ULTRAFINE FRONT SIDE METALLIZATION ON SILICON SOLAR CELLS BY INDUSTRIAL DISPENSING TECHNOLOGY

M. Pospischil[a*], M .Kuchler[a], M. Klawitter[a], C. Rodriguez[a], A. Padilla[a], R. Efinger[a], H. Gentischer[a], M. König[b], M. Hörteis[b], L. Wende[c], O. Doll[d], F. Clement[a], and D. Biro[a]

a) Fraunhofer Institute for Solar Energy Systems ISE, Heidenhofstraße 2, 79110 Freiburg, Germany

b) Heraeus Precious Metals GmbH & Co. KG, Heraeusstr 12-14, D-63450 Hanau, Germany

c) ASYS Automatisierungssysteme GmbH, Benzstr. 10, 89160 Dornstadt, Germany

d) Merck KGaA, Postcode Q004/001, Frankfurter Str. 250, D-64293 Darmstadt, Germany

ABSTRACT: This study presents a new developed, inline applicable dispensing platform that is equipped with an advanced version of previously introduced parallel dispensing print heads. At process speeds of up to 700 $mm \cdot s^{-1}$ and a substantially improved process stability, recent cell results on industrial 90 Ω/sq. emitters showed an efficiency increase of up to +0.4%abs. in comparison to standard single screen printing technology. Top values of 19.4% using standard Al-BSF technology were reached in this study. A key improvement of the technology is the new ability to process certain metal pastes originally designed for screen printing applications and thus keep in track with fast emerging paste development. Successfully evaluated screen printing pastes then can be rheologically adapted in order to reach ultrafine contact fingers at high aspect ratios and extract the whole advantage of this non-contacting printing technology.

Keywords: Silicon Solar Cell, Metallization, Dispensing

1 INTRODUCTION

Previous studies on dispensing as an alternative front side metallization process in crystalline silicon photovoltaics demonstrated, how an adaption of paste rheology allows for a precise adjustment of contact finger geometry in a wide range [1, 2].
Furthermore, a substantially improved homogeneity of dispensed fingers compared to screen printed front side contacts results in more efficient material usage. Consequently, the use of dispensing technology leads to contact finger widths down to 27µm at desired, high aspect ratios and without mesh marks and paste spreading, enabling high cell efficiencies like Lohmüller's demonstration of 20.6% in 2011 [3].

In order to demonstrate the benefit of these advantages, the analytical 2D simulative tool Gridmaster [4] was enhanced to observe the effect of various geometrical parameters on solar cell results and manufacturing costs [5]. Both however, imply a stable metallization process at high throughput rates. For this reason, a novel dispensing platform was developed, providing fully automated inline production feasibility. In the following, this platform, was equipped with an advanced parallel dispensing print head as introduced in [2] and applied for extensive solar cell metallization on state of the art industrial Cz p-type material with high ohmic (R_{sh}~90Ω/sq.) emitters.

2 APPROACH

The focus of three years lasting research project "GECKO" was mainly the development of dispensing technology aiming on an industrial implementation. Here, precise rheological analysis of dispensing pastes [1, 2] and a subsequent implementation of a rheological paste model allowed for an efficient development of parallel print heads by computational fluid dynamic (CFD) simulations [2, 6].
After providing a homogeneous mass flow distribution to all nozzles and demonstrating record finger widths of just 27µm [2], the development had to approach valve technology and cleaning cycles on the one side and process stability with state of the art silver pastes on the other. The latter implied the development of a novel, fully automated dispensing platform incorporating the parallel dispensing units that was extensively evaluated during this study.

3 RESULTS

3.1 Improving printing pastes

Due to the non-contact printing process, dispensing offers the possibility to adapt paste rheology in a much wider range than other thick film printing technologies. For this reason, the shape of resulting contact fingers on the wafer can be adjusted with respect to an optimum trade-off between mechanical robustness, shading losses and electrical contacting behaviour.
However, recent paste development in screen printing technology addresses fine line printing in order to save material costs. The characteristics of these pastes resemble more and more those required for dispensing pastes. This brings a huge advantage, since new results and findings from screen printing paste development can be directly transferred to dispensing technology. In a first step, new paste systems are then evaluated regarding their applicability for dispensing. Here, very homogeneous finger geometries (Fig. 1, top) were obtained but with medium aspect ratio. Once, the evaluation of a novel paste has been successful, paste rheology has to be adapted towards higher yield stresses allowing for even more beneficial finger geometries with high aspect ratios and substantially reduced line widths (Fig. 1, bottom).

3.2 Development of multi nozzle print heads

In order to significantly increase throughput rates during dispensing, a novel parallel print head was developed. For this reason, rheological paste characteristics were used to implement an universal paste model including Non-Newtonian flow patterns like shear thinning and yield stress [2]. After verifying this paste model using a single nozzle dispense setup, the focus was put on the development of a ten nozzle parallel dispensing prototype (Fig. 2). Here, a modular setup allowed for a separate optimization of dispensing nozzles, valves and paste distribution.

