PROJECT "ROCK-STAR" – HIGH-SPEED ROTARY PRINTING FOR SOLAR CELL METALLIZATION: FROM VISION TO REALITY

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ABSTRACT: Within this work, we will present the machine concept and the first results of passivated emitter and rear contact (PERC) solar cells fabricated on an innovative high-throughput rotary printing demonstrator machine which has been developed within the research project »Rock-Star«. The machine is designed to perform the metallization of Silicon solar cells with a printing speed of up to 600 mm/s and a cycle time down to 0.45 s/wafer using a newly developed shuttle transport system. Within a first experiment, multicrystalline Silicon (mc-Si) PERC solar cells metallized on the rear side with rotary screen printed obtained a mean conversion efficiency of η = 19.3 % which is on the same level as reference cells with standard flatbed screen printed rear side metallization (η = 19.3 %). Furthermore, a 9 cell demonstrator module with cells partly metallized on the demonstrator and SmartWire (SWCT) interconnection is presented.
Keywords: Silicon Solar Cells, Manufacturing and Processing, PERC, Metallization, Rotary Printing

1 INTRODUCTION

Flatbed screen printing (FSP) is the state-of-the-art technology for crystalline Silicon (Si) solar cells. Despite of remarkable progress in productivity within the last years, the FSP process is close to the technical limitation with respect to a further increase in throughput. A very promising approach to meet this challenge is the application of highly productive rotary printing methods, namely rotary screen printing (RSP) and flexographic printing (FXP). Within the funded research project »Rock-Star« (contract no. 13N13512), a project consortium of industry partners and research institutes has set itself the ambitious goal to develop a rotary printing demonstrator machine which is able to realize the metallization of solar cells with a printing speed of up to 600 mm/s which would be equivalent to a gross throughput of 8000 wafers per hour on a single line. Within the project, intense effort has been done in developing materials, printing processes and the machine platform. Within this work, we present the concept of the »Rock-Star« demonstrator and the I-V- results of the first PERC solar cells which have been partly metallized using the rotary screen printing unit on the demonstrator machine. Furthermore, a 9-cell demonstrator module fabricated by interconnecting »Rock-Star« PERC solar cells with SmartWire interconnection technology (SWCT) is presented.

2 ROCK-STAR DEMONSTRATOR PLATFORM

2.1 Demonstrator Machine

A major goal of the joint project »Rock-Star« was the development of an innovative machine platform for high-throughput metallization of Silicon solar cells. The ambition was to realize such a machine with a high technology readiness level (TRL) [1] based on the groundwork of a fundamental and intense evaluation of the applied rotary printing methods [2–6].

Fig. 1: Rock-Star Demonstrator Machine at the Fraunhofer ISE PV-TEC pilot line

Based on the result of these studies, several innovative features and solutions were developed for the demonstrator machine:

- A new transport concept based on shuttles with autonomous energy supply, vacuum and positioning system for a cycle time down to t_{min} = 0.45 s
- High-speed camera system for ultra-fast detection of the wafer position and subsequent alignment of the shuttle
- Granite basis for the transport system and the printing units to minimize vibrations during highly precise printing processes
- Flexographic and rotary screen printing unit with “roll-to-flat” design and maximum adjustment flexibility
- Modular integration of the printing units to enable a future application of other printing/coating methods
- Buffer system for the metallization of up to 60 wafers in one run
- Overall construction of the machine for a future integration in an inline production line

The demonstrator machine is designed and optimized for the metallization of Silicon solar cells. However, further field of application for the manufacturing of various single item components is also possible.

