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CELL TO MODULE GAINS FOR HIGH EFFICIENCY BACK CONTACT CELLS

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ABSTRACT: Back contact cells architectures, especially Interdigitated Back Contact (IBC), offer the potential for the highest efficiencies, best aesthetics, and application flexibility. Foil-based back contact module interconnect for these architectures has been shown to be a high throughput, industrially viable, and reliable solution for both IBC and Metal Wrap Through (MWT) cells. By collecting current from distributed points on the cell, foil reduces series resistance in the module interconnection, leading to lower cell-to-module (CTM) FF loss. This specific feature makes the conductive foil the interconnection technology of choice for high current back contact solar cells. In addition, the capacity of the conductive foil to tolerate higher Isc in the module with limited series resistance increase offers the opportunity to further improve module power based on light management techniques and increase of the module Isc. In this work, we focused on increasing the CTM Isc and power gains by improving capture of the light inside the module by using a reflective “Intra-Module” Foil (IMF) placed in between back contact cells interconnected with back contact foil. We present results on single-cell and 2x2 back contact laminates manufactured with IBC and MWT cells interconnected based on ECN’s conductive foil technology. CTM power gain above 5.1% is demonstrated with Isc gain more than above 8% on 2x2 laminates.

Keywords: IBC, MWT, modules, CTM, materials, light management

1 INTRODUCTION

In standard PV modules, interconnection of cells into modules results in a decrease of both power and total area efficiency. These cell-to-module losses are typically a result of resistance losses (fill factor) from the cell interconnections while the efficiency is decreased due to the existence of inactive areas in between the cells and around the edges of the module. Typical cell-to-module losses, measured on the power output, are on the order of 2%-3% and efficiency losses are often 5% or greater [1].

Back contact cells architectures, Interdigitated Back Contact (IBC) and Metal Wrap Through (MWT), offer the potential for the highest efficiencies, best aesthetics, and application flexibility. However, the higher currents in these modules also increase the risk of higher fill factor losses. Back contact foil interconnection technology is based on a metallized back sheet that is patterned with two different electrode areas to interconnect all back contact cells. Among other benefits, back contact foil interconnection improves on other back contact module interconnection technology as it is not dependent on the cell to carry current. Thereby higher currents can be generated in the cell and efficiently extracted without increased series resistance when multiple cells are interconnected in series and laminated into modules. This increases the module fill factor and decreases CTM losses. Back contact foil module interconnect technology for high efficiency cell architectures has already been shown to be a high throughput, industrially viable, and reliable solution for all back contact cells [2].

Use of back contact foil and the ability to carry higher currents with fewer resistive losses also allows optical optimization of a back contact module. A highly reflective intra-module foil (IMF) can be placed between cells and along the edges in order to reflect light incident on inactive module areas back onto the high efficiency cells. With high reflectance, module efficiency losses can be countered by making inactive module areas more active. Similar materials have been integrated into standard H-pattern stringing and tabbed modules [3] but have not been applied to back contact modules.

In this work, we focused on increasing the CTM by gaining current I_{sc} by improving capture of the light inside the module by using a reflective IMF placed in between the back contact cells connected by back contact foil. We present results on single-cell and 2x2 back contact laminates manufactured with IBC and MWT cells. Through the combination of the IMF and back contact foil technology for module interconnection, we demonstrate greater than 5% CTM power gains and decreased cell to module efficiency losses for 2x2 mini-modules.

2 OPTIMIZED LIGHT MANAGEMENT

Inactive areas make up more than 5% of the module

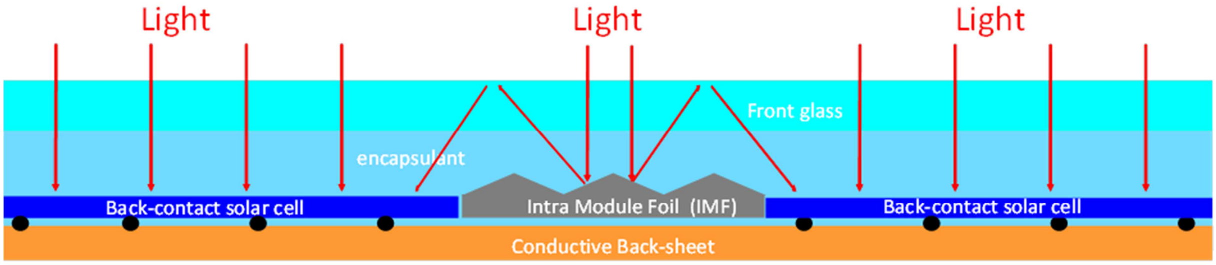

Figure 1: Schematic cross-section of a back contact module based on back contact foil technology combined with relective Intra-Module Foil (IMF).

