

# HOT MELT SCREEN PRINTING OF FRONT CONTACTS ON CRYSTALLINE SILICON SOLAR CELLS

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## ABSTRACT

This work describes a study of hot melt (HM) screen printing of front contacts as a function of print speed, print table temperature, squeegee temperature, paste composition and firing profiles. The results presented here will show it is possible to print lines with higher aspect ratio compared with standard screen printing. Optimum parameters for printing seems to be high print speed in combination high squeegee temperature. There is a trade off between the height and width of the finger lines when adjusting the table temperature. Firing with fingers facing down at high belt speeds results in shrinking of line width between 15-20 %. At present the best efficiency results from HM screen printing are at par with standard printed solar cells.

## INTRODUCTION

Hot melt screen-printing (HM) is a new and promising technology for solar cell contact formation. In HM screen printing, metal pastes with melting points of 50–80°C are used in combination with specially designed screen-printers containing heated screens, squeegees and print tables, shown in Fig. 1.

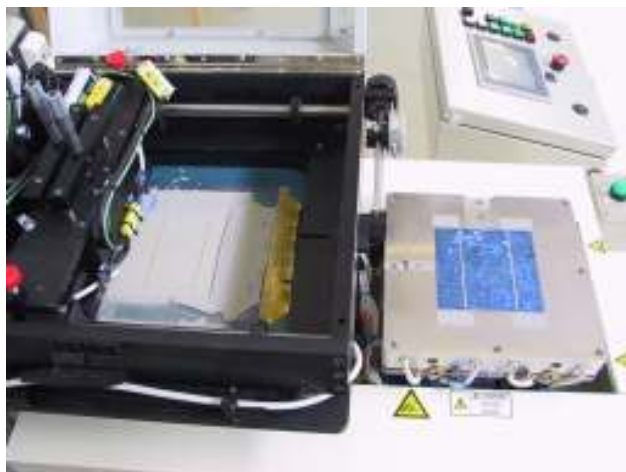


Fig. 1. Hot parts of a hot melt screen printer.

Among the advantages of this technology over conventional screen-printing are the possibility of making thin

front contacts with high aspect ratios and the use of inks that release significantly less amounts of volatile organic compounds than conventional metal pastes. Also, since hot melt inks solidify immediately after a solar cell is removed from the print table, driers are no longer required in a screen-printing line, reducing investment costs.

## METHODS

This work describes a study of HM screen printing of front contacts using a prototype screen printer built by NPC with screens supplied from Sefar Inc., HM pastes from Ferro Inc. and 12.5 x 12.5 cm<sup>2</sup> multi-crystalline solar cells without front contacts with only dried back contacts produced by ScanCell AS.

The print screen is heated by sending a current through the steel mesh of screen. Both sides of a front contact screen are shown in Fig. 2.

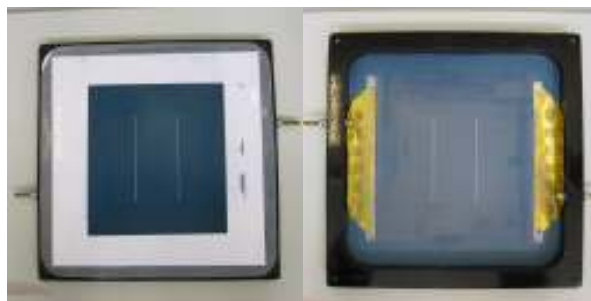


Fig. 2. Back and front size of the HM screen.

The heating of the screen is always uniform as long as no paste is on the screen. Typically settings for the heating current are 3 V and 35 A. However things starts to be complicated when paste is present, especially when ridges of paste make a line from one electrode to the other. This can happen when the electrodes are located parallel the squeegees or when the paste flows around the squeegee while printing. Under such conditions the current may take a short circuit path through these ridges. This is most prone to happen when the screen is first heated from room temperature, or after a stop of some length in the printing process, and can result in local heating and drying around the current path. If such local heating is not interrupted by removing the short circuit current path, the local hot spot might scorch the emulsion and damage the screen.

## RESULTS AND DISCUSSION

### Printing

Another problem is the heating of the squeegees. Today we are using none conductive squeegee material. Under certain conditions when the paste is not uniformly distributed on the squeegee, paste might start to solidify as ice taps hanging from the squeegee. Printing under such conditions will damage the screen and a replacement will be necessary.

As shown in Fig. 2 there is an isolating white frame on the backside of the screen to prevent shunting under heating. This layer may introduce error in the snap distance if the print table is larger than the inner frame of the isolating layer due to its variable thickness. Approximately thickness of this layer is between 0.5 and 1 mm.

