Characterization of Al Back Contact in a Silicon Solar Cell

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Abstract: Aluminum pates are commonly used for an industrial-scale silicon solar cell manufacturing to form an alloyed Back Surface Field (BSF) layer to improve the electrical performance of the cells. The most important variables to control the cell performance under industrial processing conditions are a) paste chemistry, b) deposition weight and c) firing conditions. Also, a wafer bow becomes an issue, as the solar industry is moving towards thinner wafers. Microstructure development, electrical performance, and bow reduction of new pastes developed with an additive have been discussed in this paper. New aluminum BSF pastes are developed for use with silicon wafer thicknesses below 200 microns. The bowing of < 1mm of 200 micron wafer was achieved by modifying the paste microstructure. These pastes also show excellent electrical characteristics.

Key Words: Aluminum, Silicon, Back Contact, BSF, Microstructure, TOF-SIMS, Paste.

1 Introduction

There is a need to reduce the Si wafer thickness to improve Si utilization and to reduce solar cell material cost. The wafer warpage or bow becomes an issue when the Si wafer thickness is decreased below 240 µm. Generally, bow tends to decrease with reducing paste deposit amount but there is a practical lower limit below which screen-printed Al paste will result in a non-uniform Back Surface Field (BSF) layer.

Recently, more attention has been given to understand effects of paste chemistry and firing conditions on microstructure development [1-2]. In this paper Al-back contact microstructure and stress development during the firing cycle is described.

2 Experimental Procedure

Single and polycrystalline wafers with thicknesses varying between 180 micrometers to 280 micrometers were selected for this study. First an optimum aluminum powder particle size and morphology was selected to produce bead free Al layer. The lead free glass showing the best electrical characteristics and adhesion was selected. The inorganic additive, which had the most pronounce effect on the bowing was chosen for this study. The bowing was measured by measuring the height between the lowest and the highest point on a silicon wafer.

The pastes were printed using a 200 mesh screen and varying emulsion thickness to achieve depositions varying between 0.035 grams/inch^2 to 0.055 grams/inch^2. These wafers were then fired in a three-zone infrared kiln. The zone 3 set temperature was varied from 880^{o} C to 990 ^{0}C.

3 Results

Figure 1 shows effect of inorganic additive amount on the bowing of silicon substrate at various deposition weights on a single-crystal Si cells prepared using these pastes. The bowing decreased with addition of an additive. Addition of 2 wt% of the additive gave the optimum electrical performance. The optimum composition was printed on the wafers of different thicknesses. The Table I show the bowing of these wafers. The bowing of 180 micron 125 mm X 125 mm wafer was about 1.4 mm.

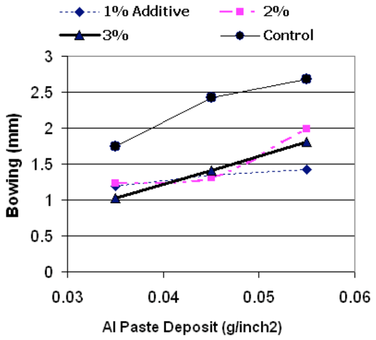

Figure 1 shows the effect of inorganic additive on bowing.

Paste deposit (gr/sq in)	Wafer Thicnkess (µm)		
	260	230	180
	Maximum Bowing (mm)		
0.045	0.50	0.60	1.31
0.055	n/m	0.79	1.99

Table I: Wafer bow with wafer thickness and deposit weight.

Figure 2 shows a typical cross section of a fired Al-paste Si back contact microstructure with three distinct layers.

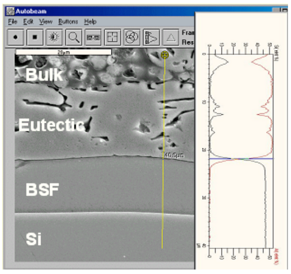

Figure 2 shows a polished SEM cross section of a fired Al paste- Si back contact consisting of a 1) BSF layer 2) an eutectic layer, and 3) bulk particulate Al paste layer.

Figure 3 shows plots of BSF and eutectic layer thickness as a function of paste deposit weight. Figure 4 shows plots of BSF and eutectic layer thickness as a function of a set temperature with the paste deposit amount of 0.45g/inch^2. The eutectic and BSF layer appears to grow as a function of temperature and amount of paste deposited.

The BSF layer properties such as Al doping level and profile, defects and uniformity have an influence on the electrical performance. Various techniques [3] have been used to study the BSF layer properties. The BSF layer was further analyzed using a Time of Flight (TOF) SIMS technique. The concentration of Al in the epitaxial BSF layer was ~1- 2 x 10^{18} atoms/cm^3 as measured by the TOF SIMS measurements.

