WORLD RECORD MODULE EFFICIENCY FOR LARGE AND THIN MC-SI MWT CELLS

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ABSTRACT: We obtained an independently confirmed module aperture area efficiency of 16.4% using 36 large and thin mc-Si metal-wrap-through (MWT) cells. This is an absolute increase of almost 1% compared to the previous world record. The module was made using a conductive rear-side foil with conductive adhesive for the interconnection. The module was constructed using a dedicated module manufacturing line that is designed to be able to work with extremely thin cells and provide a high through-put of one sixty cell module per minute.
Keywords: metal-wrap-through, back-contact, module manufacturing

1 INTRODUCTION

One of the main objectives of this work was the development of technologies which allow solar modules to be produced at a cost of 1 €/W_p. Cost calculations, taking into account a variety of high-efficiency cell and module concepts, allowed prediction of the module performance required to meet the 1 €/W_p goal [1]. At ECN, cell research has been performed on metal-wrap-through (MWT) cells on multicrystalline silicon. A cell efficiency of 17.0% is required to reach the cost target of the cost calculations. A novel method of module manufacture using large and thin mc-Si MWT cells was developed to help achieve this objective.

A module manufacturing technology was developed for back-contacting cells based on a patterned conductive foil used as the substrate [2]. A production pilot line was built with the potential to manufacture one module per minute. An interconnection technology was developed using conductive adhesive for the interconnect allowing a combined interconnection and lamination step in module fabrication. Figure 1 shows a picture of a finished module.

Figure 1: The finished module showing the characteristic cell pattern. All of the conductive back-sheet is within the active area of the cells. There is no need for bussing at the top and bottom of the module resulting in increased module efficiency when compared with H-pattern modules.

More detail on cell processing can be found in [3], which will also be presented at this conference. The combination of these cells with foil-based module manufacturing technology resulted in a world record efficiency for mc-Si modules surpassing the previous record by almost 1% absolute [4].

2 DEVELOPMENT OF THE MWT MODULE CONCEPT

The main advantages of MWT cells and module include reduced shadowing at the front of the cell due to the lack of front contacts and tabs. The cells can be placed closer together in the module as no tabs pass between the front and rear of the cell. The conductive components of the module can be wider than conventional tabbing material because they are not limited in width as there are no shadowing losses. There is also no need for bussing at the top and bottom of the module so increasing the effective area. The cell design and module layout can be integrated and optimised simultaneously with respect to module output and total costs. For example, the number of contacts between the rear of the cell and the conductive components of the module can be optimised for both cell and module efficiency.

To fully benefit from the advantages of MWT cells, an alternative module manufacturing technology is required. At ECN, a method using a patterned conductive foil as the module substrate was developed. The foil is similar to a standard TPT back-sheet foil with an additional inner layer consisting of a conductive sheet. The conductive sheet is patterned to match the contact points on the rear of the back-contact cell. This results in a series interconnection of the cells on the foil. The cells are placed on the foil using a method analogous with pick-and-place technology used for SMD in the electronics industry. This reduces cell handling to just one pick-and-place step so limiting potential damage to the cells.

Contact between the cells and the conductive foil is formed using a conductive adhesive. The adhesive is printed on the foil at contact points corresponding to the contact pattern on the rear of the MWT cell. Conductive adhesive was chosen as the contact method due to its low processing temperature and the greater mechanical flexibility of the contact relative to a soldered joint. Both these factors contribute to a lower stress at the contact with the cell which is important when working with large and thin cells. The processing temperature of the conductive adhesive matches the lamination temperature of the encapsulant (EVA). This allows a combined curing and lamination cycle with no need for a separate contact processing step.

