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DEVELOPMENT OF Al-BSF PASTE TO FIRE-THROUGH DIELECTRIC PASSIVATION LAYERS

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ABSTRACT: The overall demand to reduce the costs per watt for crystalline silicon solar cells requires that thinner and thinner wafers have to be used. Switching to thinner wafers can be beneficial only if the efficiency of the solar cell can be increased or at least be maintained at levels obtained with thicker wafers. As for thinner cells, the recombination losses at the classical Al-BSF layer become more and more important. It is required to look for back-side passivation technologies to be able to maintain or preferably increase the cell efficiency. In this paper newly developed screen-printable pastes for contacting the backside passivated high efficiency thin solar cells will be presented. Special emphasis will be laid on the formation of a localized BSF under the fine line printable Al pastes after firing through the SiN passivating coating.
Keywords: Back-Surface-Field (BSF), C-Si, Screen Printing, Passivation, Si-Nitride, Al-Paste

1 INTRODUCTION

In order to reduce the cost for solar energy there is a continuous drive to reduce the thickness of the silicon wafers. This is to reduce the cost of silicon fraction of the cell and thus overall solar energy costs. Besides handling and bowing problems associated with thinner wafers a major drawback is the increased influence of the wafer back surface on the overall cell performance. Especially the high surface recombination velocity at the lowly doped Al-BSF has to be mentioned in this regard [1], as well as lower internal reflection. In order to reduce the surface recombination velocity passivation of the backside offers an opportunity. Different passivating materials like SiNx, SiO2, SiC, TiO_2 or amorphous Si have been considered in the literature for high efficiency cell concepts [2-5]. The use of a backside passivation includes the challenge to form an adequate contact. Several comparable technologies have been proposed but most of them require additional process steps and are not compatible with the actual industrial fabrication of c-Si solar cells. A simple process to form the back-contact is to use a screen-printed back-contact grid that fires through the passivation layer on the backside of the cell in the same firing run as the front-side electrodes are firing through the antireflective coating on the front of the cell [1].

In this paper the development of screen printable Al based pastes that form a localized BSF and fire through SiN passivation layers will be discussed. The challenge of the development is to find a paste which offers optimum fine line printing capabilities and forms a good BSF under the fine electrode.

2 EXPERIMENTAL

Initial test had shown that standard lead and lead free Al-pastes for SiNx free backsides of wafer are not able to fire through the SiNx passivating coating. Therefore a matrix of experiments has been set-up in order to define a paste chemistry that allows firing through SiN and at the same time form a BSF. The BSF formation requires the presence of Al in the pastes. The glass chemistries tested have been chosen from glasses that are known to etch SiNx in the fast firing process. The initial screening has been done on SiNx on the front side of wafer with standard anti reflective SiNx coating. The firing settings of an RTC infrared kiln have been 780, 830 and 930°C for the 3 zones of 0.19, 0.39, and 0.19m, respectively. The belt speed was 3050mm/min.

Table I gives a summary of the experimental screening.

Table I: Screening matrix

Material	Al	Pb-free glas	Pb-glas	Additive
001	X			
002	X	H		
003	X	K		
004	X		X	
005	X		Y	
006	X	H		A
007	X	H		B
008	X	H		C
009	X	H		D
010	X		X	A
011	X		Y	A
012	X		Z	A

After having selected pastes that are capable of forming a BSF after firing through SiN AR coatings, solar cells have been prepared from double-sided AR coated wafers. The cell design of these cells was similar to standard cells with normal Al-BSF pastes, thus the SiNx coated backside of the cells was fully covered with the SiNx-fire through paste. As front contact Ferro paste CN33-462 has been used, no firing optimization has been performed. The firing conditions were identical to those mentioned above.

3 RESULTS AND DISCUSSION

3.1 Formation of BSF

Fig. 3.1 shows the etched cross section of the paste 002 printed on SiNx side of wafer with lead free glass in combination with Al powder. No BSF has been formed, even though the paste clearly etched away the AR coating. As indicated e.g. by the occasional formed eutectic alloy under the fired Al electrode.

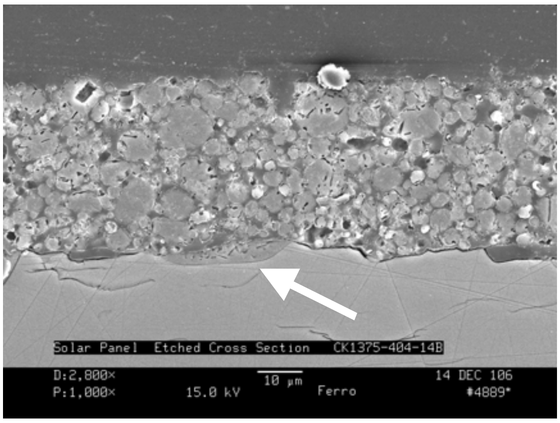

Fig. 3.1 Cross section of wafer with paste 002.

