

MWT “PLUG” METALLIZATION: IMPROVED PERFORMANCE AND PROCESS STABILITY OF PUM AND ASPIRE CELLS

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ABSTRACT: In this paper we present an alternative to our metal-wrap-through “PUM” metallization concept that simplifies the cell process and thereby reduces manufacturing costs. The simplified printing step allows complete filling of the holes with a specially designed conductive paste. With this “plug” concept of closed PUM holes we achieved a feasible, more stable process, performing better than the reference PUM process by showing an absolute increase of 0.2% in efficiency. In this form, the PUM process showed to be industrially feasible. The implementation of the plug metallization in the ASPIRe cell concept was successful as well. The first “plug” ASPIRe cells performed as well as expected from the PUM results, showing a maximum efficiency of 15.9%.

Keywords: metal-wrap-through, bifacial, plug metallization

1 INTRODUCTION

To become competitive in the energy market, it is necessary to reduce the costs per W_p in solar cell manufacturing. Simplification of the process and reaching higher cell efficiencies both contribute to this. Our metal-wrap-through (MWT) PUM concept has been shown to perform better compared to the standard H-pattern cell and is easier to interconnect [1-4].

We have improved the PUM concept further by simplifying the printing step and improving the fill factor. To achieve this, we applied a “plug” MWT metallization in the holes, instead of only covering the hole walls. The new through-hole metallization concept will be explained and discussed in the next section.

The PUM concept with this “plug” metallization has also been successfully implemented in an industrial environment, which will be explained in more detail.

Finally, the successful application of the new “plug” metallization in ASPIRe cells will be described. This cell concept, with dielectric passivation and open metallization at the rear, has been developed for processing MWT cells on thin and fragile wafers, as the bowing is reduced to zero [5,6]. Furthermore, it leaves the opportunity to improve the cell efficiency with respect to the PUM cell by a well-passivated rear surface.

2 IMPROVEMENT OF PUM METALLIZATION

2.1 MWT reference through-hole metallization

The metal-wrap-through metallization in the PUM concept, despite the good results that have been obtained, is not ideal in terms of processing and performance stability. After application of the through-hole metallization, an extra step has to be built in to remove excess paste from the hole. This is necessary to obtain a well-covered hole wall with minimal risk on cracks. Furthermore, the excess paste that is printed through the holes requires paper exchange on the printing after every print, which is time-consuming and costly.

If the excess paste removal has been insufficient, cracks may appear around the through-hole metallization after firing, due to paste shrinkage during sintering.

These cracks in the metal contacts increase the series resistance of the cell, causing a loss in fill factor and therefore in efficiency. In figure 1 an example of cracked PUM through-hole metallization is shown.



Figure 1: Cracks in the PUM through-hole metallization cause huge fill factor losses.

The fill factor instability could probably be solved in process optimization, but a more general solution has been found in the “plug” metallization.

2.2 MWT plug through-hole metallization

Both the processing as well as the cell performance has been improved by the “plug” metallization concept, as schematically drawn in figure 2.

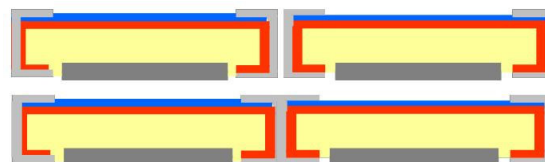


Figure 2: Cross-sectional drawing of the reference PUM metallization (upper image) and “plug” PUM metallization (lower image): red: emitter; blue: SiN_x coating; grey: Ag (front, in holes and locally on rear) and dark grey: Al (rear) metallization.

As the hole is filled completely, there is no need for extra steps to remove excess paste from the hole or from the paper below the cell after printing.

The required paste properties to surpass the conventional PUM processing in performance are i) low-shrinkage to fill and close the MWT hole without cracks

and ii) well-conducting from the front grid to the rear interconnection.

Several “plug” pastes have been developed within the Starfire project [7] and showed crack-free through-hole metallization, enabling a stable cell performance.

In a first experiment, cells processed with “plug” paste have been compared with the reference PUM metallization on 243 cm² large and 180 μm thin wafers. The differences between the two experimental groups are found in the fill factor, as is shown in figure 3. As can be concluded from the fill factor distributions, this can especially be translated to improved process stability.

The cell results, summarized in table I, are the average of approximately 15 cells per group. From these results it appears that there are only small differences in J_{sc} and V_{oc} between the two groups. The 1.4% absolute increase in average fill factor of the “plug” cells is a significant improvement compared to the reference cells. This results in 0.2% absolute increase in efficiency. Clearly, the improved hole filling contributes to the enhanced cell performance.