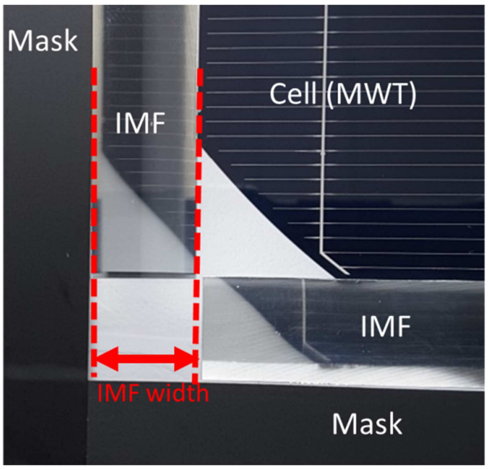

Figure 2: Photograph of corner of single cell laminate showing IMF, mask to determine the effective IMF width, and an MWT cell.

area. By optimizing the light trapping inside the module for light incident on these areas, a large I_{sc} increase can be achieved. The module structure was re-designed to allow redirecting the light falling onto the electrically inactive area of the module (in between the cells and module edges) towards the cells by mean of reflection. For high efficiency IBC and MWT cells, this light can be efficiently converted into currents. Reflection of the light is assured by the reflective IMF, a structured foil, placed in between the cells inside the module. Figure 1 shows a schematic of a cross section of the IMF integrated with back contact cells and foil. In this way, the IMF allows an effective use of the regions between the cells as it efficiently redirects more than 80% of the light toward the cells, increasing current. The IMF pattern is optimized using ray tracing modelling to maximize the internal reflection of light that falls between the cells.. This results in maximum light trapping and thereby increases the short circuit current of the module. The conductive foil interconnection technology mitigates the potential increase of the series resistance resulting from higher $I_{sc.}$ Thereby FF loss is mitigated.

3 RESULTS

3.1 Single-Cell Laminates

In order to quantify the potential current and power gain as a function of IMF width around the cell, we made a series single cell laminates using MWT and IBC cells with 1 cm IMF strips on all sides. Figure 2 shows a close up of the corner of one of the single cell laminates. As can be seen here, no special attention was given for the corners of the pseudo-square cells. Similar single cell laminates were also made with white encapsulant (EVA) for comparison. Each of the single cell laminates was masked with tape to determine the amount of IMF or white encapsulant exposed around the cells. In order to measure the impact of the IMF and white encapsulant specifically, flat glass with no anti-reflection coating was used in this experiment. The results for current and power are show in Figure 3 and Figure 4 respectively.

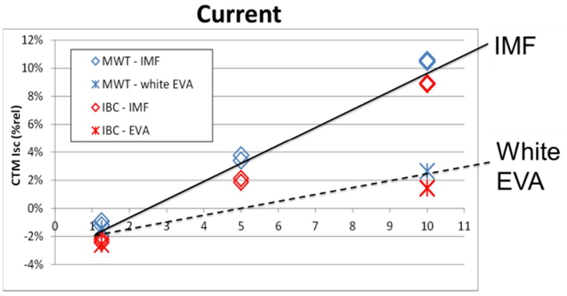

Figure 3: Cell to laminate (CTM) short circuit current gains and losses as a function of IMF width as compared with white encapsulant.

With standard cell spacing of 1.25 mm (minimum spacing measured), both MWT and IBC laminates have cell to module losses in current, probably due to the glass. The MWT laminates have slightly less current loss than the IBC laminates due to the natural light scattering off of the front side metallization. The gain in current for both cell types is approximately linear with the width of IMF or white encapsulant. With only 2.5 mm of IMF width between cells, CTM current loss is 0. With 10 mm IMF width, MWT laminates show more than 10.6% current gain and IBC laminates show more than 9% current gain. This is almost 8% more current gain than what is measured for white encapsulant.

