Stencil printing and metal squeegees for improved solar cell printing results

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ABSTRACT

Traditionally, the solar cell metallization process has been achieved through the use of mesh screens to print silver paste on the front side of the cell. Higher efficiency is generally realized by optimizing the busbar design, printing finer lines or making adjustments to the silver paste. This paper examines the use of stencil printing instead of screen printing in order to achieve improved fine line print quality for greater efficiency. In addition, a comparison of polymer and metal squeegees on fine line print performance is analyzed, with varying line apertures studied to understand the impact on the efficiency of PERC solar cells.

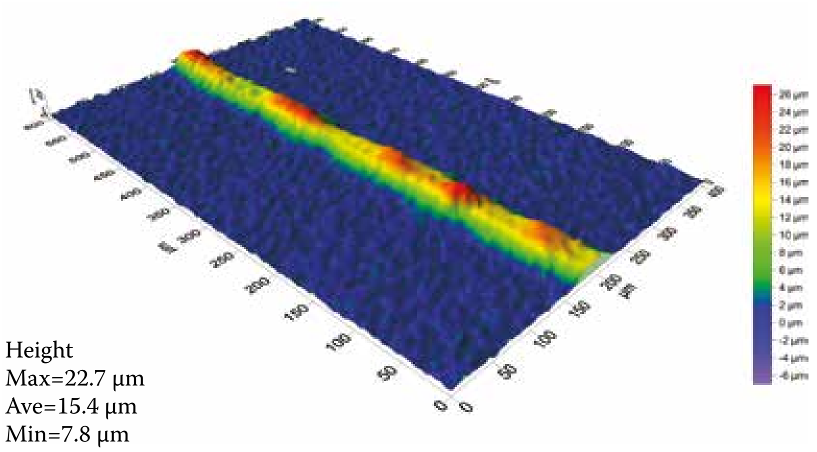
Introduction

For today's crystalline silicon (c-Si) solar cell manufacturing operations, processes generally proceed in the following steps: texturing, diffusion, edge/etch isolation, PECVD SiNx coating and metallization. For the majority of metallization processes, screen printing is the most popular method to apply conductive paste to solar cells [1]. While other techniques such as plating and ink jetting are used, although less commonly, mass imaging via screen printing has emerged as the most cost-effective high-volume metallization method.

In this study conducted by ISFH, a stencil printing process [2] was implemented to evaluate possible improvements versus the conventional screen printing approach. Analysis revealed that the screen printing technique tends to produce solar cell fingers that have a wave-like shape along the finger direction. Importantly, the top portion of the wave shape was non-functional when the electrical current passed through the finger from the PN junction to the busbar. Concurrently, the bottom part of the wave shape became a bottleneck of current collection. The expectation was that solar cell fingers printed through metal stencils would provide more uniform lines and, therefore, deliver improved performance (Figs. 1 and 2).

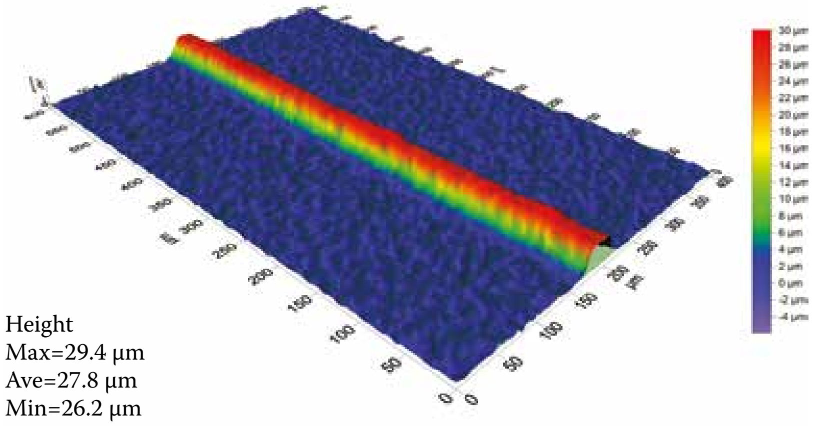
As suspected, the uniform stencil-printed fingers offer lower electrical resistance than the wave-shaped, screen-printed fingers using the same volume of silver paste [3].

