THIN FILM SILICON SOLAR CELLS IN A SEMI-TRANSPARENT MICRO-STRUCTURED METAL SUBSTRATE CONFIGURATION

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ABSTRACT: We present our work on the combination of thin film silicon solar cells and a commercial window shading device (MicroShade^{TM}, PhotoSolar) into a novel, glass integrated photovoltaic product for building integration. The development of amorphous silicon solar cells (a-Si:H) on the MicroShade^{TM} substrates was carried out following two simultaneous paths; First the deposition process for a-Si:H solar cells on this new perforated substrate was investigated and modified in order to achieve higher efficiency devices; Then the authors tackled adhesion and shunt issues that appeared on this new substrate. The deposition of solar cells on this semi-transparent structure was demonstrated to be feasible and we fabricated solar cells with an initial efficiency of 5.86% for a cell size of 450mm^2.

Keywords: Amorphous Silicon, Thin Film Solar Cell, Building Integrated PV (BIPV).

1. INTRODUCTION

This paper presents a joint project between the company PhotoSolar A/S from Denmark and the Photovoltaic laboratory (PVLab) of the IMT Neuchâtel of EPFL in Switzerland. PhotoSolar is a supplier of a window integrated shading system called MicroShade^{TM} [1]. It consists of a thin metal sheet with inclined micro perforations, as illustrated in Figure 1. The PVLab has a long standing experience in processing and fabrication of high efficiency thin film silicon solar cells and modules on different substrates, such as glass, metals or plastics [2].

The goal of the work described in this paper was to develop a new power producing version of MicroShade^{TM}, a "PowerShade" which features a combination of efficient solar shading and solar power generation.

We will first present a review of the main developments achieved so far. It includes the selection of the “ideal” MicroShade^{TM} product used as substrate for the fabrication of the photovoltaic device; here the surface quality will be mostly discussed. Then, the optimization of the cells on this specific substrate will be described, especially with focus on the layer adhesion, cell structuring and shunt reduction.

Figure 1: MicroShade^{TM} window installed on a building.

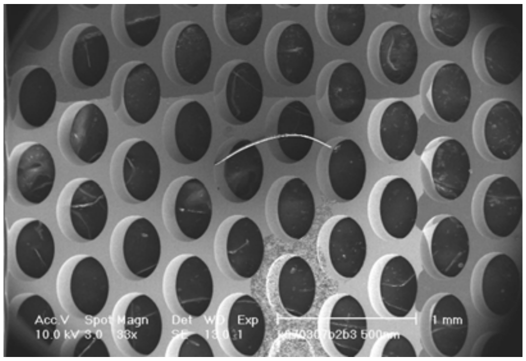

Figure 2 : Microscope view of the oval inclined holes of a MicroShade^{TM} substrate enlarged (image size approximately 4.0x2.5 mm).

2 EXPERIMENTAL

In this section, the preparation of the substrates, the deposition of the solar cells and the characterisation methods used for this work are described.

The MicroShade^{TM} substrate was covered with a double layer back contact consisting of ZnO/Al. Then, amorphous silicon (a-Si:H) thin-film solar cells [3] were deposited in the n-i-p configuration by Very High Frequency Plasma Enhanced Chemical Vapor Deposition (VHFPECVD) in a KAI R&D reactor from the company Oerlikon Solar. Finally a layer of Indium Tin Oxide (ITO) deposited by DC sputtering at room temperature was used as transparent conductive front electrode.

Due to the perforations of the substrate, it was necessary to improve the current collection at the front side of the solar cells. For that, a silver grid was deposited on the ITO.

The solar cell efficiency was characterised by current-voltage (IV) measurements at 25°C under AM1.5g solar spectrum with a solar simulator (Wacom WXS-140S-10). From that IV curve the V_{oc} and FF were determined. The short circuit current-density (J_{sc}) was measured separately by convolution of the external quantum efficiency (EQE) with the AM 1.5g spectrum and then the J(IV) was normalized with the Jsc_EQE. This method avoids uncertainties in the determination of the solar cell surface area.

Finally, IR lock-in thermography analysis was performed in parallel with Scanning Electron Microscopy (SEM) in order to determine the exact location of the shunts and to help identify the nature of each shunt (e.g. poor adhesion, presence of particles or too important roughness).

3 RESULTS AND DISCUSSION

In the following, we will discuss the main developments made to improve the efficiency of the solar cells deposited on the MicroShade^{TM} substrates.

