paste, lead-free, low-bow

1. INTRODUCTION

Photovoltaic industry is moving towards producing higher efficiency solar cells using thinner and higher sheet resistance crystalline silicon (Si) wafers.

In order to improve cell efficiency, the loss mechanism must be reduced. Strategies generally are focused on reducing carrier recombination processes. Aluminum back-surface field is used to reduce back surface recombination and is the most widely implemented efficiency enhancement.

A commonly used technique to enhance silicon solar-cell performance is the deposition of an Al layer on the back surface of the cell, followed by a thermal treatment. It is believed that the improvement is caused by gettering of defects and impurities, or by a back-surface field effect induced by the highly Al doped P+ region, or by a combination of the two. Gettering increases the minority carrier diffusion length in the bulk, whereas a BSF lowers the effective back-surface recombination velocity(1). During the firing process aluminum powders go through densification process which results in shrinkage. This shrinkage in turn induces bowing of silicon wafer. There are several ways to minimize the bowing of silicon wafer with fired aluminum paste: (1) screen print smaller amount of aluminum paste on silicon wafer which can affect the thickness of BSF layer and electrical performance, or (2) modification of the aluminum paste formulation to reduce sintering stress. As the thickness of Si wafer becomes thinner bowing caused by Al on the backside becomes more prominant.

In this paper we report on development and properties of lead-free low-bow Al paste which minimizes the bowing and beading for thinner Si wafer without sacrificing electrical performance.

2. EXPERIMENTAL

2.1 Paste formulation:

Metal powder size, morphology, glass chemistry, additives and organic medium were varied to obtain the most optimum performance. Various additives were tested to reduce sintering shrinkage and the most potent additive was selected. The amount of these additives was varied between 1% and 3%. Paste 53-038 is used as a control and does not contain any of the additives and a product made by Ferro Corp.

2.2 Processing:

Al pastes were screen-printed using 200 mesh screen and dried and cofired with front silver paste (CN33-455) and backside silver/aluminum paste (CN33-451) in three-zone IR belt furnace. The most optimum furnace zone settings for the zone lengths of 7.5inch, 15 inch and 7.5 inch, and the belt speed of 120 inch/minute were 780^{o}C, 830^{o}C and 930^{o}C. The amount of aluminum paste printed on the wafer was varied between 0.055 and 0.035 gram/square inch.

2.3 Silicon wafers 5” X 5”:

Single crystal silicon wafer with thickness of between 180 um to 260 um were used.

2.4 Bowing test:

The bowing was measured after firing the solar cells. Solar cells were put on a flat surface. The bowing was measured using a drop dial gauge.

2.5 Electrical Characterization:

Efficiency of the cells was measured using lighted I-V curve. Series resistance, Rs and Shunt resistance, Rsh were obtained from the slopes of I-V curve at Isc and Voc.

2.6 Microstructure Characterization:

The cross-section of the aluminum-BSF layer-silicon interface was characterized by SEM. The polished cross-sections were etched in a solution of HF:HNO3:CH3COOH (1:3:6) to easily identify aluminum BSF layer for SEM observation.

3. RESULTS AND DISCUSSION

3.1 Bowing as a function of the amount of additives and of control paste (53-038) at different amount of paste deposit.

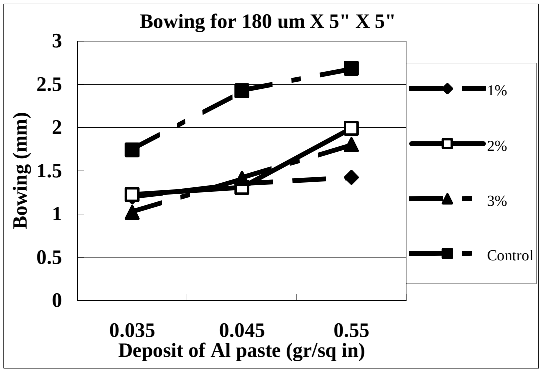


Figure 1: Bowing as a function of the amount of additives and of control paste at different amount of paste deposit.