In addition to the print performance analyzed by comparison of screens versus stencils, this study also evaluated the effect of different squeegee materials on printing efficiency. The authors undertook a comparison of polymer



Height
Max=22.7 µm
Ave=15.4 µm
Min=7.8 µm

Figure 1. 3D microscope image of a solar cell finger printed with a screen. Note the wave-like topography, with peaks and valleys.



Height
Max=29.4 µm
Ave=27.8 µm
Min=26.2 µm

Figure 2. 3D microscope image of a solar cell finger printed with a metal stencil. The silver paste is more uniformly distributed than with the screen print.

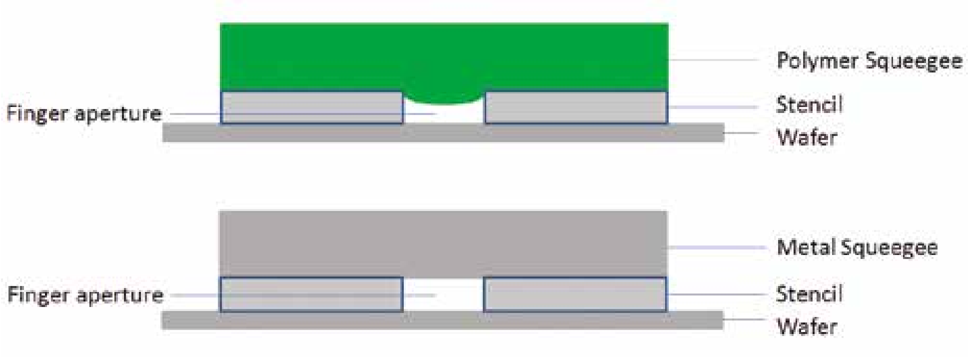


Figure 3. Polymer squeegee versus metal squeegee printing; polymer squeegees tend to result in a scooping effect, whereas metal squeegees produce a more brick-like shape.