The structure and electrical properties of front contacts were studied as a function of print speed, squeegee and print table temperature and the composition of the metal paste. The line width, height and uniformity of the front contacts were characterized using profilometry, white light interferometry (WLI), scanning electron microscopy (SEM) and optical microscope. To accurately determine the variation in finger width, which is an important indicator in this study, a plugin module to ImageJ [1] was developed. By using this tool it is possible to determine widening of the fingers after printing and firing independent of the shape, see Fig. 3.

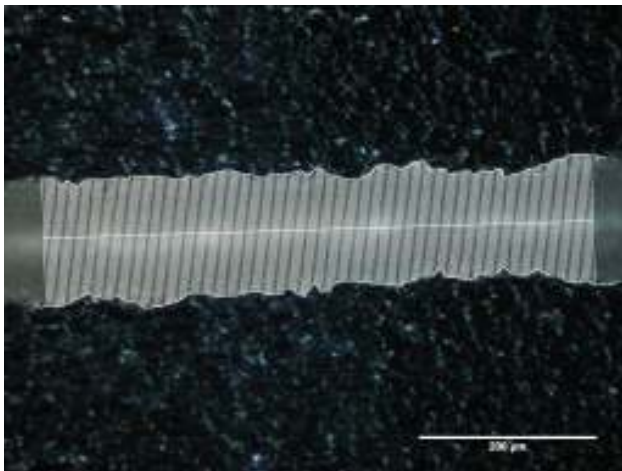


Fig. 3. An image demonstrating the result of the use of the plugin. Typically a center line is drawn parallel to the finger direction. Then by using a track pad, border lines on both sides are drawn. The plugin then calculates and display the results both numerically and graphically.

Both ImageJ and the line width plugin<sup>‡</sup> are free software and runs under most computer platforms. The contact resistance between emitter and front contact were determined using CoreScan. The efficiency of solar cells printed with HM screen-printing, were determined by IV-measurements.

<sup>‡</sup> Available from the corresponding author.

Front contacts were printed as a function of print speed, print table temperature and squeegee temperature. At low squeegee temperatures the line width was independent of the print speed. At higher squeegee temperatures the finger width decreased by increasing print speed as shown in Fig. 4. This probably means the squeegee heats the HM paste, and by making it more liquid, increases the spreading on the wafer. With higher printing speed, the time the squeegee is in contact with the paste is reduced, and thus less heat is transferred to the paste, while at low squeegee there are little heat transfer regardless of printing speed.

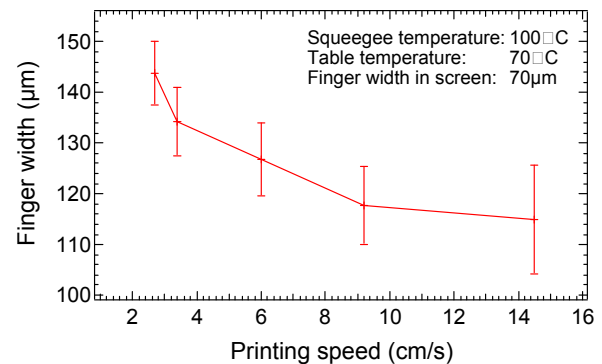


Fig. 4. Finger width as a function of print speed.

At constant squeegee temperature the finger width increased by increasing print table temperatures as shown in Fig. 5 and Fig. 6. At the same time, high print table temperatures were needed to get uniform fingers, while lower temperatures gave a rather large variation in height along the length of the fingers, as shown in Fig. 7.

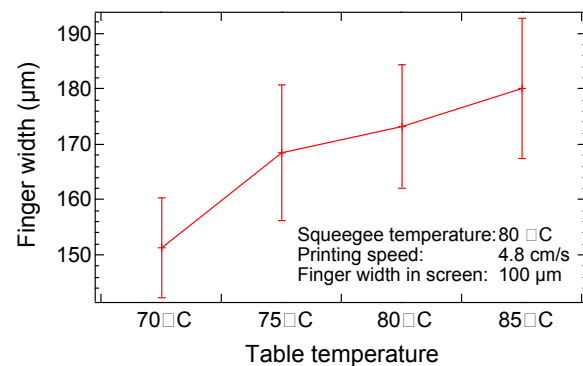


Fig. 5. Finger width as a function of table temperature.

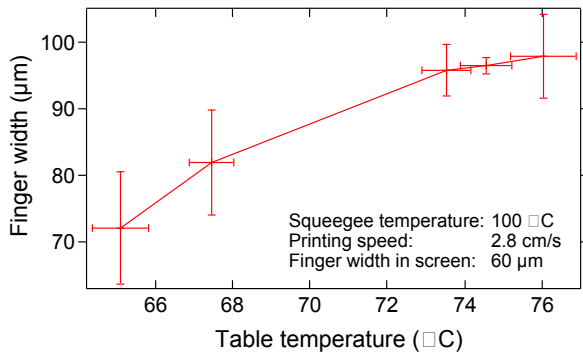


Fig. 6. Finger width as a function of table temperature.

