Front Contact Pastes With Increased Aspect Ratio To Achieve Higher Efficiency On Screen Printed Solar Cells

Dong Zhang, Jerome Moyer, Weiming Zhang
Heraeus Materials Technology LLC., Photovoltaic Materials
24 Union Hill Road, W. Conshohocken, PA 19428 USA
Tel: (610) 825-6050, Fax: (610) 825-7061
Email: dong.zhang@heraeus.com

ABSTRACT

In this paper, we discuss our approach of paste formulations on silvers, frits, vehicles, and additives, and developing several silver pastes which are capable of achieving higher aspect ratio finger lines using a standard industrial screen printer. The paste formulations played a critical role in building thick prints and fine line resolution. The improvement of the paste coupled with the printing optimization, produced higher aspect ratio Great Wall finger lines. The electrical performance of the cells that were screen-printed with this paste was better than that of the reference pastes; they showed fill factors of 0.4-1.7% and efficiencies of 0.2-1.6% greater than the reference pastes.

INTRODUCTION

Traditional screen printing is still a dominant method to print bus bars and finger lines on silicon solar cell wafers. High aspect ratio finger lines are able to provide lower line resistance thus increasing solar cell efficiency. In our previous paper [1], we developed a paste with the Great Wall finger lines and prove it had a lower line resistance and higher fill factor and efficiency.

In this work, we continue our efforts on paste formulations with emphasis on silvers, frits, vehicles, and additives. A new screen-printable paste is introduced that exhibits an extremely high aspect ratio lines, high fill factor and high efficiency.

EXPERIMENTAL PROCEDURE

Process and Equipment

Textured multi-crystalline wafers labeled as G with sheet resistance at 65 ohm/sq were used in the study. The lifetimes of all wafers were determined; only wafers with similar lifetimes were chosen for this study. Three solar cell pastes were compared. Pastes A and B were our own commercial products, and were used as the reference pastes. The third one C was a newly developed paste. The pastes were printed on the wafers, dried, and then fired in an IR Furnace. Finger line thicknesses and widths were measured, and stereoscope and SEM photos were taken after firing. Cell efficiency, fill factor, and contact resistance were measured.

Formulations

All three pastes used different silvers, frits, vehicles, solvents, but the same additives as shown in Table 1.

Table 1. Paste Formulations.

Ingredients	A	B	C
Ag 1	yes		
Ag 2		yes	
Ag 3			yes
Frit 1	yes		
Frit 2		yes	
Frit 3			yes
Vehicle 1	yes		
Vehcle 2		yes	
Vehcle 3			yes
Additives	yes	yes	yes

Screen and Printing Parameters

All pastes were printed with the same typical screen and conditions as seen in Table 2 and Table 3. The new paste C was also printed with a screen with a thicker emulsion to increase finger line thickness as seen in Table 4.

Table 2. Screen Parameters.

Screen Parameters	
Emulsion thickness	0.9 mil
Wire diameter	0.9 mil
Mesh (wires/inch)	325
Weave	30 ^{o}
Line opening	120 µm

Table 3. Printing Parameters.

Printing Parameters	
Pressure	1.2 bar
Speed	200 mm/s
Snapoff	1.7 mm
Squeegee hardness	70A
Squeegee angle	50 ^{o}

Table 4. Screen Parameters.

Screen Parameters	
Emulsion thickness	1.2 mil
Wire diameter	0.9 mil
Mesh (wires/inch)	325
Line opening	120 µm

Firing Profile

All pastes were fired with the same firing profile. Set points of the firing profile are shown in Table 5, while the corresponding profile is shown in Figure 1.

Table 5. Set points of a typical firing profile.

Zone	Set point	Gain	Integral	Derivative
1	400 ^oC	10	30	0.5
2	400 ^oC	10	30	0.5
3	550 ^oC	10	30	0.5
4	700 ^oC	10	30	0.5
5	800 ^oC	10	30	0.5
6	920 ^oC	10	20	0.5

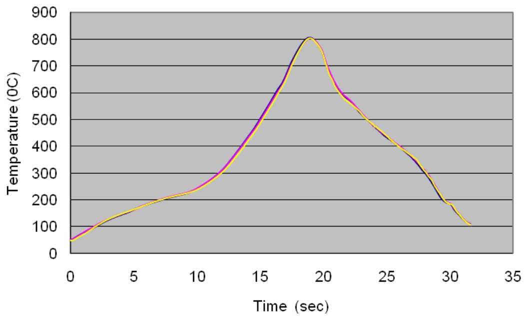

Figure 1. Firing profile.