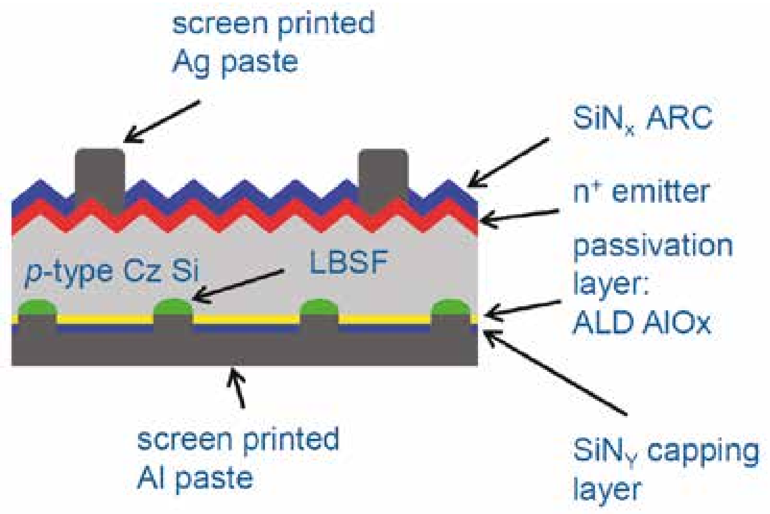


Figure 4. The substrates of this experiment

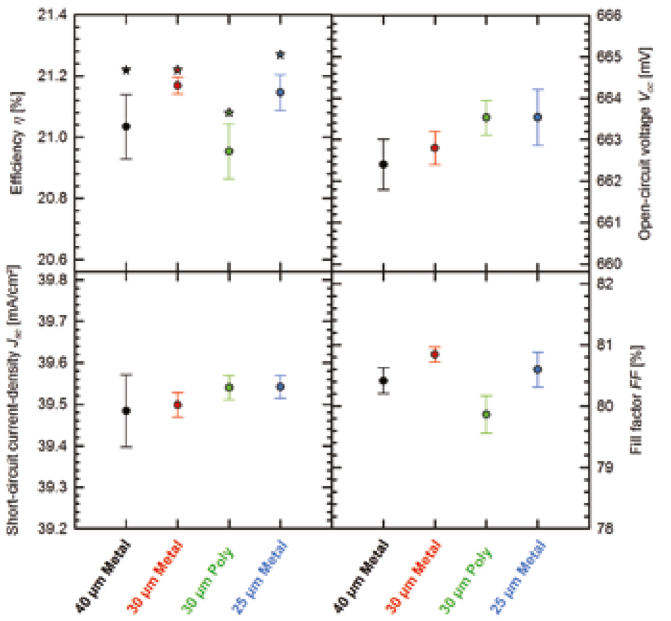


Figure 5. I/V data of four groups.

versus metal squeegees to understand the impact of squeegee material on print performance. Because polymer squeegees have elasticity, part of the squeegee will extend into the stencil aperture during stencil printing, resulting in a "scooping" effect, which produces a trough-like finger shape (Fig. 3).

Design of experiment

Experimental inputs

1. ASM Alternative Energy (ASM AE) Eclipse metallization platform, Centrotherm dryer, Centrotherm furnace, I/V tester
2. Nikon optical microscope and Wyko surface profiler
3. ASM AE VectorGuard stencil frame, Fine-Line™ stencil foil and metal squeegee
4. ASM AE Polymer squeegee, 95A shore
5. Silver pastes
6. PERC solar cell substrates from ISFH [Figure 4]

