

HIGH EFFICIENCIES ON LARGE AREA SCREEN PRINTED SILICON SOLAR CELLS AND CONTACTING HIGH SHEET RESISTANCE EMITTERS USING HOTMELT INK

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ABSTRACT: This paper presents an update on current investigations of the hotmelt technology at Fraunhofer ISE. Efficiencies up to 18% with fill factors of 79.5% on large area industrially pre-processed monocrystalline wafers were achieved. In order to further increase the efficiency, V_{oc} and j_{sc} need to be improved, by e.g. reducing the doping level of the emitter. Solar cells with an average emitter sheet resistance up to $75 \Omega/sq$ could be successfully contacted with hotmelt ink achieving fill factors up to 78%. These cells clearly showed an improvement in the short circuit current density compared to solar cells with a higher doped emitter. In a further investigation the ability of fine line printing has been analyzed.

Keywords: metallization, hotmelt, screen print

1 INTRODUCTION

In industrial production the most applied technique for the front side metallization of silicon solar cells is still screen printing, a reliable and well-known process with high throughput rates. Admittedly, the conventional screen print is limited, e.g. in attaining a high aspect (height to width) ratio of the final contact.

When using hotmelt ink for the front side metallization of silicon solar cells, higher aspect ratios can be achieved, reducing the line resistivity and hence the series resistance significantly. Thus fill factors over 80% for large area silicon solar cells with efficiencies up to 18% were achieved [1].

To further increase the efficiency of screen printed silicon solar cells, the open circuit voltage V_{oc} and the short circuit current density j_{sc} need to be improved. Focussing on the front side, this can be achieved by using lower doped emitters. However, due to less doping the series resistance of the solar cell rises, causing the fill factor to decline. One effect is that the contribution of the emitter sheet resistance to the total series resistance increases: This could be compensated by reducing the finger separation distance. But at the same time the line width needs to be reduced in order not to increase the shading loss.

The more significant effect is the difficulty to form a good electrical contact to the emitter. The contact resistance between finger and emitter rises and is at some doping level the limiting factor [2]. To utilize the advantages of lowly doped emitters, the formation of selective emitters could be an alternative to avoid contact resistance problems [3]. Nevertheless, this leads to additional process steps.

Another approach is to optimize the overall metallization process to form a contact of good quality to lowly doped emitters. This is currently under extensive investigation. Within the last years the standard sheet resistance emitter in industry increased from about $40 \Omega/sq$ to currently $55 \Omega/sq$, which is mainly due to an improvement in the front side metallization paste.

This paper presents an update about current investigations in the field of hotmelt technology at Fraunhofer ISE. This includes cell results on large area silicon solar cells, current work about contacting high

sheet resistance emitters and fine line printing using the hotmelt technology.

2 HOTMELT TECHNOLOGY

The hotmelt ink is solid at room temperature and can be processed as conventional ink when melted on a resistively heated Hotscreen [1,4,5]. Due to different paste properties compared to conventional ink, and the different printing processes applied, high aspect ratios can be achieved. Figure 1 shows a cross section of a printed and fired contact finger attained, using the hotmelt and the conventional technology. Whereas the finger width of $120 \mu m$ is the same, the height of $30 \mu m$ for the hotmelt printed contact is far higher than for the conventional printed with a maximum height of $13 \mu m$. Electrical analysis shows, that the line resistance of $14 \Omega/m$ is less than 50% of the $34 \Omega/m$ of the conventional printed finger, mainly due to the larger cross section area.

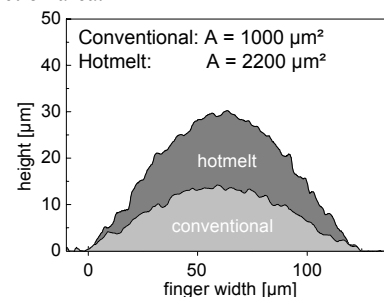


Figure 1: Cross sections of contact fingers formed by the hotmelt and the conventional technology.

Optical analysis have shown that the finger height of the hotmelt finger before the firing process is about twice as high as for conventional printed fingers; the main reason for the higher aspect ratio of the final contact finger.

Another reason for the higher aspect ratio is the higher silver content of the hotmelt ink. Figure 2 shows a thermo gravimetric analysis of a hotmelt and a conventional screen printing ink. At a temperature above $390^\circ C$ for the conventional and above $510^\circ C$ for the hotmelt ink, all solvents and organic compounds in the

4 HIGH SHEET RESISTANCE EMITTERS AND FINE LINE PRINTING

4.1 Solar Cell Processing

At Fraunhofer ISE 270 μm thin solar cells on 125 x 125 mm^2 , 0.5-2 Ωcm , p-doped, Cz silicon wafers were processed similar to the process flow shown in Figure 3. The solar cells were wet chemically textured, diffused in a POCl_3 diffusion furnace and the front surface covered by a sputtered SiNx:H antireflection coating. After the backside had been conventionally Al screen printed and dried, the front side was printed with hotmelt ink. Finally the wafers were co-fired in an inline fast firing furnace and edge isolated.