RESULTS

Electrical Data

Electrical properties were measured for the pastes. The new paste C displays a fill factor and efficiency in the range of 0.4-1.7% and 0.2-1.6% greater than the reference pastes, respectively. Average electrical performance data on the textured multi-crystalline wafers labeled as G are listed in Table 6.

Table 6. Average electrical data on textured multi-crystalline wafers.

	Paste A	Paste B	Paste C
J_{sc} (mA/cm^2)	34.22	34.45	34.86
I_{sc} (A)	8.330	8.384	8.484
V_{oc} (V)	0.6108	0.6073	0.6163
Fill Factor (%)	76.89	76.57	77.61
Efficiency (%)	16.08	16.03	16.67

SEM Cross Sections of Fired Finger Lines

SEM cross sections of the fired finger lines of the new paste C can be seen in Figure 2. Its cross sectional profile looks like the Great Wall, very different from traditionally printed finger lines for both pastes A and B. It has a much high thickness or aspect ratio, which is defined as the finger height divided by the finger width.

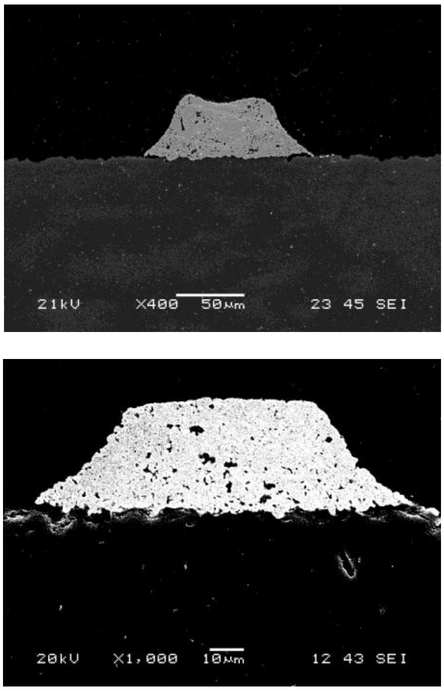

Figure 2. SEM cross section of fired finger line of paste C with screen emulsion 1.2 mil.

Images observed through a stereoscope of the fired finger lines of the pastes A, B, and C are displayed in Figures 3, 4, and 5, respectively. Again, the paste C has a profile like “The Great Wall”.

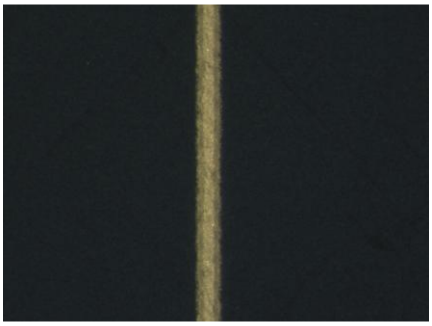

Figure 3. Fired finger line of the paste A.

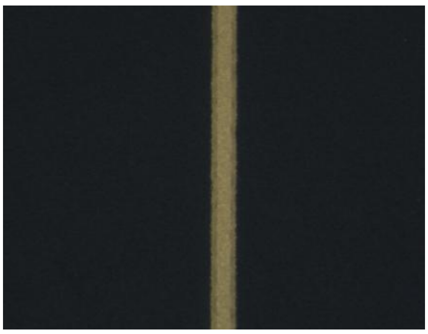

Figure 4. Fired finger line of the paste B.

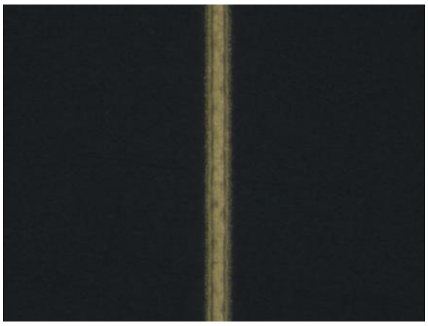

Figure 5. Fired finger line of the paste C.

