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EUPVSEC-19 – Optimising SHJ solar cell bifaciality towards a monolithic module architecture

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1. Aim and approach

According to the ITRPV roadmap, 10 % of the module market will be truly bifacial (glass/glass design) by 2020 [1]. PV manufacturers are now largely focused on this technology, as it is a straightforward way to increase the output of a PV power plant by exploiting the part of the solar spectrum arriving at the module rearside [2]. When placed vertically, bifacial modules also allow east-west configurations without multiplying the number of panels.

Bifacial cells can also be assembled in a monolithic architecture that consists of cells, whose front (FS) and rearsides (RS) are alternately placed up and down (Fig. 1), which then allows a planar interconnection between the cells, connecting front-sides to front-sides and rearsides to rearsides. We have studied the performance of such modules in relation to the bifaciality of the cells.

2. Scientific innovation and relevance

Such a monolithic architecture, as already proposed by Buck et al [3], avoids the "top/bottom" passage of cell interconnect ribbons. This observation implies several benefits [4]: (i) an increased reliability thanks to the reduction of thermo-mechanical stresses on interconnections and cells. (ii) Simplification of string and module manufacturing, notably when using wire interconnection. (iii) A reduction in the inter-cell space with two consequences: a decrease in the associated series resistance, and a gain in useful surface area and therefore in module efficiency. (iv) The possibility of using different ribbon types or sizes on front- and rearsides.

The main challenge in such a concept is to avoid electrical mismatch: the module will be limited by the photocurrent generated by the rear surfaces of the cells if bifaciality does not equal 100 %.

Buck et al. [5] have studied this 'flip-flop' architecture with two kinds of mc-cell: a p-bulk P-emitter and an n-bulk B-emitter. As the silicon heterojunction solar cell (SHJ) technology is intrinsically symmetrical, Augusto et al. [6] used it with n and

p-emitter. Using such design with two different kinds of solar cells allows to match the current of the front side, but increase the complexity of the cell integration into modules. Thus, Schulte-Huxel et al. [7] studied the possibility to use a single cell type (n-PERT) with a high bifaciality factor. In the present study, we combine both approaches: using the intrinsic bifaciality of SHJ cells (n-CZ bulk, rear emitter) to make a monolithic module with a single type of solar cells.

It is possible to make SHJ cells with 100% bifaciality by adapting the metallization on the front- and rearside. From a STC cell performance point of view, it is preferable to tend towards medium (or 85 % to 90 %) bifaciality (Fig. 2) [8]. However, for a monolithic module, it is preferable to aim for the highest bifaciality to minimize mismatch between neighbouring cells. Therefore, the purpose of this transverse study is to determine the best compromise on cell bifaciality for maximum performance of a monolithic module.

3. Preliminary results and conclusions

SHJ solar cells with different rearside metallization pitch have been made, leading to cell bifacialities from 78 % to 94 %. In standard test condition (STC – 1000 W/m² on the front side) increasing pitch and bifaciality leads to a fall in efficiency due to increasing series resistance as shown with experimental SHJ cell data and confirmed by modelling (Fig. 2).

CTM perspective. When embedded into a monolithic module, cells with bifaciality lower than 100 % evoke electrical mismatch. This has been quantified with Spice-like modelling on the front-up and rear-up cells, described by 2-diode model (with different photo generated currents). The gain in efficiency offered by the monolithic design comes from the reduction of inactive surface (intercell space). By reducing the intercell space of a 72-cell module from 3mm to 1mm, the module surface area can be reduced by 1.25 % (206 cm²) for a similar power. This percentage increases proportionally if half-cut (+2.46 %) or quarter-cells (+4.74 %) are used, as is often proposed to further increase efficiency of bifacial modules. The reduced intercell spacing also results in a small decrease in series resistance (0.1% gain in P_{mpp}). The threshold bifaciality beyond which a monolithic module is interesting from a CTM efficiency point of view is evaluated numerically at 92 %. This threshold will now be compared to the experimental values (Fig. 3).

Efficiency perspective. Higher bifaciality was found to decrease STC cell efficiency (FF losses, Fig. 2), but increases module performance (smaller mismatch). From a transversal cell/module perspective, it reveals an optimum in bifaciality (controlled here by rearside finger pitch) that maximizes the monolithic module efficiency. Numerical experiments indicate an optimal pitch of 1.2 mm, which seems to be confirmed by the manufacture and characterization of first monolithic mini-module (Fig. 5).

