INDUSTRIAL APPROACH FOR THE DEPOSITION, THROUGH-VIAS WET OPENING AND FIRING ACTIVATION OF A BACKSIDE PASSIVATION LAYER APPLIED ON SOLAR CELLS

L. Gautero[1], J. Rentsch[1], L. Weiss[1], N. Kohn[1], S. Eigner[1], M. Zimmer[1], J. Specht[1], J. Nekarda[1], D. Stüwe[1], M. Retzlaff[1], D. Biro[1], J.-M. Sallese[2] and R. Preu[1]
[1]Fraunhofer Institute for Solar Energy Systems (ISE), Heidenhofstrasse 2, D-79110 Freiburg, Germany
phone: +49 761-4588-5499; fax: +49 761-4588-9250
email: luca.gautero@ise.fraunhofer.de
[2]Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne - Switzerland

ABSTRACT: The industrial production of bulk silicon solar cells with **high efficiency** brings advantages as more efficient energy harvesting and better exploitation of materials. The candidate industrial approach conforms to good homogeneity on the whole designated active area as well as reproducible results on the local structuring, hence the scales span **4 order of length magnitude**. The approaches used here are based on the improvement of the passivation of the dark side of the cell, employing a so called **backside passivation layer (BSPL)**, this approach is compared to a reference screen printing of Aluminium paste and subsequent firing. The passivation mechanism of the deposited layer is affected by subsequent metallisation steps, some process sequences show with comparison to reference a loss in open circuit voltage and short circuit current, the fill factor can still be comparable. Cells realised with this approach are facing the constraints of the tools, adjustments of the process parameters will deliver the high efficiency that is targeted.

Keywords: Back Contact, Passivation, PECVD

1 INTRODUCTION

Upon the ever raising necessity of the nowadays society of clean energy, the demand for larger production of photovoltaic device is steadily increasing, the older and more established technology available is based on bulk silicon. The production grows also if more efficient cells are created and, nowadays, a significant point of improvement is the quality of the backside passivation [1-3], for industrial cells this means to remove the well established Aluminium Back Surface Field (Al BSF) and make use of deposited or grown layers to decrease the surface recombination velocity (SRV) at the backside of the cell. Still this has to be achieved on a functioning solar cell; we deal in this paper with the details of the process that can lead to the inclusion of a BSPL in a solar cell.

Several studies on the realisation of the process are described here; these solutions will all be performed with the industrial machines available in the PVTEC laboratory at Fraunhofer ISE.

2 EXPERIMENTAL

Two processes have been chosen to implement a backside passivation structure (Figure 1), namely a chemical opening of the backside passivation layer (BSPL) and a subsequent aluminium paste firing* indicated as **Mask and wet opening** (from now on **MaWO**) and a Laser Fired Contact (LFC) on printed and fired paste indicated as **Screen print and LFC** (from now on **SPLa**).

The material used was a p-type Cz silicon, for the MaWO process was a **1 Ω·cm, 220 µm** thick, for the SPLa process the material was a set of **130 µm** thick precursor from a Deutsche Solar production line, on this **1-3 Ω·cm** material an alkaline texturisation followed by diffusion of a 85 Ohm/sq. n-type emitter, a PECVD Anti Reflecting Coating (ARC) finished the front end pre-processing.

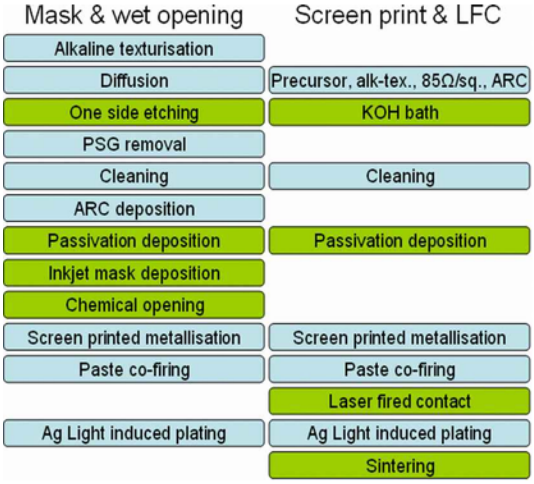

Figure 1. Depicted are the two processes under investigation, on the left a chemical opening of the BSPL and on the right a LFC approach. In cyan are depicted the steps for a reference screen print process, in green the additional steps towards a backside passivated cell.