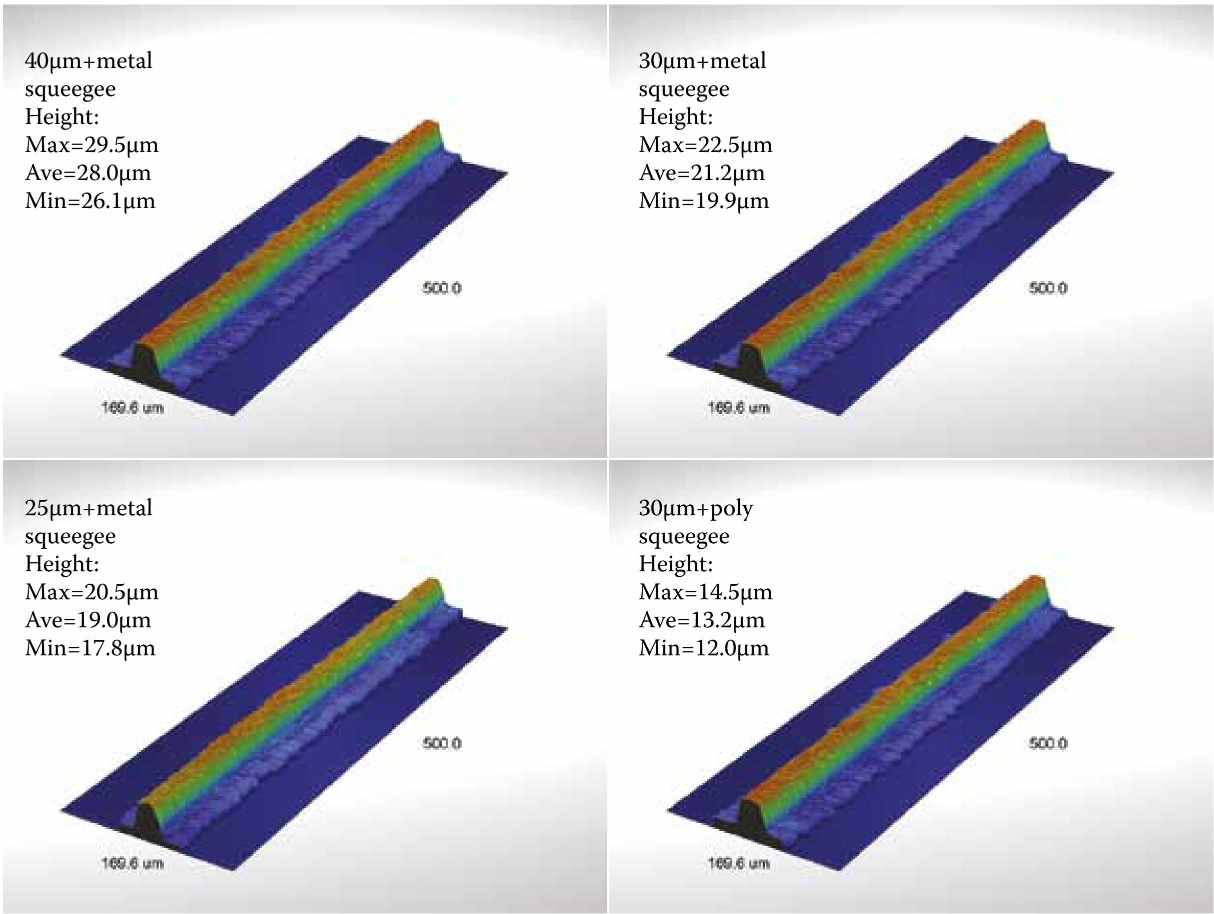


Figure 6. Resulting finger shapes and height for the different aperture/squeegee combinations.

Experimental process

PERC solar cell substrates from ISFH [4] were printed on the Eclipse metallization platform using a two-step printing process [5,6].

During step one, the busbar pattern was screen printed using a non-fire-through silver paste. Following the initial busbar print, the paste was dried and the cells were randomized into different groups. In the second step, the finger pattern was printed with a contacting silver paste with high viscosity developed for stencil printing through a VectorGuard Fine-Line stencil using a metal squeegee, following which the paste was dried. Various stencil foils with 25µm, 30µm and 40µm finger apertures were used to print three groups of solar cells. The finger number range is between 101 fingers for 40µm, 124 fingers for 30µm and 134 fingers for 25µm. Simultaneously, one group of cells was printed using 30µm apertures and a polymer squeegee. Finally, all four groups of solar cells went through thermal processing (firing) and the cells were I/V tested.

Characterization and discussion

I/V data of solar cells

I/V data results are shown in Figure 5. The star-shaped data points refer to the solar cell with the highest conversion efficiency of each group.

All cells achieved similar Jsc and Voc parameters, which are caused by nearly the same metallization area. The lowest fill factor (FF) was observed in the solar cell group printed with polymer squeegee, indicating that the finger conductivity of this group of cells was lower than the other cell groups printed with a metal squeegee.

Finger shape characterization

The finger shape of three groups was measured and included those cells printed with the following conditions: a 30µm stencil aperture and a metal squeegee, a 30µm stencil aperture and a polymer squeegee and a 25µm stencil aperture and a metal squeegee. The results are shown in Figure 6 and Figure 7.

Figure 6 and Figure 7 illustrate that when using the 30µm aperture stencil and printing with metal and polymer squeegees for comparison of squeegee type, the finger width printed with the metal squeegee group is approximately 41.40µm and that printed with the polymer squeegee is about 38.64µm. While the difference between the two line widths isn’t statistically significant, the finger height differences are quite meaningful. The finger height printed with metal squeegees is about 21.2µm high, while that printed with the polymer squeegee is approximately 13.2µm. These