3 CELL MANUFACTURE

MWT cells were manufactured at ECN using improved processing. The processing steps that were optimised include texturisation, emitter formation and contacting, SiN_x antireflection coating, MWT metallisation, Al BSF formation and diode isolation. An absolute efficiency increase of 1.6% was expected as a result of improved processing. Details of processing are given by Mewe *et al.* [3]

Cells were manufactured with thicknesses of 160 and 120 µm. The wafers were supplied by Deutsche Solar (120 µm cells) and REC (160 µm cells). For the 160 µm cells, an average efficiency of 17.5% for the best 36 cells was reached. The highest cell efficiency was 17.6%. When compared with efficiencies before implementation of processing improvements, this is an absolute efficiency gain of 1.9% compared to our industrial MWT process presented in 2006 [5].

For module manufacture, four batches of cells were produced; two of 160 µm cells and two of 120 µm. The efficiencies are given in Table I.

Table I: Average and maximum efficiencies of the cells that were selected for the four 36-cells modules.

Module number	Cell thickness (µm)	Wafer supplier	Average cell η (%)	Max. cell η (%)
1	160	REC	17.5	17.6
2	160	REC	17.3	
3	120	DS	16.8	17.1
4	120	DS	16.1	

4 MODULE COMPONENTS

For manufacture of the high-efficiency module a number of improvements in the module components were implemented. These are described below.

An improved conductive foil was developed. The accuracy with which the conductive pattern was made was increased by use of in-line processing techniques as used in the printed circuit board industry. This allows better tolerances for the printing of the conductive adhesive and for cell placement resulting in more consistent module performance.

The temperature profile of the laminator was tuned to better match the profile required for curing of both the EVA and the conductive adhesive. Differential scanning calorimetry (DSC) and dynamic mechanical analysis (DMA) measurement were used to follow curing of both materials and an optimum temperature profile derived from these measurements.

An anti-reflection coating was used on the glass sheet at the front of the module. The coating was provided by DSM (DSM Innovation Center B.V., Geleen, The Netherlands). Solar glass without a coating transmits up to 92% of light. With the anti-reflection coating up to 96% of light was transmitted so increasing the light absorbed by the cells.

5 MODULE MANUFACTURE

Module manufacture was performed on a pilot line at ECN (Figure 2). Module manufacture using this pilot line has been reported previously [6, 7]. The line consists of five stations performing the following steps:

Station 1: The patterned conductive foil is place on a carrier plate which transports the foil through the module build process. The foil is held in place by vacuum.

Station 2: The conductive adhesive is printed on the foil. The complete foil can be printed in less than one minute. A 36 cell foil requires 1116 dots of conductive adhesive.

Station 3: The first sheet of encapsulant (EVA) needs to be perforated at the positions where the conductive adhesive has been printed to allow contact with the cells. This station can perforate and place a complete EVA sheet in less than one minute. The foil is then automatically placed over the conductive foil without damaging or smearing the conductive adhesive dots.

Station 4: The cells are individually picked from a stack by a robot and placed at pre-programmed position on foil with the contacts on the cell making contact with the conductive adhesive (Figure 3). A vision system checks the cell integrity and orientation. The module assembly is then returned to station 3 for a second sheet of EVA (without holes) and a sheet of glass. In a production line, additional in-line stations would be included for these operations.

Station 5: For lamination the glass sheet needs to be at the bottom of the module stack. A conveyer belt attached to a pneumatic arm is used to invert the carrier with the module stack in place. The module is then fed out of the pilot line to be placed in the laminator.

Lamination is subsequently performed to create the monolithic assembly. The module was then finished by attachment of a frame and junction box.

Figure 2: The module pilot line at ECN. The module building starts at station 1 at the front of the picture with positioning of the foil on the carrier plate

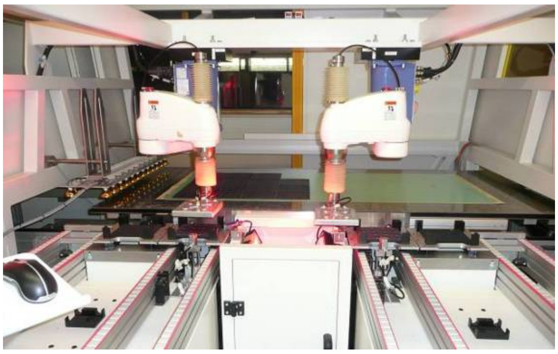

Figure 3: The pick-and-place robots of station 4. The robots pick cells from a stack and places them on the conductive foil which has been printed with conductive adhesive. A vision system between the robots checks the integrity and orientation of the cells

In production line further automation can be implemented, for example, automatic feed in of materials. A production line will also be fitted with a number of carriers with a return system taking a carrier back to the start of the line after module build up is complete. A production line has a potential through-put rate of one module per minute for 60 cell modules. This is up to 8 times faster than a tabber-stringer.