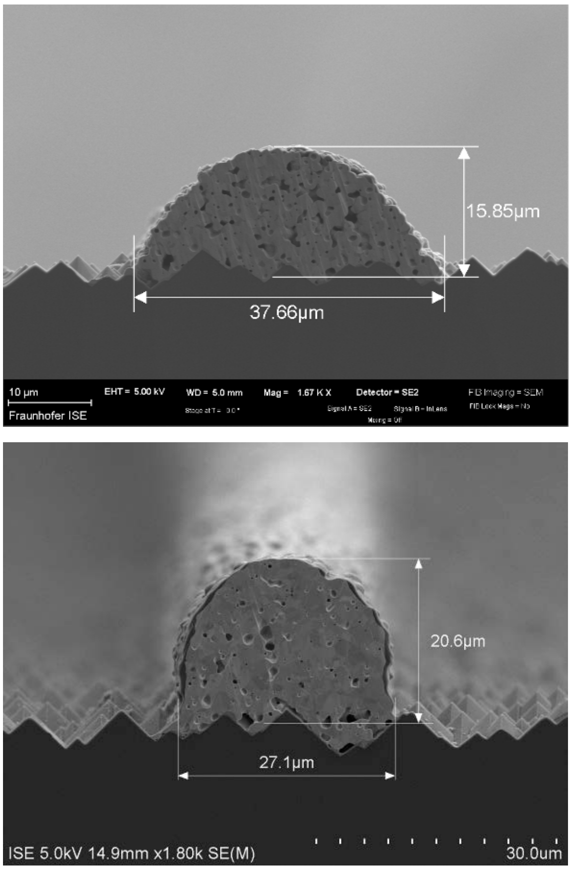

Fig. 1: Finger cross section of dispensed contact fingers using a new developed screen printing paste (top) and a dispensing paste with adapted rheology (bottom, from [2]), both printed in a parallel dispensing unit with a nozzle opening of just 40µm.

In the following, multi nozzle print head designs were tested and optimized regarding their robustness concerning fabrication tolerances. Due to specially designed nozzles, the necessary dispensing pressure was reduced by a factor of up to ten compared to commercial standard nozzles. A central fed paste supply with nozzle pitches of only 1.56 mm was realized which allows for further scalability of the design in the future.

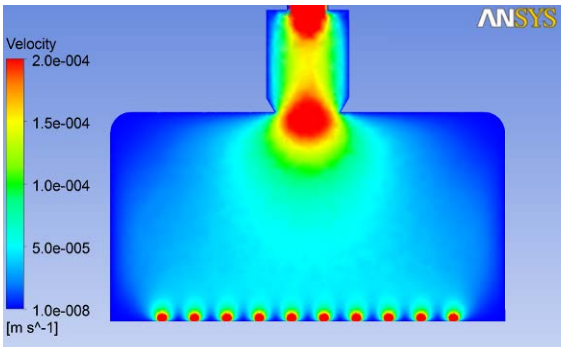

Fig. 2: Velocity profile of a parallel dispensing print head, as described in [7]: After investigating several nozzle types using this CFD-model concerning flow rate and pressure distribution, hardware design was expanded towards a multi nozzle application. Here, investigations were focusing on a homogeneous paste flow distribution within the print head with as little pressure drop as possible.

3.3 Integration into an inline applicable platform

Finally, the novel print head was integrated in a newly developed fully automated dispensing platform (Fig. 3) which permits industrial manufacturing sequences with the new setup. Here, a fully automated cell handling system allows for a precise application of dispensed grid structures on industrial solar cells.

Continuous line dispensing at line speeds of up to 700 mm·s^{-1} was already reached using this setup. Furthermore, a nozzle distance of just 50 µm can be realized during dispensing with this platform. However, rheological adaptions of the dispensing pastes also allow for a stable process at much greater distances by stretching the paste during its free flow phase.

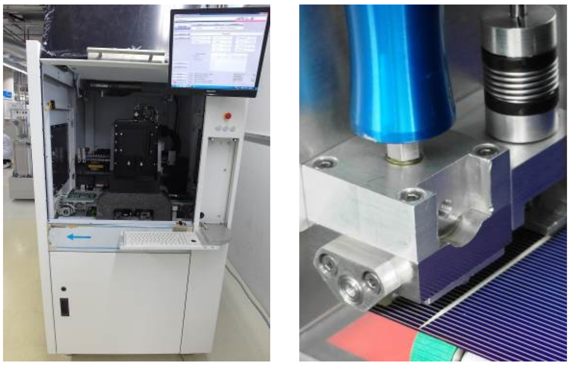

Fig. 3: Completely new developed, inline applicable dispensing platform at Fraunhofer ISE's PV-TEC (left) with integrated advanced version of the ten nozzle print head (right) during cell manufacturing.

3.4 Recent cell results on high ohmic industrial emitters

Early studies showed that an efficiency increase of around 2-3% rel. compared to screen printed solar cells is reached by replacing standard screen printed front contacts by high aspect ratio, ultrafine dispensed contact fingers [1, 8-10]. In order to make use of this benefit, especially the electrical performance of applied dispensing pastes has to keep up with state of the art screen printing pastes.

