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Extensive comparison of solar modules manufactured with single and double printed cells

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Abstract

With respect to Single Printing (SP), Fine Line Double Printing (FLDP) metallization process delivers 0.21% absolute efficiency gain and 11 mg paste saving in mass production. In fact, an average finger width of 47 µm is achieved with FLDP, with 16 µm line width decrease if compared to SP. In this work we investigate how this cell efficiency gain translates into module power by looking at extensive module production runs at Yingli. FLDP modules use 10% less Ag, have comparable Cell To Module (CTM) loss and reliability performance, and exhibit better Electroluminescence yield due to absence of interruptions.

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1. Introduction

Solar cell and module manufacturers constantly improve their metallization process, trying to simultaneously increase cell and module efficiency and reduce paste consumption, to save processing costs. Questions arise on how far this approach can go in mass production, due to potential limitations in the screen printing process. For example, by applying Single Printing (printing fingers and busbars in the same step) each paste hits a limit on the minimum applicable screen opening before it leads to finger interruptions. Consequently, frequent screen cleaning is needed, with detrimental implications in net productivity. Historically there has been a constant effort from paste manufacturers to improve their products performances towards respectively: 1) better contacting behavior to lowly doped emitters, 2) improved flowing behavior through narrow finger openings [1]. Leveraging on this development

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of printing materials, several equipment manufacturers and research institutes propose alternative methods in order to overcome the limitations of the traditional SP process. An extensive review of such methods can be found in [2].

Although some alternative techniques are investigated at research level, currently the most adopted technologies in mass production besides SP are Dual Printing (DuP – first print: busbars only, second print: fingers only) and Double Printing (DP – first print: fingers only, second print: fingers and busbars). If compared to SP the DuP process shows little or no efficiency gain (0-0.05% absolute) but a potential paste saving of 10-20 mg due to use of dedicated paste for busbars, designed for high soldering adhesion at low deposits and reduced contacting to the emitter. On the other hand, DP allows higher efficiency gain (0.15-0.25% absolute if compared to SP) and a certain degree of paste saving (5-15mg if compared to SP). The DuP process is solely aimed at reducing processing costs, while the DP can increase the cell and module performance while reducing costs at the same time.

In order to compete both on price and performance, Yingli deployed the DP technology in mass production for several years already [3]. In this work we present the latest cell and module production data from the production site of Baoding. An extensive comparison between SP and Fine Line Double Print (FLDP – DP with sub 50 μm features) process and record low 95 mg of wet paste deposit, has been carried out. In order to understand if the reduced paste consumption would impact the module performance, a sorting technique has been applied and cells with same efficiency have been selected. In total 60 modules have been produced and electrically tested, showing the same performance for SP and FLDP; in this way can conclude that the reduced paste consumption of FLDP is not impacting module IV performance. Additionally, sample EL measurements show that FLDP process delivers better overall yield.

2. Experiment

Two different experimental phases can be identified for this test, both performed with production wafers from Yingli. It's worth mentioning that the cell layout has been optimized if compared to standard layouts and one redundancy line has been introduced between the busbars in order to reduce the effect of finger interruptions also for the SP process (Fig 1).

