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ALUMINUM PASTES (LEAD-FREE/LOW-BOW) FOR THIN WAFERS

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ABSTRACT

Presently, a typical thickness of the silicon wafer used by the solar cell industries is about 280 ~ 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 < 250 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 the effect of aluminum paste deposit amount and firing temperature on BSF layer were studied. Based on this study new lead-free/ low-bow aluminum pastes are developed.

Newly developed lead-free low-bow aluminum paste (B) and (C) shows only 0.6 and 0.4 mm of bowing respectively on 240 um thick X 5” X 5” poly 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 changing rapidly to achieve the cost target of < $1/W of solar energy produced. Crystalline silicon is the dominant PV technology. At present the cost of silicon wafer is 60 % of the over all solar cell fabrication cost. To reduce the amount of silicon used, the industry is moving towards thinner wafer. The industry is targeting thickness of < 250 um from the current wafer thickness of > 280 microns. In order to reduce the wafer thickness the thick film materials compatible with thin wafers needs to be developed.

Paste containing aluminum powder is screen printed on the back surface of the cell and is followed by a thermal treatment to create a p^+ back-surface field (BSF). The BSF reduces back surface recombination and enhances efficiency. It is also believed that there is a gettering of defects and impurities during the BSF formation. The gettering increases the minority carrier diffusion length in the bulk, whereas a BSF lowers the effective back-surface recombination velocity. (1). Aluminum Back-surface field doping profiles with surface recombination velocities below 200 cm/s (1). The combination of these two effects leads to improvement of electrical performance. However, the interfacial stresses at Al-Si interface lead to the bowing of Silicon wafers.

During the heat treatment process aluminum powders go through densification process that results in shrinkage stresses. These shrinkage stresses and the stresses associated with mismatch of thermal expansion coefficient of Aluminum and Silicon cause bowing of silicon wafer. As the wafer thickness decreases, the bowing of the cell due to the shrinkage stress generated by aluminum increases.

Secondly, the solar industry is moving towards environmentally friendly materials and processes. The industry has already eliminated use of lead based solders in solar module and the next largest contributor of lead is the back contact Al. It is estimated that standard Aluminum ink contributes to approximately 7 mg/watt of lead in a solar module. This paper deals with a development of lead-free/low-bow aluminum paste for thin wafers.

A typical aluminum paste contains 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 pastes (B) and (C) are developed.

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. 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 lead-free silver paste (CN33-466) 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°C, 830°C and 930°C. The amount of aluminum paste printed on the wafer was varied between 0.055 and 0.035

gram/square inch.

2.3 Bowing test:

Poly crystal silicon wafers (5”X5”X235 um and 180 um) was used for bowing test. The bowing was measured after firing the wafer with aluminum paste only. The wafers were put on a flat surface. The bowing was measured using a drop dial gauge.

2.4 Electrical Characterization:

Electrical performance was done on single crystal silicon wafer. 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.

2.5 Microstructure Characterization:

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

3. RESULTS AND DISCUSSION

3.1 Bowing of aluminum pastes with different formulations.

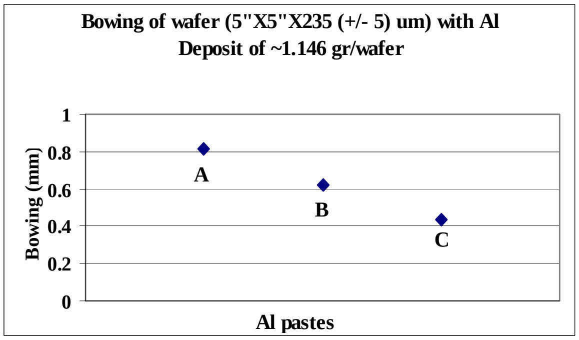

Figure 1: Bowing of aluminum pastes with different formulations.

Figure 1 shows bowing of aluminum pastes with different formulations at aluminum deposit of 0.045 gram per square inch for 5”X5”X240 um thick silicon wafers. Formulation A is a leaded aluminum paste showing about 0.8 mm of bowing. Formulation B and C are lead-free aluminum pastes showing about 0.6 and 0.4 mm of bowing, respectively. Bowing of aluminum can be modified by formulation adjustment.

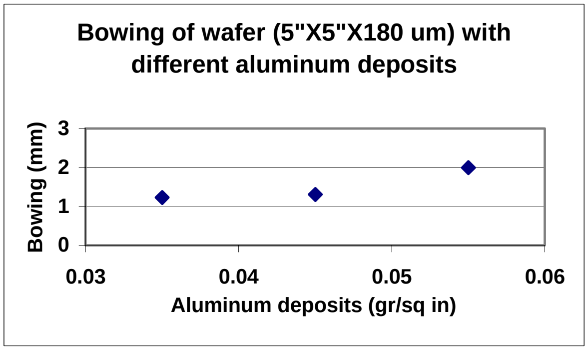

Figure2: Bowing of aluminum paste (B) at different amount of paste deposit.

Figure 2 shows that amount of bowing increases with increasing paste deposit. When silicon wafer is coated with more aluminum paste and is fired at high temperature, densification of aluminum powders occurs. During densification the voids between powders are eliminated or shrunk. It creates stress that makes silicon wafers bow. The thicker the aluminum paste deposit, the greater the stress and the greater the bow.

