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Reliable Metallization Process for Ultra Fine Line Printing

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Abstract

In this paper we present an approach to achieve both 100mg paste deposit on a c-Si solar cell and efficiency gains with no impact on peel strength at extremely narrow finger widths. Using the double print process with suitable pastes and screens we demonstrate an 0.18% absolute efficiency gain and 20% paste saving over the standard process. This benefit is correlated to the finger width reduction from 63 µm to 47 µm, leading to an increase in Isc and Voc, due to the reduced recombination area under the metal contacts. The peel strength is also shown to increase from 1.5 N to 3 N for the same busbar thickness, when different paste compositions for the DP process are used. We also show screen lifetimes above 30k prints in production, with a stable process in terms of efficiency gain and paste saving.

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1. Introduction

Screen printing is a simple, cost-effective and to-date the most reliable method for c-Si solar cells metallization. One of the major process requirements is to constantly reduce the laydown of Ag paste, which represents the main contribution to the total cost of the cell.

According to the industry roadmap [1] the current finger width in production is 80 µm with 150 mg Ag weight for both front and back metallization. The expected trend in finger width reduction and paste consumption decrease

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can be supported by constantly decreasing screen openings (currently at 45 μm for the most advanced cell manufacturers).

A possible option to reach the target using single printing (SP) is to limit screen opening widths to 35 μm or less, so that the total paste consumption on the front side can be lower than 100 mg. This can be done by using a combination of a high resolution of the screen openings enabled by a proper screen emulsion and exposure, and a paste with optimized rheology, able to flow through narrow apertures. However, when printed lines are narrower than 50-55 μm, as can be expected when using such small screen openings, the narrow openings result in interruptions, leading to high grid resistivity and electrical performances degradation.

Double Printing (DP) of fingers is a consolidated technique to overcome these issues [2], as the double print pass on fingers prevents losses associated with interrupted lines. Additionally, in DP the reduced metalized surface increases the short circuit current and consequently the efficiency. Tool repeatability and accuracy are necessary condition for a good overlap of the two layers.

The goal of this work was to present production data from a fully optimized DP manufacturing line with 0.17% absolute efficiency gain and 20 mg paste savings, and the latest results on DP at laboratory scale, with 0.18% absolute efficiency gain and 102 mg front side paste consumption, a finger width below 50 μm and no impact to peel strength performance.

2. Experimental details – Fine Line Single Printing

The first process we evaluated, with the goal of decreasing the amount of paste deposited, was based on Fine Line Single Printing (FLSP) with 35 μm screen opening, in comparison to the production proven SP with 45 μm screen opening. For both conditions screen mesh was 290/20 and Emulsion Over Mesh (EOM) 15 μm. For FLSP we used an ultra-calendered mesh, reducing the total screen thickness to 22 μm from the standard 45 μm. In this way we expected to reduce the busbar thickness and consequently the overall paste consumption, and at the same time to improve the paste flowing behavior through narrow openings.

We used commercially available production pastes and 156 mm multi-crystalline wafers with 65 Ohm/sq POCl emitter, iso-texturing, PECVD SiN, full Back Surface Field and Laser Edge Isolation. The front side layout had 3 continuous busbars and 85 fingers.

The finger morphology and electrical data are reported in Table 1. Finger and busbar thickness were measured using a laser profilometer and then averaged for all the printed samples (25): in particular, fingers thickness was measured in 9 different points for each wafer, representative of the entire printed area. In the same points, finger width was measured using an automatic optical microscope. Reported electrical data are calculated as average of the 25 samples for each condition as well.

As expected, for FLSP the finger cross section is reduced and the busbar thickness is halved. Interestingly, this did not lead to a drop in efficiency, because the decrease in fill factor (FF) for FLSP cells is compensated by an Isc increase, correlated with the finger width reduction.

Table 1. SP And FLSP Morphological And Electrical Data: average values

	Screen Opening (μm)	Finger Width (μm)	Finger Thick. (μm)	Busbar Thick. (μm)	Paste Weight (mg)	Eff (%)	Isc (A)	Voc (V)	FF (%)	Rs (mΩ)	Rsh (Ω)	Grid Res. (mΩ)	Peel Force (N)
SP	45	70	21	9	139	16.94	8.41	621	78.79	2.6	231	30.5	3.2
FLSP	35	61	11	5	89	16.96	8.52	624	77.58	3.1	534	45.9	0.7

As can be seen from the grid resistance and peel force data, there are two clear drawbacks to this approach, particularly when applied in production by cell manufacturers that need to guarantee a high cell quality. The first issue is the metallization yield, as shown by Electroluminescence (EL) images (Fig. 1). FLSP cells show a higher incidence of line interruptions and severe finger cross-section narrowing (not easily detectable by optical microscope or in-line vision systems), leading to an increase in grid resistance, directly correlated with the Rs and

FF values. The second effect is on the peel strength after soldering, which would be consistently reduced by the low busbar deposit especially if the same paste is used [3, 4].