Explanatory Page

DESIGN. A monolithic module diagram is presented in Figure 1. The absence of the elbow made by the cell interconnection ribbons is an additional factor of reliability and simplifies the module assembly: there are only front-to-front and back-to-back connections.

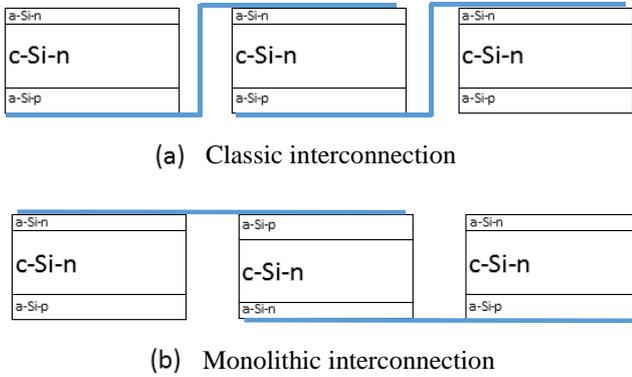


Figure 1: Schematic diagram of a classic interconnected module (a) and a monolithic module with planar interconnect (b)

CELLS. Various cells with different rear side pitches have been made, leading to cell bifaciality from 78 % to 94 %. The numerical modelling of the cells involve: series resistance breakdown (bulk, a-Si, lateral conduction, TCO, contact, finger, ribbons) [9], two-diodes model parameters (I01, n1, I02, n2), and a photo generated current affected by metallisation shadowing and absorptions.

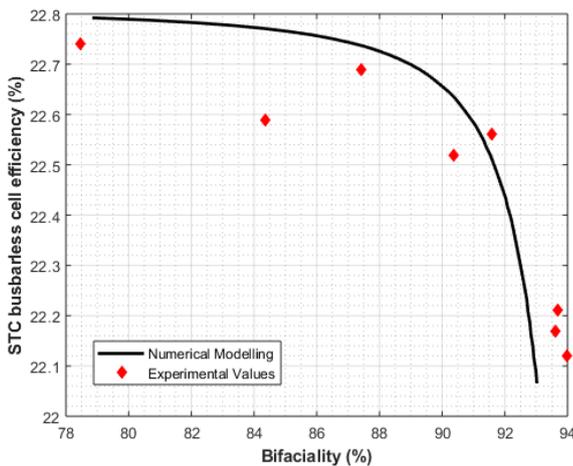


Figure 2: Influence of cell bifaciality controlled by rear side finger pitch on cell efficiency. Red diamonds: experimental values. Black line: numerical simulations

MODULE. The bifaciality to be taken into account when calculating the electrical mismatch is that of the module. It is therefore necessary to study how module bifaciality differs from cell bifaciality. In a first part, we will thus investigate how the module assembly and its bill of materials (BOM) will influence cell bifaciality.

The cell bifaciality in photo generated current is expressed as: $BF_{cell-isc} = ISC_{FAR} / ISC_{FAV}$. When looking at how the photo generated current is modified by the moduling step, we have to focus on several points [10]:

- Optical stack
 - Air/Glass & Glass/encapsulant reflection
 - Glass & encapsulant absorption
 - Refractive index adaptation encapsulant / cell
- Effective shading of ribbons cell interconnect
- Coupling between finger and air / glass interface

With monolithic design, a symmetrical bill of materials will be employed: the same glass, encapsulant, and ribbons are used for front- and rearside of the module. These components therefore have no effect on module bifaciality. The difference between frontside metallization and rearside metallization changes the bifaciality of the module. This is due to the effective shading of 1-pass screen-printed fingers [11] differing in cell (95 %) and encapsulated module (72 %) as shown in Figure 3.