3.1 Adhesion

The first step of this project was to establish a cleaning process of the MicroShade^{TM} plates which turned out to be critical for a good adhesion of the subsequent Al, ZnO and silicon layers. Figure 3 presents a case of bad adhesion between the aluminium layer deposited and the substrate; the Al is peeling off at different places between the holes.

To solve this issue, we optimised a 2-step wet cleaning process that was applied to the substrates before the deposition of the back contact layers. The first step is a basic bath cleaning for lubricant and dust removal. The second step is an acid bath which removes the oxides and hydroxides at the surface. The concentration of solvent, temperature and time of cleaning are very critical parameters for the improvement of the adhesion.

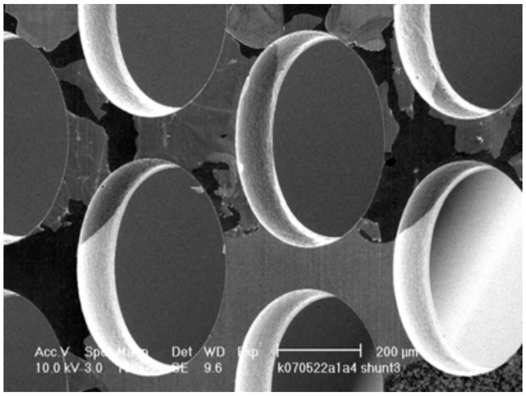

Figure 3: SEM image of a layer that peels off after deposition due to its bad adhesion with the metallic substrate.

3.2 Holes and serial resistance

Figure 4 illustrates that the high density of holes in the substrate requires a longer way for the collection of the photogenerated charge carriers, resulting in a high serial resistance. In order to overcome this limitation, we increased the ITO thickness from 70nm to 210nm. However, even at this front contact thickness, the resistive losses are still too high to effectively collect the current from the standard cell size of 450mm^2. With the help of simulations, an improved conductivity was achieved by adding silver grid contacts on the ITO layer. The evaporation of a 1µm thick silver layer, structured in lines of 1mm width avoids discontinuities at the substrate holes, Thus, we obtain a reduced serial resistance of about 40 Ωcm^2 that is still very high.

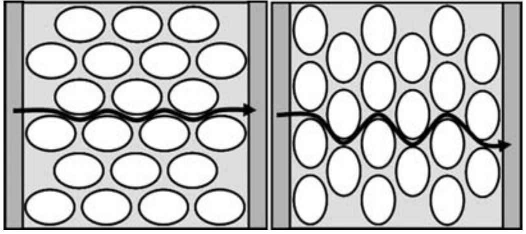

Figure 4: Illustration of the current path through the substrate in between the holes. The serial resistance depends of the holes orientation parallel or perpendicular to the current way.

3.3. Reduction of shunts

The special structure of the MicroShade^{TM} substrate can lead to more shunts compared to cells on continuous substrates. The impact of these shunts were analysed by SEM (Scanning Electron Microscope) and IR lock-in thermography. We could catalogue eleven different types of shunts, coming either from dust particles or surface defects as observed in Figure 5 and Figure 6. Taking into account these observations, the fabrication process could be improved by significantly reducing the number of shunt paths as shown in Figure 7. The resulting cells show slightly higher efficiency and better yield.

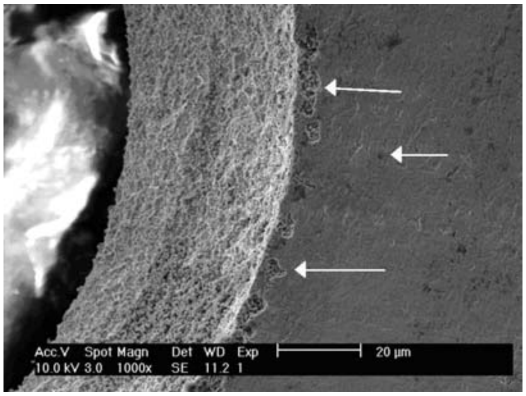

Figure 5: SEM image of a hole edge from the MicroShade^{TM} substrate. We can observe a surface with big crevices.

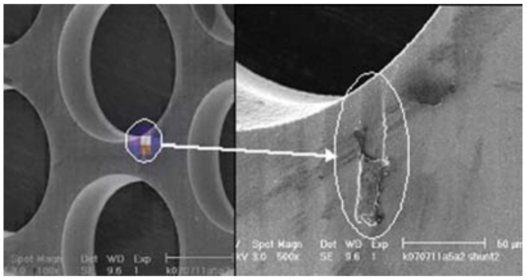

Figure 6: Lock-in thermography photograph of MicroShade^{TM} solar cell showing a shunt path (left). A SEM observation of the same area reveals that the defect is due to a scratch (right). .

