WET CHEMICAL SINGLE-SIDE EMITTER ETCH BACK FOR MWT SOLAR CELLS WITH AL-BSF AND CHALLENGES FOR VIA PASTE SELECTION

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ABSTRACT: This work investigates the integration of a wet chemical single-side emitter etching process into the process sequence of screen printed p-type Czochralski-grown silicon MWT-BSF (metal wrap through aluminum back surface field) solar cells. The MWT-BSF solar cells fabricated with single-side emitter etch back achieve a median conversion efficiency of 18.4 % (as processed), while MWT-BSF solar cells isolated by laser grooves show a slightly lower median conversion efficiency of 18.2 % (as processed). Repeated current-voltage (*I-V)* measurements under forward and reverse bias using stabilized MWT-BSF solar cells with single-side emitter etch back confirm that a novel via paste enables stable results under forward bias (standard operation mode), although the via paste is in direct contact with the p-type base. MWT-BSF solar cells with single-side emitter etch back show increasing current densities under reverse bias without affecting the cell performance after repeated *I-V* measurements, this behaviour could be used for an integrated bypass approach. The results confirm the successful integration of single-side emitter etch back into the MWT-BSF process sequence allowing for the reduction of the process sequence by one process step compared to MWT-BSF solar cells isolated by laser grooves.
Keywords: MWT-BSF, p-type, silicon solar cell, via metallisation

1 INTRODUCTION

Achieving lower costs per watt peak is still a major goal of solar cell R&D. It has been shown that the metal wrap through (MWT) cell concept [1] allows for higher conversion efficiencies than H-pattern solar cells [2, 3] However, two additional process steps for fabrication of p-type MWT solar cells with aluminum back surface field (MWT-BSF), namely via drilling and rear contact isolation, still require additional effort. To overcome this drawback the rear contact isolation can be combined with the edge isolation and be realized by a single wet chemical process step: single-side emitter etch back, which removes the emitter on the rear [4]. Reducing the process sequence for p-type MWT-BSF cells by one process step contributes to achieving lower costs per watt peak. The MWT-BSF fabrication process with single-side emitter etch back features only one additional process step in comparison to H-pattern solar cells. Having no emitter on the rear (see Figure 1), however, evokes the challenge of finding a suitable via paste, which can be printed directly onto the p-type silicon base without affecting the cell performance [5]. The present work considers this challenge by utilising a novel via paste that is especially designed for such an application.

The integration of the single-side emitter etch back process from RENA into the fabrication sequence of p-type MWT-BSF cells with vias drilled before texturing is closely considered. Drilling the vias directly before screen printing without removing the laser damage is in principle possible [6] but could cause increased recombination around and in the via [7].

2 APPROACH

To evaluate the adapted process sequence for MWT-BSF solar cells on p-type Czochralski-grown silicon (Cz-Si) we used two pre-selected via pastes: via paste H1 is commercially available and commonly used for MWT-BSF solar cells with rear emitter, whereas via paste H2 is a novel paste especially developed for being printed directly on the p-type silicon base. MWT-BSF cells with-

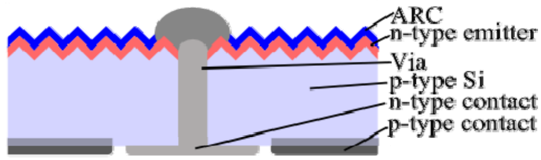


Figure 1: Schematic cross section of a p-type silicon MWT-BSF+ solar cell without rear emitter resulting from the process sequence shown in Figure 2. The rear emitter is removed by a single-side emitter etch back, which most likely also removes the emitter in the vias.

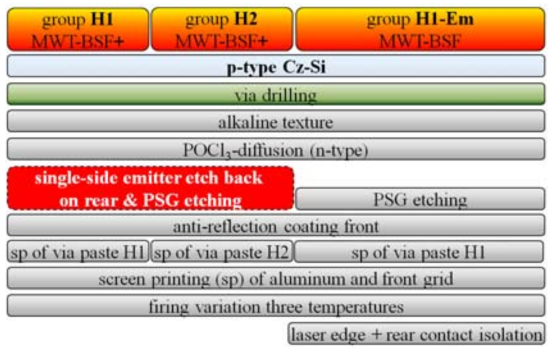


Figure 2: Process sequence for fabrication of p-type MWT-BSF solar cells without (left) and with rear emitter (right). The process sequence for MWT-BSF solar cells without rear emitter consists of one process step less than the process for MWT-BSF cells with rear emitter as the emitter etch back and the PSG etch are realized in one process step.

out emitter on the rear and in the vias are denoted with “+” in the following. The two via pastes were tested on cell level with the experiment shown in Figure 2 which consists of three groups: one group for each of the two via pastes without rear emitter (H1, H2) and one reference group H1-Em with rear emitter and via paste H1.

