HIGH THROUGHPUT PRINTING FOR HIGHLY EFFICIENT COST-EFFECTIVE SI SOLAR CELLS

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ABSTRACT: One of the main challenges within Si solar cell production is the increase of throughput rates. With throughput rates in the range of 2400 Wafers / hour, metallization lines based on flatbed screen printing are typically the bottleneck of a modern solar cell production. Within this work we present innovative printing technologies allowing for higher throughput rates, e.g. rotational printing technologies as flexographic printing and rotational screen printing and as well multi-nozzle dispensing. In principle, flatbed screen printing processes can be completely replaced by using e.g. rotational screen printing for rear side printing and e.g. flexographic printing or dispensing for front side printing.. Hence, the realization of higher throughput rates and thus lower production costs is addressed. Moreover, new printing technologies allow for Ag paste savings up to 20% and efficiency increases of 1-2% relative by optimizing the finger geometry.
Keywords: Metallization, Printing, Production Technology, Si solar cell

1 MOTIVATION

Flatbed screen printing allows for throughput rates in the range of 2400 wafers / hour. Du to process limitations as for example a restricted squeegee speed and a non-continuous process flow, a further increase is limited. So, there is a big need on the market for alternative approaches allowing for significantly higher throughput rates especially for metallization processes. Innovative printing technologies as rotational printing [1-4] or mulit-nozzle dispensing [5-7] have the potential to increase throughput rates. Hence, this work focusses on the evaluation of innovative printing technologies in order to allow high printing speeds.

Rotational printing technology allows for high printing speeds, an inline process flow, rear and front side metallization processes and a significant increase of throughput rates. Very crucial points on the roadmap to future solar cell production. Furthermore, multi-nozzle dispensing as front side metallization approach is also a promising printing technology allowing high printing speeds and in principle an inline process flow. Moreover, dispensing prevents “meshmarks” and thus increases the contact finger homogeneity.

2 EXPERIMENTAL APPROACH

In this study, latest improvements concerning rotational printing and dispensing are presented. First, rotational screen printing as technology for rear side metallization is discussed. Second, rotational flexographic printing and dispensing are evaluated as printing technology for fine line contacts with contact widths below 30µm on the front side of the solar cell. Third, a future concept for an innovative printing machine allowing a continuous process flow during printing, high throughputs and cost savings is discussed.

3 RESULTS & DISCUSSION

Within this work innovative printing technologies are presented aiming at the realization of much higher throughput rates in comparison to flatbed screen printing. A new machine concept allowing a continuous process flow during printing is discussed. Rotational printing units, e.g. for flexographic or rotational screen printing can be integrated. With this machine concept we see a huge potential to realize the rear and front side metallization of Si solar cells based on high throughput printing technologies leading to significant cost savings.

3.1 Rotary screen printing

Using rotary screen printing (RSP) the realization of a full area rear side Al metallization with high throughput rates is demonstrated on Si solar cells for the first time [4]. With an experimental setup using a roll-to-roll printing machine it was possible to process Si solar cells (see Fig. 1).

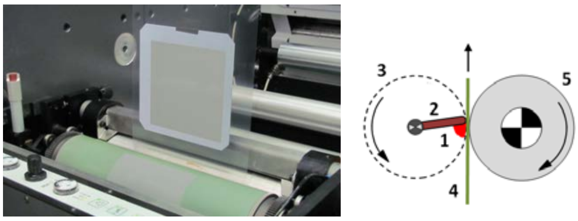

Figure 1: <u>Left:</u> Rotary screen printing unit of the Gallus EM 280 printing machine which is used for the experiment. The silicon solar cell is fixed with tapes on web-based material. <u>Right:</u> Schematic of the RSP setup. Paste (1) is pressed by a fixed squeegee (2) through the openings of the rotating cylinder screen (3). The substrate (4) is guided by an impression cylinder (5).

A first experiment on Al-BSF Cz-Si solar cells shows that the rear side metallization of Al BSF solar cells can be realized by RSP technology without any performance losses. The best group of solar cells with RSP rear side metallization even achieved a slightly better conversion efficiency of 19.4% compared to the flatbed screen printing (FSP) reference group with 19.3% (Fig. 2). A SEM investigation of the best RSP group and the FSP group showed a comparable Al layer thickness of 26µm and depth of the Al BSF of 4-6µm to the FSP reference group (see Fig. 3).

We show in summary that RSP technology is well-suited for rear side metallization of Si solar cells.