6 RESULTS

Four modules were manufactured with 100% yields i.e. no cells were broken during module processing. This is a particularly good result for the 120 µm cells demonstrating the low stress handling and interconnection technologies as described in section 5.

The module efficiency was measured at ECN and confirmed by measurements at TÜV Rheinland. The two best modules (module 1 and 2) were also measured at JRC-ESTI. The cell efficiencies measured at ECN and module efficiencies measured at TÜV Rheinland and JRC-ESTI are shown in Table II.

Table II: Cell and module efficiencies. Modules 1 and 2 were made with 160 µm cells, module 3 and 4 with 120 µm cells. Aperture area for JRC-ESTI was 8904 cm^2, for TÜV, 8867 cm^2

	Module number and cell thickness (µm)			
	Mod. 1 (160)	Mod. 2 (160)	Mod. 3 (120)	Mod. 4 (120)
Avg. cell η (ECN) (%)	17.5	17.3	16.8	16.1
Encap. cell η (TÜV) (%)	16.63	16.56	16.23	15.74
Encap. cell η (ESTI) (%)	16.63	16.60	-	-
Aperture area η (TÜV) (%)	16.43	16.36	16.04	15.55
Aperture area η (ESTI) (%)	16.44	16.37	-	-

An aperture area was used for the efficiency measurements. The aperture was defined by taping off the module with the tape positioned as close as possible parallel to the outer edge of the cells [8]. The aperture area measure by JRC-ESTI was 8904 cm^2, at the TÜV, 8867 cm^2. The aperture area was measured at the TÜV using a standard rule and at JRC-ESTI with a calibrated measurement device attached to a jig. The apertures were also taped at different dates. This explains the difference in the two values.

The efficiency results show a low loss between the cell efficiency and the encapsulated cell efficiency. The two values are measured using different apparatus, but the small difference does demonstrate the advantages of the MWT concept. The loss in efficiency between cell and encapsulated cell efficiency with H-pattern cells would be expected to be at least twice as high as the values measured here. The improved encapsulated cell efficiency is a result of improved current transport from the cell to the conductive foil and through the conductive foil when compared with straight, narrow tabs as used with H-pattern cells.

The world record efficiencies achieved for all modules are a result of all the advantages of MWT cells and modules as described in section 2. The cell design is more efficient than an H-pattern cell. The packing density of the cells is higher than for an H-pattern module. The lack of bussing at the top and bottom of the module increases the aperture area efficiency. The highest efficiencies were found with the 160 µm cells. This is at least partially due to the silicon material quality, as indicated by lifetime measurements on the material. The aperture area efficiency of 16.44% (±0.33%) achieved with module 1 is a new world record for multicrystalline silicon modules. This value has been put forward to be included in the Solar Cell Efficiency Tables as published in Progress in Photovoltaics.

7 CONCLUSIONS

A cell and module concept was developed which enable the manufacture of modules with a high efficiency using large and thin cells. A significant improvement over the previous world record efficiency on mc-Si modules was achieved.

The module pilot-line was used to successfully manufacture four 36-cell modules with cells of 160 and 120 µm thickness. No cells were damaged during the manufacturing process demonstrating that the conductive foil module concept is an enabler for the production of modules with very thin cells.

Improvements to the module manufacturing process including an improved conductive foil, improved curing of encapsulant and conductive adhesive and the use of an anti-reflective coating on the front-side glass sheet all contributed to a consistent and high module quality as demonstrated by the high efficiencies achieved for all four modules.

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