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Cost, efficiency and material optimisation of back-contact cell and module design

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Abstract

Back-contact modules made using a conductive back-sheet foil have a number of advantages over standard H-pattern modules including a higher power output, compatibility with very thin cells and rapid, high yield manufacturing. In this paper, we present the results of efficiency and material optimisation for cost reduction: decreasing the encapsulant thickness, printing smaller contact pads and reducing the Ag paste consumption in combination with increasing the number of metal wrap through vias. Experimental and modelling data show that the cell and module performance can be improved whilst reducing the module costs.

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Keywords: photovoltaic module; cost optimisation; metal wrap through

1. Introduction

Metal wrap through (MWT) solar cells have a higher efficiency [1, 2] than comparable front-to-back-contact cells. A dedicated process has been developed to manufacture modules using these back-contact cells. This module process uses a conductive back-sheet foil, with a low temperature interconnection process which is combined with the lamination process [3]. MWT-modules comprising MWT-cells, back-contact foil and conductive adhesive interconnection have achieved IEC-61215 industry standard certifications.

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The back-contact foil product is, at the moment, the only fully integrated cell and module concept available. The interconnection process is suitable for thin and fragile wafers, giving potential for significant cost reduction of the cell. Because of the integration of cell and module, it is even possible to combine a cost reduction, e.g. less Ag consumption, with an improved module output.

However, standard module costs are also reducing and for MWT to remain competitive further optimisation is required. In this paper, we will show that laminates fabricated with thinner encapsulants and lower conductive adhesive (CA) usage will not reduce the power output of the module, but allow for >70% less CA usage. We also present the results of 2×2 laminates made with solar cells with smaller contact pads in combination with the smaller CA dots and thinner encapsulant. Finally we have modelled the influence of the number of MWT vias and CA contacts, both for the cell efficiency and for the module cost.

2. MWT cell and module design

The present design of the MWT cell and module consists of a 4 by 4 grid of vias that connect the front grid with the emitter contacts on the rear. On the rear, 3 rows of 5 contact points are placed as base contacts. For the present 4×4 front side design, the metallisation pattern is optimised for the highest conductivity with lowest coverage, so balancing the fill-factor and current generation. The advantage in performance of this cell design relative to three bus-bar H-pattern cells has been shown both for p-type multicrystalline Si solar cells [1] and also for n-type monocrystalline Si solar cells [2]. Typically an absolute improvement of 0.1% to 0.3% in cell efficiency has been observed.

Interconnecting these cells in full-size, 6×10 cells, modules using back-contact foil results in a very small cell-to-module (CtM) loss (1%$_{rel}$) due to the low series resistance. Combined with the improved cell efficiency this leads to an increase of about 8 W, i.e. 0.5%abs increase in encapsulated cell efficiency, compared to H-pattern soldered modules incorporating similarly processed solar cells. To allow the conductive adhesive to make interconnection between the back-contact foil and the solar cells, the rear-side encapsulant is perforated. The standard thickness of the encapsulant is 200 μm. This puts a restraint on the minimum height, *h*, of the printed CA dots: they should be higher than the encapsulant to ensure good contact. The present standard is 400 μm. Secondly, the stencil thickness puts a lower limit on the CA dot diameter *D*, presently 1.7 mm. As a rule of thumb the contact area, $\frac{1}{4}\pi D^2$, should be larger than the stencil-dot interface πDh., i.e. $D > 4h$.

Recently, a number of approaches have been introduced for front-to-back contact modules to reduce material usage in metallisation and at the same time improve the solar cell performance. These include plating, high aspect ratio printing and multi bus-bar concepts. One key aspect of the multi bus-bar approach is the reduction of the finger length, as the resistive losses of the metallisation fingers scale with the square of their length. For MWT this can easily be achieved by increasing the number of emitter contacts.

3. Results and discussion

2×2 modules have been fabricated with 200 and 100 micron thick encapsulant, applying the same thickness behind and in front of the solar cells. In Fig. 1 we compare the fill factor (FF) CtM change of two MWT laminates for each design. Both encapsulant thicknesses show about 2-3%$_{rel}$ FF CtM change, compared to 4% for comparable 2×2 soldered H-pattern modules. One should keep in mind that the FF CtM for 2×2 modules is larger than for 6×10 modules, as some losses, e.g. those associated with contacting the module, are invariable and do not scale with the number of cells. Since the total power generated is a factor 15 smaller, these losses have on a relative scale a 15 times larger contribution. The EL and DLIT images show a good, uniform interconnection. Although the smaller CA dots have a contact resistance that is 3× larger and a bulk resistance that is 50% larger, the contribution to the resistive CtM losses is not limiting as the FF loss does not depend on the size of the CA dots, as shown in Fig. 1.