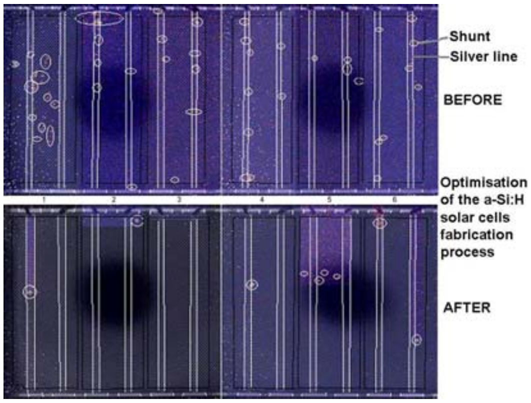

Figure 7: Lock-in thermography photographs of MicroShade^{TM} modules with identification of shunts. The top and bottom images have been taken on MicroShade^{TM} modules deposited before and after some optimization of the a-Si:H solar cell fabrication process, respectively. This optimization allowed to strongly reduce the number of shunts (represented here with small white circles) in the MicroShade^{TM} modules.

3.4. Efficiency of MicroShade^{TM} modules

Single a-Si:H solar cells were first deposited on glass substrates in order to avoid the apparition of shunts and serial resistance as discussed in the previous chapters. As shown in Figure 8, the best initial results of a 450mm^2 amorphous solar cell on MicroShade^{TM} substrate obtained so far are:

V_{oc}=844mV, FF=50%, J_{sc}=7.5mA. Reported to the surface of the substrate without the holes, the best initial efficiency obtained is 5.86%..

It is important to note here that if the device scheme might appear not ideal for perpendicular irradiation (with 50% opening), at higher angle the structure is such that the ratio of active area to hole areas is increased, which is a specific advantage of the PowerShade geometry compared to standard semi-transparent thin film modules. However, the perforated substrate requires a high thickness of the a-Si:H intrinsic layer which will induce a significant Staebler-Wronski degradation effect [4]. Better stability and reduced collection losses are expected for a-Si/a-Si tandem cells with the same thickness of the active layers.

Table 1 shows the degradation of a 25mm^2 tandem cell deposited on glass substrate; the degradation of the 120nm thick top solar cell is low, but the 850nm thick bottom cell shows significant loss in current. Therefore, to improve the total efficiency and to reduce the solar cells degradation, the next steps will be the development of a microcrystalline bottom cell and eventually a micromorph tandem structure.

Figure 9 shows a first generation PowerShade demonstrator incorporating a-Si solar cells. Performance tests will be done in the next months.

Table 1: IV and EQE performance of amorphous tandem solar cells before and after light soaking under one sun.

	V_{oc} (mV)	FF (%)	J_{sc} bott. (mA/cm^2)	J_{sc} top (mA/cm^2)	L.soak. (%)
Initial	1713	61.0	6.75	4.56	0.0
100h	1725	59.8	6.01	4.51	1.1
1000h	1706	58.6	5.50	4.50	4.3

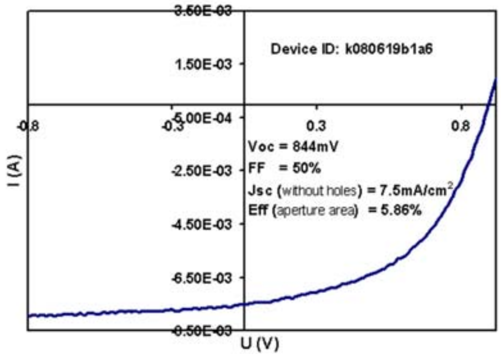

Figure 8: Initial IV curve of the best 450mm^2 a-Si:H solar cell deposited on MicroShade^{TM} substrate.

Figure 9: Sight through a window covered by PowerShades.

4. CONCLUSION

The deposition of thin film silicon solar cells on the MicroShade^{TM} substrate could be demonstrated. The adhesion issues observed at the beginning of the project could be solved. A detailed investigation of shunts on these specific substrates have led to significant improvements in the cleaning process of the substrate and important reduction of the number and size of shunts. The best efficiencies obtained with 450mm^2 solar cells so far are 5.86% (w.r. to the aperture area of the perforated surface), and next step will be the implementation of micromorph tandem cells in order to enhance the efficiency and reduce the Staebler-Wronski effect.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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