THICK-FILM BURIED CONTACT SOLAR CELLS AS A FUTURE TREND FOR INDUSTRIAL CRYSTALLINE SILICON SOLAR CELLS

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ABSTRACT: Nowadays over 80 % of the produced solar cells look the same: they have a homogeneous emitter, a PECVD-SiN layer as an antireflective coating and screen printed contacts on both sides. For the backside an aluminium paste is used to create a back surface filed during firing of the contacts. With this structure up to 15 % averaged efficiencies are reached in industry which is a large improvement to the values that were common some years ago. Further optimisation can still improve efficiency a little bit, but for larger steps new cell concepts have to be developed. By combining the buried contact solar cell concept with the common printing techniques it is possible to reach high efficiencies, avoid the critical plating sequence and adapt the actual processing sequence only a little. In addition old equipment can be used further and only lasers and a advanced printing system is required to realise this process. In this paper it will be shown, that the printable paste volume is much higher for wafers with grooves compared to reference wafers and therefore there is potential to develop improved pastes for this application. First solar cell results have shown that the series resistance of the cells can be reduced by 25 % and the averaged efficiency has improved from 14.8 % to 15.3 % for cells with grooves. In addition there is high potential to combine this technique with relying and simple selective emitter cell concepts.
Keywords: Buried Contact 1; Screen Printing 2; Shading 3

1 INTRODUCTION

In the last few years a certain kind of mc-Si solar cell has been established in industry: the alkaline etched, screen printed firing through PECVD-SiN:H cell with aluminium back surface field. A huge part of the PV industries turnover is made with this kind of cells and especially for mc-Si this is the dominant product. With this technique mean efficiencies between 14 and 15 % are possible in production, which is a large improvement to the former used TiO_2. But for a further improvement new techniques are needed. One of them is surface texturisation and especially acidic texturisation of mc-Si. Others are new cell concepts or modifications of existing concepts like the buried contact solar cell. These cells are in production for many years but a plating sequence is needed, that has some disadvantages like stability of process or used chemicals. Therefore we combined the well established screen printing technique with the buried contact concept.

2 MOTIVATION

The main losses of industrial crystalline silicon solar cells that are nowadays produced are: recombination in the bulk, the base and the backside, reflection at the surface of the cell, grid shading due to the metal contacts on the front side and series resistance of the cell.

The latter two loss mechanisms, shading and series resistance, can be reduced by new metallization schemes. Almost all multicrystalline and monocrystalline solar cells are manufactured by using the screen printing technique on a surface without grooves. Only BP Solar has commercialized the buried contact solar cell that was first introduced by Green and Wenham at the University of New South Wales [1]. For this type of cell an insulating layer is deposited on the surface that is opened by groove formation. Electroless plating afterwards leads to metallization only in the grooves and not on the surface of the wafer.

But mass production for this type of cell is only done on monocrystalline wafer material until now. Latterly efforts were made to adjust this process also to mc-Si. Some encouraging results came from a cooperation between BP Solar and University of Konstanz [2].

There are some cell concepts to reduce shading by bringing the emitter contacts to the back side, but none of them is in mass production until now and for some of them a lot of problems still have to be solved.

Therefore our focus was to combine two well known process steps that are already in mass production but not in this combination: The screen printing technique or printing techniques in general and the process of groove formation using a laser. Printing in grooves has been published earlier [3], but no cell results have been presented and grooves were made mechanically only.

Using the screen printing technique on a flat surface the paste has to fulfil a couple of certain features. During the printing process itself it should be fluid to penetrate well through the meshes of the screen, afterwards it should be pasty not to smear out and broaden too much. In addition it has to have a good conductivity and the feature to give good contact resistance to the emitter. To fulfil all these conditions will always be a compromise.

But if printing in grooves and making sure that the cross section of the finger is large enough and therefore the conductivity is not a problem anymore the paste can be optimised for better contact resistance. And if there is no chance of broadening more effort can be made on depositing high paste volumes in the grooves in a very short time.

In addition also other printing techniques like stencil or syringe printing can be optimised for printing in grooves. First experiments with stencil printing will be shown later in this paper. Stencil printing on wafers without grooves was carried out earlier [4], but printing in grooves with this technique brings even more advantages.