We have achieved similar results for a range of encapsulant types, including EVA, ionomer and polyolefin encapsulant brands. For these materials, punching of the 5 mm holes was possible and their lamination profiles are compatible with the curing of standard conductive adhesives. This amount of encapsulant is sufficient for isolation between the solar cells and the conductive Cu foil.

Thinner encapsulants at the rear allow thinner stencils for CA printing and thus smaller openings in the stencil. The drastic decrease in CA usage per dot, by >70%, allows an increase in the number of contact points whilst maintaining a lower material usage and improving the device performance. This has important knock-on effects as it allows less metallisation, e.g. thinner pseudo bus bars, on the solar cells. Furthermore, recent advances in CA development has reduced the silver content from >80% to <20%, realising a combined cost-saving of ~50%.

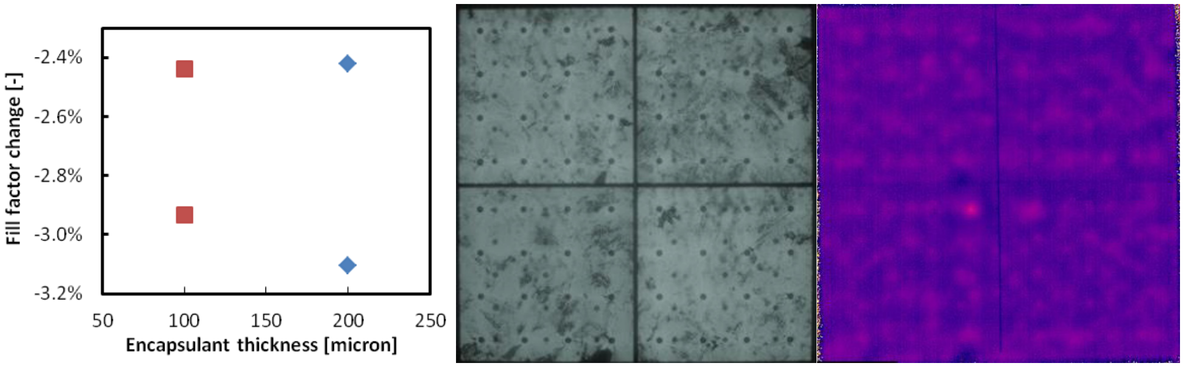

Fig. 1. Left: decrease in module fill factor for four 2×2 cell laminates, two laminates with 100 µm encapsulant and small CA dots (red squares) and two laminates with 200 µm encapsulant and large CA dots (blue diamonds). Middle and right: EL and DLIT phase image of a 2×2 cell laminate with 100 µm encapsulant and small CA dots.

One advantage of the smaller CA dots is that the corresponding areas on the solar cells, i.e. the contact pads, can be decreased in diameter, thus further reducing the Ag consumption. In the next experiment, the smaller CA dots and thinner encapsulant have been combined with solar cells with smaller contact pads. These solar cells, with 2 mm contact pads, have a 40% lower Ag paste consumption, compared to the standard 3 mm contact pads. Due to the increased Al-BSF area and decreased Ag contact area, which reduces the recombination losses, we observe a small increase in FF on cell level. 2×2 laminates were made, employing 200 and 100 micron encapsulant, respectively for solar cells with 3 and 2 mm contact pad diameter. Up to 5 laminates were made of each design. Fig. 2 shows the FF CtM change for the best three laminates per design. No difference between the standard and new layout is observed.

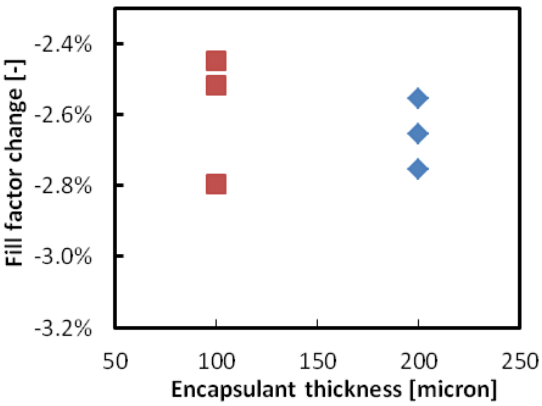

Fig. 2. Cell-to-module change of the fill factor for 2×2 cell laminates with 100 µm encapsulant, small CA dots and 2 mm contact pads (red squares) and 200 µm encapsulant, large CA dots and 3 mm contact pads (blue diamonds). Note the difference with Fig. 1 where only the encapsulant thickness and CA dot volume is varied, whereas in this figure also the contact pad diameter is varied.

