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Author(s)		
Name	**Organisation**	**E-mail**
Buchholz, Florian	ISC Konstanz	Florian.buchholz@isc-konstanz.de

Abstract

An advanced metallization scheme was developed in the scope of the Ecosolar project. The goal was to reduce the silver consumption of screen printing metallization. As the Apollon Solar interconnection technique does not require soldering pads or busbars the low hanging fruits were to leave out those features. However, without busbars the IV measurement of the solar cells gets more complicated, as no longer a small contact pin number is required. A measuring chuck was designed and built to surpass this problem. First tests with cells with and without busbars are shown. The second part of the layout is advanced finger metallization by fineline print-on-print technology. An overall reduction of silver printed on mc cells could be reduced to an equivalent of .3.9g per 60 cell module and to 9g per 60 cell module for bifacial solar cells (BiSoN) could be reached. Further potential lies in the application in industrial scale printing lines.

Public introduction[1]

ISC Konstanz has developed an advanced metallization scheme. Profiting from Apollon Solar's NICE interconnection technology, busbars and soldering pads were left out. Finger cross sections were optimized by fineline print-on-print technology.

[1] All deliverables which are not public will contain an introduction that will be made public through the project WEBsite

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1 INTRODUCTION

Silver, as used for the contact formation and on solderable areas of a solar cell, is the most expensive consumable in solar cell manufacturing. Hence, solar cell producers have spent tremendous effort to reduce the overall silver amount. As shown in Figure 1, the silver amount has decreased by a factor of four since 2009.

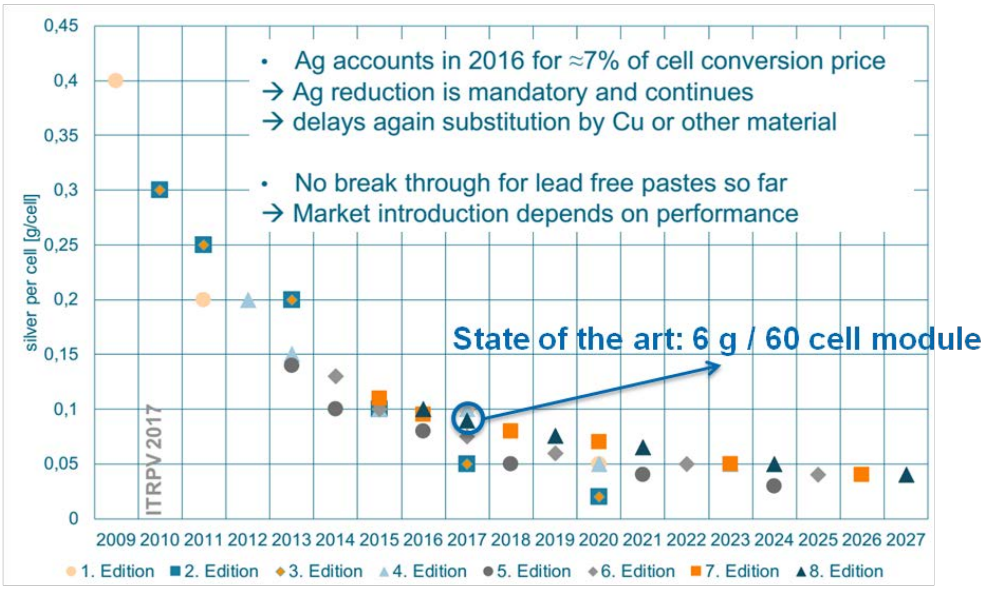

Figure 1: Predicted and actual silver consumption per cell since 2009 from this year’s ITRPV roadmap.

As the curve indicates, a saturation point in terms of decrease has been reached, and further reduction is not so straight forward using classical screen printing metallization. The past decrease has mainly been fuelled by improvement of metallization pastes – the paste manufacturer more and more understand the fundamentals of silicon-silver contact formation and continuously improve the printability of their pastes.

There are two key steps that still leave room for improvement: Firstly, new interconnection technology, such as the Apollon Solar NICE module technology, makes busbars and soldering pads obsolete. However, especially no-busbar bifacial cells are not measurable with standard IV measurement equipment. Therefore, we developed a measurement setup to overcome this problem.

