# Dispensing of Etching Paste and Inkjetting of Diffusion Barrier for MWT Solar Cell Processing

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ABSTRACT: MWT (metal wrap through) solar cells [1] address the target of reaching higher efficiencies, while only requiring two additional process steps compared with conventional solar cells [2]. To further reduce the production costs of MWT solar cells one possibility is to reduce the breakage, which mainly occurs during the production from cell to module and is caused by laser grooves on the rear. These laser grooves isolate the n- from the p-contacts and almost run across the whole cell. For this purpose two alternative isolation methods have been developed; one is based on the etching paste SolarEtch® SiD [3], which etches a groove that replaces the laser groove; the other developed method is based on the diffusion barrier SolarResist™ [4]. Apart from the advantage of less breakage the damaging impact of the laser on the crystalline structure of the wafer is avoided.
The functionality of the developed methods has been verified on appropriate test structures. Furthermore the adaptability of the methods has been proved by processing functional MWT solar cells with *pFF* values of around 82%. At the same time the comparability with the laser groove has been shown by producing reference cells. The reliability was shown during repeated runs of MWT cell production.
Keywords: MWT, Back Contact, Contact Isolation

## 1 INTRODUCTION

Reducing the costs of solar energy is a major goal of research and development in crystalline silicon solar cell production. This goal can be addressed by reducing the production costs, increasing the efficiency of the solar cell or using thinner material. The possibility concerned within this paper is the decrease of production costs. However, MWT (Metal Wrap Through) [1] solar cells already targeting a higher efficiency while using a very similar production process in comparison to conventional solar cells [2]. But, a further reduction of the production costs of MWT solar cells is necessary to decrease the absolute costs per Wp.

For MWT solar cells one important production step separating them from conventional solar cells is the contact isolation (CI) between the p- and the n-contact on the rear. Figure 1 shows the position of the contact isolation on the rear of a mono-crystalline MWT solar cell. Usually, the contact isolation has been accomplished by making a groove through the emitter with a laser. This groove is approximately 20 to30µm deep and therefore can cause quite a lot of breakage in the further production from cell to module since the groove runs almost across the whole cell (see fig. 1). The mechanical and thermal pressure during the soldering step with tabbing material can cause cell breakage. This breakage increases the production costs for laser processing. Moreover, the laser causes damage in the crystalline material because of the heat impact and thus leads to more recombination of charge carriers in the area around the laser groove. The high amount of breakage and the structural damage are indicating that an alternative method, which causes less breakage and ideally no structural damage, is required. Such an isolation method would save material, costs and should allow at least the same efficiency.

Especially the higher number of breakages within the MWT production caused by the laser groove, isolating p- and n-contact on the rear of MWT solar cells, prevents the MWT cells from becoming even more advantageous compared to conventional solar cells. To reduce the breakage of MWT cells two alternative methods for contact isolation have been developed.

Another approach to reduce the breakage of MWT cells is to use a rear design with pads instead of continuous busbars [5].

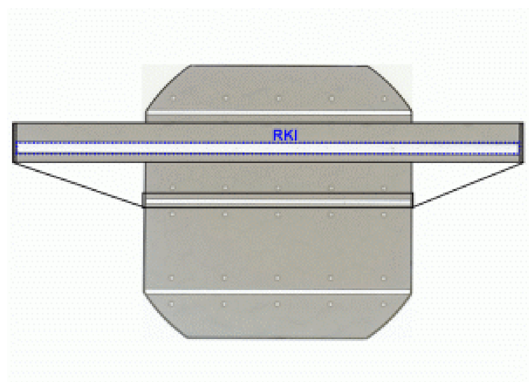


**Figure 1**: Picture of the rear of a MWT solar cell. Accentuated is a busbar with the surrounding contact isolation. The Busbar represents the n-contact while the grey aluminum between the busbars is the p-contact with round soldering pads [6].

## 2 EXPERIMENTAL APPROACH

### 2.1 The diffusion barrier SolarResist™

One method is the application of the diffusion barrier SolarResist™ before the phosphorus diffusion and thereby preventing the formation of an emitter. The areas where no emitter is build are not conductive and therefore workings as isolation between the p- and n-contact. The SolarResist™ is applied with an inkjet, during the application the substrate is heated, therefore the SolarResist™ dries immediately. The wafer is put into diffusion; afterwards the PSG-etching takes of the diffusion barrier. A detailed description of the applications and the functionality of the diffusion barrier SolarResist™ is given in [4].