These laminates have been exposed to damp-heat (DH) and thermal cycling (TC) conditions according to IEC61215. After each half IEC-test period, the modules have been flashed to determine the IV-parameters. Fig. 3 shows the DH degradation for these two laminate types, one with 3 mm contact pads on the rear side of the cells, 200 micron encapsulant and larger CA dots (standard layout), the other with small 2 mm contact pads, 100 micron encapsulant and small CA dots (new layout). The short-circuit current and the fill factor have been plotted relative to the Isc and FF before lamination.

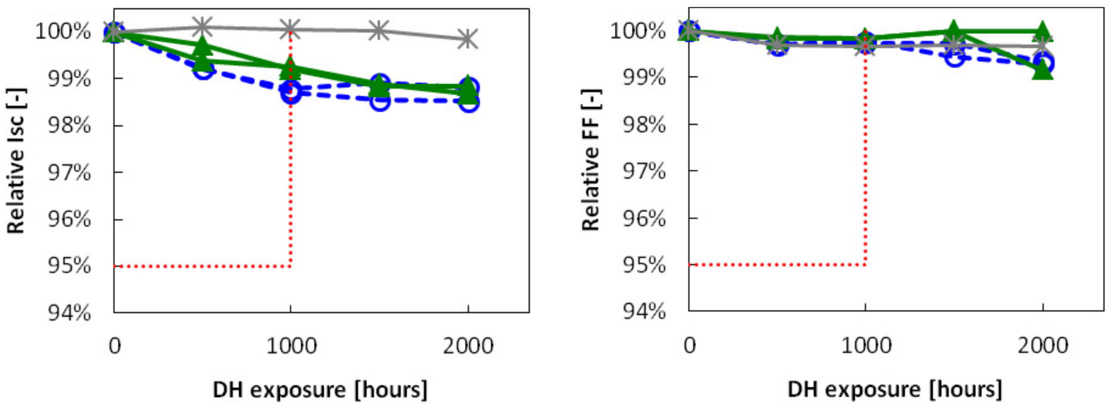

Fig. 3. Damp-heat degradation of 2×2 laminates with small contact pads, small CA dots and thin encapsulant (blue, open symbols) and large contact pads, large CA dots and thick encapsulant (green, closed symbols). A non-degraded laminate is shown as reference in grey symbol+line. The red dotted line indicates 5% degradation after 1000 hours, corresponding to 1× IEC. (left) Short circuit current relative to the Isc after lamination; (right) Fill factor relative to the FF after lamination.

Both the standard layout (green, closed symbols) and the new layout (blue, open symbols) show a small, linear decrease in Isc with increasing DH exposure. The identical degradation behaviour for the standard and new layout confirms that this is not related to the reduction in encapsulant thickness, contact pad diameter or CA dot volume, thus proving the reliability of the new layout relative to the standard layout. The observed, modest decrease in Isc, for both layouts, is attributed to the lack of frame around the 2×2 laminates. Moisture ingress between the encapsulant and the patterned Cu back sheet causes a decrease in total reflection of the Cu layer, reducing the light harvesting properties.

Fig. 4 shows Isc and FF of the same two layouts after degradation in steps of 100 TC periods. All Isc degradation falls within the experimental accuracy. For the FF degradation, we, again, observe a modest degradation of 2% after 2× IEC (400 TC periods), well within the criterion of less than 5% loss after 200 TC periods.