2.2 Rotary Screen Printing

Rotary screen printing (RSP) is commonly applied in the field of textile or label printing using highly developed high-speed printing machines based on a roll-to-roll concept [7]. Such web-fed machines with rotary screen printing units can realize a printing speed of up to 160 m/min. (2.7 m/s) [8]. Like flatbed screen printing (FSP), RSP is able to apply precise thick film patterns on various substrates. Combining the high metallization quality of screen printing with the rotary principle of RSP is a highly promising path for a future high-throughput metallization line. The working principle of the rotary screen printing unit within the demonstrator machine is shown in Fig. 2. First attempts to use this technology for solar cell metallization already date back to the year 1999 [9], however no published results are known from these activities. Intense evaluation of the applicability for the rear and front side metallization has been done within the framework of the »Rock-Star« project [5,6]. The successful application of RSP for the high-quality rear side metallization of PERC solar cells has been demonstrated [5]. It has been further shown that even the front side metallization grid with finger widths down to $w_f \approx 45$ µm [10] and less can be printed by RSP. However, obtaining finer contacts with sufficient finger height and homogeneity requires further research and development with respect to screen and pastes.

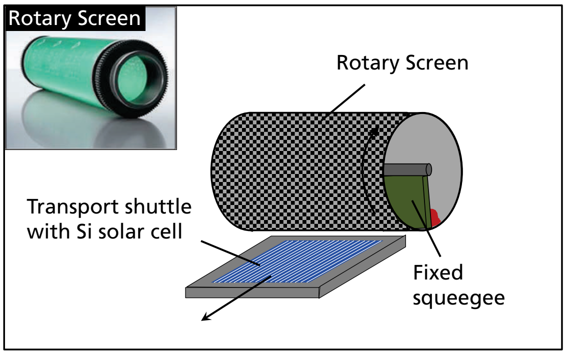

Fig. 2: Working principle of the rotary screen printing unit in the demonstrator machine. The paste is pressed by a fixed squeegee through the openings of the rotating cylinder screen and printed onto the Silicon wafer which is fixed on the vacuum shuttle.

2.3 Flexographic Printing

Flexographic printing (FXP) is a well-known and widely used printing technology which is commonly applied for graphic arts printing on substrates like card-board, paper or foil. FXP machines with roll-to-roll principle obtain printing speeds up to 800 m/min on web-based materials. This is obviously unrealistic for printing processes on single-item substrates like Silicon solar cells. However, applying FXP for the front side metallization opens the potential to increase the throughput of solar cell metallization considerably compared to the state-of-the-art flatbed screen printing method. Fig. 3 illustrates the working principle of the flexographic printing unit within the demonstrator machine.

Beside graphic arts and package printing, FXP is successfully applied for various printed electronics applications like micro-scale conductive networks [11], circuitry [12,13], roll-to-roll polymer solar cell modules are usually fabricated on roll-to-roll machines.

The application of flexography for a seed-and-plate metallization approach for Si solar cells with subsequent plating has been evaluated by Fraunhofer ISE and TU Darmstadt as well as other research groups since 2010 [16–18,2]. Within the project »Rock-Star«, the focus has been shifted to the direct fine line metallization of busbarless solar cells without subsequent plating. To achieve this ambitious goal, a comprehensive evaluation and optimization of the laser-engraved printing form [3,19], ink formulation [6], printing parameters [19] and anilox roller [3,6] has been performed. Cz-Si Al BSF solar cells with flexo-printed front side metallization obtaining a conversion efficiency up to $\eta = 19.4$ % [4] as well as successful interconnection using a SmartWire approach [20] have been demonstrated. It has been further shown that flexography is able to realize fine line contacts for Si solar cell front side metallization down to a mean width of approx. 30 µm [6].

The ongoing trend to interconnect Si solar cells with multiple soldered ribbons or wires increases the demand to reduce the contact width and silver consumption on the front side. A higher lateral resistance of such contacts does not necessarily limit the fill factor of the cell due to strongly decreasing finger segment lengths. This trend makes new metallization approaches like flexography particularly attractive which can combine these requirements with a high printing speed.