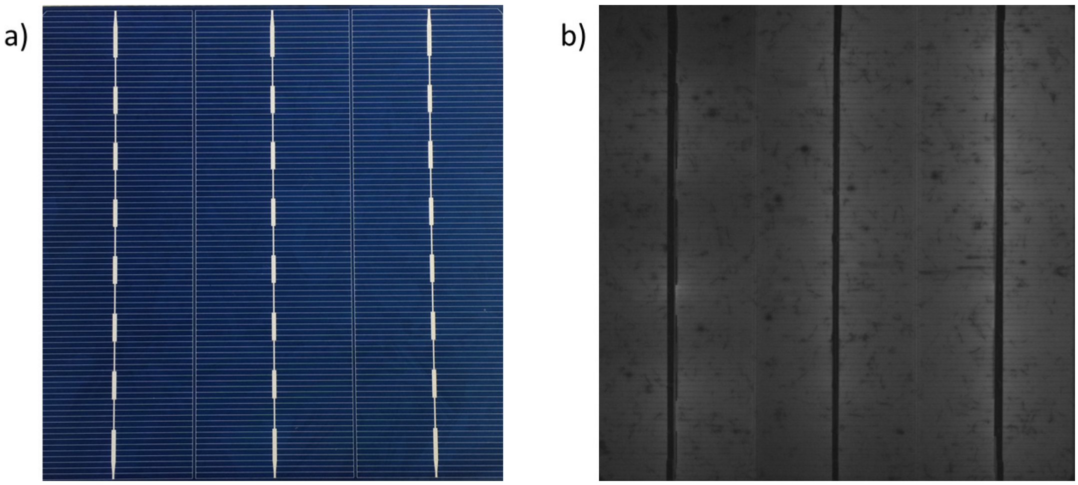

Fig.1: Cell layout image for SP and FLDP process (a): two redundancy lines with two vertical fingers have been added between busbars. In (b) the EL image of a solar cell with such layout is shown, with brighter lines between busbars due to the vertical redundancy lines.

In the first phase we compared SP and FLDP for two limited lots of 200 mc-Si wafers with the same quality. Purpose of this test is to assess the cell efficiency gain achievable with the FLDP process in production and measure all the relevant parameters, such as paste consumption and finger morphology. One difference that we should consider is the use of two different paste models for SP and for DP cells. In fact, the SP paste could not achieve suitable printing performance on the narrow openings of the DP and a different paste has been qualified. For this reason it is not possible to fully discriminate the impact of the paste type as opposite to the metallization process, and this is a limitation related to the need to perform these tests in a production environment that we will try to address in future experiments.

In the second phase we selected two groups of cells with the same efficiency binning, manufactured 60+60 modules and tested them with a module solar simulator. Then we statistically analyzed the electrical parameters to address potential losses correlated with the lower paste deposit of FLDP cells. Subsequently, we sampled 10 modules per each condition for Electroluminescence (EL) testing and performed image processing to be able to distinguish metallization related defects. Additionally we looked at reliability data for a module selected for both groups by performing Thermal Cycling and Damp Heat tests according to IEC 61215.

3. Results and Discussion

3.1 Cell manufacturing data

Two sets of 200 mc-Si Al-BSF wafers with the same quality have been processed using SP and FLDP metallization. Processed wafers have 156 mm x 156 mm size, 180 µm thickness, 1.5 ±0.5 Ωcm resistivity, 85 Ω/sq emitter sheet resistance and 80 nm SiN coating on the frontside. The screen and process parameters for the two lots are summarized in Tab.1.

Table 1: Process parameters for SP and FLDP cells comparative test.

Lot	Cell #	Paste	Screen Mesh	Screen Thickness [µm]	EOM [µm]	Opening (Topside) [µm]	Squeegee Angle [deg]	Frame Size [inch]	Finger number
SP	200	A	400/18	30	15	43	45	12”	85
FLDP	200	B+B	360/16	20+20	15+10	25+28	70+70	15”	95

As previously indicated, both conditions use the same layout with additional redundancy line between the busbars. In order to perform the FLDP process with <30 µm screen opening a thinner mesh has been selected with a reduced number of wires to increase the open area and enhance the paste transfer mechanism (from 400/18 mesh to 360/16 mesh). At the same time, the screen calendering grade has been modified to reduce mesh screen thickness for FLDP to 20µm, from 30 µm of SP. This reduction is enabled by the possibility of printing twice the fingers for the FLDP, with higher overall tolerance for interruptions for each printing step. Additionally, the number of fingers has been increased in FLDP to account for potential FF losses induced by a narrower finger width, according to [4]. The last difference is the utilization of a 15” frame for FLDP, allowing lower mechanical stress on the metal mesh and longer screen lifetime.

Under these conditions, there is a significant enhancement in morphology and electrical performance obtained with FLDP, as summarized in Tab.2.

Table 2: Morphology and IV data for SP and FLDP cells.

Lot	Finger Width [µm]	Finger Thickness [µm]	Aspect Ratio	Busbar Thickness [µm]	Paste Weight [mg]	Voc [V]	Isc [A]	Rs [Ω]	Rsh [Ω]	FF [%]	Eff [%]
SP	63	16	0.25	11	106	0.626	8.69	0.0032	88.3	79.34	17.72
FLDP	47	17	0.36	8	95	0.626	8.79	0.0033	254.1	79.28	17.93

In fact, due to a finger width reduction of 16 µm and increased height of 3 µm the FLDP cells have an increase in Short Circuit Current (Isc) of 0.1A, with comparable Open Circuit Voltage (Voc) and Fill Factor (FF) to SP. At the same time, the reduction of 3 µm in busbar thickness allows an overall paste saving of 11 mg. In Fig.2 the SEM and laser scan measurements are reported.

