Industrial printed Seed-Layer for Front Side Metallization of Crystalline Silicon Solar Cells

Uwe Buerklin; Schmid Technology GmbH; Opelstrasse 1, D-68789 St.Leon-Rot, Germany

Abstract

An industrial scale ink-jet and light induced plating (LIP) based front side metallization process for crystalline silicon solar cells is presented. Via Schmid ink-jet printer "NanoJet" a < 1µm thin seed layer is printed that opens the isolating SiNx antireflective layer and creates a metal contact from cell surface to cell by burn-in in a high temperature furnace. Via LIP, a highly conductive silver layer is grown on the printed areas.

Following this strategy, fine finger lines with a width of 30-35µm after printing and 50-55µm after plating on mono- and poly-crystalline silicon cells were deposited. This lead to a 20% reduction of silver consumption and a gain of 0.3%$_{abs}$ of cell efficiency compared to standard screen printing process.

Motivation

Related to the grown importance of renewable energy, and hence of photovoltaic as one of its main pillars, competition has become increasingly fierce in the cell manufacturing industry over the last decade. Many companies invested in the lucrative market and expended their production capacity. With reduction of national subsidies, however, the demand for PV decreased. Consequently, this led into an overcapacity in cell production. Thus the only way for solar cell manufacturers to remain competitive is to increase cell production efficiency or productivity. A common number to measure the productivity is the price per power generation [ct/W_{peak}]. Hence there are two variables which can be changed for a cell manufacturer to remain competitive: decrease production cost or increase cell efficiency; or in best case: do both.

With about 10% of total cost, cell metallization is, after silicon substrate price, one of the leading cost factors in cell production. The most commonly used method for front side metallization is screen printing: PV pastes usually contain conductive silver particles and glass frit. In a high temperature furnace the glass frit etches through the circa 20 nm thick isolating SiN_x blue antireflection layer. In the same step the silver nanoparticles melt and build an electrical contact to the now locally opened cell emitter. Besides silver and glass frit the paste contains several other components, which make it printable, but on the other hand reduce conductivity. The resistivity of typical SP pastes is with 2.8-3 µOhm*cm by a factor of 1.5-2 times higher than bulk silver. A lower conductivity of the front side grid leads to losses in cell performance, either because of a higher series resistance, or because one needs more material to get the same conductivity.

In 2006 S.Glunz and A.Mette presented several new concepts for front side metallization using light induced plating and different seed print technologies [1] [2]. Schmid´s aim is to scale this process up to industrial level by using an inline cell metallization line with inline inkjet, furnace and LIP silver galvanic.

Strategy: Inkjetted seed layer – LIP metallization

To optimize cell production efficiency, Schmid´s strategy is to combine inkjet technology with light induced plating for front side metallization in the Schmid "HiMet" metallization line. In contrast to competitive ink jet cell metallization processes, like for example presented by Ebong et al. [3], Schmid prints a single layer seed, which means printing a finger in one single pass. This reduces the consumption of high expensive solar ink. After printing the thickness of the jetted structures is less than 1µm. The ink, analogous to the screen print paste, contains a glass frit and Ag nanoparticles and is also being fired in a high temperature furnace.

For efficient electron transport, the printed structures have to have high line conductivity. So the printed structures have to be enhanced by high conductive material. Doing this, less material has to be deposited. Another benefit of this method is the reduction of shaded areas because of less deposited material. Especially for the finger structures, which collect the charge carriers from the cell emitter, the metallization diameter is relevant to the cell efficiency. Line interruptions on the other hand, will discard charge carrier collection in worst case for the whole finger. This means that the printed structure has to be as small as possible, but in any case completely closed. To also reach high throughput the implemented printhead has to print very stable with low drop volume at high print frequency. As continuously printing nozzles are most stable each finger is printed with a single nozzle.

Being very rough, the solar cell surface has great influence on the behavior of the printed ink drops. Spreading is very high on both, mono- and multi-crystalline material. To reduce reflection losses, the surface is textured with a roughness of R_a =2-4 µm. The ink spreads wide in the valleys of the textures. Especially on mono-crystalline wafer material, where the texture shows a pyramidal shape, which makes the capillary forces in the sharp valleys extremely strong, and hence leads to a wide spreading factor. To address this issue Schmid uses a high wafer surface temperature, which prevents spreading and leads to very thin finger structures on both material types.