The first two groups H1 and H2 are processed using single-side emitter etch back on the rear as edge and rear contact isolation, whereas the edge and contact isolation of the reference group H1-Em is accomplished by laser grooves [8]. The single-side emitter etch back process is carried out after emitter diffusion in a process tool at RENA with vias already drilled; therefore the process was optimized in order to prevent the etching solution from soaking through the vias.

3 RESULTS

3.1 Current-voltage measurements

In the following, only results achieved for the optimal firing temperature will be discussed. As previous investigations show, via pastes printed directly on the p-type silicon base can change the *I-V* characteristics of the cells after the application of reverse bias [5]. With respect to these results the groups without rear emitter were consecutively measured using the measurement sequence shown in Table I. The reference group H1-Em was only measured once in a standard measurement sequence starting with reverse bias.

The short-circuit current density j_{SC} (see Figure 3) is influenced by unexpected paste bleeding during front contact printing resulting in finger widths up to 130 µm. The decreased j_{SC} of group H1-Em compared to the other two groups without rear emitter can be attributed to the laser edge isolation, which was carried out on the front and thus cuts part of the collecting emitter.

Table I: *I-V* measurement sequence for the processed MWT-BSF+ cells without rear emitter. The standard measurement sequence starts with 7 ms reverse bias of up to -13.5 V or until a current density of 45 mA/cm^2 is reached, it follows a forward measurement with 40 ms plateau time. To ensure unaffected forward results, the first measurement was carried out without reverse bias.

sequence	1.	2.
1. meas. (1st day)	no reverse bias	forward measurement 40 ms
2. meas. (1st day)	reverse bias 7 ms	forward measurement 40 ms
3. meas. (2nd day)	reverse bias 7 ms	forward measurement 40 ms

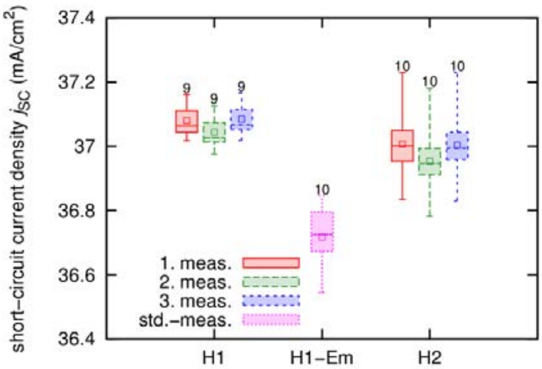


Figure 3: Short-cicuit current density j_{SC} of the fabricated MWT-BSF cells according to the *I-V* measurement sequence shown in Table I. The whisker reaches from minimum to maximum, the box is from the lower to the upper quartile, the horizontal line indicates the median and the square the average. The number above the whisker states the number of measured cells.

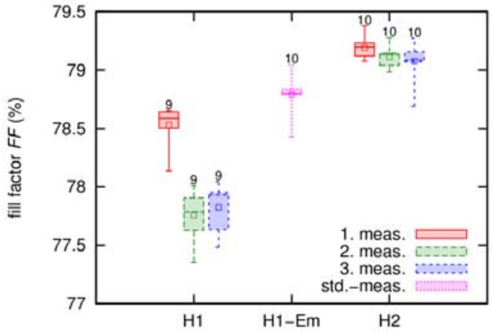


Figure 4: Measured fill factors *FF*.

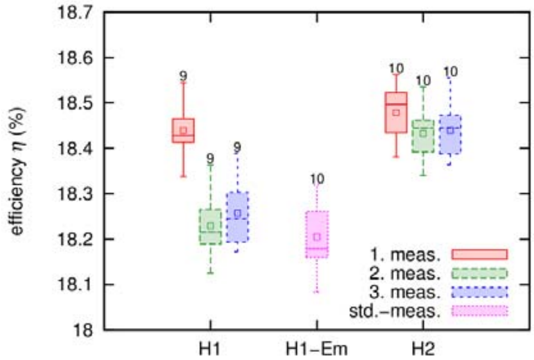


Figure 5: Measured conversion efficiencies η.

Laser edge isolation with 200 µm gap between wafer edge and laser groove is known to cause losses in j_{SC} of approximately 0.2 mA/cm^2 [9]. For group H1 and H2, no significant difference between first and third measurement is observed.