3.2 Silicon-aluminum reaction layer thickness as a function of firing temperature and aluminum paste deposit amount

Figure 3 shows etched cross-section of fired aluminum paste on top of silicon wafer. There are two distinctive layers between aluminum and silicon showing a different etching behavior due to different alloying between aluminum and silicon. X-ray linescan shows that there are different compositions of aluminum and silicon from aluminum rich region to silicon rich region extending about 25 microns.

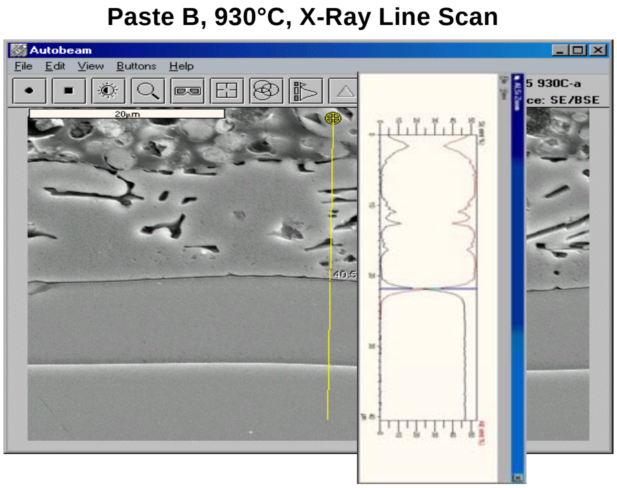
Paste B, 930°C, X-Ray Line Scan

Figure 3: Two distinctive layers between aluminum and silicon. Percentage in X-ray linescan is not normalized.

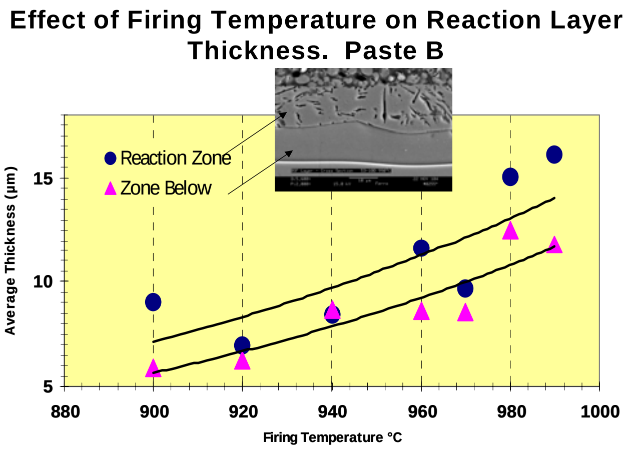

Figure 4: Reaction layer thickness and zone below as a function of firing temperature.

Figure 4 also shows reaction layer thickness and zone below as a function of firing temperature. These two layer thickness increases with increasing firing temperature. Eutectic temperature for silicon and aluminum is about 577 C. When the firing temperature increases, aluminum and silicon stays longer at above the eutectic temperature, and more aluminum and silicon can participate in forming an alloy, i.e., reaction layers.

Figure 5 shows thickness of cross section of fired aluminum paste, reaction layers and silicon wafer. The average reaction layer thickness increases with increasing aluminum paste deposit amount up to 0.055 gram per square inch in this experiment. Even though alloying between silicon and aluminum does not reach to the top of aluminum layer a thicker aluminum creates a thicker alloying layer between silicon and aluminum. More study will be done to see the effect of aluminum thickness on the reaction layers and electrical properties.

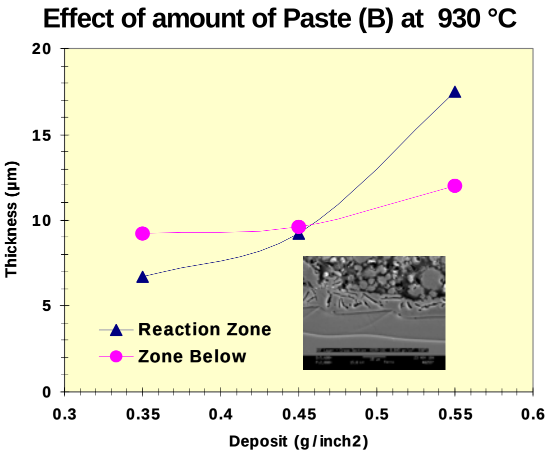

Figure 5: Thickness of cross section of fired aluminum paste, reaction layer and silicon wafer.

3.4. Electrical properties of optimized paste (B)

FF	Eff	Rs	Rsh
76.5	16.21	0.0088	13.28

Table 1 . Electrical performance of single crystal wafer coated with SN ARC and paste B.

4. CONCLUSIONS

Newly developed lead-free low-bow aluminum paste (B) and (C) showed only 0.6 mm and 0.4 mm of bowing respectively on 235 um thick X 5" X 5" poly crystal wafer when the wet deposition amount is ~1.146 gram per wafer.

The reaction layer thickness increases with increasing firing temperature or increasing amount of Al paste.

More study will be done to understand the layer between the reaction zone and the bulk silicon.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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