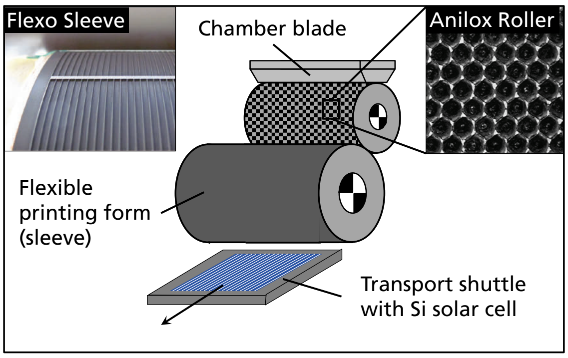

Fig. 3: Working principle of the flexographic printing unit in the demonstrator machine. The elevated areas of the printing form are inked by an anilox roller with a finely textured surface of microscopic wells and directly printed onto the substrate.

3 EXPERIMENTAL SETUP

2.1 Outline and parameters of the experiment

An experiment has been set up to test the functionality of the demonstrator machine for solar cell metallization (Fig. 4). Industrial pre-processed mc-Si PERC precursors with rear side passivation and local contact opening (LCO) on the rear side and SiNx anti-reflection coating on the front side have been used. For the metallization of the PERC solar cells, a busbarless layout (100 contact fingers, nominal finger width $w_n = 35$ µm) has been selected for the front side and a layout for full-area Al metallization for the rear side. It was further planned to fabricate 2 demonstrator modules by inter-connecting 9 cells per module via SmartWire connection technology (SWCT). Within the experiment, the rear side metallization has been varied using flatbed screen printing for the (reference) group 1 and rotary screen printing for group 2 with 100 cells per group in total. The cells of group 1 have been metallized on the rear side using flatbed screen printing on an industrial screen printing line at Fraunhofer ISE. The rear side metallization for the cells of group 2 has been carried out on the demonstrator machine using rotary screen printing (Fig. 4). A commercial Al PERC paste has been used for both groups. For the RSP rear side metallization (group 2) the viscosity of the paste has been modified by adding 3 wt.% of a suitable thinner. To enable a direct comparison of both groups, all cells were equipped with a FSP front side metallization within one process run on an industrial (flatbed) screen printing line at Fraunhofer ISE PVTEC. A fast firing variation at 3 peak set temperatures has been carried out after the metallization step using solar cells from group 1. All solar cells of group 2 have been fired at optimal peak set temperature. All cells have been subsequently regenerated using ultra-fast regeneration technology (RLID). The I-V-results of all cells have been measured on a GridTouch unit of an industrial cell tester. 18 solar cells from group 2 have been selected to fabricate 2 9-cell demonstrator modules externally using SWCT multiwire interconnection. The I-V-results of the modules have been measured by an industrial module tester.

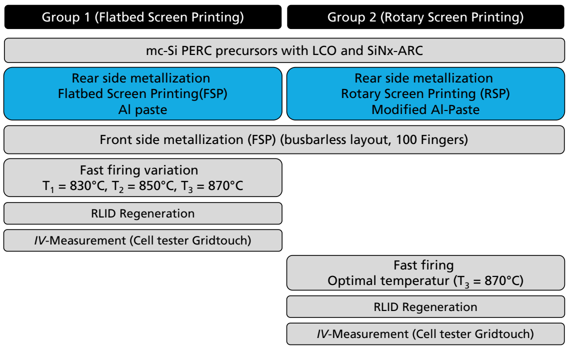

Fig. 4: Experimental plan

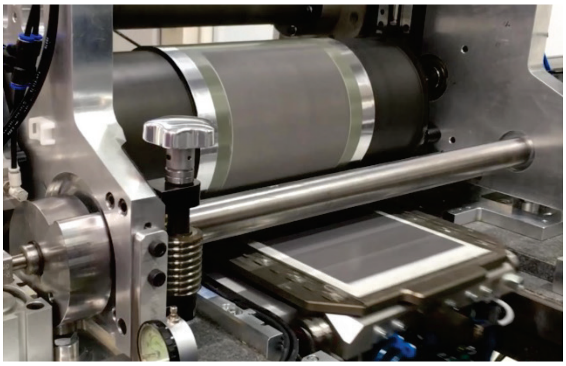

Fig. 5: Rotary screen printing unit of the demonstrator machine.