The second step is to use print-on-print technology for the screen printing of contact fingers. When going to finer and finer screen openings the lateral conductivity suffers. On the one hand the finger cross section decreases significantly, on the other hand mesh-induced “valleys” in the finger lead to “bottlenecks”. Thus we use the print-on-print approach by replacing the printing step that would have been used for pads or busbars by another finger printing step with a matching finger screen slightly shifted in the direction of the fingers (200µm), adding another “layer” of finger on top, filling up the bottlenecks. An example for strong variations in finger cross section is given in Figure 2.

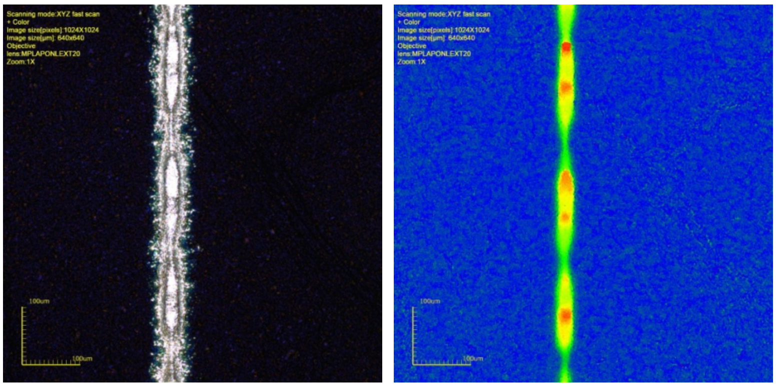

Figure 2: Optical and laser scanning microscope image of a fineline printed finger (single print).

2 EXPERIMENTAL DETAILS AND RESULTS

For this work we have used commercial state of-the-art fineline printing silver pastes and screens with finger openings as small as 20µm. In the reference case 35 to 45 µm screen opening were used. The screen printing was performed using a manually operated Baccini screen printer (built 2007) with wafer edge alignment. Alignment for the print on print process was accurate, as the same screen was used for the first and the second step. In an industrial line, more accurate alignment technology may be necessary, as two screens have to be used after each other. After each printing step, the wafers were dried and eventually fast fired in a Centrotherm fast firing furnace.

The two solar cell types (mc standard and n-type bifacial cells) that were used for optimization and typical screen printing data are shown in Figure 3.

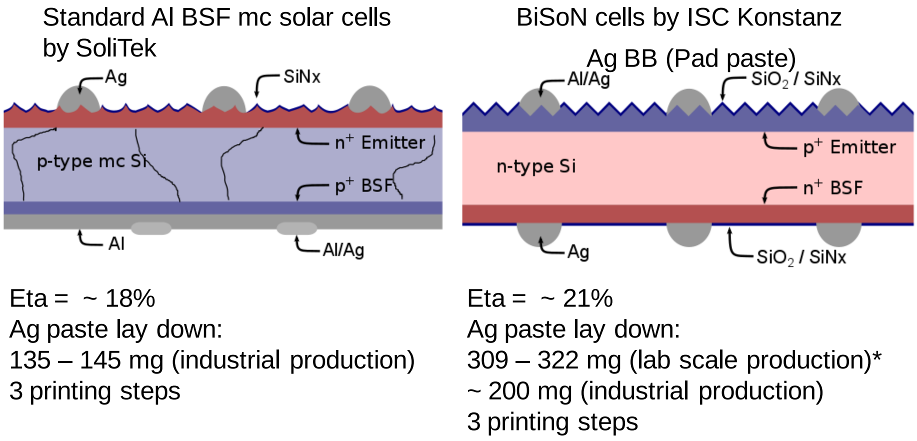

Figure 3: mc solar cell and BiSoN scheme and metallization overview. Note: Ag/Al paste means that a small fraction of Al is added to the silver paste for improve contacting for p^+ structure

Absolute numbers for silver content in printing pastes are difficult to obtain. According to our knowledge, the content of silver paste used for contact formation (finger paste) is in the range of 80 to 90%wt. In the following we assume 85%wt. (95% of solid mass). The silver content of soldering pad paste is assumed to be 50%wt. of the solid mass.

For measurement purposes (to validate the new measurement setup), half of the solar cells without busbars were printed with an extra set of busbars after firing, using a low temperature curing silver paste.