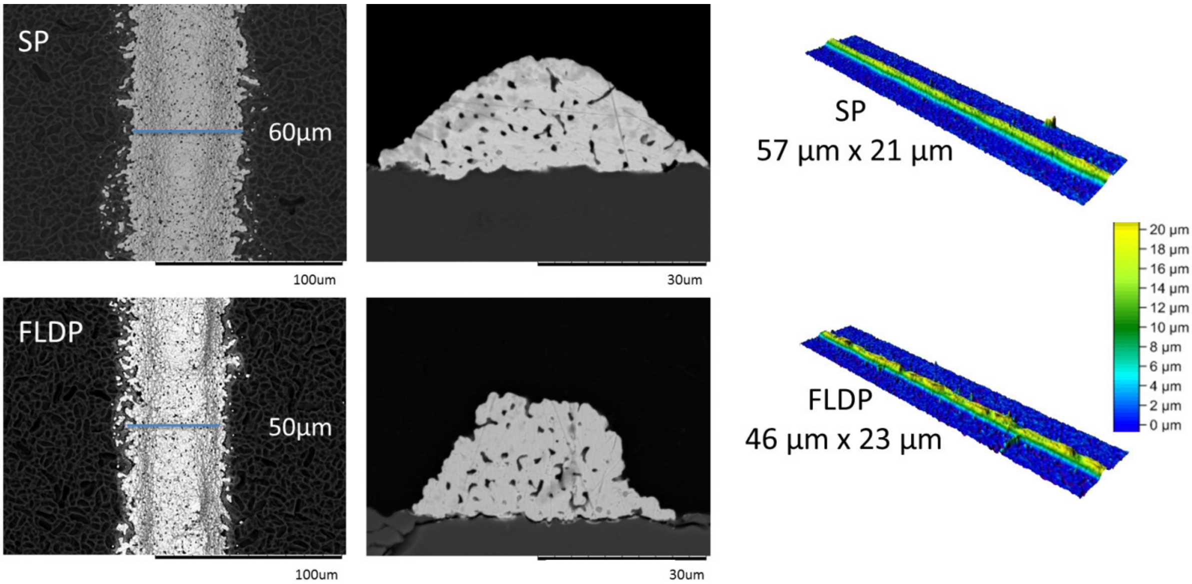

Fig.2: Top row images relative to SP and bottom row relative to FLDP: from left to right SEM planar images, SEM cross sections and 3d profilometer scans.

3.2 Module manufacturing data

In the module line two groups of SP and FLDP cells with the same efficiency binning have been selected. Purpose of this pre-sorting is to manufacture homogeneous modules for each condition and understand if additional losses at any level would occur when paste consumption is reduced below 100 mg per wafer. The cell and module IV data are reported in Tab.3, for 60 modules per condition.

Table 3. Electrical data for SP and FLDP cells with the same binning. 60 modules per each condition have been manufactured.

Lot	Cell data (Same binning)				Module data					
	Voc [V]	Isc [A]	FF [%]	Eff [%]	Voc [V]	Isc [A]	Vm [V]	Im [A]	FF [%]	Pmax [W]
SP	0.630	8.70	78.80	17.75	37.51	9.02	30.13	8.44	75.17	254.2
FLDP	0.629	8.72	78.76	17.75	37.44	9.03	30.12	8.47	75.42	255.0

Looking at the distributions of the electrical data the Voc, Isc, and maximum power differences are maintained when moving from cell to module. The only parameter that increases significantly for FLDP from cell to module is the FF, and this behavior could be correlated either to a different soldering performance of the paste or to absence of interruptions for FLDP. This FF increase justifies the 0.8W additional power gain for FLDP modules, however it's difficult to clearly discriminate the effect of different paste versus the metallization process itself and more tests would be needed in more controlled conditions. Statistically, FLDP modules have comparable IV performance to SP, even using 10% less paste (see Fig.3).