2.1 Mask and wet opening (MaWO)

After the alkaline texturisation we had a closer look to the diffusion step, the emitter has an average value of 50 ± 1 Ω/Sq. (measure system detailed elsewhere [4])

The One side etching process removed the emitter on the designated backside, it was accomplished etching almost 2 µm of silicon (measured by weight comparison) in a HNO3/HF solution, and sheet resistance measurements confirmed the correct emitter removal.

The cleaning was an industrial SC1-SC2 performed on a batch machine, straight after the ARC and the BSPL deposition took place respectively on the front and on the

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* In this text we will indicate as firing a high temperature (>800°C) step of few seconds.

rear of the wafer, the latter PECVD deposition has a high etching rate in an HF solution.

The printing of hot melt ink on both sides of the substrate was realised with the SCHMID InkjetSystem DoD300, the front side was completely covered to protect the ARC, on the backside the resulting mask had holes with 50 µm radius, and the pitch between them was 549 µm, the resulting coverage is close to 3 %.

After the etching in HF, the vias were opened, the mask on the rear side was positively reproduced with a slightly larger radius, and the coverage was increased to almost 4%. The screen-printing step was performed with commercially available pastes; the aluminium paste was chosen glass-frits free. The firing variation revealed a low optimum peak set point temperature; it was also decided to prevent blistering. Finally silver was additionally plated on the front.

2.2 Screen print and LFC (SPLa)

The precursor with the complete front end applied had also an n-doped emitter layer on the backside. A KOH bath was used to remove this emitter and allow a correct passivation of the p-type base, the ARC was used as a mask for the front side, and it prevented any emitter attack.

An SC1-SC2 cleaning was performed, followed by the PECVD of the BSPL.

After the screen print step, the paste was fired with three different temperatures (A, B, C), in order to find the best firing temperature for the front contact. Then the LFC step has been performed. A reinforcement of the front side contact was achieved with silver Light Induced Plating (Ag LIP), finally an optimized sintering was realised on the cells.

3 RESULTS

3.1 Back side passivation layer

The passivation used in both process sequence was composed by a stack of amorphous Silicon Oxide (a-SiO_x) deposited directly on the silicon and an amorphous Silicon Nitride (a-SiN_x:H) [5]. This deposition scheme is able to give lifetime values (see Table 1) with a good homogeneity on symmetrically passivated samples realised on CZ material with high resistivity of the base, namely 3-6 Ω·cm (Figure 2).

The measurements shown (Table 1) have been done after a firing-like high temperature step, which improved both homogeneity and the effective lifetime.

Figure 2. The lifetime samples were prepared following this depicted procedure.

Table 1. Lifetime results from the deposition of the two layer passivation averaged on 5 wafers, the MWPCD refers to a complete mapping.

	Average (µs)	Std Dev (µs)
MWPCD (5)	316	23

The passivation stack was also tested with an additional PECVD layer; the measured consequence was a decrease in process fluctuations in terms of effective lifetime (Figure 3), but leads to spiking of the aluminium paste through the PECVD layers (see §3.2).

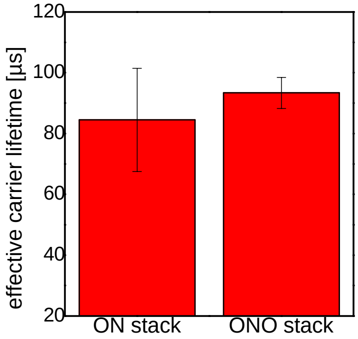

Figure 3. The stack with two layers (Oxide Nitride ON) was compared with a three layers (Oxide Nitride Oxide ONO)

The ON scheme was used for the cell processing; in the SPLa process the thickness of the oxide layer was varied.

Further characterisation was done during the MaWO process, to evaluate the influence of the wet chemical opening on the passivation quality (Table 2), two cells were investigated for their effective lifetime after the deposition and after the wet opening of vias, and we see that the passivation, limited by the emitter on the frontside, has comparable values before and after the chemical process.

Table 2. Process control realised on the wet opening sequence.