The open-circuit voltages with $V_{OC} \geq 630$ mV are on a sufficiently high level for all fabricated MWT-BSF solar cells.

The variations in the fill factor *FF* (see Figur 4) of the first measurement between groups H1 and H2 is caused by lower pseudo fill factors *pFF* values for group H1 (see Figure 7). The decreased *pFF* (1. meas.) might be caused by higher recombination losses in the depletion region (j_{02}) or by non-linear leakage currents already existent for group H1 even without prior reverse load. After the first reverse load (2nd measurement) group H1 shows a considerable decrease in *FF* of about -0.8%$_{abs}$ caused by increased leakage currents, whereas group H2 is clearly less affected with a fill factor loss of only -0.1 %$_{abs}$. The third measurement does not significantly differ from the second measurement.

Both groups without rear emitter show higher median and maximum conversion efficiencies for the first measurement. While the median efficiency of group H1 decreases to 18.2 % after reverse load (2nd and 3rd measurement) caused by decreased fill factors; the median conversion efficiency of group H2 stays above 18.4 % and clearly exceeds the median conversion efficiency of the reference group H1-Em with 18.2 %. As all measurements were carried out directly after processing a slight influence of degradation cannot be neglected. The results demonstrate the advantage of MWT-BSF+ process sequences with single-side emitter etch back.

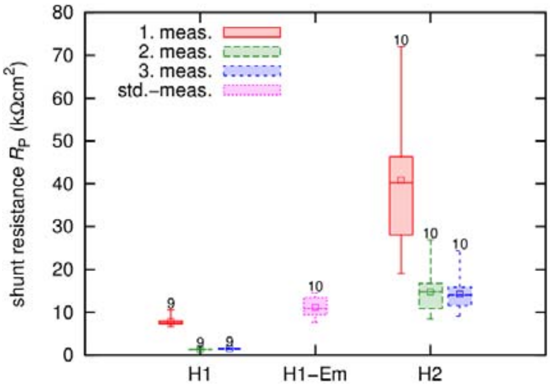


Figure 6: Shunt resistances R_P.

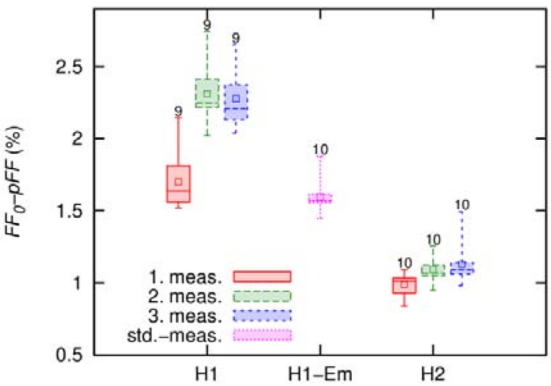


Figure 7: Difference between ideal fill factor (FF_0) and series resistance-independent pseudo fill factor (pFF) FF_0-pFF.

As can be seen in Figure 6, the shunt resistance R_P of both groups without rear emitter decreases significantly after reverse load (2nd and 3rd measurement). The median shunt resistance of group H1 decreases from 7.5 kΩcm^2 before to constant 1.5 kΩcm^2 after reverse load, while the median shunt resistance of group H2 decreases from 40.3 kΩcm^2 to 14.8 kΩcm^2. No significant change due to a second reverse load occurs. Nevertheless, the median shunt resistance of group H2 after reverse load is still higher than for the reference group H1-Em which shows a median value of 10.8 kΩcm^2. These results show that the fabrication of MWT-BSF+ solar cells with appropriate shunt resistances can be achieved by using an appropriate via paste.

The difference between ideal fill factor (FF_0) and series-resistance independent pseudo fill factor (pFF) FF_0-pFF (Figure 7) of group H1 increases by 0.6 %, which is the main reason for the decreased fill factors after reverse load. This effect can be explained by increased non-linear leakage currents between p-type base and rear n-type contacts [5]. The comparatively low FF_0-pFF-values of group H2 suggest that the p-n-junction in the vias is in a well-defined state since undefined emitter properties are known to significantly reduce the pseudo fill factor [10]. Even after reverse load only a slight increase of FF_0-pFF can be observed for group H2.

The results highlight the importance of an extended reverse bias investigation for MWT-BSF+ solar cells without rear emitter. Despite the observed slight drop in *FF* due to slightly increased leakage currents after reverse load, the data indicates that single-side emitter removal is a suitable process for the fabrication of MWT-BSF solar cells provided that an appropriate via paste is used.