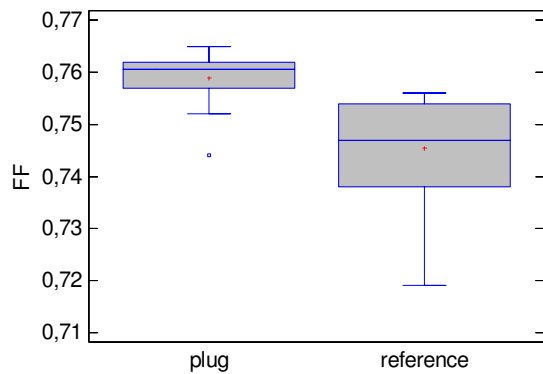


Figure 3: Improved (+1.4% on average) and more stable fill factor for filled PUM holes with “plug” paste, compared to the reference PUM cells.

Table I: Average cell results (approximately 15 cells per group) of the comparison between cells processed with “plug” paste and the reference process; 180 μm thin, 243 cm² wafers.

	Jsc [mA/cm ²]	Voc [mV]	FF [%]	eta [%]
Reference	34.0	612	74.5	15.5
Plug paste	33.9	611	75.9	15.7

The more stable value of the fill factor of the cells processed with “plug” paste could be ascribed to a more constant amount of conducting paste that is printed in the hole, as the hole is always filled completely. As a result of fill factor stability, the variation in cell efficiency is smaller for the “plug” cells. This means that the prediction of cell performance is more reliable for the “plug” metallization, which is very important for stable industrial processing.

3 INDUSTRIAL PROCESSING OF “PLUG” PUM CELLS

The PUM concept with the new “plug” metallization has been successfully implemented in an industrial inline system at Solland Solar.

3.1 First results

A comparison between a group of standard H-pattern cells and a group of plug PUM cells on neighboring wafers has been made.

In figure 4 the PUM cells show a current increase of over 3% relative compared to the H-pattern reference. This can be attributed to the lower front metallization coverage for PUM, due to the absence of interconnection bus bars and a smart grid design. The relative efficiency gain on cell level for the PUM concept is 1.8%. Although the fill factor on cell level is still slightly higher for the H-pattern cell, a fair comparison can only be made on module level. From previously published results [3,4], it is known that the module fill factor loss is smaller for PUM cells than for H-pattern cells, enhancing the performance gain even more.

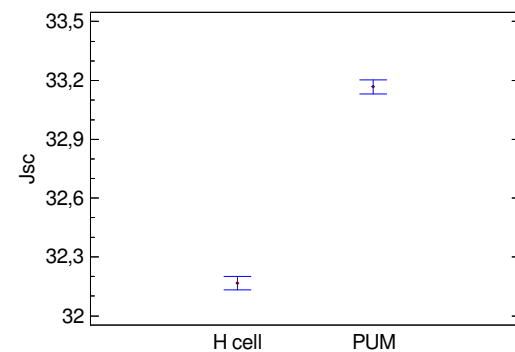


Figure 4: The PUM cells show a current gain of 3.1% relative to the H-pattern reference.

3.2 Feasibility and robustness of concept

More recent and larger runs of several hundreds of cells show the experience that has been gathered in the industrial PUM processing. Improved fill factors of well above 76% also prove the industrial feasibility of the plug metallization concept in the MWT cell. The shunt values of the cells are an important indication to the robustness of the concept. As can be seen in figure 5, the shunt level was very good, about 25 kΩcm² on average. The normal distribution is indicated by the blue line.

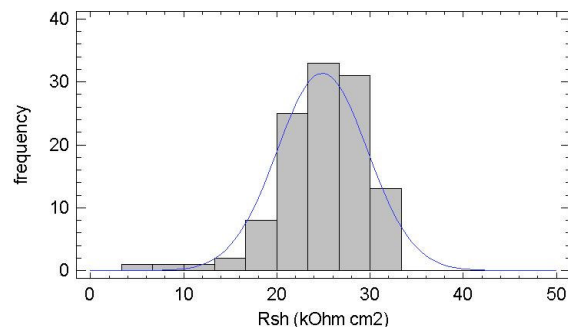


Figure 5: Very high shunt resistance for industrially processed “plug” MWT cells.

4 PLUG METALLIZATION IN ASPIRE CELLS

4.1 Concept

As already mentioned in the introduction, we have developed a rear side passivated MWT cell concept [8,9], called ASPIRE (All Sides Passivated and Interconnected

at the **Rear**). Similar to PUM, the ASPIRe cell is a back-contacted cell with easy interconnection. The processing of the ASPIRe is only slightly different from the PUM processing: there is additional rear side preparation and SiN_x deposition to obtain good rear passivation and furthermore, an Al pattern is used on the rear that contacts the base through the SiN_x after the firing step. In figure 6, both the front and the rear of the ASPIRe cell are shown. The well-passivated rear introduces the possibility to improve the cell performance.



Figure 6: Front pattern (left) and rear pattern (right) of the ASPIRe cell.