One problem by printing on hot substrates is the thermal management. Over time the hot substrate heats up the printhead and also the ink. A complex cooling system would be needed to keep the printhead on constant temperature. This is why Schmid chose a "side shooter" printhead where the ink circulates constantly through the printhead. With such a printhead, the ink itself can be used as coolant. Beside the temperature management the side shooter printheads also proved to be much less sensitive to air bubbles or other impurities in the ink. The printhead chosen for the machine is a side-shooter 1000 nozzle printhead with 6 pl drop volumes and a native resolution of 360 dpi. With this, single

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nozzle finger structures of 30-35µm were repeatable printed without interruptions, which corresponds to a consumption of 15-20mg ink/cell.

Analogue to a screen printing process, the ink is getting burned-in in a furnace. There the glass frit opens the SiNx layer by etching through whereas the silver particles allow the electrical contact. As such printed cells have poor line conductivity related to the high resistance of the ink and the low line diameter; the printed structures have to be enhanced by high conductive material. For this, the LIP process is used. The solar cells are fully functional at this stage, so the cell produces a potential while getting illuminated. As the antireflective layer is isolating, the electric field will focus in direction of the burned-in and pre-metallized areas so that the silver ions will settle only there.

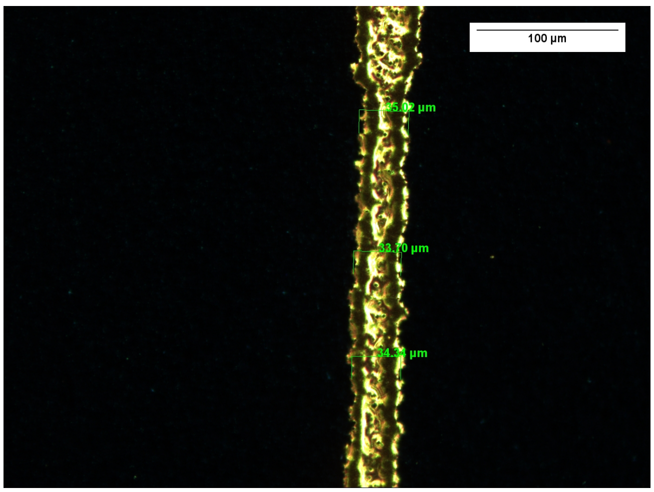

Figure 1*: Finger structure after printing on alkaline textured mono-crystalline silicon wafer*

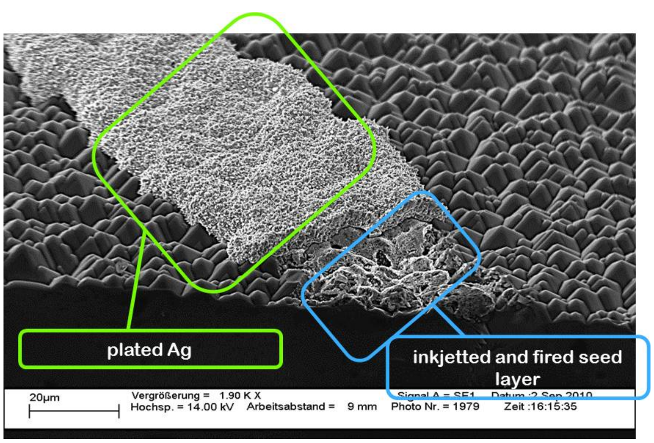

Figure 2*. Finger structure before and after plating on alkaline textured mono-crystalline silicon wafer*

In former publications of the Fraunhofer ISE it was shown, that by using LIP the cell efficiency can be increased by 0.2-0.3%$_{abs}$. As LIP is a nearly contactless process the risk of breakage of cells during metallization is minimized. [1][2]

Print tool: NanoJet

For printing cells with high throughput, one singe printhead is not enough. To cover the whole area of a 6 inch wafer at once, 3 printheads have to be placed side by side in a print head array. The strategy is to print finger and busbar structures with the same printhead. As finger structures are more sensitive to interruptions, the fingers are getting printed in print direction, the busbars cross print directions. Regarding the need of printing very fine lines and the limited native resolution of the printhead, the busbar will be filled up in 3 interlaces. The printhead module includes the whole ink circulation system, the data processing electronics and of course the printheads. For maintenance, a whole printhead module can easily be replaced by another. This facilitates print head module maintenance and reduces the overall down time of the printer

The Schmid inkjet platform for front side metallization, called "NanoJet", is designed for printing 6 inch wafers with a throughput of 1650 Wafer/h. For a common 120 MW$_{peak}$ line, two NanoJet printers can be installed serially. The NanoJet is a one track processing inline machine. To allow 3300 Wafer/h, a second bypass conveyer belt just handles the second track through the machine. For second NanoJet printer, the process- and bypass-tracks are interchanged.

