EFFECT OF PROCESSING AND FORMULATIONS ON MICROSTRUCTURE DEVELOPMENT IN BACK SURFACE FIELD ALUMINUM CONDUCTOR

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ABSTRACT

Al paste applied on the back surface of silicon solar cells, plays a critical role in the overall performance of solar cells. The quality of the BSF (back surface field) impacts the Voc values and thus the efficiency obtained in the solar cell [1,2]. A Taguchi screening experiment was conducted to study effects of processing and formulation on paste viscosity, uniformity of BSF, wafer bowing and dusting. The thickness and uniformity of BSF (back surface field) formed was found to be a direct function of various factors including type of Al powder, chemistry of glass, other oxide and metal additives as well as the firing conditions used. The electrical performance, bowing and dusting are correlated with microstructure and paste compositions, and are discussed below.

Table I L12 Taguchi Screening Design Matrix

Factor	A	B	C	D	E	F	G		Sun Voc
Row #	Al powder	Glass	Additive A	Additive A	Additive A	Dispersant	Additive A4		Y1
1	-1	-1	-1	-1	-1	-1	-1		0.602
2	-1	-1	-1	-1	-1	1	1		0.613
3	-1	-1	1	1	1	-1	-1		0.604
4	-1	1	-1	1	1	-1	1		0.595
5	-1	1	1	-1	1	1	-1		0.612
6	-1	1	1	1	-1	1	1		0.61
7	1	-1	1	1	-1	-1	1		0.59
8	1	-1	1	-1	1	1	1		0.588
9	1	-1	-1	1	1	1	-1		0.594
10	1	1	1	-1	-1	-1	-1		0.612
11	1	1	-1	1	-1	1	-1		0.609
12	1	1	-1	-1	1	-1	1		0.591

[Note: make cleaner/crisper table]

Table I shows the L12 screening design used for the study. It includes 7 factors studied at two levels, namely, Al powder type , glass composition, one metal additive A2), three oxide additives (A1, A3 and A4) and a dispersant D. The sign + indicates presence of the factor and – indicates absence of the factor, except for Al powder and glass where the signs indicate two types of Al powders and glasses used.

Table II Regression table for Sun Voc, bowing, dusting and viscosity using DOE PRO.

Y-hat Model		Sun Voc				Bowing				Dusting				Viscosity			
Factor	Name	Coeff	P(2 Tail)	Tol	Active	Coeff	P(2 Tail)	Tol	Active	Coeff	P(2 Tail)	Tol	Active	Coeff	P(2 Tail)	Tol	Active
Const		0.60167	0.0000			1.327	0.0000			3.500	0.0005			435.13	0.0001		
A	Al powder	-0.00433	0.0670	1	X	-0.05708	0.3453	1	X	0.16667	0.6433	1	X	-8.050	0.7969	1	X
B	Glass	0.00317	0.1422	1	X	0.10792	0.1134	1	X	-0.16667	0.6433	1	X	10.517	0.7375	1	X
C	Additive A1	0.00100	0.5955	1	X	-0.09958	0.1356	1	X	-0.16667	0.6433	1	X	-59.933	0.1100	1	X
D	Additive A2	-0.00133	0.4853	1	X	0.04025	0.4930	1	X	0.0000000	1.0000	1	X	-41.383	0.2303	1	X
E	Additive A3	-0.00433	0.0670	1	X	-0.11225	0.1034	1	X	-0.83333	0.0668	1	X	-55.017	0.1333	1	X
F	Dispersant D	0.00267	0.1993	1	X	-0.01042	0.8549	1	X	0.16667	0.6433	1	X	-80.967	0.0505	1	X
G	Additive A4	-0.00383	0.0918	1	X	-0.09942	0.1361	1	X	0.0000000	1.0000	1	X	-15.433	0.6259	1	X
	R^2	0.8569				0.8113				0.6444				0.8170			
	Adj R^2	0.6064				0.4810				0.0222				0.4968			
	Std Error	0.0060				0.1850				1.1547				101.3951			
	F	3.4207				2.4563				1.0357				2.5513			
	Sig F	0.1259				0.2014				0.5178				0.1913			
	F_{LOF}	NA				NA				NA				NA			
	Sig F_{LOF}	NA				NA				NA				NA			
	Source	SS	df	MS		SS	df	MS		SS	df	MS		SS	df	MS	
	Regression	0.0	7	0.0		0.6	7	0.1		9.7	7	1.4		183607.3	7	26229.6	
	Error	0.0	4	0.0		0.1	4	0.0		5.3	4	1.3		41123.8	4	10281.0	
	$Error_{Pure}$	NA	0	NA		NA	0	NA		NA	0	NA		NA	0	NA	
	$Error_{LOF}$	NA	0	NA		NA	0	NA		NA	0	NA		NA	0	NA	
	Total	0.0	11			0.7	11			15.0	11			224731.2	11		