2.1 Measurement setup

The main downturn from BB-less cell designs is the measurability of the resulting cells. Typical IV measuring devices (classifier) contact the BB of the cells via contacting pins (for current and voltage extraction separately). A typical number of pins are about 20. If now a cell without BB is to be measured, those pins would only contact a small number of fingers (cells may have up to 100 fingers) and would extract only a small amount of the current and in particular underestimate the contact and line resistance. In consequence the FF are measured nowhere near the correct value. In order to be able to measure BB-less cells, ISC Konstanz built a measuring setup that allows the measurement of bifacial cells without BB on both sides. The front-side contacts are from an old "Day4Energy" BB-less measuring set-up transformed to fit our H.A.L.M. classifier, the base chuck is made from a brass chuck, which was fitted with an insulated voltage extraction bar. Pictures of the measurement setup can be found in Figure 4. The frontside contact plates are pressed on the cell, the springs in the top bars are meant to ensure evenly distributed pressure on the cell to prevent breakage.

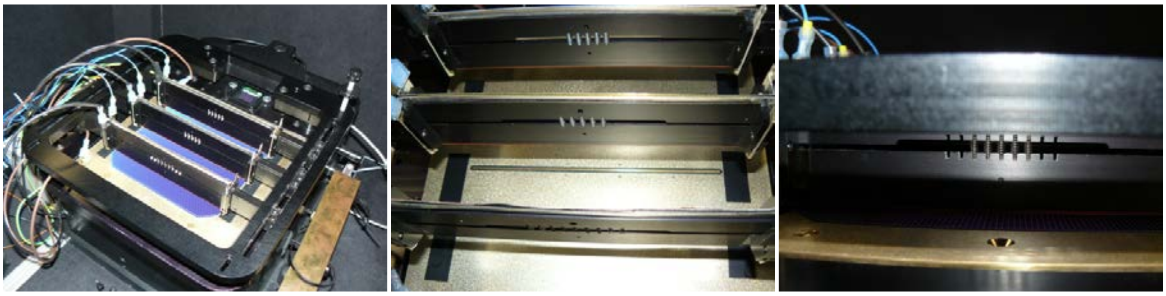

Figure 4: Left measurement setup top view with cell. Middle measurement setup without cell. Brass base chuck has insulated voltage extraction. Right side view on the top measuring bar featuring springs to ensure a defined pressure on front side metallization.

In order to test whether the chuck measures correctly (or may require additional correction) cells without BB were printed and one half of the groups was printed with an additional, low temperature curing BB paste. This paste is applied after fast firing and requires "drying" at 250°C for about 15 min. IV data of the cells with extra busbars with the new and the standard setup are compared in Figure 5.

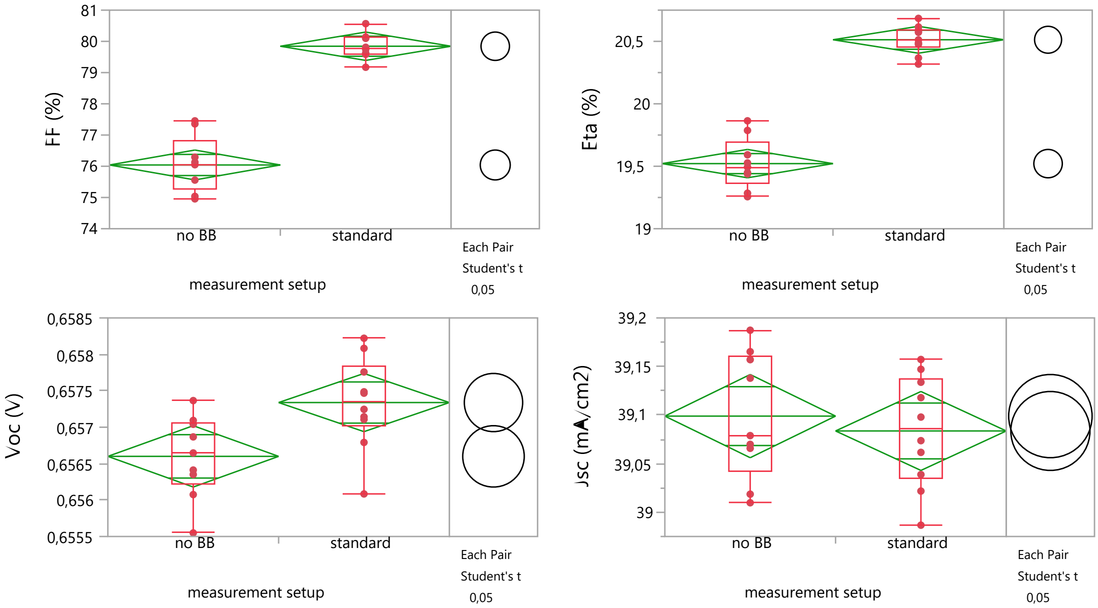

Figure 5: Measurement of BiSoN cells with additional BB using the two possible measurement setups.

