AN ARCHITECTURAL APPROACH FOR IMPROVING AESTHETICS OF PV

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ABSTRACT: In order to improve the social acceptance of photovoltaic modules, the choice in panel color and size should be enlarged. Although various approaches have been reported to change the appearance of PV modules, it often adds complexity to the manufacturing process. Here an approach is presented in which a design module can be manufactured on standard module lines, by adding a print interlayer to the module. First results are shown on small PV panels, including performance and stability tests. Also full size panels are shown with an aluminum back panel including mounting structures for easy mounting on roofs and facades. The results show that although there is a drop in conversion efficiency by applying a print, the overall drop is lower than expected based on the print coverage. The stability tests show promising results after thermal cycling, damp heat, UV degradation and outdoor exposure.
Keywords: Colored PV, design, photovoltaic, PV modules, performance

1 INTRODUCTION

The installed cumulative PV capacity has increased almost exponentially in last decade [1]. If this increase continues, PV will become much more visible in urban areas. Nowadays, the appearance of photovoltaic (PV) modules on buildings is not very attractive. Partly because the modules have a standard size that does not allow coverage of the full roof, partly because the panels are sensitive to shade and are thus only used in positions that are not affected by shade, but also because they have a completely different look compared to the surrounding surfaces. This often results in a patch-work like arrangement of visibly prominent panels as in Fig. 1. This aesthetically unappealing look will not favor large scale implementation of PV in urban areas. It needs better tuning of the aesthetics of the modules and more size flexibility.

Figure 1: Typical PV systems as installed on rooftops and facades.

2 COLORED PV MODULES

Various research groups and companies are developing modules with a different appearance compared to the traditional c-Si modules [2]. These concepts differ in the way the color is added to the module. Manz e.g. adds color by printing a ceramic layer on the front glass [3] Swiss Inco also uses the front glass but adds a multilayered coating to generate the color [4]. Others, like LOF e.g., vary the thickness of the anti-reflection coating of the cell, thereby tuning the color [5]. Other groups use multilayers on the cell [6]. There are also studies on nanoparticles on the cell that give the cell a nice color.[7] And there are several companies that insert a foil with a uniform or graphical print [8-11]. At ECN a procedure has been developed that adds the colored graphics at the inside of the module. The fabrication procedure is based on ECN's back contact foil technology [12-14] but can be used in combination with other module technologies as well. The modules can be manufactured without adding manufacturing complexity and thus cost.

3 DUTCH SOLAR DESIGN

In the back contact foil technology the back contact cells are interconnected via a conducting foil. This allows easy variation of the module size without the need for large changes in the module line. The appearance of the modules is easily changed by applying graphics at the inside of the module. The application of such colored modules typically lies in renovation of buildings in which the appearance of the buildings must not change and thus the modules have to mimic traditional building materials like bricks, stone, wood, marble and roof tiles. On the other hand they can be used in eye catching offices or company buildings for which more artistic designs might be used. The technology allows both approaches. In fact, the options are endless and will offer a new playing field for architects and designers.

As a start small brick modules have been made that look like a piece of brick wall, see Fig. 2. In this series quarter cells were aligned such that they form brick-like patterns. The coverage of the print was changed from 0% at the cell positions, left picture in Fig. 2 where the "cement" of the print was positioned between the cells, up to almost 45% in the most right picture of Fig. 2.

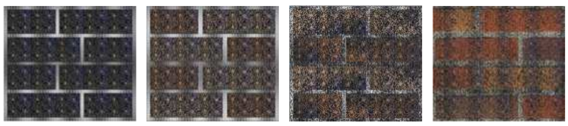

Figure 2: Typical PV systems as installed on rooftops and facades.

Of course, adding the color print does affect the power output of the panel, but the overall loss is much less than what is expected based on the coverage of the print. This is shown in Fig. 3, where the power loss of the panels is plotted as a function of the coverage of the print. The relatively low loss is due to the fact that the ink of the print is partly transparent. Fig. 3. shows also the results for a panel with the highest coverage with a structured front glass. As can be seen, the relative loss is comparable as with the flat glass. However, the appearance of the two panels is quite different.