As the diffusion barrier causes no groove at all it can be assumed that the breakage potential of the wafers decreases. This will reduce the production costs of MWT solar cells. Another advantage of SolarResist™ is that it has no damaging impact on the wafer and therefore causes no additional recombination of charge carriers.

Figure 2 and 3 show the process schemes of MWT solar cells using the alternative contact isolation methods in comparison with the currently used laser groove. Compared to the laser groove the contact isolation with SolarResist™ as a diffusion barrier does not need an additional step. The printing of SolarResist™ replaces the contact isolation by laser.

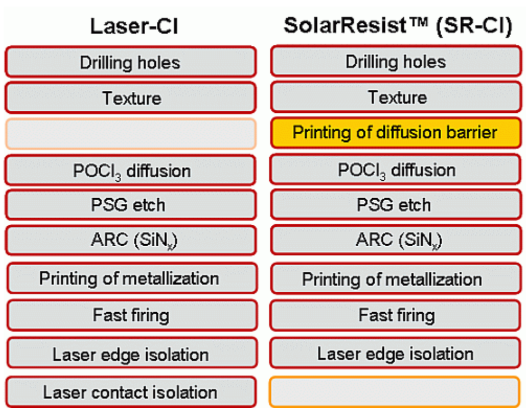


**Figure 2**: Process scheme of MWT solar cells with a laser groove and with SolarResist™ as a diffusion barrier for back side contact isolation

2.2 The etching paste SolarEtch® SiD

The second alternative contact isolation method is the selective etching of the emitter after the diffusion. This etching is realized with the etching paste SolarEtch® SiD. The etching paste is applied with a dispenser and subsequently heated/activated in a furnace. Afterwards the etching paste can be removed with water in an ultra sonic bath or during the PSG-etching. The created etching groove needs to be at least as deep as the emitter which is around 0.5 µm. The experimentally identified depth of the etching groove is 1 to 2 µm. Therefore it is unlikely to cause as much breakage as the 20 to 30 µm deep laser groove. Furthermore the etching paste only etches off the silicon without damaging the crystalline structure; therefore the etching groove should cause less recombination of charge carrier. A detailed description of the applications and the functionality of SolarEtch® SiD can be found in [3].

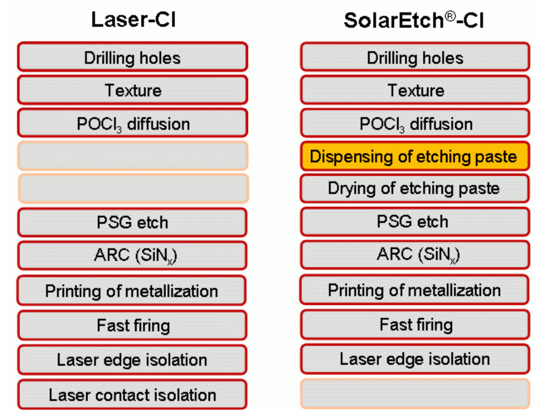


**Figure 3**: Process scheme of MWT solar cells with a laser groove and with an etching groove realised with SolarEtch® SiD as contact isolation.

As can be seen in figure 3 using SolarEtch® SiD to produce an etching groove takes one additional step with the drying/heating of the paste. For industrial production the heating could be included in an inline system for dispensing and heating the etching paste.

Overall the expected lower breakage rate at least equals the additional complexity of the process.

## 3 RESULTS AND DISCUSSION

After identifying adequate alternatives for the contact isolation on MWT solar cells suitable dispensing and inkjetting conditions had to be found. For this purpose a series of tests was performed. With parameters being suitable deduced from those pre-evaluating tests, the two methods had to be tested on test structures for their efficiency, as well as on MWT cells for their adaptability and their reliability to generate sufficient contact isolation.

Alternatives for the contact isolation on the rear of MWT solar cells need to fulfill specific requirements to be of advantage over the existing contact isolation by laser. First the alternative method needs to provide secure contact isolation; this can be concluded from the parallel resistance ($R_P$). Second, the cell performance under application of the alternative contact isolation needs to be equal or even better. An advantage in the cell performance can probably be achieved due to less $j_{02}$-losses which are caused by the damage the laser groove causes. The laser melts some of the silicon and thereby damages the crystalline structure of the cell. This damage leads to an increase of $j_{02}$ which reduces the fill factor and furthermore the efficiency. Third the alternative methods should be nearly as fast as the laser but overall not taking more than two seconds per wafer. Otherwise they are not usable for industrial production.

3.1 Functionality tests

To develop the two alternative contact isolation methods first tests were carried out to prove there ability to isolate two contacts. Therefore the test structure shown in figure 4 was designed.