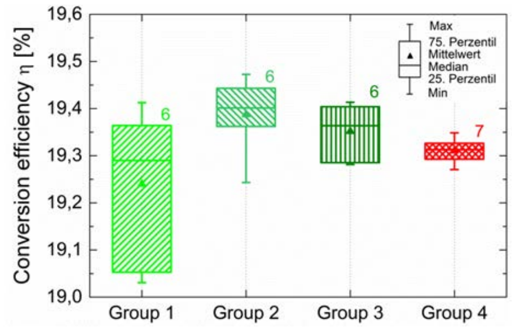

Figure 2: Conversion efficiency of Al-BSF Cz-Si solar cells with RSP rear side metallization (group 1 to 3 represent 3 different rotary screens) and FSP rear side metallization (group 4)

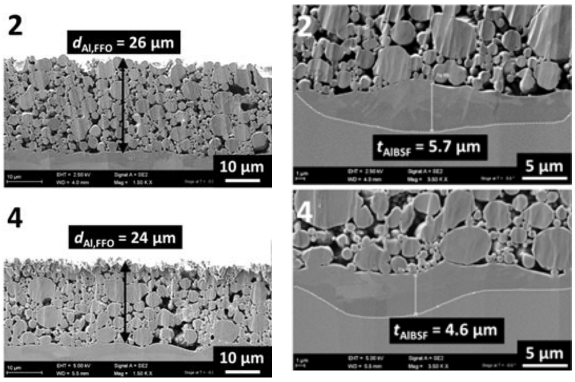

Figure 3: SEM cross sectional images of the rear side metallization after firing realized with a flatbed screen (group 4) and a rotary screen (group 2). The thickness of the printed Al layer (left) and the Al-BSF (right) is comparable.

3.2 Flexographic printing

With rotational flexographic printing (see Fig. 4) fine line printing of contact fingers can be realized. This is shown within an experiment ([3]) using an anilox roller with three different band sections (dip volume and line screening is varied) and laser engraved flexible printing plate with test structures (line width is varied). The experimental setup is shown in Fig. 5. Using an anilox roller with a large ink transfer capacity (band 2) and a highly viscous, in-house developed Ag ink led to contact fingers with a mean width below 30 µm (see Fig. 6) and very low Ag consumptions of ~20mg (calculation with GridMaster). However, realizing such narrow contact fingers with a sufficiently low lateral finger resistance using flexographic technology is still challenging. With mean lateral finger resistances (see Fig. 7) down to ~6 Ω/cm (flatbed screen printing: ~0.4 Ω/cm), flexographic printing is currently well applicable for the front side metallization of busbarless solar cells with multi busbar/wire interconnection technology (i.e. MeyerBurger's SmartWire concept). In principle, depending on printing parameters and paste rheology, the finger height and therefore the lateral finger resistance can be adjusted for different module integration technologies.

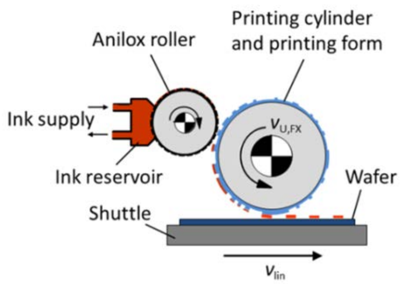

Figure 4: Schematic of a flexographic printing unit for the metallization of Si wafers: The ink is transferred from the annilox roller onto elevated areas of the printing form on the printing cylinder and from there directly onto the wafer.

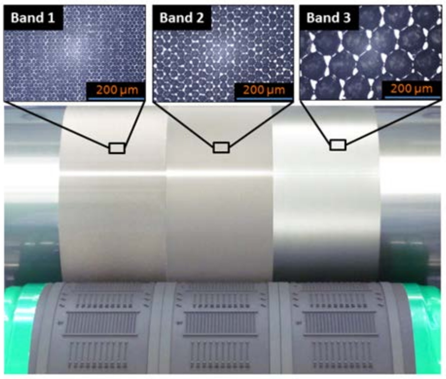

Figure 5: Experimental setup for a flexographic printing test varying different printing parameters. The microscopic images show the annilox roller with three differently engraved band sections. A ContiTech Laserline CSC flexographic printing form is used for the experiment. The test layout contains finger elements with nominal widths between 5 and 50 µm

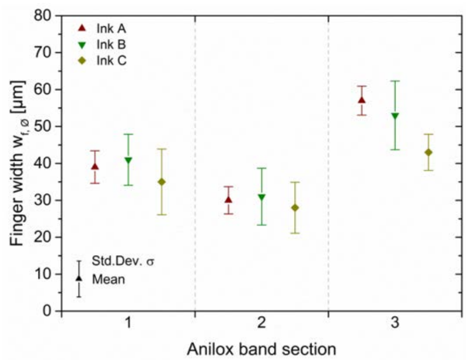

Figure 6: Finger width of flexographic printed contacts using three different in-house developed Ag-inks and three different annilox roller parameters. The nominal finger width on the printing plate was 5µm.

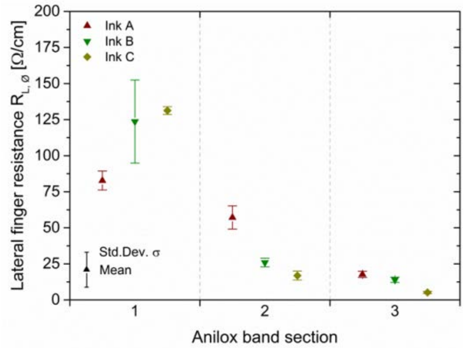

Figure 7: Lateral finger resistance of flexographic printed fingers using three different in-house developed Ag-inks and three different anilox roller parameters. The nominal finger width on the printing plate was 5µm.