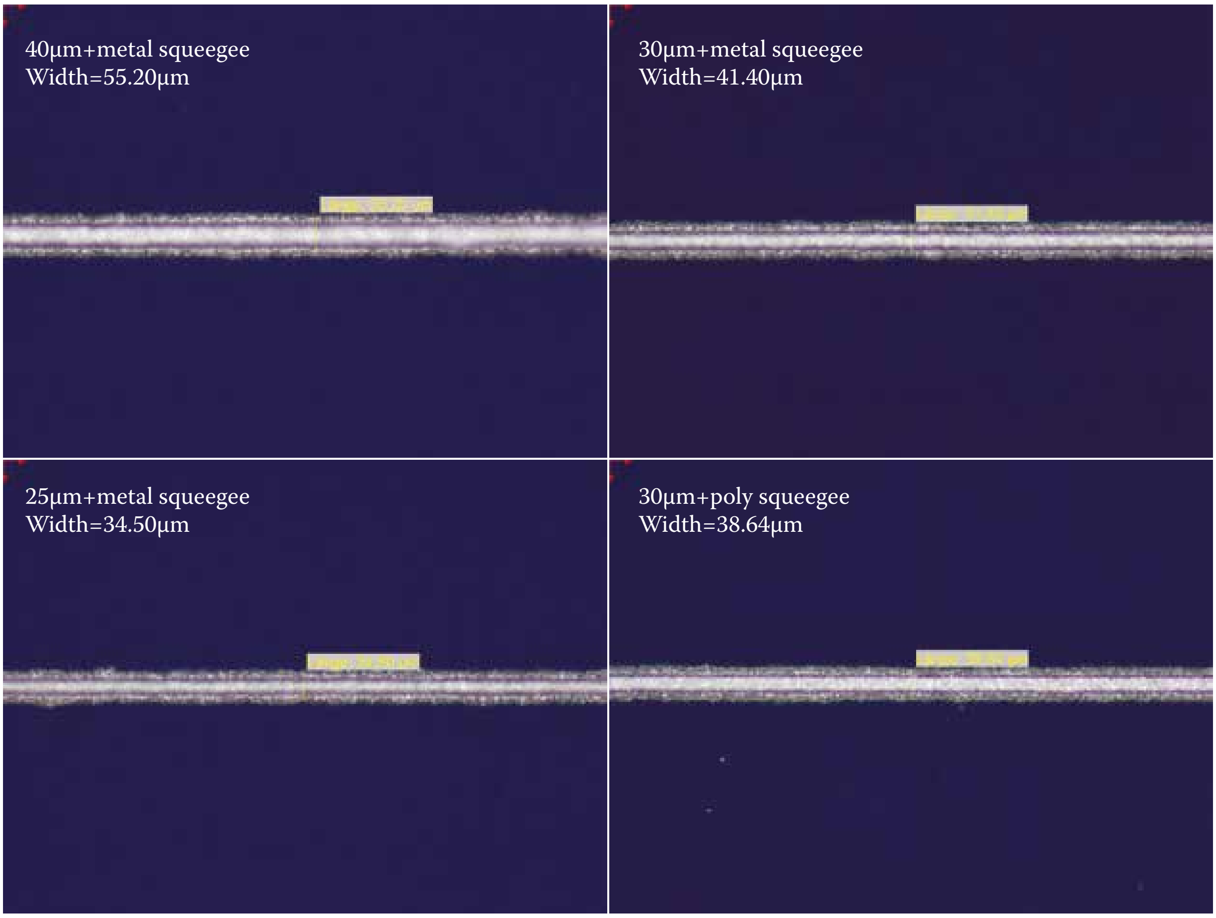


Figure 7. Resulting finger width for the different aperture/squeegee combinations.

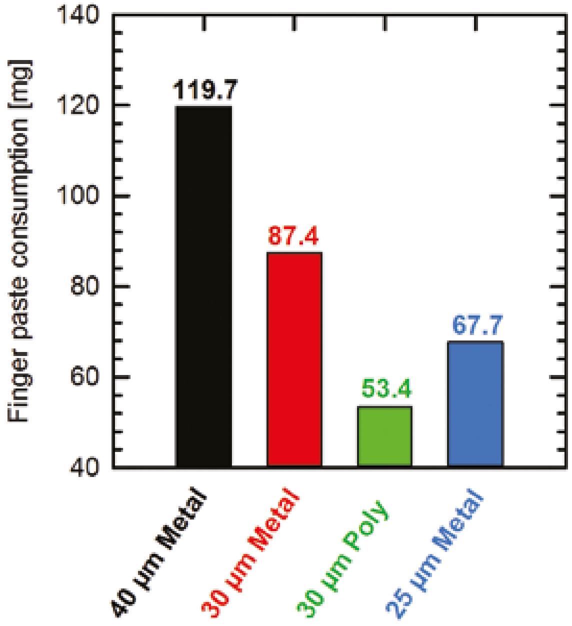


Figure 8: Silver paste consumption of four groups

results substantiate the "scooping effect" observed with polymer squeegee printing. With the 25µm aperture stencil and metal squeegee prints, finger widths of 34.50µm and heights of 19µm were produced.