Table II shows regression table results from running DOE PRO software[note – need to reference ACAD]. We used four output results, namely Sun Voc., bowing, dusting and paste viscosity. This table shows how each of the factors impact the four output values that we monitored.

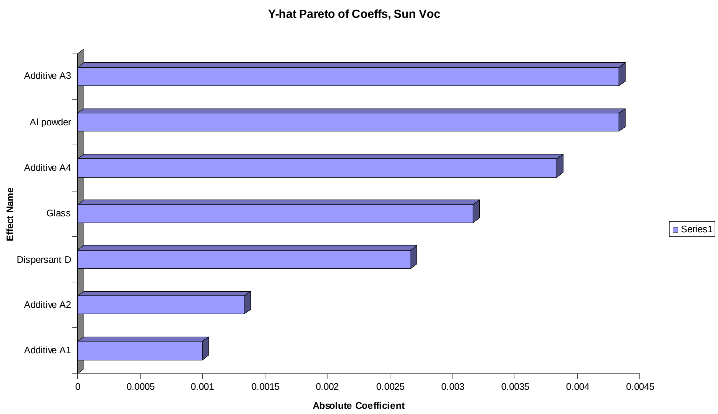


Figure 1 Pareto chart showing effect of 7 factors on Sun Voc

Figure 1 shows a Pareto chart for factors that impact Sun Voc. It is clear that additives A3 and Al powder type have biggest impact on Sun Voc whereas additive A4 and glass composition have slightly less impact on Sun Voc.

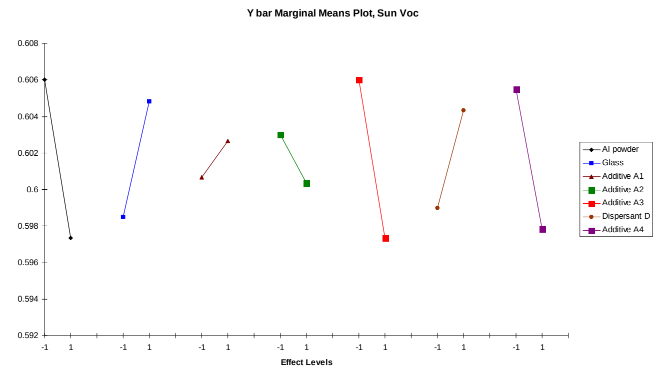
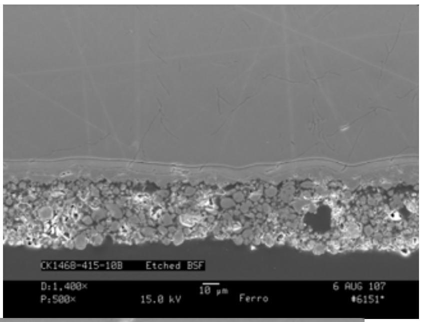
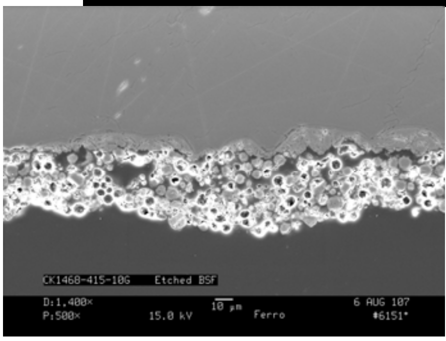


Figure 2. Marginal Means plots showing how each factor impacts Sun Voc.

Figure 2 shows the extent and the direction of impact of each the factors on Sun Voc. For example, from this plot, it is evident that Al powder B (-) , glass G2(+) and absence (-) of additives A3 and A4 give the highest Sun Voc values.