The acceleration and deceleration of the handling system has to be quite high as the wafer has to change print direction twice to print 3 interlaces. To keep the inertia of the wafer handling low and to guarantee a fast transport at the same time, Schmid uses its patented handling system. The wafer hovers on an air bearing while the horizontal transport is done by small vacuum grippers, mounted on a linear axis. There are two grippers, one on each side of the air bearing. While one gripper transport a wafer, the second gripper moves back to catch the next wafer.

Another advantage of this handling system is that the air bearing can also be used for wafer heating. By heating up the air bearing, a constant and homogeneous wafer temperature is maintained. To heat up the wafer quickly however, the energy is not enough. That is why the wafers run through a high temperature pre-heater before sliding over to the air bearing. By printing ink on the heated wafer, the solvent evaporates immediately. To prevent the printhead and other components in the system from condensations of the aggressive solvent, a special exhaust system was designed, with integrated particle filters for aerosols.

To increase cell efficiency even further, the front side metallization has to match the underlying structure of the selective emitter. The selective emitter technology increases the conductivity of the cell emitter selectively under the regions where the metal contacts are applied. Usually this is done by generating different doping concentrations in a very thin layer below the surface of the silicon crystal. Further process optimization can be done by narrowing the selective emitter regions. The better the seed layer matches to the selective emitter, the smaller the selective emitter structure can be designed. This leads to an improvement of cell performance. Therefore the NanoJet alignment has to be as precise as possible. Usually in digital imaging, the print pattern is rotated digitally to fit a given substrate. However, this leads to pixel steps in tilted lines. Such pixel steps could lead to interruptions (and hence electrical losses) in the very thin fingers of the front side grid. The NanoJet corrects the angle mechanically by rotating the vacuum grippers in such a way that the corresponding wafer lies precisely in the printing grid of the machine and hence no tilted fingers or pixel steps occur.

The layout of the NanoJet is optimized for uptime and print stability. In order to maintain a stable jetting process and to keep the ink condensate from accumulating on the nozzle plate, periodic cleaning of the nozzle plate is necessary. Since we do not want to stop the machine for cleaning, we equipped the printer with two print head modules which take turns in printing the wafers. The modules are interchanged without stopping the printing process, and without reduction of the overall throughput. Besides of providing a convenient way to maintain a very "high uptime" inkjet process, this machine concept also builds some redundancy into the printer and improves the reliability of the whole metallization line.

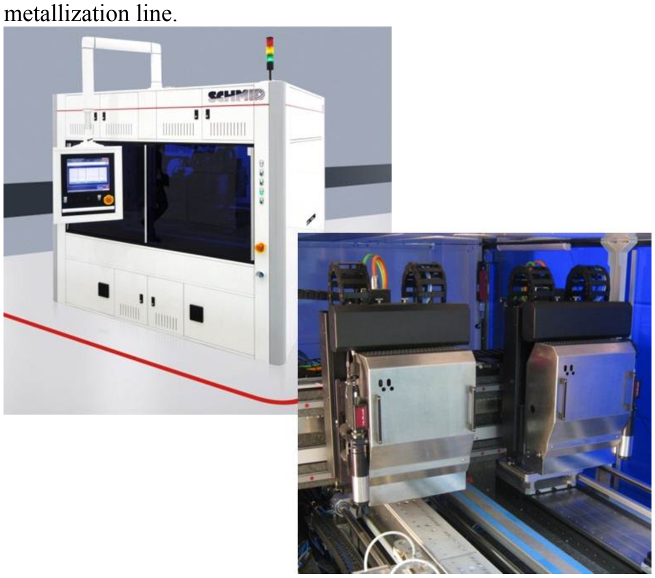

Figure 3: *Schmid print tool "NanoJet" in- and out-side view*

Plating Tool: LIP

The Schmid LIP tool is an inline tool for galvanic silver deposition. The wafers run sunny-side down through the bath while getting illuminated by a red light source. The rear-side of the cell is connected electrically by the transport wheels. The other electrode is connected to pure bulk silver blocks. Depending on wafer speed and light intensity the deposition rate can be adjusted. Depending on the front electrode layout, in actual cell production we deposit 2µm [5], or 10µm anisotropy around the seed structures which corresponds to a deposition of 15-20mg or 80-100mg silver / cell, respectively