Anyhow, the required BSF is missing between the eutectic alloy and the bulk Si. Similar pictures have been obtained for the pastes 003 to 005, in which 004 and 005 contained lead based glasses.

In pastes 006 to 009 different additives A to D have been added to the Al paste 002 and only for additive A a very narrow BSF has been detected under the eutectic alloy (see fig. 3.2) while the rest of the pastes did not show any indication of the a BSF (see fig. 3.3).

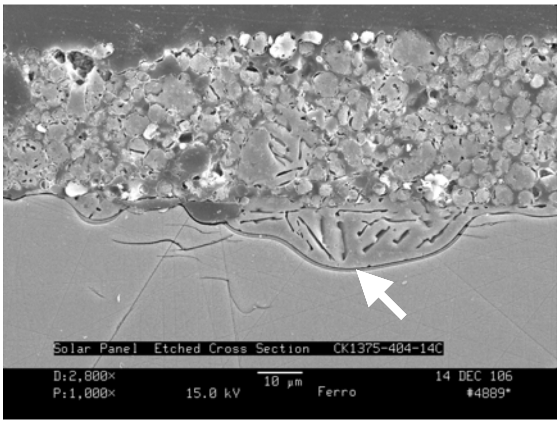

Fig.3.2 Very fine BSF present in fired electrode of paste 006 (additive A addition)

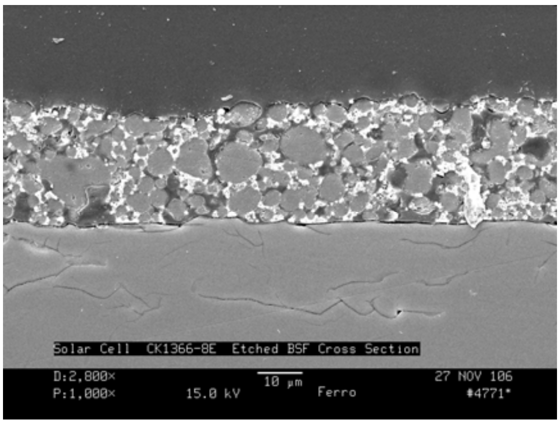

Fig. 3.3 No BSF detectable for paste 007 (additive B)

Much better BSF layers can be obtained, when the glass system is exchanged to lead based glasses in combination with the addition of additive A. Wavy BSF layer can be detected for the paste 010 and 012, while the paste 011 does not exhibit any visible BSF even though it contains a leaded glass and additive A.

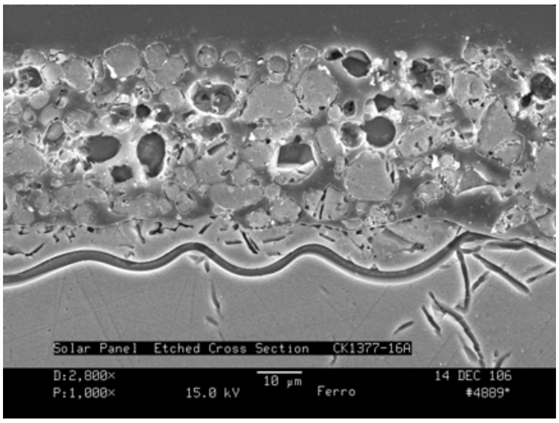

Fig. 3.4 SEM cross section showing wavy BSF formed for paste 010 with additive A.

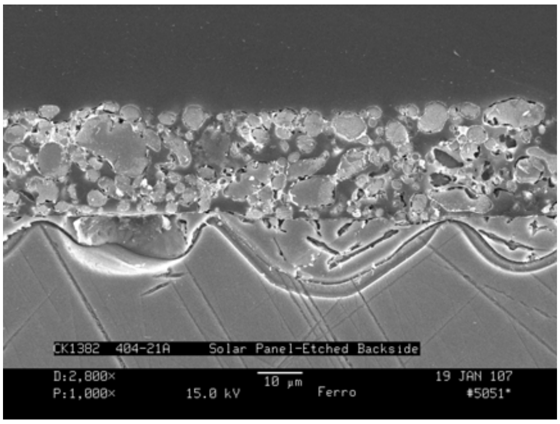

Fig. 3.5 SEM cross-section showing wavy BSF for a paste 012 with additive A.