Figure 1 shows bowing as a function of the amount of additives and of control paste at different amount of paste deposit. Overall, the addition of additive decreases the bowing 34 to 44 % at different amount of paste deposit compared to the control.

At the aluminum paste deposition of 0.035 grams per square inches the solar cells printed with pastes containing 1 %, 2 % and 3 % additive addition bow 1.20 mm, 1.23 mm and 1.02 mm respectively.

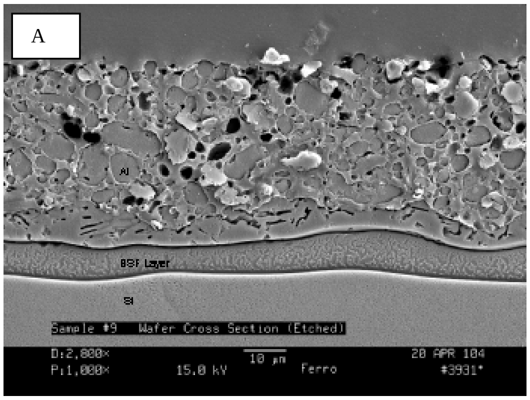
At the aluminum paste deposition of 0.045 grams per square inches the cells printed with pastes containing 1 %, 2 % and 3 % additive addition bow 1.35 mm, 1.31 mm and 1.41 mm respectively.

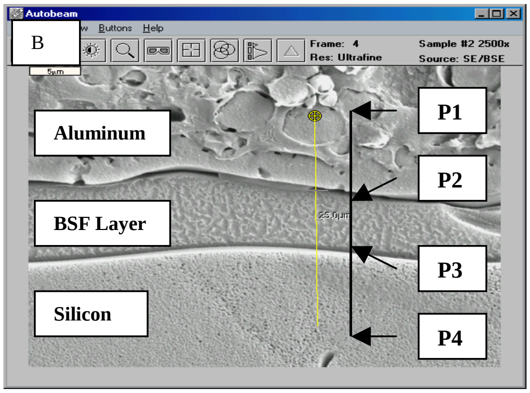
At the aluminum paste deposition of 0.055 grams per square inches the cells printed with pastes containing 1 %, 2 % and 3 % additive addition bow 1.43 mm, 1.99 mm and 1.80 mm respectively.

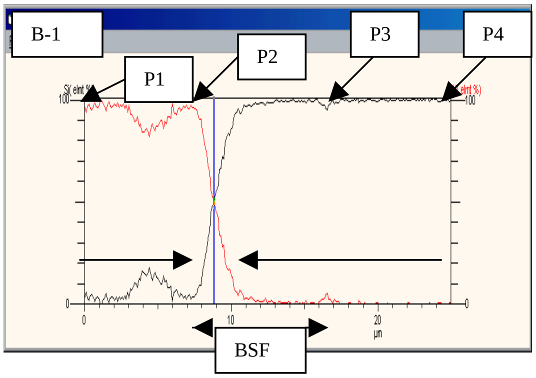
When the aluminum deposit is 0.035 gram per sq inch, the smallest amount of bowing is achieved at 3 % additive addition. The higher the amount of additives, the lower the amount of bowing. However, this trend is not consistent at higher amount of aluminum paste deposit. This needs to be further investigated.

3.2 BSF layer as a function of aluminum paste deposit amount of an optimum paste

Figure 2 shows a cross-section of a fired aluminum paste, BSF layer and silicon wafer. The average BSF layer thickness of these three samples is about the same. Alloying between silicon and aluminum during firing process forms BSF layer. Eutectic temperature for silicon and aluminum is about 577 C. The greater the thickness of deposited aluminum, the deeper the resulting BSF junction. Similarly the higher the alloying temperature, the more heavily doped the p+ region (2).