From the data it becomes obvious that the two measurement setups do not measure identical values. Whereas differences between current and voltage is small, the FF values, and in turn the efficiencies, differ strongly. Comparing these cells with the cells without additional BB, measured on the new setup, even lower FF values are measured (see Figure 6).

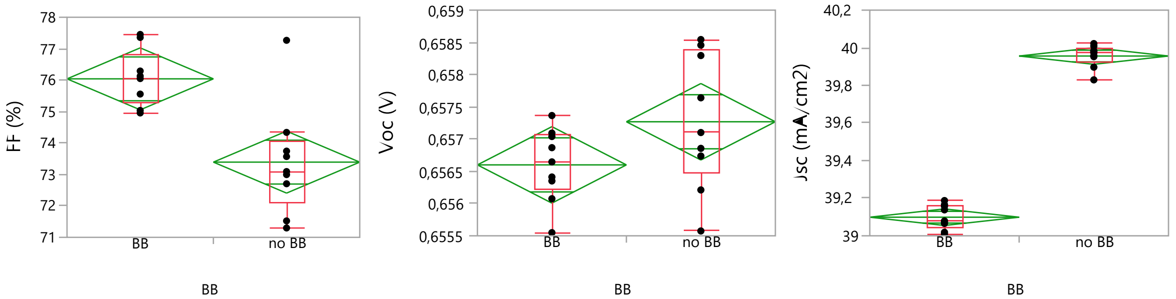

Figure 6: Measurement of BiSoN cells without BB using the no BB measuring chuck.

Voltage and current are measured very similarly in all three cases (additional BB, additional BB measured with the no BB chuck, no additional BB). The only deviation is in the case of the no additional BB: the current is higher without the BB – a fact that is not so surprising, as the shading fraction of the front side is reduced to about half. From the results it can be concluded that the additional BB do not change the actual electrical performance of the solar cells, only the electrical contact in the measurement setup is improved. In consequence, further work on the contacting setup is required. The measured solar cell efficiencies with the additional BB and measured in the standard configuration, however, may well be compared to the respective reference processes, which is done in the following.

2.2 Multi crystalline solar cells

Multi-crystalline solar cell precursors were processed using the best known method (diffusion recipe MC01). The rear side was printed without soldering pads, a commercial silver paste was used, no difference has been observed in previous experiments on whether the PSG had been removed or not. In the reported case no PSG was present.

No rear side pads were printed. A common amount of silver paste used for rear side soldering pads is 30-35 mg. This value was provided by SolitTek and will be added to the calculations of silver savings.

Table 1 summarizes the amount of silver paste printed, the amount of silver consumed and the solar cell parameters obtained. Note that the reference already is much lower than the baseline assumed in the proposal of the Ecosolar project (8,5 g/60 cell module). Mean values of two weight measurements are shown. Ten cells were manufactured and the median values of the electrical performance are shown.

Table 1: Summary of measured silver paste consumption, finger properties and obtained efficiencies.

	Best known method	Ecosolar approach	Relative savings / change in performance
Finger screen opening width	35 µm	20 µm	
Finger width	47 µm	45 µm	
Fingers (1st print)	83 mg	57 mg	
Fingers (2nd print)	-	21 mg	
Busbars	34 mg	-	
Rear side pads (assumed)	35 mg	-	
Total paste	152 mg	78 mg	49 %
Total silver (contact paste 85% silver, pad paste 50%) [per 60 cell module]	117 mg [7 g]	66 mg [3,9 g]	36 %
Eta (measured with extra BB)	17,6 %	17,5 %	- 0,6%
FF (measured with extra BB)	79,0 %	78,8 %	- 0,2%
Voc (measured with extra BB)	626 mV	626 mV	0 %
Jsc (measured with extra BB)	35,6 mA/cm²	35,6 mA/cm²	0 %

Of course, as stated above, the exact composition of the silver paste is not known, therefore the silver value may differ.

As can be deduced from the IV-data, both metallization schemes perform quite similarly. Only slightly lower FF values were observed. From the fact that the current does not increase with the fineline printing it can be deduced that the “bleeding” of the silver paste contributes to similar amounts of front side shading. Indeed, the color images show similar finger widths (see Figure 7). We assume that further optimization (especially when performed in a production line) should yield in a gain in current and most likely also in even further silver paste reduction.