Silver paste consumption

Achieving cost competitiveness in the solar cell manufacturing industry is a necessity; both for manufacturer competitive advantage and for the production of lower-cost cells to bring solar energy costs in line with consumer expectations. Silver paste is generally considered one of the higher cost inputs in solar cell manufacturing, so the ability to reduce the consumption of silver paste while simultaneously improving cell efficiency has been and continues to be a driver of technology development [7,8].

In this study, silver paste consumption was also recorded after printing prior to drying and the results are illustrated in Figure 8. The chart shows the silver paste consumption for the contact fingers. The standard rectangular-shaped five busbar design results in an Ag paste consumption for the busbars of 14.2mg.

Figures 5 and 8 indicate that the relationship between silver paste consumption and cell efficiency is not a direct ratio. In stencil printed cells, the higher efficiency groups were printed by 30µm and 25µm finger aperture stencils. The 30µm group has better fill factor and more concentrated efficiency distribution compared to the 25µm group, which suggests that the 30µm finger aperture stencil has better printing performance than the 25µm finger aperture stencil when using the DuPont silver paste for the contact finger. In addition, the highest efficiency cell appeared in the 25µm finger aperture group, indicating a higher average efficiency could be achievable given optimization of the stencil and silver paste.

Conclusion

Results from this study conducted by ISFH indicate that a metal squeegee produces improved fine line printing performance as compared to a polymer squeegee resulting in higher aspect ratios using a metal squeegee. In the final I-V ISFH data from the PERC cell analysis, the 3µm finger aperture stencil printed group produced the best average efficiency, and the highest individual efficiency appeared in 25µm finger aperture stencil printed group. The study also revealed that the correlation between silver paste consumption and cell efficiency is not directly proportional and that further research is required to understand the relationship between the front side pattern and silver paste.

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About the Authors

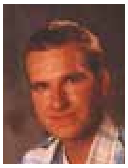
Jessen Cunnusamy is a Process Engineer with ASM Assembly Systems and is part of the Electroform Stencil Team, focusing on the development of advanced stencil printing processes and products. Prior to joining ASM, Cunnusamy held a research engineering position with SERIS, where he specialized in back-end processes.

Andrew Zhou is a Senior Process Consultant for ASM Alternative Energy and leads research and development with an emphasis on improving printing technologies and processes. Before joining ASM AE, Andrew held various roles including that of R&D Engineer for optical disc and amorphous silicon solar module manufacture, Senior R&D Engineer for crystalline silicon solar cell manufacture, and Field Application Engineer for advanced materials and technologies.

Tom Falcon is Principal Engineer at ASM Alternative Energy and has worked in the printing technology sector since 2001, initially specializing in process development for the Semiconductor Packaging Technologies Team before moving to solar in 2008. He is currently responsible for developing metallization processes for silicon solar cells. Previously, he held senior engineering positions with IBM, Nortel and Cookson Electronics.

ASM Alternative Energy Consultant, **Rado Yang**, works closely with ASM AE's Greater China-based customers in support of their metallization processes and ongoing new product development. His tenure with ASM also includes past experience as a Support Engineer, serving the company's Alternative Energy and Assembly Systems businesses.

Dr. Thorsten Dullweber leads the industrial solar cells R&D group at ISFH. His research work focuses on high-efficiency, industrial-type, PERC silicon solar cells and on ultra-fine-line, screen-printed, Ag front contacts. Before joining ISFH in 2009, he worked for nine years as a project leader in the microelectronics industry at Siemens AG and then at Infineon Technologies AG.



Helge Hannebauer studied technical physics at the Leibniz University of Hanover from 2005 to 2009. For his diploma thesis at ISFH he investigated the optimization of screen-printed solar cells. In 2010 he started a PhD programme at ISFH, focusing on advanced screen printing and selective emitters.

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