3a





3b

Figures 3a and 3b show SEM etched cross-sections of wafers printed with paste containing Al powder B(-) and A(+) respectively. Powder A gives smooth BSF compared to Al powder B. [??]

Figure 3a and 3b show SEM micrographs of etched cross sections of wafers printed with paste containing Al powders A and B respectively. From the figures, it is evident that Al powder B gives very strong and smooth BSF layer compared to that made with Al powder A. The corresponding Sun Voc values obtained for this paste was 0.613 V and was much higher than that obtained for paste with powder A (0.590 V). However, the bowing found for paste with powder B was higher (1.6 mm on 180 micron wafer) compared to paste with powder A (0.94 mm on 180 micron wafer). Since the eutectic layer is continuous for paste with Al powder A, there is a larger strain observed on wafer with paste containing powder A as compared to paste with powder B, which shows a thinner discontinuous BSF. Electrical performance, (Sun Voc), is a strong function of quality of BSF, and the cell with Al powder B gives much higher Sun Voc than the cell with Al powder A. However, when it comes to bowing, the cell with Al powder A gives lower bowing, due to discontinuous BSF layer that helps in strain relief at the silicon-aluminum interface.

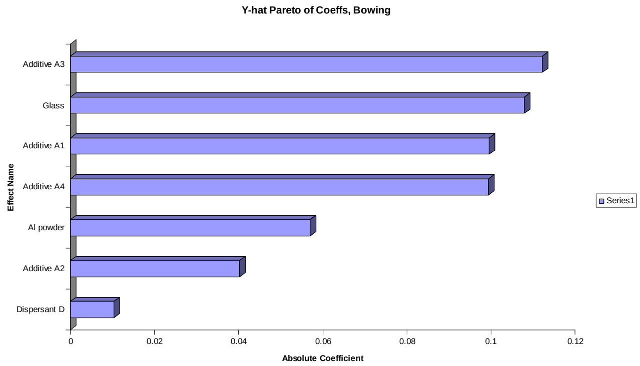


Figure 4 Pareto chart showing effect of 7 factors on bowing

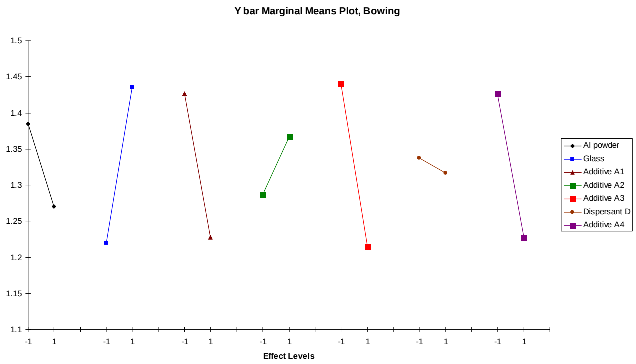


Figure 5 Marginal Means plot showing the extent of each factors effect on bowing

From Figures 4 and 5 it is quite evident that additives A3, type of glass and additives A1 and A4 have biggest impact on bowing. Since it is desirable to minimize wafer bowing, the presence of additives A3 (+), Glass G1 (-), presence of additives A1(+) and A4 (+) are preferred. Presence of Al powder A (+) also has small impact in reducing bowing.