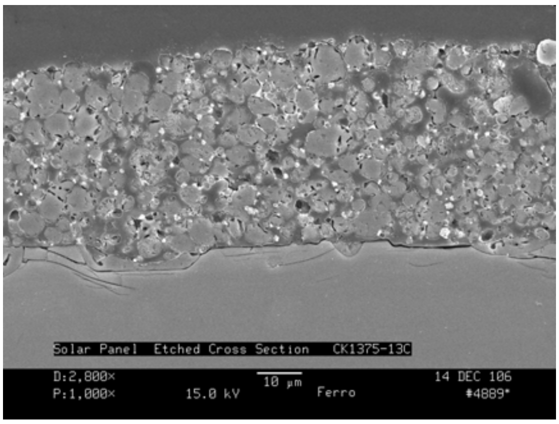

Fig. 3.6 No BSF formation for paste 011 with lead glass Y and additive A.

In summary it can be stated that a lead or lead free chemistry without a second additive do not form a BSF. The best BSF has been obtained for leaded glass chemistries for the leaded glass chemistries Xand Z, while for glass Y eventhough it is etching through SiN no BSF is formed.

3.2 Electrical results

The cell results for cells made with double sided SiNx coated wafers in combination with Al paste containing leaded glass X and Z and additive A are presented in the following table. The cell results are only indicative, because the wafer quantity of the double side coated wafers was small and did not allow a firing optimization for the front side electrodes with respect to these wafers.

Table II: Cell results (wafer size is 125x125 mm)

Material	Voc[V]	Sun Voc[V]	Isc[A]	FF	eta[%]
010	0.58	0.605	4.59	0.71	11.9
012	0.59	0.595	4.68	0.69	11.7
013	0.58	0.591	4.61	0.68	11.6
014	0.57	0.581	4.57	0.70	11.4

The paste 013 and 13 are modifications of paste 010 and 012, respectively, in order to further improve the electrical properties. But the results are very similar to those of paste 012. Anyhow especially the SunVoc data obtained for the combination of lead glass X and additive A show that it should be possible to obtain cell results which are comparable to standard cells. The use of backside passivation and optimized fine line printing should allow further improvement of the cell.

3.3 Fine line printing of Al-based pastes

As mention in the introduction, the paste does not only have to form a good local BSF, but it should have fine line printing capability. This is demonstrated in the following cross sections, in which the paste has been printed through a 280µm mesh screen with 100µm line openings.

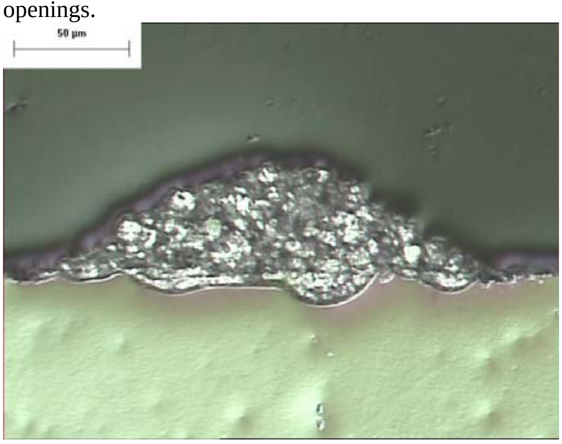

Fig. 3.7 Optical microscope cross-section of fine line printed paste.

The picture shows a significant broadening of the electrode to about 190 µm, compared to the screen openings of 100µm. The higher magnification picture shown in fig. 3.8 shows the BSF under the electrode, and some spread out metal electrode at the edges, where metal has been bleeding out onto the SiNx.

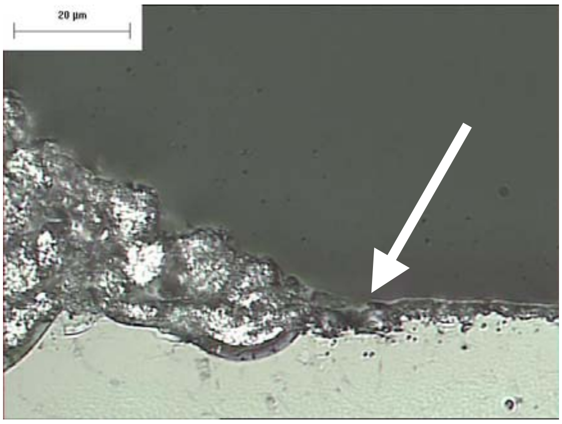

Fig. 3.8 Optical microscope cross-section of fine line printed paste with bleeding area (arrow).

4 DISCUSSION

- It has been shown that it is possible to develop an Al-paste that fires through SiNx antireflective coatings. It is assumes that these properties are maintained if the chemistry of the coating is slightly modified in order to optimize the SiNx layer for passivation purposes.
- The Sun Voc date obtained for the best cell indicate that the paste is capable of getting similar open circuit voltages as for standard cell.
- The fine-line printability of the paste still needs further attention, but it has also to be considered that in order to form a good BSF the Al has to be liquid and the paste composition is required to wet and etch the SiNx layer and thus some line widening due to flow of the mostly liquid electrode can not be excluded.

5 ACKNOWLEDGEMENTS

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