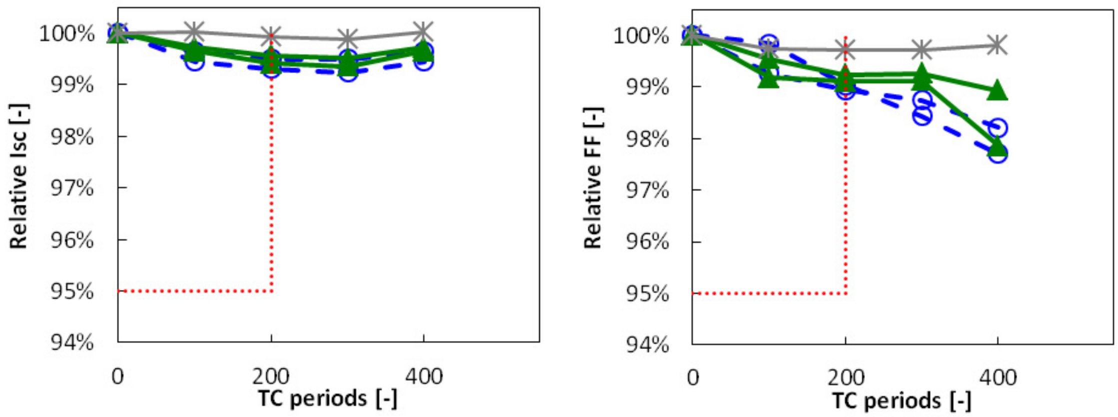

Fig. 4. Thermal cycling degradation of 2×2 laminates with standard layout (green, closed symbols) and new layout (blue, open symbols). A non-degraded laminate is shown as reference in grey symbol+line. The red dotted line indicates 5% degradation after 1000 hours, corresponding to 1× IEC. (left) Short circuit current relative to the Isc after lamination; (right) Fill factor relative to the FF after lamination.

We have modelled the new device layout in a simplified, finite element model, taking into account the open area and resistive losses only. The optimal number of emitter contacts, for either highest device efficiency or lowest device costs in €/Wp, depends strongly on the metallisation parameters. For typical metallisation grids, e.g. 70 μm wide fingers and a line resistivity of 0.36 Ω/cm, the efficiency has an optimum at 7×7 to 8×8 emitter contacts as shown in Fig. 5a. As an example, the modelling results are also given for an advanced metallisation pattern, consisting of more narrow fingers, width = 35 μm, and a factor 2 lower height and thus a four times higher resistivity. In this illustrative case, the modelled device efficiency is higher and has a maximum above 10×10 vias.

We also calculated the optimised module costs (see Fig. 5b) for the device with 100 μm encapsulant, front and rear side, and small CA dots. For the standard metallisation there is not much improvement possible, but for thinner fingers a large reduction in costs of up to 4% is possible by increasing the number of emitter contacts from 4×4 to about 6×6 up to 8×8.

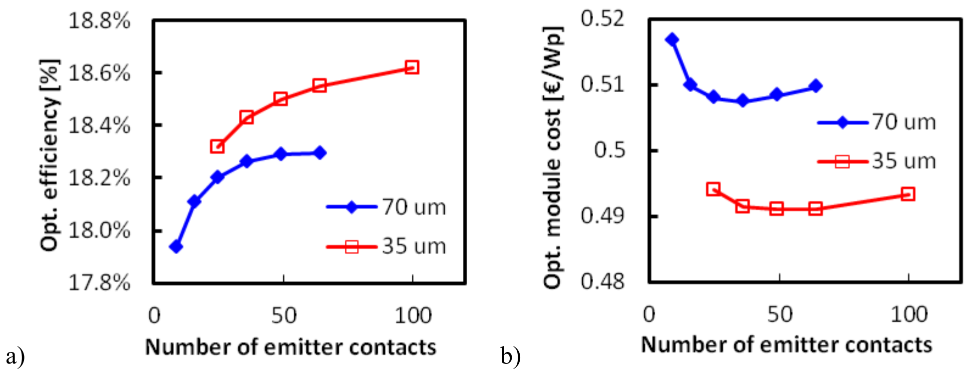

Fig. 5. (a) optimised device efficiency as a function of the number of emitter contacts for (blue) 70 μm and 0.36 Ω/cm and (red) 35 μm and 1.44 Ω/cm metallisation fingers; (b) optimised module costs for the devices of Fig. 5a.

4. Conclusions

We presented MWT modules with reduced Ag consumption, by decreasing the CA dot and the Ag contact pad volumes, and less encapsulant. We show that 100 μm thin encapsulants can be used in 2×2 laminates. The thinner encapsulant allows a device layout that combines a reduction of >80% in CA costs with 40% smaller Ag contact pads on the rear side of the solar cells. Furthermore, the cost reduction is not accompanied by an increase in the cell-to-module losses; apparently the contribution of the CA dots to the resistive losses is still negligible.

A second improvement step can be made if we merge the new device layout with a new metallisation layout, i.e. more emitter contacts and a narrow line print for the front side metallisation. The modelling data show that a 4% reduction in module costs, €/Wp, can be achieved. The reduction consists of an increase in module power by 2% and a decrease in costs with a similar 2%. The increased number of emitter contacts significantly reduces the finger length, allowing both the narrow line print and still have a overall decrease of the resistive losses. These results show the potential and importance of an integrated cell and module optimisation.

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