Line Thicknesses, Widths, and Aspect Ratios

The fired line thicknesses, widths, and aspect ratios of the pastes A, B, and C are listed in Table 7. The paste C has higher aspect ratio than pastes A and B.

Table 7. Line thicknesses, widths, and aspect ratios.

	Thickness (µm)	Width (µm)	Aspect ratio
Paste A	23.5 ± 2.0	137.2 ± 4.9	0.17
Paste B	24.4 ± 1.8	146.8 ± 3.2	0.17
Paste C	27.6 ± 3.6	144.7 ± 4.4	0.19
Paste C*	38.7 ± 2.8	138.8 ± 6.9	0.28

*Printed with a screen with an emulsion thickness of 1.2 mil.

Contact Resistance Map

The contact resistances of the wafers with the pastes A, B, and C were measured. The contact resistance maps are shown in Figures 6, 7, and 8. Paste A has a slightly higher contact resistance.

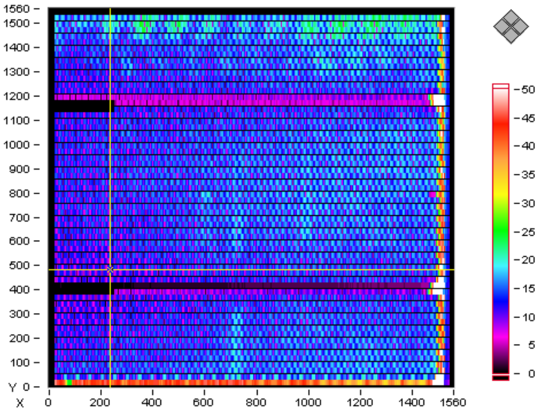

Figure 6. Contact resistance map of the paste A.

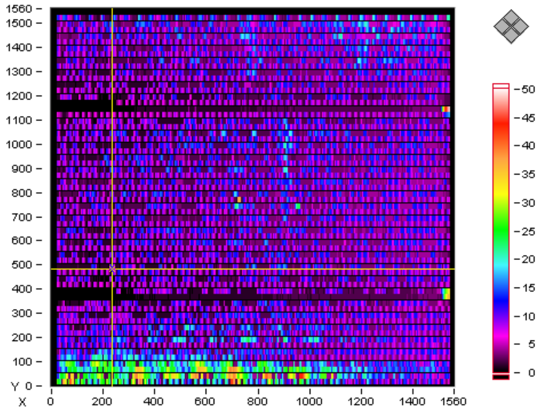

Figure 7. Contact resistance map of the paste B.

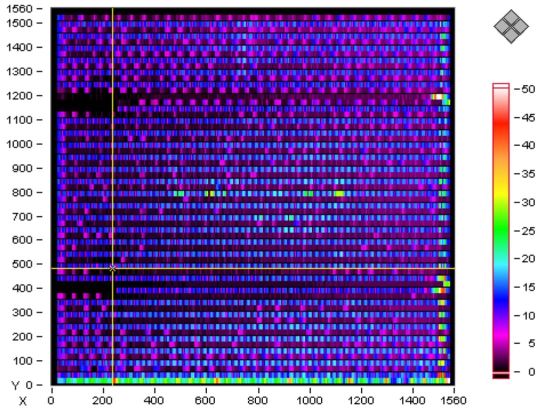

Figure 8. Contact resistance map of the paste C.

SUMMARY

Silvers, frits, vehicles, and additives in the formulations have been investigated. A new silver paste for solar cell front side metallization has been developed and printed on solar cell wafers using a typical screen printer. The new paste printed lines with a higher aspect ratio such as “The Great Wall” than the references. It provided higher cell fill factors and higher efficiencies than the reference pastes. A new record of cell efficiencies on this kind of wafers has been observed.

ACKNOLODGEMENTS

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REFERENCES

[1] Dong Zhang et al., “A Screen Printable Front Side Silver Conductor Paste Achieving High Aspect Ratio Finger Lines For Solar Cell Applications”, 23rd European Photovoltaic Solar Energy Conference, 1-5 September 2008, 1458, Valencia, Spain.