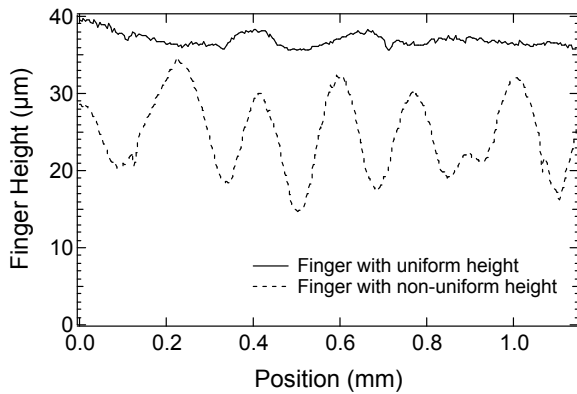


Fig. 7. Height profiles of printed fingers using different print table temperature.

The roller-coaster shape seen in Fig. 7 most probably comes from the steel mesh of the screen. On a screen with 325 mesh and a mesh angle of  $22.5^\circ$ , there will be approximately  $200\ \mu\text{m}$  between each intersection where both wires crosses a line on the finger at once. This corresponds well with the dips seen on the non-uniform finger in Fig. 7, and it seems like the squeegee is able to press the hot-melt around a single wire, but fails wherever there are a crossing of two wires, see Fig. 8.

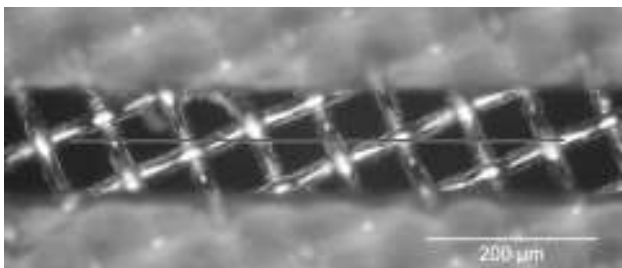


Fig. 8. Optical microscope image a finger opening on a 325 mesh/inch screen with mesh angle  $22.5^\circ$ . The black line marks a typical position for a height scan like the ones in Fig. 7.

Using the observation that intersections between two wires in the mesh give lower finger height, it should be

possible to reduce the non-uniformity of the fingers at low print table temperature either by reducing the diameter of the wires, or by changing the mesh angle in such a way that the distance between intersections along the fingers increases. This will be a subject for further studies.

In order to avoid the widening of lines at high print table temperature, paste with higher viscosity was tried. However, such pastes showed even larger non-uniformity along the fingers, both in height and width of the fingers, and looked more like a string of pearls than a continuous conductor.

To get better flowing properties for the high viscosity HM paste, increased temperature on the screen was tried. However this caused drying, and thereby clogging of the screen, due to evaporation of the solvents in the paste. In addition under these conditions the porosity of the printed finger increased. We were not able to print fingers with uniform heights at any table temperatures.

Overall, high squeegee and print table temperature in combination with rapid print speed gave the best results. Under these conditions we were able to print uniform and uninterrupted fingers, shown in Fig. 9. Finger heights up to 40 microns were obtained when using screens with an emulsion thickness of 30 microns, see figure Fig. 7. However, the finger widths always expanded from 30-80% during the printing process, dependent on the print table temperature. To compensate for this effect, screens with narrower finger opening can be used.

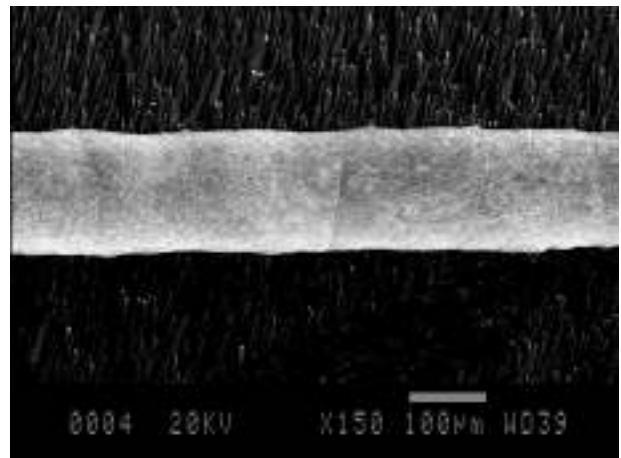


Fig. 9. A SEM image of HM printed front contacts with low viscosity after printing. The screen parameters are 120 microns finger openings and emulsion 30 microns.

### Firing

Solar cells were fired with front contacts facing both up and down on the furnace belt. In both cases, different peak firing temperatures, gas flows and belt speeds were tested. The results showed different optimum firing conditions based on which way the front contacts were facing.