4 RESULTS AND DISCUSSION

Using the RSP unit on the demonstrator machine, a high-speed metallization of more than 100 solar cells could be successfully carried out. However, due to an existing (meanwhile fixed) positioning problem at this time, the Al rear side metallization layout was partly printed over the the edge of the wafers leading to local shunting after firing. Thus, solar cells with a parallel resistance $R_p \leq 1500\ \Omega$ have been sorted out after IV-measurement. Fig. 6 shows the conversion efficiency η of cells from both groups with optimal firing conditions.

Group 2 (RSP rear side metallization) obtained a mean conversion efficiency of η = 19.3 % (best cell ηmax = 19.7 %) which matches the quality level of the FSP reference group 1 with a mean conversion efficiency of η = 19.3 % (best cell η_{max} = 19.5 %), see Fig. 6. Cells of both groups showed a good visual quality and homogeneity of the rear side metallization.

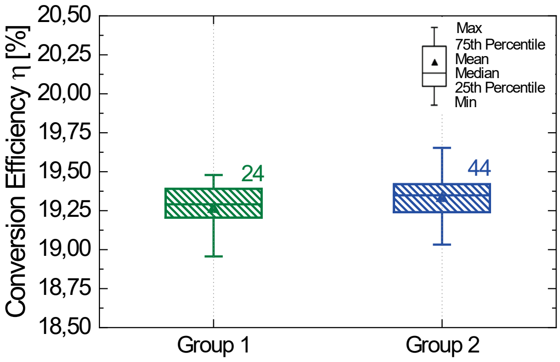

Fig. 6: I-V-results of group 1 (reference with FSP front and rear side metallization) and 2 (RSP rear side metallization, FSP front side metallization)

Two demonstrator modules consisting of 9 selected PERC cells of group 2 with rotary printed rear side metallization were fabricated externally using SWCT interconnection technology (Fig. 7). The modules obtained a module efficiency of η_{mod1} = 17.7 % and η_{mod2} = 17.6 % related to the total cell area. Within the next step, modules with rotary printed metallization on the front and rear side will be fabricated.

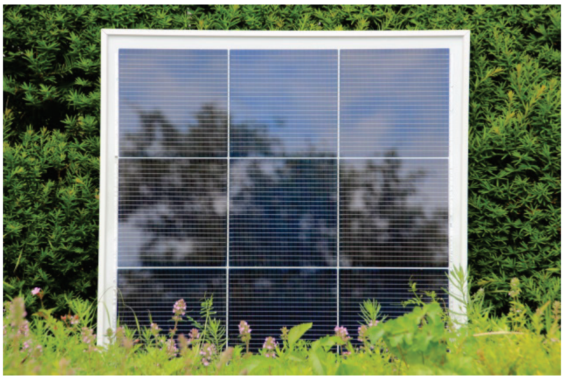

Fig. 7: Demonstrator module fabricated by inter-connecting 9 PERC solar cells from group 2 with RSP rear side metallization using SWCT interconnection.

5 CONCLUSION

In summary, we demonstrated the capacity of the »Rock-Star«-demonstrator to realize a high-throughput rear side metallization for PERC solar cells with the same quality as the flatbed screen printing standard process but significantly lower cycle time down to 0.45 s per cell. Previous results within project »Rock-Star« showed that both printing methods – rotary screen printing and flexographic printing – are also able to realize the fine line front side metallization of Silicon solar cells with adequate electric and optical quality. Further research and development activities will thus focus on realizing both front and rear side metallization on the »Rock-Star« demonstrator machine.

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