4.2 Results

The implementation of the plug metallization in the ASPIRe concept proved to be feasible in a first comparison experiment. The ASPIRe group with the “plug” through-hole metallization showed similar fill factor stability as the PUM cells with the “plug” metallization. This is shown in figure 7. We observe, even with a non-optimized rear ASPIRe pattern, a high average FF of 75% in this experiment. The “plug” metallization certainly contributes to this.

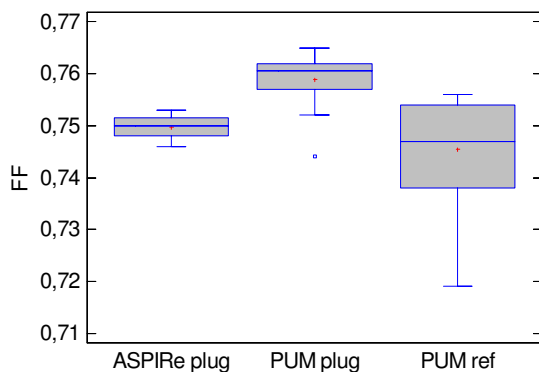


Figure 7: High and stable fill factors for the ASPIRe and PUM cells with “plug” metallization, compared to the PUM reference metallization.

The IV results of the ASPIRe cells with “plug” metallization are presented in figure 8, and compared to a neighboring group of PUM cells.

The tuning of the aluminum paste properties and grid geometry is crucial to the ASPIRe cell performance. The aluminum contacts the cell base through the SiN_x passivating layer. The contact resistance with the base and the rear line resistance should be sufficiently low to obtain high fill factors. On the other hand, a low metal coverage is desired to maximize the performance benefit of the dielectric passivation. At the interface of Al and Si a good BSF is required to minimize passivation losses compared to the SiN_x passivation.

As the rear aluminum pattern is not yet optimized, we still have a relatively high line resistance. Anticipating on improvements that have been made in the rear pattern [9], we exclude the influence of the high line resistance on the results by shorting the rear lines. In this way a better comparison can be made between the cell parameters of PUM and ASPIRe, using this non-optimized pattern.

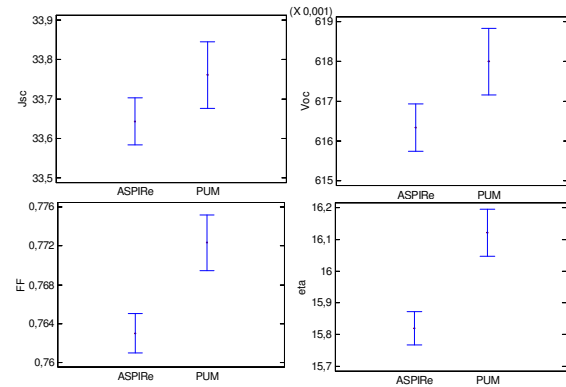


Figure 8: IV results of ASPIRe cells (left), compared to a PUM group (right). The rear pattern of the ASPIRe cells has been shorted.

From these figures, it is immediately clear that the J_{sc} and V_{oc} of the ASPIRe cells are slightly lower compared to the PUM group. This can be explained by the relatively high aluminum coverage on the rear, decreasing the effective rear passivation and internal reflection. For lower Al coverage, better $J_{sc} \times V_{oc}$ results compared to PUM have been obtained [9]. This trend has been confirmed in calculations for bifacial H-pattern cells [10].

Summarized in table II, the fill factor has improved to 76.3% average for the ASPIRe cells. In this group the best cell was found with 15.9% efficiency. The obtained ASPIRe fill factors are significantly higher than the values reported earlier, which can be ascribed to the use of “plug” metallization in the holes. However, the rear side pattern can still be further optimized. The PUM cells perform better with average FF values over 77% and 16.1% efficiency. The maximum cell efficiency for this group is 16.2%.

Table II: Average cell results and best values of the comparison between “plug” ASPIRe and the PUM reference group on 243 cm^2 wafers. The rear pattern of the ASPIRe cells has been shorted.

	J_{sc} [mA/cm^2]	V_{oc} [mV]	FF [%]	eta [%]
ASPIRe	33.6	616	76.3	15.8
best	33.7	617	76.7	15.9
PUM	33.8	618	77.2	16.1
best	33.8	619	77.3	16.2

5 CONCLUSIONS

In this paper we present the “plug” metallization concept for MWT cells. Compared to the reference through-hole metallization, the “plug” concept leads to more stable fill factors and improves the PUM cell efficiency with 0.2% absolute. The concept has been demonstrated to be feasible at industrial conditions,

gaining 1.8% relative in efficiency compared to the H-pattern cell, due to the increased current. The introduction of the new concept in ASPIRe cell metallization has been successful, leading to stable fill factors and cell efficiencies up to 15.9%.

Higher ASPIRe cell efficiencies will be achieved after further tuning of the aluminum properties and geometry. After implementation of recently developed cell improvements at the rear and the front side [9,11], ASPIRe cells with 17% efficiency will be within reach.

6 ACKNOWLEDGEMENTS

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