3.2 Behaviour under reverse bias

Figure 8 shows current densities j_{-12V} measured under reverse bias at a voltage of -12 V for group H1-Em and H2. All cells of group H1 exceed the maximum measureable current density of j = 45 mA/cm^2. The j_{-12V} values for group H2 of the 2nd measurement are on the same level as for the reference group H1-Em, but show a slight increase in the 3rd measurement.

The dark lock-in thermography (DLIT) [11] images shown in Figure 9 a) and b) confirm the findings of the

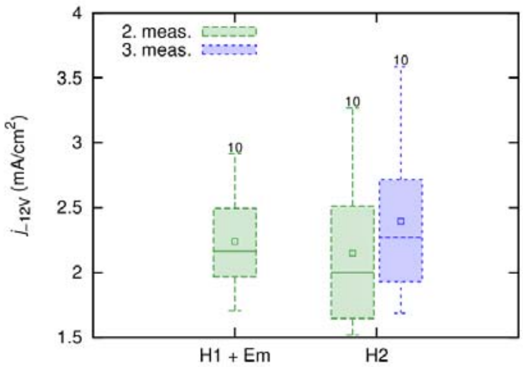
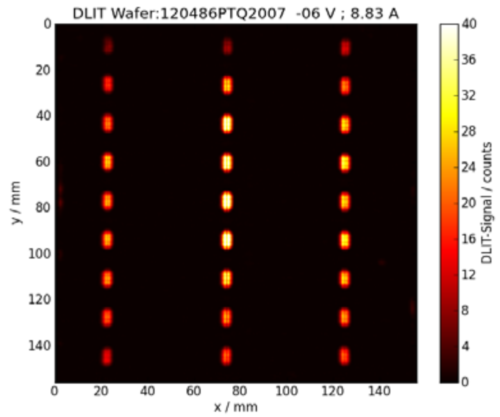


Figure 8: Current densities j_{-12V} at reverse bias of V = -12 V for group H1-Em and H2. For via paste H1, j_{-12} exceeds 45 mA/cm^2 throughout the experiment.

a)



b)

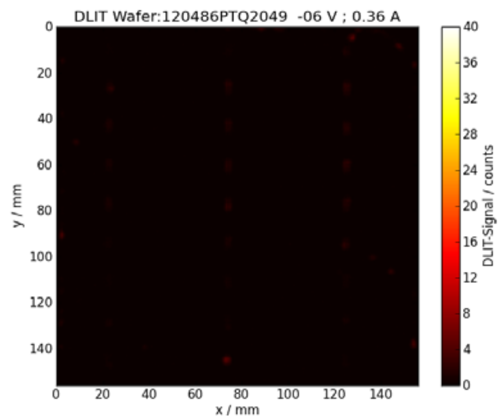


Figure 9: DLIT images for MWT-BSF solar cells with via pastes (a) H1 and (b) H2 printed directly on the p-type silicon base.

I-V measurements. Both pictures are taken at a voltage $V = -6$ V. The cell metallised with via paste H1 shows a current of 8.83 A that is rather homogeneously distributed over all n-type contact pads, visible in three rows with nine pads each (Figure 9 a). In contrast, the cell metallized with via paste H2 only shows a current of 0.36 A (Figure 9 b), no significant signal is visible.

3.3 Stability during repeated reverse loads

For further investigation of the reverse bias behaviour of the fabricated MWT-BSF solar cells the cells were degraded under 0.2 suns for 48 h to rule out any influence of degradation. Subsequently, a 1000-fold measurement under reverse bias of up to a voltage of $V = -13.5$ V and forward bias were carried out. The measured values for j_{-12V} are shown in Figure 10. Via paste H1 exceeded $j_{-12V} = 45$ mA/cm^2 throughout the experiment and is not shown.

As can be seen in Figure 10, each group shows a clear tendency. The j_{-12V} of group H1-Em shows only a very slight average increase of below 0.3 mA/cm^2. In contrast, the j_{-12V} of group H2 starts at almost the same value but shows a drastic average increase of

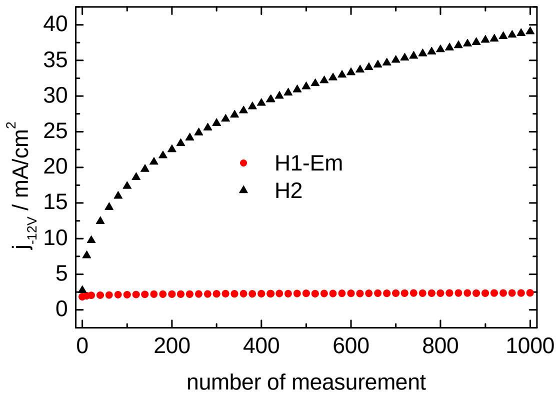


Figure 10: Current densities j_{-12V} measured at a reverse bias of $V = -12$ V of repeated *I-V* measurements of one representative cell per group H1-Em and H2 after degradation. The cells were measured 1000 times under reverse and forward bias. For reasons of clarity only each 20th measurement is presented. Group H1 exceeded $j_{-12V} = 45$ mA/cm^2 throughout the experiment.