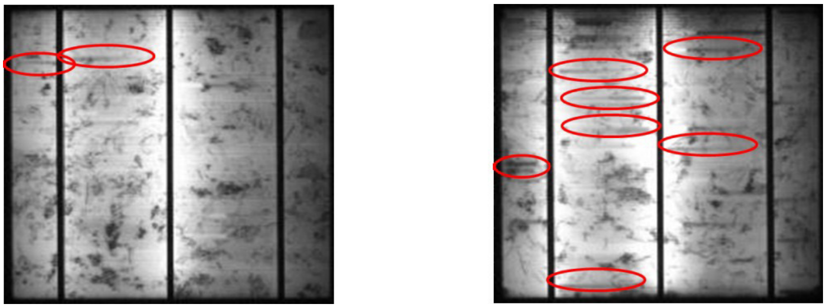

Figure 1 (a) SP 45um opening EL image; (b) FLSP 35um opening EL image. The incidence of micro-interruptions, evidenced by the red circles, is significantly higher in the FLSP process

We measured the peel strength by manually soldering 1.7 mm wide and 200 µm thick solder coated Cu ribbons and peeling with an automatic unit, registering the average and maximum peel force. As shown recently by other groups [5], one possible approach to overcome this issue could be the introduction of Dual Printing (DuP), which would likely still suffer from the EL yield issue when using aggressive openings below 40 µm.
An effective approach to simultaneously solve EL yield and peel force issues is to introduce the DP process in the standard manufacturing line.

3. Double Printing – Production Data

We present data from a joint process development activity with Tianjin Yingli, where DP has been adopted in multiple production lines. Process stability is presented in terms of efficiency, paste consumption and screen lifetime.

During a marathon run of 13k wafers SP and DP performance were compared using the same wafer source. Table 2 shows the resulting average 0.17% absolute efficiency gain and 20 mg paste saving: all wafers were measured in-line for electrical characterization, while paste weight was measured every 1K printed wafers (same sampling method was used to collect data reported in Table 3).

The efficiency gain for DP is related to an increase in Isc and FF, which are due to the decrease in finger width from 68 µm to 59 µm, with a simultaneous increase of finger thickness from 18 µm to 22 µm.

Table 2. SP And DP Production Data For 13k Wafers At Tianjin Yingli: average data

	Finger Width (µm)	Finger Thickness (µm)	Paste Weight (mg)	Eff (%)	Isc (A)	Voc (V)	FF (%)	Rs (mΩ)	Rsh (Ω)	Eff <15% (%cells)	Eff <16% (%cells)
SP	68	18	118	17.23	8.45	625	79.36	1.87	278	0.05	0.69
DP	59	22	98	17.40	8.53	624	79.50	1.88	887	0.01	0.45

As shown in the last two columns of Table 2, the shift in efficiency for DP wafers also improves the overall yield, diminishing the impact of the low efficiency tails. In fact, depending on the cut-off efficiency threshold, the rejection rate difference from SP to DP can range from 0.04% (<15%) to 0.24% (<16%).

In a second stage of optimization 12” and 15” screen lifetime performance were compared. The same screen parameters of 290/20 mesh and 15 µm EOM were used. The other process variables (paste, squeegee, tool configuration) were kept constant.

As summarized in Table 3, average lifetimes of 23.5k wafers for 12” screens and 33.5k wafers for 15” screens were demonstrated. The main reason for screen replacement during these runs was mechanical wear of the emulsion, which led to finger widening and a progressive increase of paste consumption. The process stability for the 35k wafer run can be seen by tracking finger width and paste consumption (Fig. 2).

Table 3. 12” and 15” Screens Production

	DP Weight (mg)	Lifetime (cells)
12” run 1	119	24000
12” run 2	114	23000
15” run 3	102	35000
15” run 4	112	33500

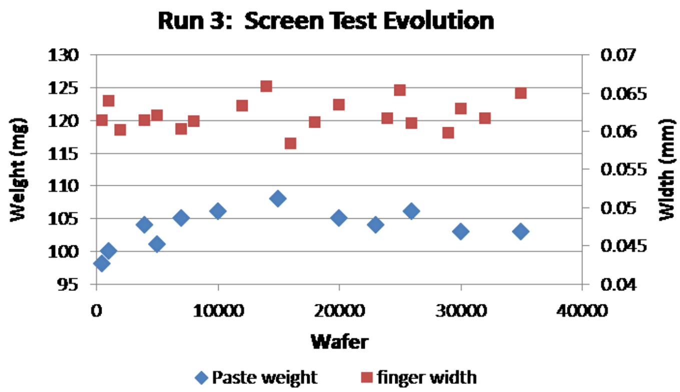

Figure 2 Results of data monitoring during run 3 (35k) wafers.