	Cell #	After deposition	After wet opening
Effective lifetime (µs)	1	30,48	31,70
	2	35,33	36,89

3.2 Screen printed pastes

Different aluminium pastes have been applied on the BSPL to investigate the adhesion to the cell backside.

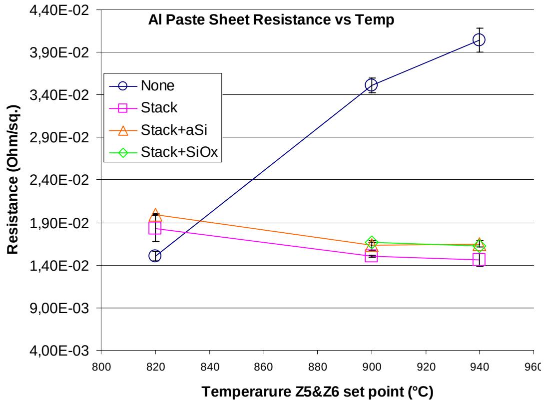

Figure 4. The co-firing temperature has a different influence on the aluminium paste sheet resistivity depending on the surface on which is applied, the legend details the surface layer on the back.

Sheet conductivity (van der Pauws method[6]) and contact resistivity (TLM method[7]) have been performed on especially prepared wafers for a set of pastes and passivation schemes.

All pad (AgAl) pastes could spike the PECVD layers erasing any passivation effect; this effect gives also the high degree of adhesion which is needed for the soldering of the cell.

Aluminium pastes with glass frits or other agents were able to create a contact through a closed BSPL layer (Table 3). The TLM method was able to quantify the spiking of the paste measuring the contact from the paste to the silicon.

The van der Pauws method, which can evaluate the sheet resistivity of metal sheet of any shape, was able to show the resistance of screen printed aluminium mesh whether on top of the passivation or not. In Figure 4 we show the sheet resistivity of the same paste detailed in Table 3. We can see that the less interaction with the silicon (higher contact resistance) lead to lower sheet resistivity.

From the model introduced by Huster [8, 9] we can expect that hindering the aluminium alloying with silicon we obtain a pure aluminium mesh, that gets denser with temperature. Higher contact resistances measured with TLM show better aluminium mesh sheet conductivity.

Table 3. Values of contact resistivity of an Aluminium paste with glass frits on four different backside preparations, "None" represents aluminium on silicon and SiOx and aSi are intended as capping layers on top of the BSPL.

Backside surface	Tape test	Contact resistance (Ω·cm^2)	Abs err (±Ω·cm^2)
None	OK	0,031	0,002
Stack	OK	1,6	0,9
Stack+SiOx	OK	0,14	0,01
Stack+aSi	OK	0,19	0,02

A glass frits free Aluminium paste was selected because even thought the adhesion is depending on the firing temperature, it guarantees a low interaction with the BSPL during the fast firing process.

The Local Back Surface Field (LBSF) creation was also investigated on processed samples from MaWO.

The Aluminium melts with the exposed silicon and creates the aluminium silicide alloy and this can be removed with a metal etching which is selective to silicon, the LBSF trace can be seen as a hollow in the silicon (Figure 5)

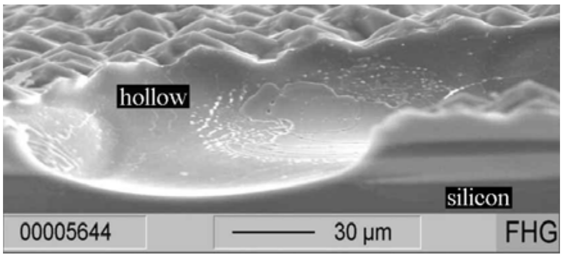

Figure 5. Fresh cut of a solar cell, with the backside aluminium completely removed; the sample shows the LBSF formation as a hollow, we can see that the texturisation structures on the backside are preserved where the PECVD layers are still present.

Even a successful LBSF formation does not guarantee the paste adhesion

3.3 Rear contacts

The rear contacts are a compromise between the amount of passivated area and the conductivity. The local contact points impose a term of spreading resistance in the material, and this depends on the conductivity of the material as well as the thickness of the cell [10].

At the same time the SRV of the local contact and the SRV of the passivated area play an important role as entities that can decide what will be the correct radius and pitch dimensioning.