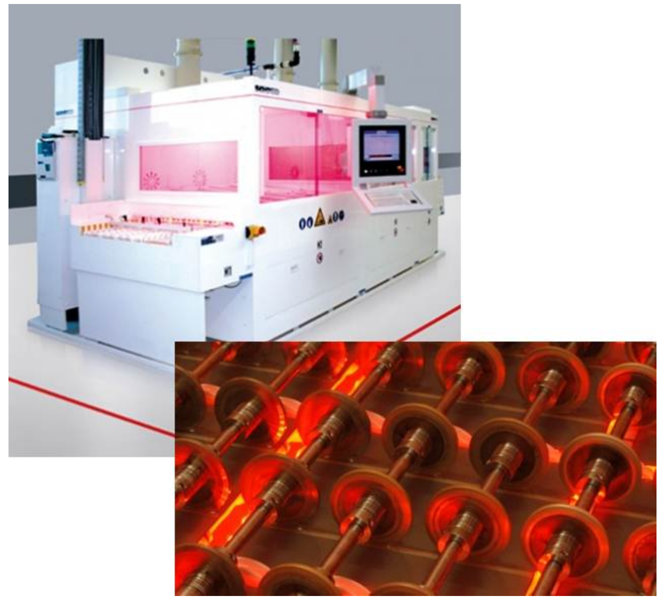

Figure 4: *Schmid galvanic tool "LIP" in- and out-side view*

Results

Using NanoJet printer, burning furnace and LIP for front side metallization, cells with an average cell efficiency of 19.3% on mono-crystalline 6inch cz-wafer were achieved in internal tests. Best cell in test showed an efficiency of 20.3%. Compared to the reference group using screen printer and furnace (Schmid standard), an improvement of the expected $0.3\%_{abs}$ was observed with 20% less silver consumption. For both groups wafers of the same batch were used with following preprocess steps:

- Boron-doped 6 inch cz-wafer
- Alkaline texture
- POCl doping
- Selective emitter (inkjet mask + back etching)
- SiNx PECVD
- Screenprinted backside Al + Ag

Discussion

The presented metallization technology achieves cell performance comparable to the nowadays available high end screen printer. However, the process has not yet reached its full potential. For example by increasing the line conductivity to a value closer to bulk silver (goal is 90%), the consumption of silver could once more be reduced. Also using future printheads with drop volume of less than 2pl and the thereby expected printed single nozzle line width of less than 25 µm, the cell efficiency will also be increased by reduction of shading effects. However, such printheads that can provide the required reliability are currently in development of the printhead manufacturers, and are not yet commercially available.

The technology is also suitable for sour textured multi-crystalline solar cells.

One big advantage of the technology is its flexibility regarding the cell design. So for example it is compatible with the

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multi busbar concept that once more has the potential to increase cell efficiency while simultaneously saving silver. [4] [5]

Conclusion

A process chain for front side metallization of crystalline silicon solar cells was presented using inkjet and LIP technology. It was shown that a significant efficiency gain is possible while simultaneously saving silver in industrial scale cell production. The technology has advantages regarding flexibility, low breakage and low silver consumption. By further increasing line conductivity of LIP plated silver and printing finer lines by using new available low drop-volume printheads the technology has further potential of improvement.

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References

[1] S. W. Glunz, A. Mette, M. Aleman, P. L. Richter; A. Filipovic, G. Willeke, New Concepts for the front side metallization of silicon solar cells, Proc. 21st EU PVSEC, Dresden, 2006

[2] A.Mette, et all, , "Increasing the efficiency of screen-printed silicon solar cells by light-induced silver plating, Proc. 4th IEEE WCPEC, Hawaii, 2006,

[3] A. Ebong, B. Rounsaville, B.Cooper, K. Tate, A.rohatgi, S. Glunz, M. Horteis, A. Mette, M. Gundermann, High Efficiency Silicon Solar Cells with Ink Jetted Seed and Plated Grid on high sheet resistance Emitter, Proc. 35th IEEE PVSC, Hawaii, 2010

[4] S. Braun, G. Micard, G. Hahn, Solar cell improvement by using a multi busbar design as front side electrode, Energy Procedia 2012, 21,227-33

[5] S. Braun, G. Hahn, R. Nissler, C. Poenisch, D. Habermann, Multi-busbar solar cells and modules: high efficiencies and low silver consumption, Energy Procedia 2013

Author Biography

Uwe Buerklin is system development engineer at Schmid Technology GmbH. He joined the company in 2010. His responsibilities are process-, application- and system development of Schmid´s inkjet systems. In 2010 he finished his diploma thesis in the field of sensors and microfluidics at Albert-Ludwigs University, Freiburg.