4. Experimental Details – Ultra Fine Line Double Printing

The DP process illustrated above is based on first and second printing with the same paste, and finger width greater than 60 µm. Multiple DP tests were run in the laboratory, with the goal of introducing different pastes for first and second printing in order to achieve efficiency gain and paste reduction simultaneously while preserving the peel strength and achieving a finger width below 50 µm. Lots of 25 wafers each were processed and compared.

156mm mono-crystalline wafers with implanted emitter from Applied Materials Varian[6] were used. The different lots characteristics are summarized in Table 4. SP and DPI (where the same paste has been used for both layers) were tested and compared with the DPII process (where pastes with different formulations have been used for first and second print). Finally we added one more DP split, where the screen openings were reduced in order to further decrease finger widths to less than 50 µm (Ultra FLDPII). Paste A is a commercially available Ag paste designed for fine line printing. Paste B has a modified composition in order to guarantee high adhesion, especially when busbars thickness is lower than 6 μm as in the case of Ultra Fine Line DP.

Table 4. SP, DP And FLDP Morphological And Electrical Data.

	Screen Opening (μm)	Paste Type	Finger Width (μm)	Finger Thick. (μm)	Cross Sect. (μm2)	Busbar Thick. (μm)	Paste Weight (mg)	Eff (%)	Isc (A)	Voc (V)	FF (%)	Rs (mΩ)	Rsh (Ω)	Peel Force (N)
SP	45	A	63	15	635	7	126	19.01	9.03	641	78.53	2.4	51	1.4
DPI	35+35	A+A	56	21	559	6	119	19.27	9.11	643	78.61	2.1	57	1
DPII	35+35	A+B	55	22	602	10	112	19.17	9.09	642	78.48	2.2	66	4.3
FLDPII	30+25	A+B	47	21	405	7	102	19.19	9.12	642	78.27	2.3	46	3

As in the case of FLSP, screen mesh has been calendered for better paste release and thickness control. The mesh count is 290-20 for SP and standard DP lots, 360-16 for Ultra FLDPII, where an increased mesh resolution is required. Moreover, in order to compensate for FF losses when going to narrow fingers the number of fingers in the screen layout has been increased from 78 to 90, while the number of busbars is kept constant at three, with continuous (non-sectioned) shape.

With respect to the reference process at 126 mg paste consumption, it was possible to reduce the deposit for all the DP lots, with the expected relevant decrease to 102 mg for the Ultra FLDPII condition. This is mainly correlated to a decrease of paste consumption for the fingers. In fact, the busbar is constant for all conditions at 6 μm thickness, except for DPII where the combination of 290/20 mesh and higher viscosity of Paste B lead to 10 μm thickness.

The electrical performance data demonstrated that the DPI process achieved the highest efficiency gain compared to SP, however the DPII processes allows for better peel strength performance with a limited efficiency drop. We can see that the overall compatibility of Paste A and Paste B is good, and this combination is promising in terms of paste weight reduction without impacting the peel strength performance.

Comparing DPII and Ultra FLDPII data, the benefit of narrower screen openings becomes evident in terms of finger width and paste consumption. From the morphology analysis in Fig.3 it can be noted that the finger profile for DPII paste combinations can be further improved. We tend to associate this effect to suboptimal paste conditions and solvent concentration.

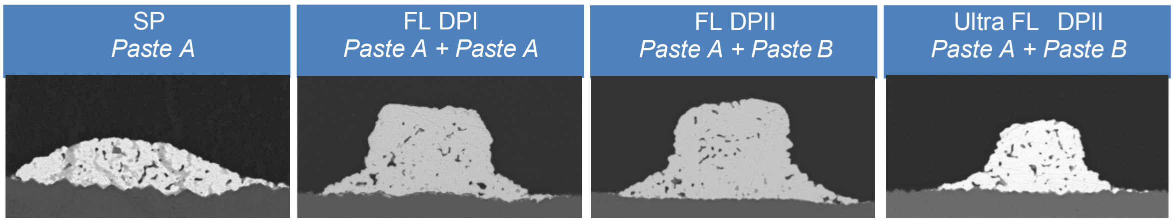

Figure 3 Morphology comparison of SP and DP lots. It can be seen the increased roughness for the DPII conditions

5. Conclusion

In this paper we demonstrated that the deployment of FLSP process at 35 μm screen openings to reduce paste consumption and preserve efficiency is not a recommended solution because of severe issues in terms of EL yield and peel strength performance. Moreover, to our knowledge, production performance of FLSP has not yet been demonstrated.

We showed at laboratory scale that DP enables an ultra fine line metallization at <50 µm finger width (and <30 µm screen openings) with significant benefits of 0.18% absolute efficiency gain and 19% Ag paste saving over a production type SP process.

Moreover, the EL yield issue could be solved by printing the fingers twice, while the peel strength could be improved by careful paste optimization. More importantly, these latter results have been proven in a manufacturing environment, where a screen lifetime of more than 30k prints has been demonstrated.

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