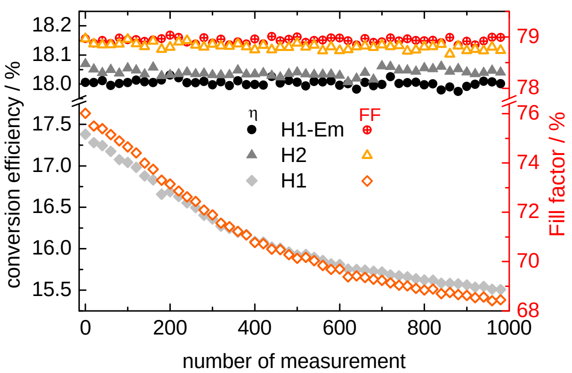


Figure 11: Conversion efficiencies η (filled markers) and fill factors *FF* (hollow markers) of repeated *I-V* measurements of one representative cell of each group after degradation. For reasons of clarity only each 20th measurement is presented.

≈ 40 mA/cm^2, without any tendency of saturation after 1000 measurements..

The results presented in Figure 11 show that the fill factor *FF* of group H2 stays on the same level even though j_{-12V} for H2 constantly increases over the experiment (Figure 10). After the first measurement with reverse bias a drop of -0.1 $\%_{abs}$ was observed (see Figure 4); during the following 1000 measurements only an additional decrease of approximately -0.1 $\%_{abs}$ follows. In contrast via paste H1 shows an overall drop in *FF* of around 4 $\%_{abs}$. This dramatic decrease of the *FF* over 1000 measurements is mainly caused by increasing leakage currents (see fig 10). Group H1-Em shows almost constant *FF* and η values over the 1000 measurements. The short-circuit current densities j_{SC} and the open-circuit voltages V_{OC} of all groups do not change significantly during the 1000 measurements, thus the evolution of the conversion efficiency is mainly determined by the *FF*.

The fact that neither *FF* nor η of group H2 shows a significant change over 1000 measurements leads to the conclusion that the forward characteristics of cells with via paste H2 printed directly on the p-type silicon base are as stable as the reference group H1-Em with paste H1 and an intermediate emitter. Another DLIT image shows a homogeneously current distribution under reverse bias over all 27 n-type pads, therefore the MWT-BSF+ cell structure in combination with the novel via paste H2 is promising for an integrated bypass diode approach [12]

4 CONCLUSION

Our results show the successful implementation of wet chemical single-side emitter removal into the fabrication process for p-type Cz-Si MWT-BSF solar cells. With the simplified process sequence, which only features one additional step for MWT-BSF+ compared to H-pattern solar cells, namely the laser drilling of vias, median conversion efficiencies of 18.4 % (as processed) are achieved by using a novel via paste H2. No additional j_{02}-related losses due to emitter etch back are observed. The simultaneously processed reference group with rear emitter as well as laser edge and contact isolation show median conversion efficiencies of 18.2 % (as processed).

Although a slight drop of -0.1 $\%_{abs}$ in the fill factor is observed after the first reverse load for via paste H2 printed directly on the p-type silicon base, 1000-fold measurements on a degraded MWT-BSF+ cell show almost constant values of fill factor and conversion efficiency. Furthermore the 1000-fold measurement show a continuous increase of the reverse current density j_{-12V}, measured at -12 V, up to ≈ 40 mA/cm² for via paste H2. Despite this drastic increase of j_{-12V} the novel via paste H2 enables unaffected forward characteristics; the fill factor as well as the conversion efficiency is not significantly affected. In addition, the reverse current is homogeneously distributed over all 27 n-type pads, thus, the MWT-BSF+ cell structure in combination with via paste H2 is promising for an integrated bypass diode approach. Via paste H1 can be used for MWT-BSF solar cells with intermediate rear emitter, however, this paste is not appropriate for the metallization of MWT-BSF+ cells without rear emitter.

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