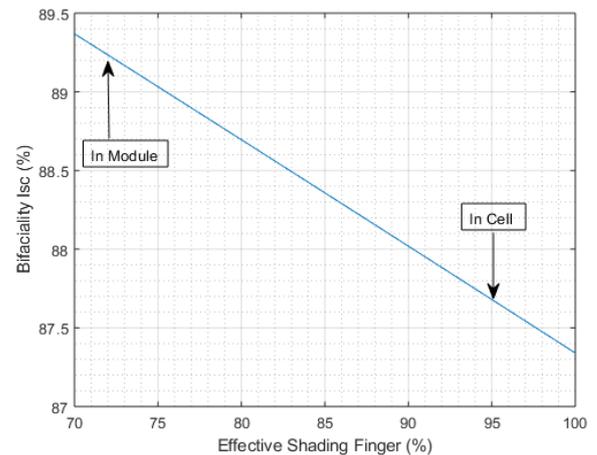


Figure 3: Influence of effective shading of fingers on the value of bifaciality for a front pitch of 2.1 mm and a back pitch of 0.6 mm. The Isc bifaciality is better in encapsulated module (+1.5 %)

CTM perspective: Focusing on the CTM value, the better the bifaciality, the better the cell-to-module ratio. In Figure 4, absorption losses in optical stack and additional resistance effects have been included in the cell performance, in such a way that CTM only represents electrical mismatch losses.

Table 1: Bifacial limit above which monolithic architecture is beneficial. For different spacing values in the monolithic case (0.0, 0.5 and 1.0 mm), in the case of an architecture with full, half and quarter cells. Given for a cell spacing in the standard case of 3 mm (bold) and 2 mm (italic).

$d_{monolithic}$	Full-Cell	Half-Cell	Quarter-Cell
0.0 mm	91.0 / 92.9	86.7 / 89.5	79.9 / 84.3
0.5 mm	91.9 / 94.0	88.1 / 91.1	82.0 / 86.9
1.0 mm	93.0 / 95.0	89.5 / 93.0	84.2 / 89.5

Topic 4: Photovoltaic Modules and BoS Components
Subtopic 4.1: PV Module Design, Manufacture, Performance and Reliability

Efficiency perspective: Focusing on the global efficiency of the module, which includes cell performance, mismatch losses, optical stack and ribbon resistance, we obtain an optimal value of the rearside pitch of 1.2 mm, corresponding to a solar cell bifaciality of 93% (Fig. 5).

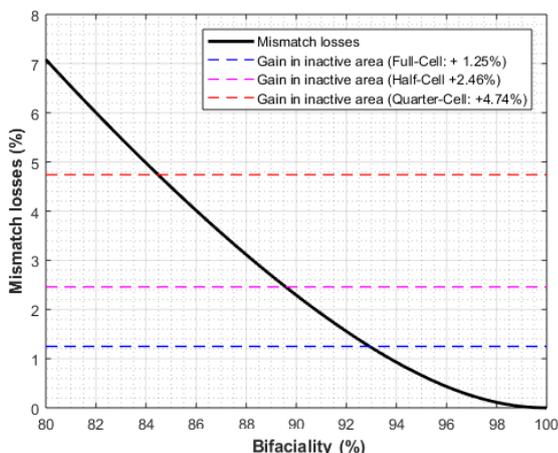


Figure 4: Losses in CTM efficiency caused by electrical mismatch as a function of module bifaciality (black). The horizontal lines (blue, magenta & red) show the efficiency gain caused by the reduction of inactive area for full-cells, half-cells, and quarter-cells respectively.

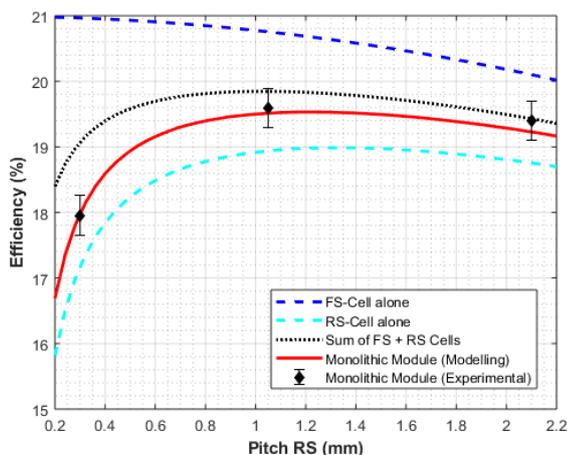


Figure 5: Monolithic module efficiency as a function of rear side pitch of HJT solar cell. Varying the rear side pitch directly affects cell bifaciality. Experimental mini-modules show good agreement with modelling.

Three monolithic mini-modules (2*2 full-cells) have been made with three different rearside pitch: 0.3, 1.05 & 2.1 mm. Measurements - with sun simulator uncertainty of 0.3% abs - show a good agreement with numerical modelling. These results will be statistically consolidated with a larger number of modules.

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