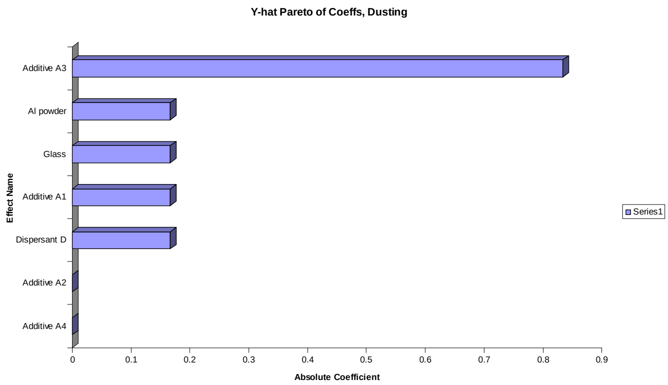


Figure 6 Pareto chart on effect of various factors on dusting

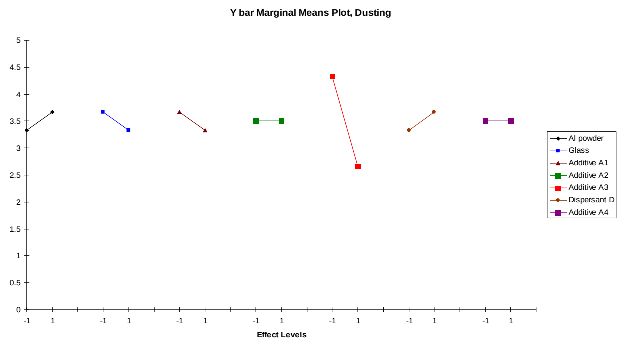


Figure 7 Marginal means plot showing extent of the effect of various factors on dusting

Figures 6 and 7 show Pareto chart and Marginal Means plots respectively of the effect of various factors on dusting of fired Al films on back side of Si wafers. From the plots, it is very clear that additive A3 has the strongest effect on dusting, whereas factors such as type of Al powder, type of glass, additives A1 and dispersant D have a small impact on dusting. Additives A2 and A4 have no effect on dusting. Since wafer dusting is to be minimized, the presence of additive A3 (+) is preferred for obtaining lower dusting.

Figures 8 and 9 show the effect of various factors on paste viscosity. From the plots it is evident that dispersant D has a very strong effect on viscosity, whereas additives A1, A3 and A2 have moderate impact on paste viscosity.
For obtaining a low viscosity paste, the presence of dispersant D (+), additives A1(+), A3(+) and A2(+) are desired in the paste chemistry.

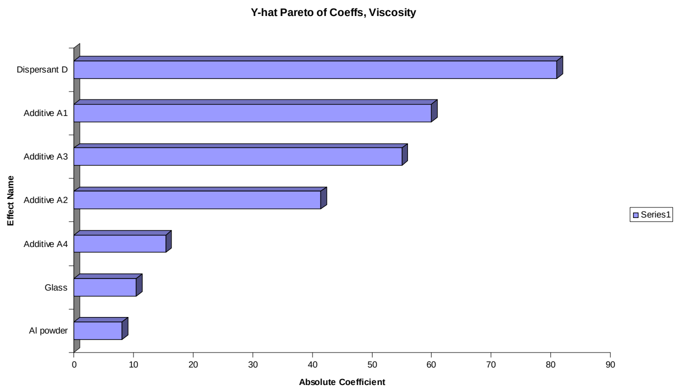


Figure 8 Pareto chart showing effect of various factors on viscosity of paste.

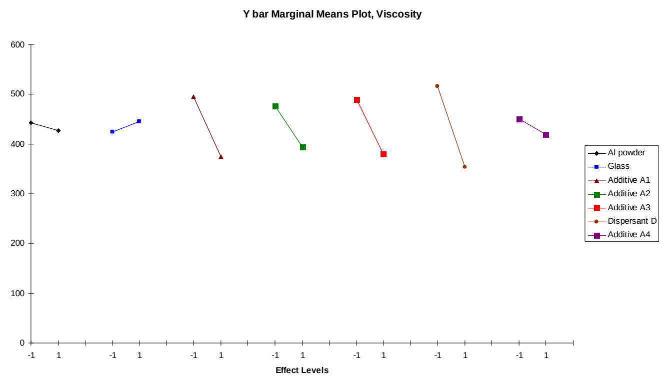


Figure 9 Marginal means plot showing effect of various factors on paste viscosity.

Depending on which property is most important to a customer, paste optimization can be achieved. Often, there are conflicting requirements for electrical, bowing, dusting and paste viscosity, resulting in trade offs that are required to get the most optimum results. The DOE software and the screening design thus become an important tool for paste development, allowing conscious decisions to be made regarding the impact of various decisions. It reduces much of the guess work in experimental design and gives a scientific basis for paste development.

REFRENCES

[1] J.Mandelkorn et al., Proc. **9th** *IEEE Phot. Spec. Conf.*, Silver Springs, 1972, pp. 66.

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[3] A. Rohatgi et al,Proc. **23rd** *IEEE Phot. Spec. Conf.*,1993, pp. 52