3 LASER GROOVES

In first experiments grooves were made with a dicing saw. Doing so the width of the grooves could be chosen very accurate and also the shape of the groove is very reproducible. Using standard mc-Si the thickness variations from wafer to wafer and even on one wafer are too high to get comparable groove depth. The mechanical formation of the grooves is not an industrial process as well, therefore a Nd:YAG laser was used soon to create the grooves.

The grooves should have a high aspect ratio to maximise paste volume and minimise shading, but on the one hand the width of the grooves mustn't be too small, because the printing is not self aligned like the plating process and on the other hand it is not clear, that it is possible to deposit more paste in a very deep groove and to make sure, that the paste has contact to the emitter surface. Therefore a compromise had to be found, to ensure successful alignment of the printing and the wish to have thin and deep fingers.

Simulations have shown that with a width of 70–80 µm and a depth of 15-20 µm a sufficient cross section of the fingers is ensured and first experiments have shown that alignment is still possible for this width. Besides the width and the depth also the shape of the groove has an influence on the cross section and also on the probability that the groove can be totally filled and the paste has good contact to the emitter even after drying. During drying namely the paste shrinks and therefore can loose contact where it had before.

Different dimensions and shapes of laser grooves have been tested and only after satisfying results also printing in grooves was performed. In Fig. 1 & 2 some electron and optical microscope pictures are shown. The cross section pictures reveal a good alignment of the printing and also good filling and contact area between paste and emitter. The top view pictures shows, that in some cases part of the paste remains outside of the grooves. This is due to the fact, that in the beginning standard screens with a finger width of 100 µm or 80 µm have been used. Having optimised the paste consistence to this special application screens with narrower fingers or stencils can be used.

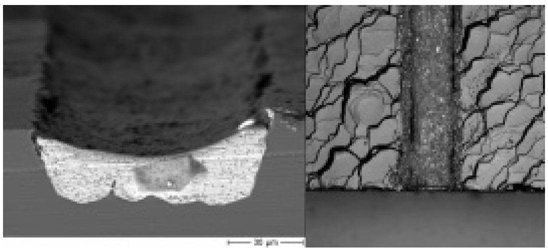

Fig 1: Left: SEM picture of groove filled with screen printing paste. Right: Optical microscope top view of a filled groove.

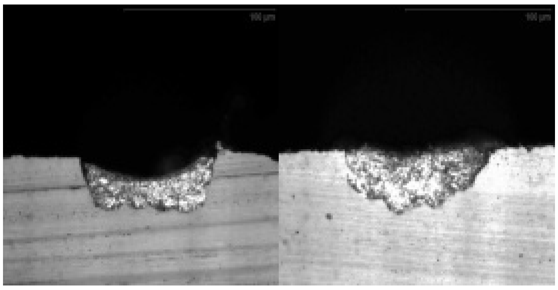

Fig 2: Different groove shapes filled with screen printing paste.

Assuming an almost rectangular shape of the groove, a width of 70 µm and a depth of 20 µm, the cross section of the fingers would be 1400 µm². If the paste shrinks during drying the cross section is still well larger than for a standard screen printed finger.

Regarding the shading, a reduction in width from 140 µm for example to 70 µm halves the shading of the fingers and can reduce the overall shading of the cell from app. 7.5 % to app. 5 %. For a cell with textured surface and high J_{sc}, this can increase current by up to 1 mA/cm².

4 PRINTING

It is clear that compared to the plated buried contact solar cells the metallization is not self aligned, therefore precise printing equipment and a good alignment is needed to print into the grooves and not aside of them. For this investigation a half-automatic printer from EKRA with an optical alignment system was used. The camera system is in principle able to identify certain structures like the edge of the cell or grooves as well, but for this investigation it was only used to align and control manually the position of the fingers in relation to the grooves.

Another important issue is the offset of the screens during printing and during a life cycle of a screen. Even with a new screen there is a small difference between the position and spacing between fingers on the screen and on the printed cell. And this effect can and will change during the life cycle of a screen, because the tension of the screen changes and therefore the snap off is increased by the operators during life cycle.

But not only for the paste, also could the screens be optimised for this special application. As an alternative to standard screens stencils seem to be a favourable solution for this technique. Stencil should be more stable than screen, which means that the offset in the beginning and also during a life cycle is smaller. Even more advantageous is the open area of the stencils. For standard screen the open area lies in the range of 40 %, therefore the amount of paste going through a certain finger width is limited. For stencils the open area can be up to 85 % or even higher (see Fig. 3). Therefore narrower finger openings are possible while keeping the possibility of blocked meshes lower than for screens. For this trial a finger opening of 70 µm was chosen, but even narrower openings seem to be promising.