For this reason, a large number of cell batches were processed in the last months, all based on large area industrial preprocessed Cz p-type material with an emitter sheet resistance of R_{sh}~90Ω/sq. Printed Al back surfaces as well as floating busbars were applied previously to the dispensing step at Fraunhofer ISE's PVTEC. Single screen printed as well as double printed solar cells of the same material always served as reference groups with only the latter having floating busbars.

Applying a similar number of contact fingers (N=100), dispensed contact fingers allowed for a reduction of line width by a factor of 20% compared to both reference technologies in this batch. Consequently, a substantially improved j_{sc} in the range of +0.8 to 1.0 mA/cm² was reached with the dispensed group (Fig. 4).

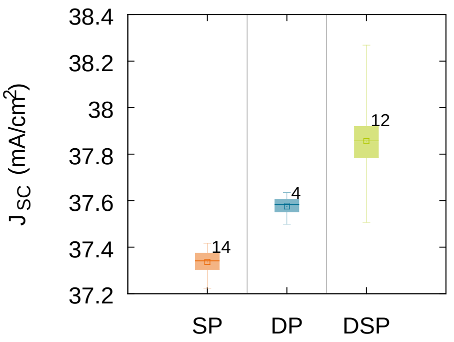

Fig. 4: Resulting short ciruit current j_{sc} of the three applied printing technologies, i.e. single screen printing (SP), double screen printed (DP) and dispensed (DSP) technology.

Regarding the open circuit voltage, the floating busbar design allows for a slightly increased V_{oc} (Fig. 5) which is in good correlation to similar experiments [11]. A substantially descreased grid resistance at a slightly higher contact resistance leads to a FF level, that is inbetween both reference technologies and certainly allows for further improvements.

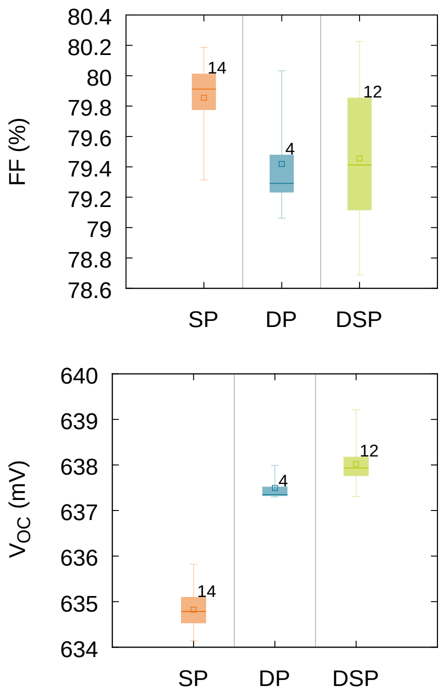

Fig. 5: Fill Factor FF and V_{oc}, respectively of the three printing technologies in comparison.

Finally, cell efficiencies of up to 19.4% (Fig. 6) and thus an increase of 0.7% abs. in comparison with previously published cell results on the same material [5] were reached thanks to a substantially improved dispensing paste and an advanced process stability. Both reference groups perform clearly less, mainly due to their known geometrical drawbacks, namely low aspect ratio and a substantially reduced finger homogeneity due to meshmarks.

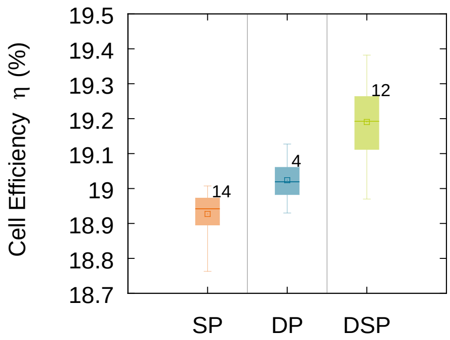

Fig. 6: Cell efficiencies on 156x156mm² Cz-p-type material with industrial high ohmic emitters. Single screen printing (SP) is compared with double screen printed (DP) and dispensed (DSP) technology.

4 CONCLUSIONS AND OUTLOOK

Fast emerging thick film printing technologies remain a dynamic challenge for any kind of alternative metallization technology. The possibility to directly transfer results and findings from screen printing paste development however, allows for the enhancement of dispensing technology towards industrial cell processing. Consequently, increases in cell efficiencies of up to +0.4%abs. in comparison with standard single screen printing and +0.3%abs. with double printed reference were demonstrated on solar cells with industrial high-ohmic emitters. With the new developed, inline applicable dispensing platform, a continuous printing process was demonstrated at printing speeds up to 700 mm·s^{-1}. The integrated, advanced version of a ten nozzle parallel dispensing print head can be easily scaled for a future application in cell production.

5 ACKNOWLEDGMENTS

The authors would like to thank all co-workers at the Photovoltaic Technology Evaluation Center (PV-TEC) and the mechanical workshop at Fraunhofer ISE for processing of the samples. This work was supported by the German Federal Ministry for Economic Affairs and Energy within the research project “GECKO” under contract number 0325404.

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