Similar results are seen for power in **Fout! Verwijzingsbron niet gevonden.**. With 1.25 mm IMF or white encapsulant, the laminates have almost 5% CTM loss. At 5 mm cell spacing, there are no CTM power losses and with 10 mm cell spacing there is almost 5% gain in power from CTM. For white encapsulant, gains in CTM power are not realized for 10 mm cell spacing. We note that the slope of both the power CTM and current CTM as a function of cell spacing are approximately the same. This suggests that the module FF is not decreased due to the increased current.

3.2 2x2 Mini-Modules

To further optimize the IMF performance, IBC 2x2 mini-modules were made with anti-reflection coated glass on the front. The cell spacing was set at 8 mm to maximize the impact IMF and minimize module size. A picture of one of these mini-modules is seen in Figure 5. For the mini-modules, IMF was also integrated into the corners between cells and oriented to maximize current gain. The photograph in Figure 5 is taken at an angle so that the IMF can be seen between the cells. When photographed directly, the IMF is more difficult to see as it reflects the all-black surface of the IBC cells. This all black appearance may be useful in aesthetic applications for high power modules.

Two sets of mini-modules were made. One with a standard glass/back contact foil structure and another

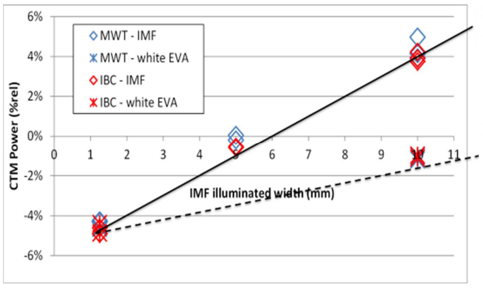

Figure 4: Cell-to-laminate (CTM) change in maximum power of IBC and MWT single cell laminates with IMF and compared to white EVA.

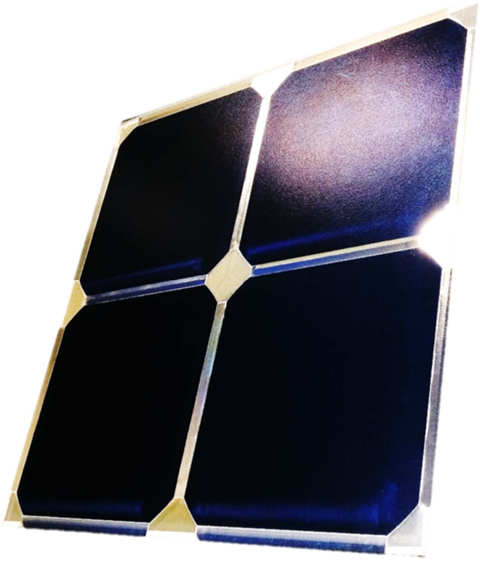

Figure 5: IBC mini-module with 8mm wide IMF integrated along cell edges and corners.

with glass/back contact foil/glass structure. Table 1 shows the CTM results for these two constructions. The double glass module suffered some problems during lamination due to slight shifts in the IMF such that it was about 1 mm away from the edges of the cell in some places. This decreased the current gain in CTM and resulted in 4.8% CTM power gain. However, the glass/foil module had 5.1% cell to module power gain due to a CTM gain in short circuit current of more than 8%. For both material stacks, the FF CTM loss was slightly higher than expected. This is likely due to alignment issues in the lamination process. Further optimization is ongoing and will be applied in full-size modules integrated with IMF.

Table 1: Cell-to-module relative changes for 2x2 IBC modules. All measurements are masked.

Laminate Architecture	CTM			
	P_{mpp}	I_{sc}	V_{oc}	FF
Glass/foil/glass	+4.8%	+7.8%	-0.4%	-2.5%
Glass/foil	+5.1%	+8.4%	-0.1%	-2.9%

4 CONCLUSIONS

We demonstrate increased module power and efficiency by improved module design. In this case, integration of IMF with back contact foil and high efficiency IBC cells result in a 5.1% cell to module power gain for mini-modules. We will expand this concept to full-size modules to demonstrate similar CTM gains in 60 cells.

Module technology should enhance cell performance rather than decrease cell performance. With proper light management and electrical optimization, this is possible for all back contact cell structures. Such innovation can also be of benefit in residential rooftop, area-limited, or BIPV applications where module power should be maximized in order to realize the most cost competitive electricity production combined with aesthetic.

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