For high sheet resistance investigations an emitter variation of 40 Ω/sq , 55 Ω/sq and 75 Ω/sq was performed. The front side metallization pattern consists of three 50 x 50 mm^2 grids with a finger width of 70 μm , 80 μm and 100 μm as well as test structures for optical and electrical investigations. This included structures for "fine line printability" and contact and line resistance measurements. For each finger width an optimum cell design was calculated, expecting a fairly good contact resistance and line conductivity. For screen-printing a Hotscreen with a 350 mesh was used. Due to processing problems the final wafer thickness of the solar cells with a sheet resistivity of 40 Ω/sq and 55 Ω/sq was 200 μm , compared to 250 μm for the 75 Ω/sq emitter.

4.2 High sheet resistance emitter

Representative IV-parameters for each type of emitter doping level are shown in Table 3. The fill factor declines from a value of about 80% for cells with a 40 Ω/sq emitter sheet resistance to about 78% for the 75 Ω/sq . Corescan [8] and transfer length method (TLM) [7] measurements were performed to compare the voltage drop due to the emitter sheet resistance as well as the contact resistance between the finger and the emitter.

The TLM measurements showed that for both, the cells with 40 Ω/sq and 55 Ω/sq emitter sheet resistance, the contact resistivity between emitter and finger is sufficiently low not to influence the series resistance significantly. Values in the range of 2 to 6 $\text{m}\Omega\text{cm}^2$ were measured. The contact resistivity for the 75 Ω/sq emitter is in the range of 9 to 15 $\text{m}\Omega\text{cm}^2$. This relatively high value has certainly a significant effect on the series resistance of the solar cell. The low voltage also indicates a J_{02} problem. Nevertheless, fill factors up to 78% could be achieved.

The Corescan measurements showed that for all cells the contact and sheet resistance was homogeny over the cell surface. As illustrated in Figure 4, the voltage

Table 3: IV-parameters of processed 50 x 50 mm^2 monocrystalline silicon solar cells printed with hotmelt ink and different sheet resistance emitters with a finger width of about 100 μm .

R_{sh} [Ω/sq]	thickness [μm]	V_{oc} [mV]	j_{sc} [mA/cm^2]	FF [%]	η [%]	R_{S} [Ωcm^2]
40	200	620.6	34.7	79.9	17.2	0.46
55	200	621.7	35.0	79.6	17.3	0.53
75	250	620.3	36.3	78.0	17.6	0.70

potential between the fingers increases with increasing emitter sheet resistance. This is on the one hand due to the increased voltage parabola caused by the emitter sheet resistance, on the other hand due to the increased voltage jump at the finger edge caused by the contact resistivity.

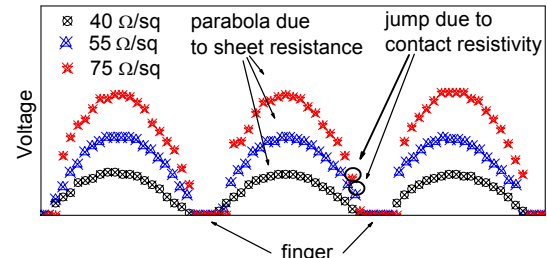


Figure 4: Voltage potential over the length of four fingers, measured by Corescan.

The higher current for the 55 Ω/sq emitter compared to the 40 Ω/sq emitter can be explained by the improved internal quantum efficiency in the short wavelength region as illustrated in Figure 5. The same is valid for the 75 Ω/sq emitter. The higher IQE in the long wavelength region of the cell with the 75 Ω/sq emitter sheet resistance is due to the thickness of the solar cell.

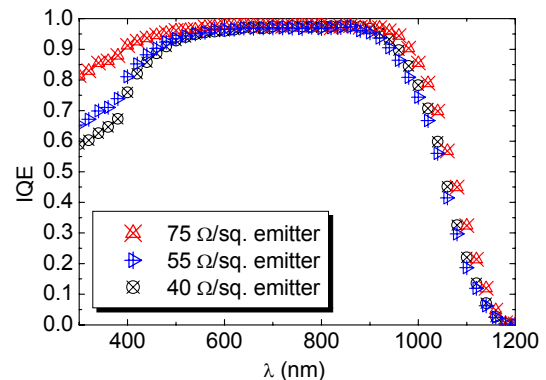


Figure 5: IQE data of the solar cells with 40 Ω/sq , 55 Ω/sq and 75 Ω/sq emitter sheet resistance.

4.3 Fine line printing

An advantage of printing thinner lines is that the power losses caused by the emitter sheet resistance can be decreased by increasing the amount of printed fingers, but without increasing the shaded area. The main challenge is on the one hand to print continuous lines with a high aspect ratio, on the other hand to achieve a low contact resistance to the silicon surface, as the total contact area is typically reduced.

Printed lines with a width between 50 μm and 120 μm were optically and electrically investigated. With decreasing width, also the height of the finger declines as illustrated by the cross sections in Figure 6.

As also illustrated in Figure 6, the finger resistance increases slowly up to a printed width of about 80 μm . Below this value the risk of line interruptions increases significantly, causing the line resistance for those fingers to rise strongly. However, at a width of 70 μm or below the line resistance is higher than for a typically conventional printed finger with a width of 120 μm .

As mentioned above 50 x 50 mm^2 silicon solar cells were processed with different finger widths and emitter