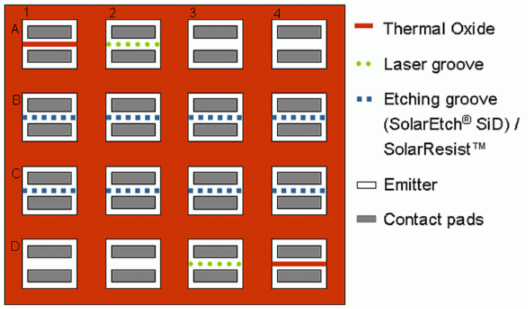


**Figure 4**: Designed test structure.

The test structure is designed to verify that the alternative isolation methods apply the same resistance and therefore the same quality of isolation as the approved laser groove and the thermal oxide. As additional references two of the squares are left without isolation, on these squares the resistance in between the two contact pads with conductive emitter can be measured. That gives an orientation on how much higher the resistance is due to the different isolation methods.

The test structures were processed as shown in figure 5. The chosen process is close to the actual cell process to make the results easily transferable to complete processed solar cells

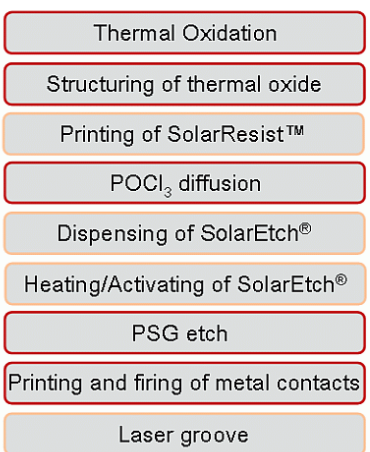


**Figure 5**: Process scheme of the test structure. The process steps 3, 5, 6 and 9 are only applied on selected squares. The thermal oxide shows the same design on all processed test structures.

After processing the test structures a 4-point-measurement is performed. The results of these measurements are shown in figure 6 for the use of SolarResist™ and in figure 7 for the use of SolarEtch® SiD.

In figure 6 the results of the test structure, which were processed by using SolarResist™ as a diffusion barrier and thereby generating contact isolation are shown. Enlisted are: no CI, thermal oxide, laser groove and SolarResist™ printed once as well as twice. All isolation methods show a significantly higher resistance than the squares without CI. Hence, sufficient contact isolation can be achieved with SolarResist™. The absolute resistance is not decisive. As it does not seem to bring an advantage to print the SolarResist™ twice, prospectively it is always printed once.

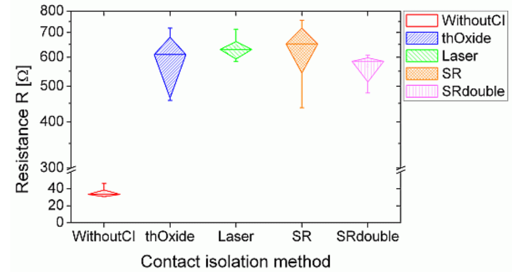


**Figure 6**: Results of the 4-point-measurement of the test structure under use of SolarResist™.

The test structure results for the use of SolarEtch® are presented in figure 7. Enlisted are: Squares without CI, with thermal oxide as CI, with a laser groove as CI and with SolarEtch used for CI, dispensed at the speeds 80, 90, 100, 110 and 120 mm/s. As obvious all contact isolation methods allow a considerably higher resistance than no CI at all. The differences between the isolation methods are not significant enough to have any informative value. Hence, sufficient contact isolation can be achieved using SolarEtch® SiD for creating an etching groove.

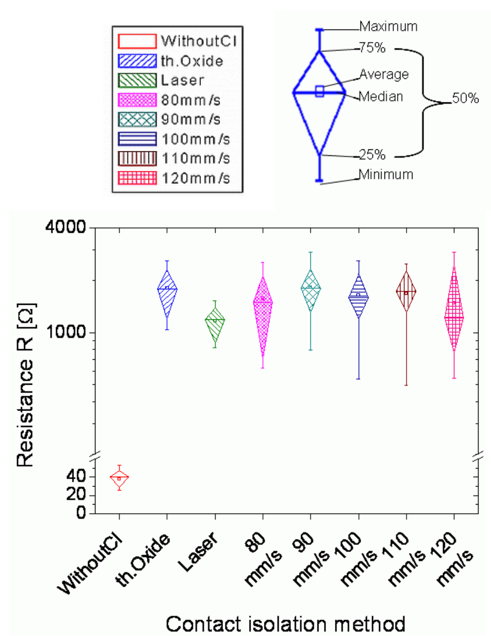


**Figure 7**: Results of 4-point-measurment of the contact isolation of the test structure for the use of SolarEtch® SiD, which was dispensed at five different velocities.