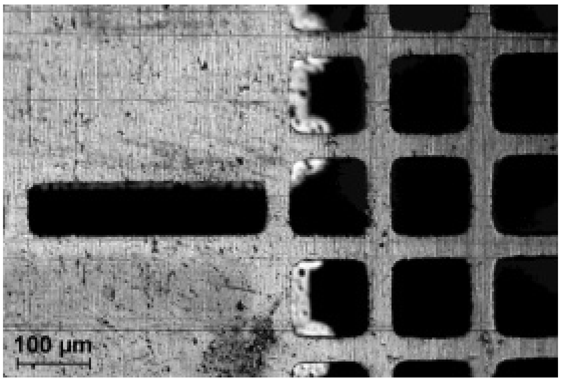

Fig 3: Picture of a double layer stencil. The beginning of a finger and part of the busbar are shown. The finger width is 75 µm.

To quantify the advantage of groves compared to flat surfaces and of stencils compared to grooves printing was carried out on comparable mc wafers (125x125 mm²). For this trial a standard Ag paste without any adaptation was used. For the wafers with grooves and without grooves the same screen was used. The finger opening was 50 µm, which is much lower than for standard screens, but also for the wafers without grooves fine line printing should be simulated. The amount of printed Ag paste was determined by weighing every wafer before printing and after drying of the printed paste.

The measured results are shown in Fig. 4. Two different laser systems and parameters were used to create the grooves. One parameter set lead to larger grooves therefore the wafers from no. 130 to no. 170 show a higher paste volume than the wafers with small nos. But both groups have an increase in the printed paste weight compared to the group without grooves. Averaged over all wafers the paste weight after drying is 82 mg for the wafers with grooves compared to 71 mg for the references.

The averaged value for the wafers printed with the stencil is 121 mg, which is much higher than for the wafers printed with a screen. This shows the high potential of this technique.

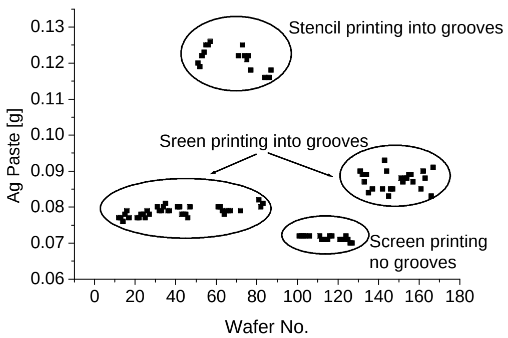

Fig 4: Paste weight after printing and drying for different printing methods. For both screen printing methods the same screen was used.

5 SOLAR CELL RESULTS

25 neighbouring 125x125 mm² mc 330 µm thick wafers were divided in 5 groups and pre-etched in NaOH. Then four groups received grooves by laser, the remaining group was held back as reference. In the following the group without grooves was etched for 5 min, while the other groups with grooves were etched for 2, 5, 8 and 11 min. respectively in NaOH at 80°C to remove damage caused by the laser. After that all wafers were treated the same: $POCl_3$ diffusion leading to 45 Ω/sq; plasma etching for edge isolation; PECVD-SiN deposition; printing and firing. For this experiment a standard screen with a finger opening of 80 µm was used for all wafers. The average cell results with error bars are shown in Fig. 5 & 6.

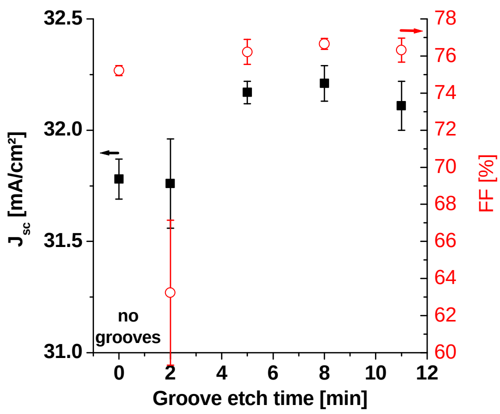

Fig 5: Dependence of J_{SC} and FF on groove etch time compared to cells without groove.