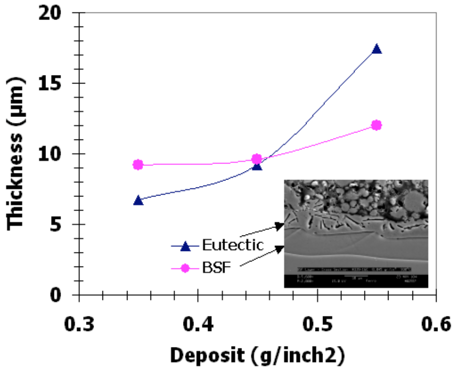

Figure 3 shows influence of the deposit weight on the BSF and eutectic layer thickness for samples fired at the set temperature of 930 °C.

4 Discussion

The wafer bows and forms a convex body during cooling due to a higher Coefficient of Thermal Expansion (CTE) of a fired paste structure compared to Si. The amount of bow depends on the fired paste microstructures themo-mechanical response to stresses generated due to differences in CTE's during cooling. For a given geometry and firing profile, the elastic modulus of the paste microstructure has the most significant effect on a wafer bow. Bow starts to develop when the paste start to resist the stresses generated due to CTE mismatch. For Al back contact paste, observed bow is significantly less compared to a bow predicted by the elastic model if nominal values for elastic modulii of ~70 GPa for Al and ~110 GPa for Si are used. The observed reduced bow has been explained by plastic deformation of the fired paste layer [4]. It is expected that the Al-Si eutectic structure can plastically deform and can also show a creep flow at temperature as low as 300 °C in response to stress due to CTE mismatch to relieve the stress.

The increased amount of bow with increasing deposit weight as observed in Figure 1 can be related to higher thickness ratio (thickness of Al/thickness of Si). The decreased bow with additive addition at a given level of deposit as shown in Figure 1 indicates that a) the elastic modulus of the paste microstructure seems to have decreased and or b) temperature at which the Al film has become rigid has decreased with the addition of an additive.

Al particles are oxidized during heating to a higher temperature. It is expected that Al particle-to-particle contact formation will be more favorable when the oxide layer is not continuous. The presence of oxide layer may be responsible for the observed paste microstructure where the fired paste away from the Si interface shows a particulate structure as shown in Figures 2.

The firing temperature will determine the amount of Si dissolved into molten Al liquid. From the Al-Si phase diagram, an Al-Si alloy with ~30 wt% Si is formed at ~800 °C. During cooling from a peak firing temperature to eutectic temperature Teut of ~577 °C, liquid-phase epitaxial growth of Si on Si wafer occurs. The concentration of Al dissolved into Si at ~800 °C is ~0.001 wt% leading to a formation of p+ epitaxial layer. The Si concentration in the melt progressively decreases from ~30 wt% to eutectic composition of ~ 12% Si. At or below Teut~ 577 °C (with some under cooling) remaining ~80% of the molten liquid with eutectic composition solidifies near the BSF layer and inside the oxide shells. The resulting solidified paste microstructure consists of three layers as shown in Figure 2. The increased BSF and eutectic layer thickness with a peak firing temperature as shown in Figure 4 can be explained by increased amount of Si dissolution and increased amount of liquid formation with increasing temperature. Thus, the thickness of BSF layer, Al concentration in the BSF layer, thermo-mechanical properties of the eutectic layer, and a weak particulate structure are important parameters in controlling a bow (Figure 1).

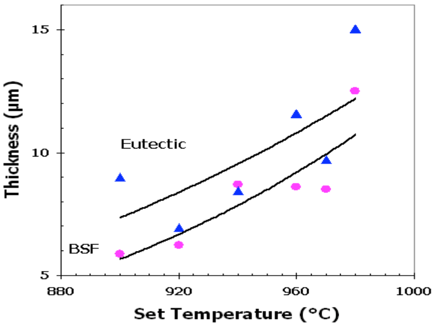

Figure 4 shows effect of furnace set temperature on the eutectic and BSF layer. Deposit amount ~0.45 g/inch^2.

5 Summary

A new paste with an additive has been developed. The additive decreases the wafer bow for ~180µm wafer to about 1.4mm. The reduced bowing appears to be due to decreased elastic modulus of a fired microstructure with an additive and also lowering of temperature at which the paste becomes more rigid. The peak firing temperature and the deposit weight has a strong influence on the back surface field (BSF) layer thickness. The concentration of Al in the epitaxial BSF layer was ~ 1- 2 x 10^{18} atoms/cm^3 as measured by the TOF SIMS measurements. The electrical performance as measured by cell efficiency was dependent on deposit amount, additive amount and the peak firing temperature.

6 References

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