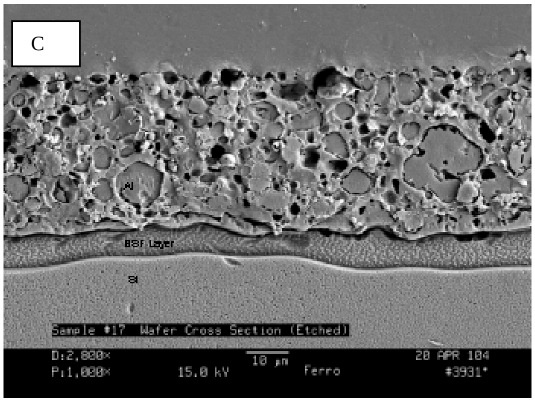


Figure 2-A, B and C: SEM cross-sections showing Al layer, BSF layer and silicon wafer as a function of paste deposit. (A) 1.294, (B) 1.047, and (C) 0.841 gram per wafer.

Figure 2-B-1: X-ray line scan of the sample (b) showing percentage of aluminum and silicon.

Figure 2-b-1 shows the X-ray line scan of the Figure 2-b. In this X-ray line scan the concentration aluminum and silicon are measured through the cross-section from aluminum to BSF layer and to silicon wafer. This shows that the BSF layer is an alloy of silicon and aluminum. There is a concentration gradient of silicon and aluminum within the of BSF layer. The concentration of aluminum decreases as more silicon is alloyed eith aluminum.

3.3 **Electrical property vs. aluminum paste deposit amount with different amount of additives.**

Figure 3 shows that solar cell efficiency improves with increasing amount of aluminum deposit for the control pastes and paste with1 % additive addition. However, when the additive amount increases to 2 and 3 %, best efficiency is achieved at aluminum deposit amount of 0.045 gram/square inch, and then efficiency decreases. The reason needs to be further investigated.

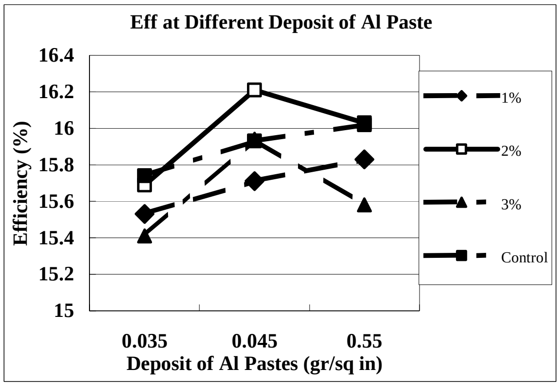


Figure 3: Efficiency as a function of the amount of additives and of control paste (53-038) at different amount of paste deposit.

When 1 % of additive is added, the efficiency becomes lower than the control paste. When 2 % of the additive is added, the efficiency becomes highest at aluminum depositon of 0.045 gram/square inch. However, when 3 % of additive is added, the efficiency decreases. This needs more investigation to find the reason.

3.4. **Properties of optimized paste (53-100)**

Table 1 shows bowing of wafers of different thicknesses as a function of amount of aluminum paste.

Paste deposit (gr/sq in)	Wafer Thicnkess (um)		
	260	230	180
	Maximum Bowing (mm)		
0.045	0.5 mm	0.6 mm	1.31 mm
0.055	n/m	0.791 mm	1.99 mm

Table 1. Bowing of 5” X 5” wafers with CN53-100 lead-free/low-bow aluminum paste.

As expected bowing increases with decrease in wafer thickness and increases in paste deposit. 53-100 paste shows < 1 mm of bowing of 230 um thick wafer.

FF	Eff	Rs	Rsh
76.5	16.21	0.0088	13.28

Table 2. . Electrical performance of single crystal wafer coated with SN ARC and CN53-100

4. CONCLUSIONS

Newly developed lead-free low-bow aluminum paste (CN53-100) showed only 0.5 mm of bowing on 260 um thick X 5” X 5” single crystal wafer when the wet deposition amount is 1.14 gram per wafer.

Overall, the addition of additive decreases the bowing 34 to 44 % at different amount of paste deposit compared to the control.

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