Values were taken to prove the possibility of a high BSPL coverage (>95%) and a good contact to the cell backside.

One finished solar cell from process MaWO was etched of its Aluminium to verify the actual radius of the LBSF (Figure 5 and Figure 6), the coverage was still 4% as defined with the ink mask.

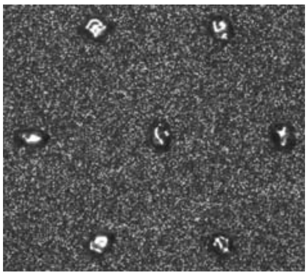

Figure 6. Structuring of the cell backside.

3.4 Laser Fired Contacts

Screen printed aluminium paste in combination with PECVD layers represents still a challenge for the optimisation of the process [11].

With the SPLa process the laser power was investigated to find out the best compromise between the contact resistivity and the radius of the contact.

The radius that we obtain with the selected process parameters was used to calculate the pitch necessary for a good contact and resulted in coverage between 4% and 5%.

3.5 Back side reflection properties

The light trapping of the cell is improved by increasing the reflectance of the backside of the cell; the thinner the cells are, the more important is the increment of the optical path inside the material.

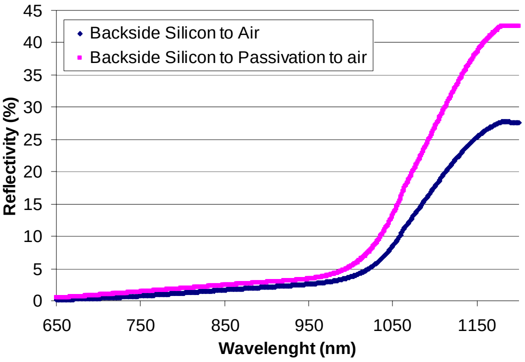

Figure 7. The BSPL is able to create a "reflective coating" at the back of the cell for the long wavelength.

Avoiding the formation of an aluminium-silicide on the whole backside, applying a barrier like the BSPL not only can increase the reflectance created by the big refractive index difference between silicon and air but can also decrease the transmission from silicon to air (Figure 7).

The backside reflection of the PECVD deposited layer was measured also towards an aluminium covered backside on finished solar cells.

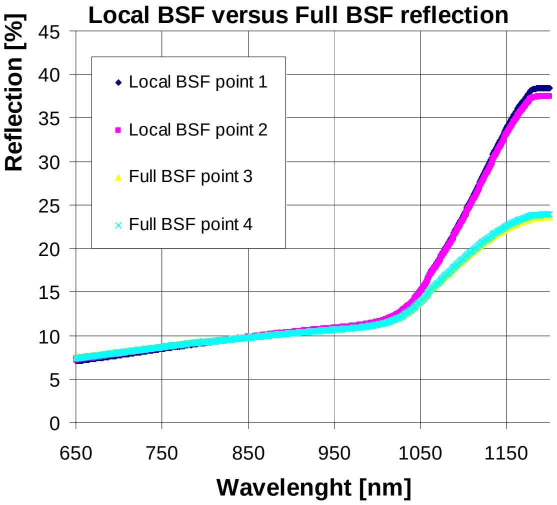

Figure 8. The reflection of the backside changes only when the bare silicon melts with the aluminium.

On these samples (Figure 8) we have the confirmation that the metal do not optically interact with the BSPL layer.

3.6 Sintering

For the SPLa process a final sintering was performed in order to recover any damage created by the laser pulses on the interface between silicon and the BSPL.

The wafers experienced increases in J_{sc} and V_{oc} and a higher gain in fill factor (Table 4), this gain is also strongly related with the firing temperature variation, which suggests that both the BSPL and the contact on the front had a benefit from this high temperature step.

Table 4. Improvements after sintering.

Oxide thickness (nm)	Temperature (A = lower)	Voc	Jsc	FF
340	A	0,56%	0,60%	2,09%
340	B	0,38%	0,55%	1,35%
340	C	0,33%	0,58%	1,24%

4 CELL RESULTS

4.1 Process MaWO

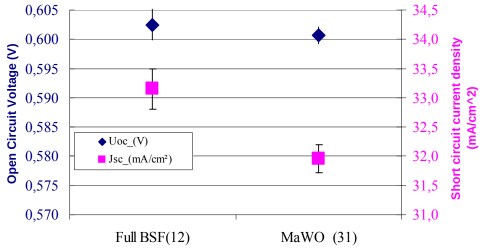

Figure 9. These are the IV curve details from process MaWO and from an Al BSF reference. In brackets the number of cells averaged.