Figure 8 shows the results of the 4-point-measurement of further test structures, which were processed with SolarEtch® SiD dispensed at higher velocities of up to 800 mm/s. A faster dispensing speed results in less dispensed etching paste. Observable is, that even using a high velocity a contact isolation can still be achieved.

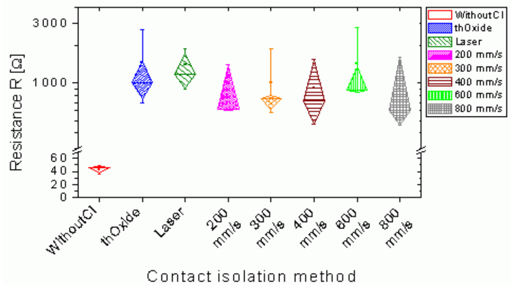


**Figure 8**: Results of 4-point-measurment of the contact isolation of the test structure for the use of SolarEtch® SiD dispensed at high speeds.

**Table I:** Process times for a three nozzle dispenser for dispensing SolarEtch® SiD at various velocities to achieve contact isolation.

| Velocity [mm/s] | 120 | 300 | 400 | 600 | 800 |
|---|---|---|---|---|---|
| Process time [s] | 2.61 | 1.04 | 0.78 | 0.52 | 0.39 |

Table I shows the results of the calculated process times. The calculation of the process times are based on the results shown in figure 8 and the assumption that a dispenser with three parallel nozzles could be used for dispensing the SolarEtch® SiD in an industrial inline-process. A dispensing length of 313 mm per nozzle, which relates to a 156*156 $mm^2$ wafer, is assumed. Process times of about half a second can be achieved while still assuring sufficient contact isolation. These are suitable process times for industrial cell production.

3.2 Results of MWT solar cells

After the functionality of the alternative isolation methods has been assessed on the test structures the two methods were refined and implemented into the standard MWT cell process, which is described in [2]. All 28 MWT cells have been processed on mono-crystalline material with a base resistance of 2 to 6 Ωcm and received a laser groove as edge isolation. MWT cells with contact isolation realised by an etching groove as well as the inkjettable diffusion barrier have been processed.

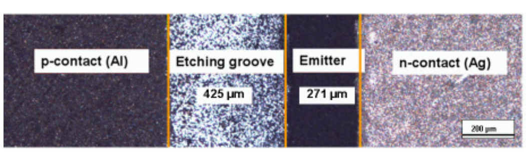


**Figure 9**: Picture of a contact isolation on the rear of a MWT solar cell realized by an etching groove using SolarEtch® SiD. Around 2/3 of the etching groove are visible while one third is covered by aluminum.

A section of the rear of a complete processed MWT solar cell is shown in figure 9. Observable is a gap of around 275 µm between the etching groove and the n-contact. In this gap the emitter is disclosed. The contact isolation is realized by the etching groove between the emitter and the p-contact. The spacing shown in figure 9 can be reduced using a more precise alignment of dispensing the etching paste.

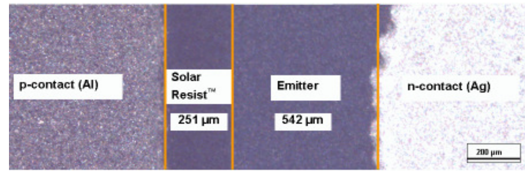


**Figure 10**: Picture of a contact isolation on the rear of a MWT solar cell realized by SolarResist™.

Figure 10 shows a fraction of the rear of a processed MWT cell, which illustrates part of the contact isolation. The section in figure 10 which is labelled SolarResist™ marks the area where the SolarResist™ was printed. As the SolarResist™ has been removed during the PSG-etching the slight difference of shade is most likely caused by the different doping. While the left, slightly darker part is boron doped area, which has previously been printed with SolarResist™, the right part is open lying phosphorus doped emitter. The contact isolation is achieved by the boron doped area beneath the previously printed area and the diffused emitter, which belongs to the p-contact.