Event though our IR firing furnace has equal power and lamp configuration below and above the belt, firing solar cells face up showed a 50°C lower optimum furnace temperature compared with solar cells fired face down. In one of our firing furnace setups the optimum peak firing temperature was 980°C in a 7.5 inch wide peak zone at a belt speed of 120 inch/min for face down fired cells, while front contacts fired face up had an optimum peak firing temperature of 930°C. The wafer temperature under these two conditions were 735°C and 710°C respectively. In both cases the efficiency of the solar cells were in the range 14-14.5%, comparable with solar cells printed with regular front paste.

Firing of solar cells facing up under near optimum temperature for face down firing were also tried in this work. In this case the contact resistance at the interface between the silver metal and the silicon emitter of the solar cell was increased by a factor 10, as shown in Fig. 10. This may be due to formation of a thick glass interface layer between silver and silicon [2].

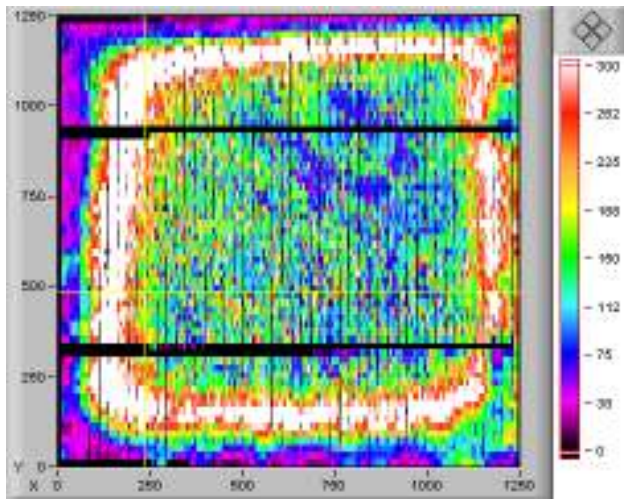


Fig. 10. Contact resistance of solar cell fired face up at 970 °C, 40 degrees above the optimum temperature for face up firing. Typical for good solar cells values in the range below 25 mV at 30 mA were observed.

The main reason for firing fingers facing down in this work was to try to avoid further widening of the fingers in the firing process. By using high belt speeds, this was achieved, and a shrinking of the printed lines by between 15 and 20% were observed in the firing process, see **Error! Reference source not found.**

The shrinking occurred both for bus bars and finger contacts. When finger contacts shrank, there was often left some disconnected, metallic residue on the solar cells also shown in Fig. 11. Thus, even though the finger contacts shrank quite a bit, the shadowing was not necessar-

ily reduced by the same amount. Also, in some instances, shrinkage of the bus bars could tear of the connection between fingers and bus bars. This happened even though the fingers and bus bars were part of the same contact pattern printed with the same screen.

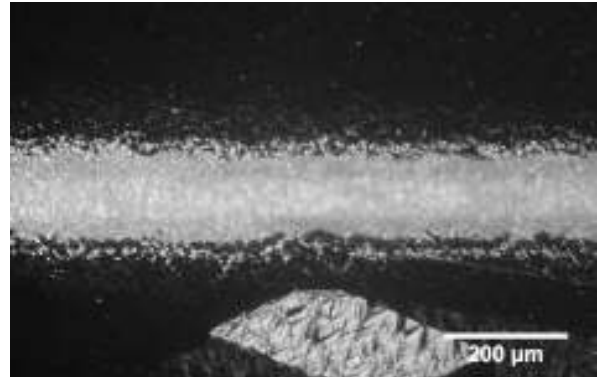


Fig. 11. An optical microscope image of a finger after face down firing.

## CONCLUSIONS

Hot melt screen printing is a promising upcoming technology. The results presented here have shown it is possible to print lines with higher aspect ratio compared with standard screen printing. Optimum parameters for printing seems to be high print speed in combination high squeegee temperature. There is a trade off between the height and width of the finger lines when adjusting the table temperature. High print table temperature gives uniform and high fingers, but results in wide lines. Low print table temperature, on the other hand, gives narrower fingers, but non-uniform height. Firing with fingers facing down at high belt speeds results in shrinking of line width between 15 and 20%.

At present the best efficiency results from HM screen printing are at par with standard printed solar cells. There are still some unsolved stability issues related to clogging of screens over time, shunting of screen under heating and during print stops, and screen design.

## ACKNOWLEDGEMENTS

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## REFERENCES

- [1] Wayne Rasband, ImageJ, <http://rsb.info.nih.gov/ij/>
- [2] C. Hadikar, S. Kim, T Pham, A Shaikh and S Sridharan, "Characterisation of Silver Front Contact in a Solar Cell", Technical Digest of the International PVSEC 14 (2004) pp. 443-444.