We show in summary that flexographic printing technology is well-suited for front side metallization of Si solar cells especially for wire-based or multi-busbar module integration.

3.3 Multi-nozzle Dispensing

Within the experiment, industrial pre-processed PERC solar cells (Cz, p-type, 156x156mm², LCO) were equipped with a screen printed five busbar layout followed by a dispensed contact finger grid (nozzle opening D = 35µm, number of contact fingers: N=100) and compared with single-step screen printed samples (opening width w = 40µm, N = 100). At optimum firing conditions (temperature variation at three temperatures), dispensed samples reached top conversion efficiencies of 21.3% and 21.4% with the two applied industrial screen printing pastes, respectively, best screen printed cells reached 21.1% with both pastes (see Fig. 10). The main reason for this increase was a substantially reduced finger width reaching 33µm and 27µm (see. Fig 9) for the dispensed samples compared to around 45µm reached by screen printing. It was further demonstrated how dispensing benefits from screen printing paste development regarding an improvement of contact geometries: Some pastes already allow the application of 25µm nozzle openings reducing the Ag consumption per cell below 50mg featuring contact geometries close to the simulated optimum regarding aspect ratio and finger width and especially cross section homogeneity. Finally, a dispensing speed of 1m/s demonstrates a high throughput potential.

We show in summary that multi-nozzle dispensing (see Fig. 8) as further solution for high throughput printing of fine line contacts with high aspect-ratio allows for efficiency advantages of ~1.5%rel. (see Fig. 10) and a reduction of Ag paste consumption by ~15% in comparison to flatbed single-step screen printing leading to a significant reduction of production costs.

Figure 8: “Full wafer size” multi-nozzle dispense print head developed by Fraunhofer ISE and integrated in ASYS platform allowing for high printing speeds

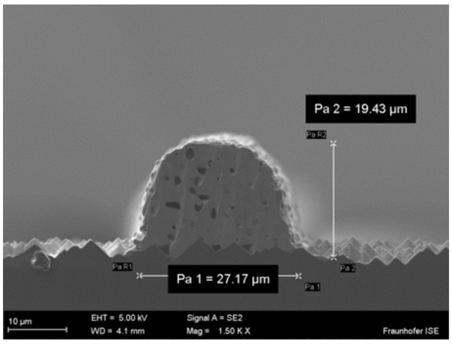

Figure 9: SEM image of a dispensed finger with a finger width below 30µm and finger height of ~20µm. The homogenous finger geometry allows for a more efficient material usage of the applied Ag paste.

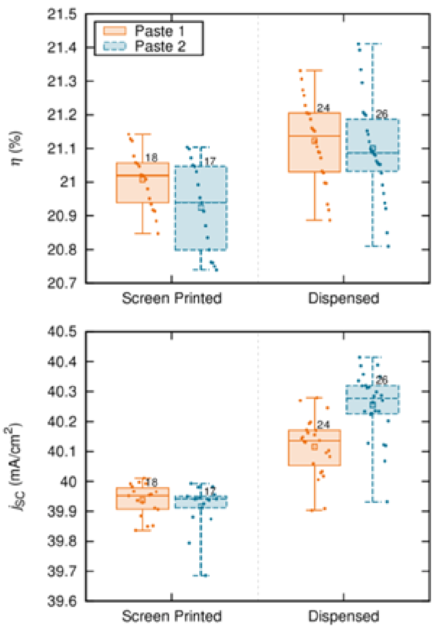

Figure 10: IV parameters (Jsc, eff.) of a PERC cell run based on contact finger metallization by dispensing and single step screen printing applying the same two commercially available screen printing pastes to both technologies. An efficiency increase of around 1.5%rel. is demonstrated for dispensing mainly driven by an increase in the short circuit current due to less shading of the contact fingers.

4 SUMMARY AND OUTLOOK

Within this work, innovative printing technologies are demonstrated aiming at the realization of much higher throughput rates, higher efficiencies and reduced production costs in comparison to flatbed screen printing. The proof of principle for rotary rear side metallization and flexographic as well as multi-nozzle dispensing front side metallization is shown.

At the moment, a new machine concept is under development and construction which addresses a continuous process flow during printing. Rotational printing units for flexographic printing (front side printing) and rotary screen printing (rear side and busbar printing) will be integrated. In principle, the integration of a dispensing unit for high aspect ratio fine line printing is also possible.

Hence, we see a huge potential to realize the rear and front side metallization of Si solar cells based on these high throughput printing technologies leading to higher throughput rates and significantly lower production costs. A first estimation of possible throughput rates shows that values above 6000wph are reachable.

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