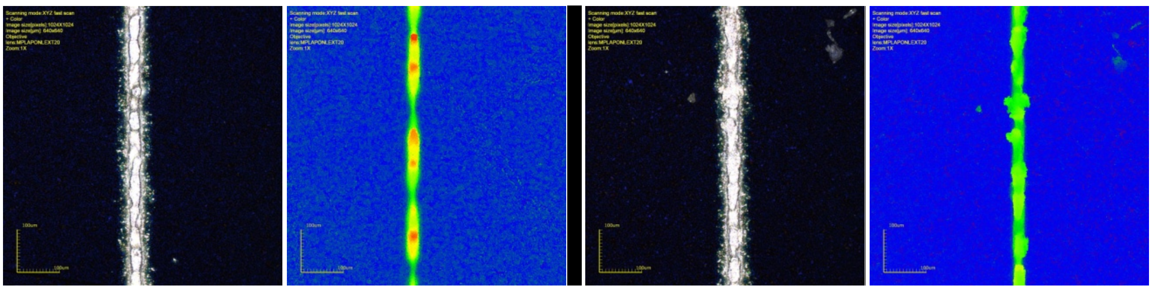

Figure 7: Color microscopy and laser scanning profile image of mc-reference (left) and of the fineline print-on-print (right).

2.3 Mono-crystalline bifacial n-type cells (BiSoN)

Bifacial solar cells have silver fingers and busbars on both sides, allowing them to collect radiation from both sides. The gain in energy harvest from bifacial module instalment may be up to 30%. The downturn from this technology is the higher silver consumption. The commonly required Ag/Al-paste (silver paste with a small fraction of Al added) could be replaced by a pure silver paste in the Ecosolar approach. Thus the metallization induced recombination (J_{0met}) could be reduced and the same paste could be used for front side and back side finger printing.

Table 2: Summary of measured silver paste consumption, finger properties and obtained efficiencies.

	Best known method	Ecosolar approach	Relative savings / change in performance
Front side			
Finger screen opening width	35 µm	20 µm	
Finger width	47 µm	43 µm	
Fingers (1st print)	75 mg	62 mg	
Fingers (2nd print)	-	30 mg	
Busbars	38 mg	-	
Rear side			
Finger screen opening width	35 µm	20 µm	
Finger width	60 µm	50 µm	
Fingers (1st print)	115 mg	53 mg	
Fingers (2nd print)		36 mg	
Busbars		-	
Total paste	228 mg	181 mg	20 %
Total silver (contact paste 85% silver, pad paste 50%) [per 60 cell module]	193 mg [11 g]	154 mg [9 g]	20 %
Eta (measured with extra BB)	20,3 %	20,5	+ 1 %
FF (measured with extra BB)	79,7 %	80,1 %	+ 0,5 %
Voc (measured with extra BB)	652 mV	657 mV	+ 0,7 %
Jsc (measured with extra BB)	38,6 mA/cm²	39,1 mA/cm²	+ 1,2 %

Note that the printing of the BiSoN cells was not ideal; the viscosity of the paste was observed to be slightly higher than normal, so that bleeding occurred. Lower paste lay downs have been observed in the past, so that the overall silver amount was higher than expected. In electrical terms, the performance of the solar cells printed with the Ecosolar layout was superior to the reference.

3 SUMMARY AND OUTLOOK

A metallization layout for the reduction of silver consumption was presented to fulfill the deliverable D3.3. A working setup to measure the cells without additional busbars could not be provided, yet. The constructed setup still strongly underestimates the FF and thus requires further optimization. In order to measure the cells correctly, additional busbars were printed on half of the cells from each group. The paste that was used for the additional BB was applied after firing and required only drying and no additional firing step.

The amount of silver required to print mc solar cells could be reduced to 66 mg in the case of mc full Al-BSF standard solar cells, using standard state of the art silver pastes and fineline priting screens. The BiSoN-cells still require 154 mg. The total amount of Silver that would be required in a 60 cell mc module could thus be lowered to 3,9 g and in the case of a 60 cell BiSoN module to 9 g. Noteworthy here would be also that the lower silver consumption in the case of the BiSoN cells is accompanied by increase in solar cell efficiency by $0.2\%_{absolute}$.

According to our experience, automation and large scale production will allow for further optimization and thus reduction of paste laydown. A measuring setup for cells without busbars has been built. In the next step the solar cells from this experiment will be used for the manufacturing of test modules using the Apollon NICE technology to prove that good contact for the interconnection in modules is possible.