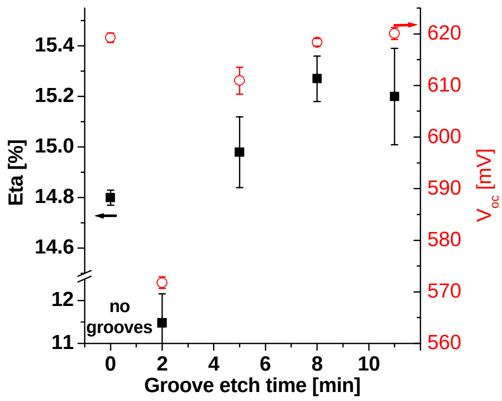

Fig 6: Dependence of Eta and V_{OC} on groove etch time compared to cells without groove.

All shown results are mean values of 4 cells. The reference cells ended in an efficiency of 14.8 % (V_{oc} = 619.2 mV, J_{sc} = 31.8 mA/cm², FF = 75.2 %). The cells that are groove etched for only 2 min have a loss in V_{oc} of 48 mV and in FF of 12 % caused by the remaining damage of the laser. After 5 min etching the I-V values are almost on the same level than for the references. After 8 min a maximum improvement has been reached (Eta + 0.5 %, V_{oc} - 0.9 mV, J_{sc} + 0.4 mA/cm², FF + 1.5 %). And after 11 min there is still a large improvement compared to the references, but lower than for the cells that are etched for 8 min.

To better understand the increase in fillfactor of the cells with grooves for all cells dark I-V and J_{sc}-V_{oc} measurements were carried out. Afterwards fitting of the I-V curves was done for all cells and series resistance R_s, parallel resistance R_p, and the diode saturation currents J_{01} and J_{02} were evaluated. Only for the series resistance a significant difference between the different groups was detected (see Table I).

Table I: Comparison of neighbouring cells with and without grooves.

Mean values	#	FF %	J_{sc} mA/cm²	V_{oc} mV	Eta %	R_S Wcm²
Ref.	4	75.2	31.8	619.2	14.8	0.83
Groove	6	76.7	32.2	619.6	15.3	0.60
Diff		1.5	0.4	0.4	0.5	0.23

The wafers with grooves showed a series resistance of 0.6 Ωcm², which is more than 25 % lower than the 0.83 Ωcm² for the wafers without grooves.

To see the influence of the finger resistivity on the series resistance of the solar cell, 3 cells of each group shown in Tab. I were tabbed and the resistance between the two busbars was measured with a four point probe. From this resistance the mean conductivity of the 47 fingers between the busbars can be calculated. It is obvious from Table II that for the cells with grooves the series resistance of the fingers is significant lower than for the reference group. This is in accordance to the printed paste weight that was measured on random samples in this trial. The paste weight for the cells with grooves was 10-20 % higher than for the references.

In addition it is assumable, that also the contact resistance could be improved for the wafers with grooves, because the contact area between paste and emitter is larger for this kind of cell.

Table II: Specific finger resistance of fingers in grooves and on flat surface.

Mean values	#	r [mW/cm]
Ref.	3	485
Groove	3	313
Diff.		171

6 SUMMARY

Two of the main loss mechanisms of standard industrial type solar cells, grid shading and series resistance, can be reduced by printing in grooves. Although reducing the finger width and therefore minimising the shading, the cross section of the fingers remains on a high level because of the very good aspect ratio that is possible by defining the finger geometry by grooves.

Paste composition could be optimised, because the demands for printing in grooves are different and the conductivity of the fingers is not a problem anymore. At the same time screens have to be optimised for this application and the new type of paste. Alternatively stencils show a high potential for this technique. In principle syringe printing has a high potential in combination with grooves as well.

Groove geometries have been optimised for this application and printing in different kind of grooves has been carried out to check filling of the grooves after shrinking of the paste during drying. It has been shown that the amount of Ag paste printed onto the wafer is 10-20 % higher when printing in grooves using the same screen. Using a stencil even much higher paste volumes are possible.

First solar cell results on comparable wafers have shown a considerable improvement of 0.5 % absolute compared to cells without grooves that were processed simultaneously. There was an increase in J_{sc} by 0.4 mA/cm² due to less shading, which could be optimised to app. 1 mA/cm². The fillfactor increased by 1.5 % absolute due to a reduced series resistance in the fingers and probably a reduced contact resistance.

In addition this cell concept show further potential, because several selective emitter concepts suit well together with grooves and most of them only need one diffusion.

7 ACKNOWLEDGEMENTS

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