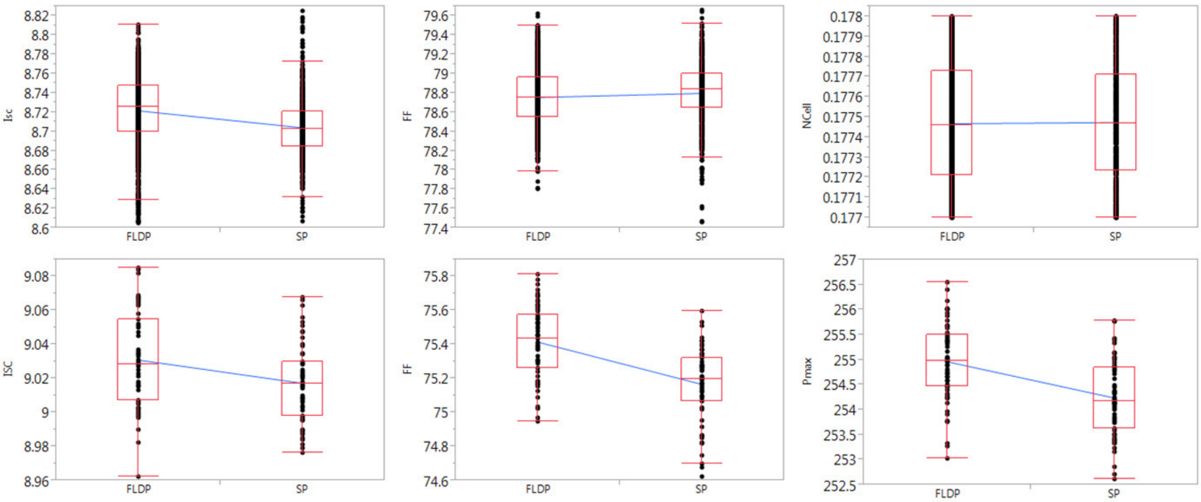

Fig. 3: electrical data trends for cell (top row graphs) and modules (bottom row) based on SP and FLDP metallization.

To further characterize the modules, they have been tested with Electroluminescence [5]. Since no automated image recognition for EL was available at customer site, also due to the difficulties intrinsic with the defect recognition on mc-Si wafers, we used an empirical method based on judgment of four different operators, taking as reference one SP module image with several metallization related defects, as shown in Fig.4.

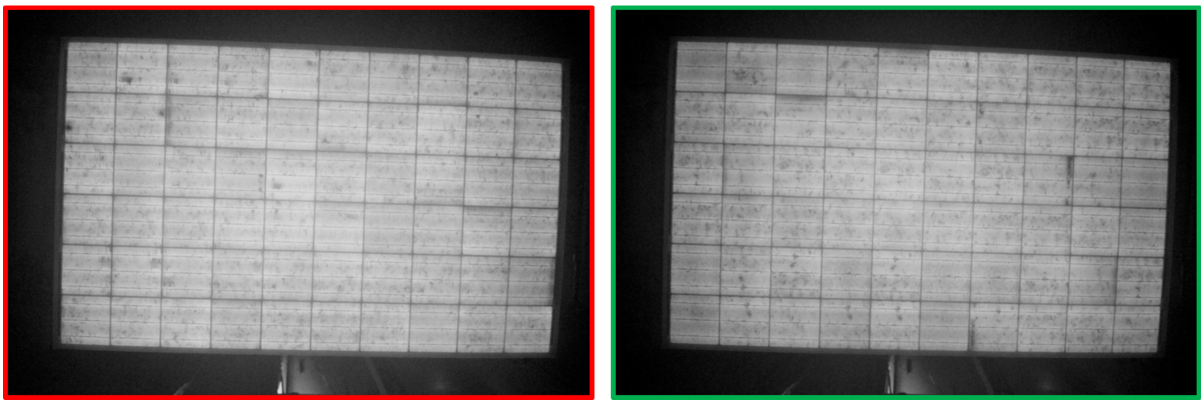

Fig. 4: Electroluminensce data for SP (left) and FLDP (right) module. This SP module has been used as reference for detecting metallization related defects, characterized by recurrent position in different cells.

Based on this approach 10 modules have been analyzed for each condition and the results of the analysis are reported in Fig. 5.a. According to this procedure the percentage of cells with metallization defects is 6.9% for SP and 1.7% for FLDP, and the difference is clearly related to the absence of interruptions of FLDP cells.

In addition, three modules per condition have been tested for reliability according to IEC 61215, through respectively Damp Heat 1000 hours, Thermal Cycling (200 cycles) and Thermal Cycling 50 cycles+ Humidity Freeze 10 cycles. The results are summarized in Fig.5.b, where FLDP modules have comparable performance with SP, all being within the 5% maximum tolerance allowed by the standard.