For all processed MWT solar cells IV-measurement were performed. The graph of the resulting pseudo fill factor (*pFF*) is shown in figure 11. The pseudo fill factor is the fill factor without any losses due to series resistances; therefore it is a value for the losses caused by parallel resistance and $j_{02}$. Each group, SolarEtch®-CI (SE-CI) and SolarResist™-CI (SR-CI), has its one reference group, which has been processed together apart from the contact isolation. For the reference groups the CI was accomplished by laser grooves. The cells with SolarEtch®-CI can not be compared with the cells with SolarResist™-CI as they were processed separately.

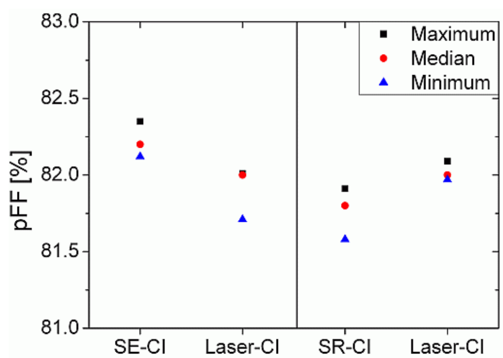


**Figure 11**: Pseudo fill factors of the produced MWT solar cells. For one group each the contact isolation was realized by using SolarEtch® SiD (SE-CI) and SolarResist™ (SR-CI) and Laser-CI as reference.

As shown in figure 11 the results of MWT solar cells processed with the alternative contact isolation methods are in the case of SolarResist™ nearly as good as the reference. The MWT cells processed with SolarEtch® SiD are even better than the references.

The exact numbers of the median are shown in table II. Overall the *pFF*s of all groups are on the same level. Only little differences of up to 0.2 $\%_{abs.}$ are observed, which can be neglected. Furthermore the results of the parallel resistances are shown in table II. All groups have a median parallel resistance above 10 kΩ*$cm^2$, which implies that on the cells of all groups a sufficient contact isolation is achieved. Although the SolarResist™ group shows considerably less parallel resistances than its reference group a median of 11.5 kΩ*cm² can still be considered as sufficient contact isolation. The SolarEtch® group even shows a slightly higher parallel resistance than its reference group.

**Table II:** Median of the parallel resistances from each group. SR – SolarResist™, SE – SolarEtch®

| | SR | Ref. SR | SE | Ref. SE |
|---|---|---|---|---|
| $R_p$ [kΩ*cm²] | 11.5 | 14.8 | 12.5 | 12.3 |
| *pFF* [%] | 81.8 | 82.0 | 82.2 | 82.0 |

**Table III:** Parallel resistances and *pFF*s of the best cells from each group. SR – SolarResist™, SE – SolarEtch®

| | SR | Ref. SR | SE | Ref. SE |
|---|---|---|---|---|
| $R_p$ [kΩ*cm$^2$] | 18.3 | 21.5 | 15.7 | 13.9 |
| *pFF* [%] | 81.9 | 82.1 | 82.4 | 82.0 |

As can be seen in table III, the best cells processed with the alternative CI methods are in both cases showing high parallel resistances. In this case the SolarEtch® SiD group shows a 0.4 $\%_{abs.}$ higher *pFF* on the best cell a slight advantage compared to the Laser-CI. With an only 0.2 $\%_{abs.}$ lower *pFF* on the best cell the SolarResist™ group is on the same level as its reference. Both alternative methods show high parallel resistances on their best cells. Even though SolarResist™ did not reach the height of its reference it still shows a $R_P$, which is high enough for assuring sufficient contact isolation.

These results prove the adaptability of the alternative contact isolation methods as it was possible to process several MWT solar cells with both alternative contact isolation methods, which achieved the same or even higher cell efficiencies as their references as well as high parallel resistances and *pFF*s.

Furthermore the reliability of the developed methods has been shown during several runs of MWT cell production.

## 4 CONCLUSIONS

Two alternative isolation methods for MWT solar cells were developed. The functionality and adaptability of both methods has been shown by processing MWT cells using the alternative contact isolation methods as well as the contact isolation using a laser groove. As shown the produced cells with alternative contact isolation achieved the same or even higher parallel resistances as well as pFFs as the reference cells. Parallel resistances of 15.7 kΩ*cm² (SolarEtch®) and 18.3 kΩ*cm² (SolarResist™) have been achieved with the developed contact isolation methods. At the same time the processed MWT cells reached the same or even higher efficiencies as the references.

Also it was demonstrated, that while using SolarEtch® SiD for contact isolation a high throughput can be achieved.

These results indicate that the production of MWT solar cells with theses alternative isolation methods is a way towards less expensive cells with less damage and therefore fewer $j_{02}$-losses.

## 5 ACKNOWLEDGEMENTS

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