The finished solar cells were measured for their IV curve (Figure 9 and Table 5), the process was able to give on average a higher FF then the normal screen printed cell realized starting form the same material. The applied BSPL provide the cell with an open circuit voltage of the same order of magnitude as the Al BSF reference, but the current is lower.

Table 5. Cell results from process MaWO, in brackets is the number averaged cells.

Group	*Voc (V)*	*Jsc (mA/cm^2)*	*FF (%)*	*Eta (%)*
Al BSF (12)	**0,602**	**33,2**	**72,3**	**14,5**
STDEV	0,003	0,3	1,0	0,4
MaWO (31)	**0,601**	**32,0**	**74,5**	**14,3**
STDEV	0,001	0,3	0,8	0,2

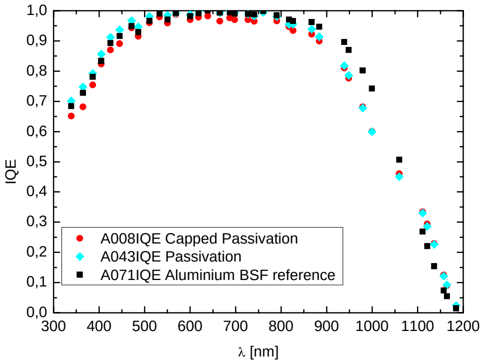

Figure 10. IQE from process MaWO. The "capped passivation" sample has a sacrificial PECVD SiOx layer between the BSPL and the aluminium paste.

In order to understand where this current loss could have taken place, IQE measurements have been realised (Figure 10); it can be seen that although the reflectance is high in the red response (Figure 8), photons of that range are not all exploited for the current generation. A special set of finished cells were realised with a capping PECVD silicon oxide between the BSPL and the aluminium paste, the short circuit current of this sample was comparable with the highest currents obtained on the described BSPL process, this further dielectric layer though was not preventing the main loss, further characterisation of cells and structures will tell us more.

4.2 Process SPLa

This different sequence was able to deliver fill factor higher then 70%, meaning that any further optimization of BSPL will find a cell structure able to correctly host them.

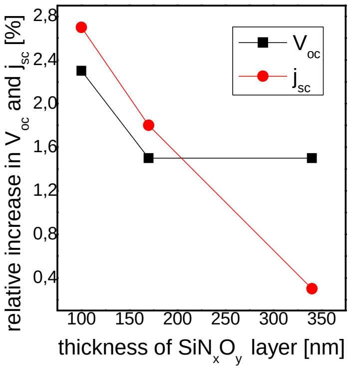

Figure 11. The variation of the oxide thickness showed its effects on both optical confinement and passivation quality compared to Al BSF cells

The thickness variation of the PECVD oxide has an influence on the cells results (Figure 11); the results are compared toward a standard process with an Al BSF formation.

We understand through the short circuit current (j_{sc}) trend that the optical confinement works better with thinner layers, the open circuit voltage also benefit from a thinner passivation.

This approach delivered a 130µm thin silicon solar cell with an efficiency close to 16%. (Table 6)

Table 6. Best SPLa cell.

Voc [mV]	Jsc [mA/cm²]	FF [%]	eta [%]
600	34,9	76,0	15,9

The batch started with 60 wafers of **130 µm** and we were able to measure 42 cells, we have a satisfying 70% yield, all processes (screen print, firing and Ag LIP) still need optimizations to handle this thickness.

5 CONCLUSIONS

The structuring realised leaves the freedom of tailoring any BSPL layer to these contacting schemes, either when a chemical etching is possible, either when the best approach is a laser formed contact. Good fill factor can be realised with both techniques.

Two industrial approaches have been demonstrated, one with a inkjet masking technique, able to define a pattern with a precision of 4 order of length magnitude and the other able to contact locally after the paste co-firing.

Process SPLa had also the additional constraints of processing extremely thin wafers; the result had an acceptable yield.

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