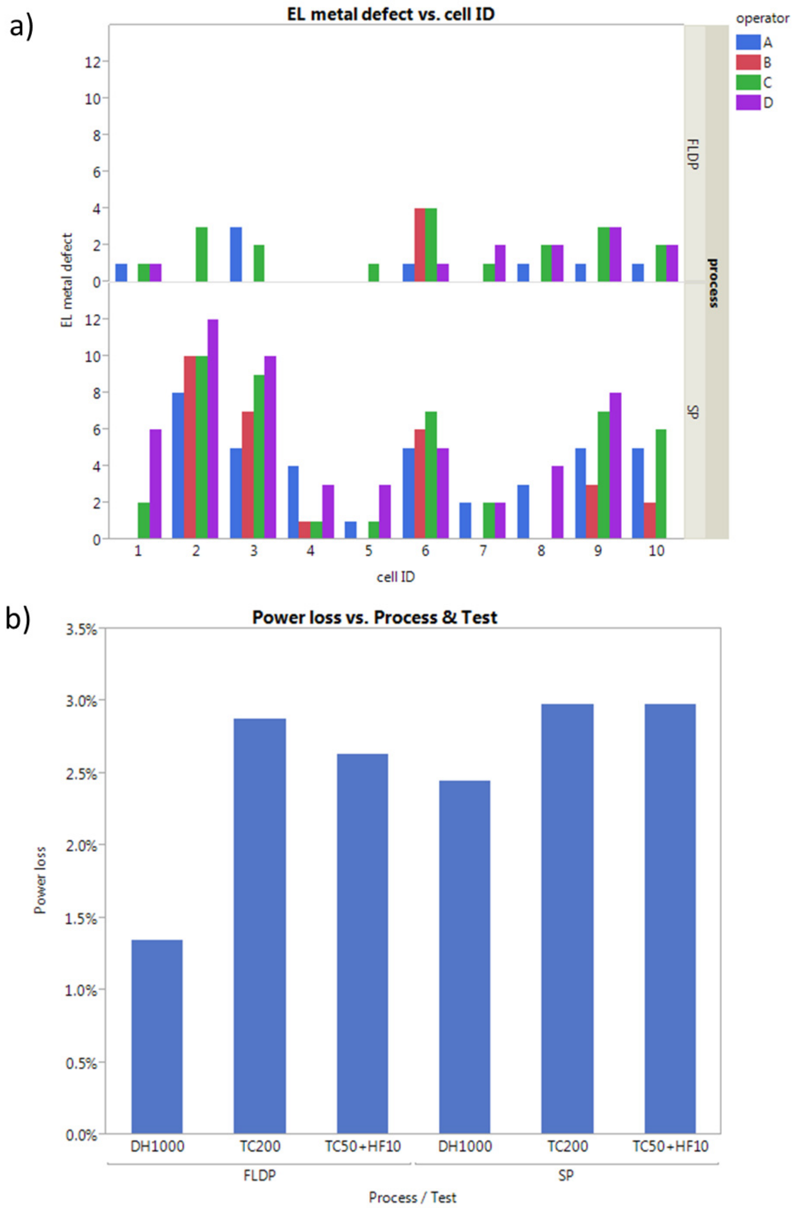

Fig 5: (a) Analysis of EL defect related to metallization for FLDP (top row) and SP (bottom row). 4 operators analyzed 10 modules per condition. (b) Results of module reliability tests according to IEC61215. All modules perform within the limit of 5% maximum allowed power losses.

Based on the efficiency gain at cell level, if modules were manufactured without pre-sorting cells with the same efficiency, a power gain of 2.5-3W would have been achieved by FLDP modules, with 10% paste saving. Using our cost modeling and considering a paste price of 930$/kg this would transfer in yearly cost savings for a 90MW cell and module line in the range of 550k$, fully justifying the current adoption trend of FLDP in mass production.

4. Conclusion

By applying FLDP process in mass production at Yingli a cell efficiency gain of 0.21% and 11 mg paste saving have been demonstrated. Solar modules manufactured with this technology do not show additional power losses even if the paste consumption is consistently lower, at the opposite due to absence of finger interruptions they show better Electroluminescence yield. Reliability data according to IEC 61215 standard are comparable for both technologies, regardless of the paste consumption. In the next phases we will try to study the impact of such interruptions in the long term reliability of the modules.

Acknowledgments

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