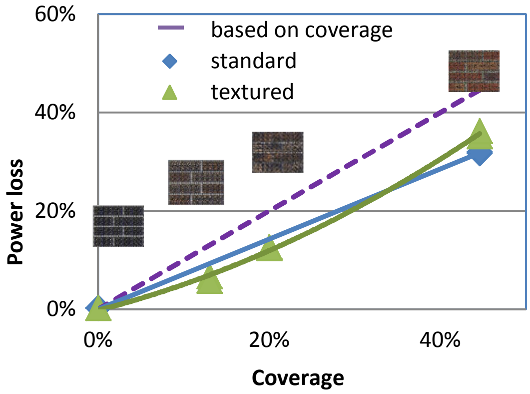

Figure 3: Power loss as a function of the print coverage. Also shown is a 1:1 relationship, showing that the actual measured loss is substantial lower than the coverage fraction.

Fig. 4 shows the panel with flat glass on the left and structured glass on the right. Clearly the left panel has much stronger reflections than the right panel in which the brick print remains clearly visible.

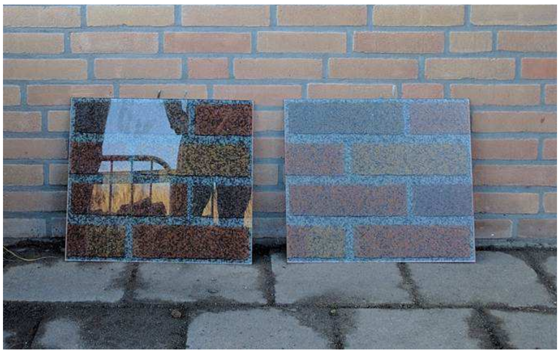

Figure 4: Panels with a brick design coverage of 45% with flat front glass on the left and structured front glass on the right.

As mentioned above, the ink of the print is partly transparent. Increasing the transparency will at some point start to affect the appearance of the panel. The transparency could still be improved without changing the appearance much. The output of the improved panel showed 7% less loss for the highest coverage of the print, resulting in an overall loss of about 25% for a coverage of 45%. Fig. 5 shows the two panels next to each other. There is only a very small difference, where the colors of the left panel are slightly lighter than of the panel on the right. The latter is the panel with the increased transparency of the ink.

Figure 5: Panels with a different ink transparency: left lower transparency than on the right.

Colored prints are built up from the basic colors: cyan, magenta, yellow and white. In a first step to be able to predict the performance of multi-colored prints, the performance of monochromic prints was measured, where both the coverage and dot size of the print was varied. Each panel consisted of 4 cells that could be measured individually. An example of the panels is shown in Fig. 6 for a dot size of 2 mm and different coverage fractions.

Current voltage measurements on these panels show that the current of the cells is hardly dependent on the dot size, but does depend on the coverage. This dependence differs per color. The results are given in Fig. 7. Cyan has the highest loss, followed by magenta, yellow and white.

Initial stability tests were performed on these panels. Figure 8 shows the result of outdoor testing, where the short circuit current is shown as a function of outdoor hours. Data are shown for irradiances between 450 and 550 W/m^2 for the cells behind the white and the cyan print with a dot size of 3 mm and coverage of 30%. The current is nicely stable for both white and cyan. The other colors are not monitored continuously so they cannot be shown. There might be a very small (0.7%) degradation observed after 900 hours, but this can also be due to dirt on the panels. Similar panels are also subjected to IEC 61215-2 thermal cycling, 2 panels, and damp heat tests, 2 other panels. Figure 9 shows the results for panels that had an additional Al panel laminated to the back side of the panel. The results show that after 1000 hrs damp heat testing (full IEC test) and 300 thermal cycling testing (1.5 times IEC test), the panels perform slightly better than at the beginning and also better than the reference that was kept in the dark at room temperature. The change is smaller after damp heat testing than after thermal cycling testing. Further inspection is needed to see where the differences arise from. As mentioned the panels shown above in the stability tests had a large size Al back panel laminated to the backsheet. This was done to be able to

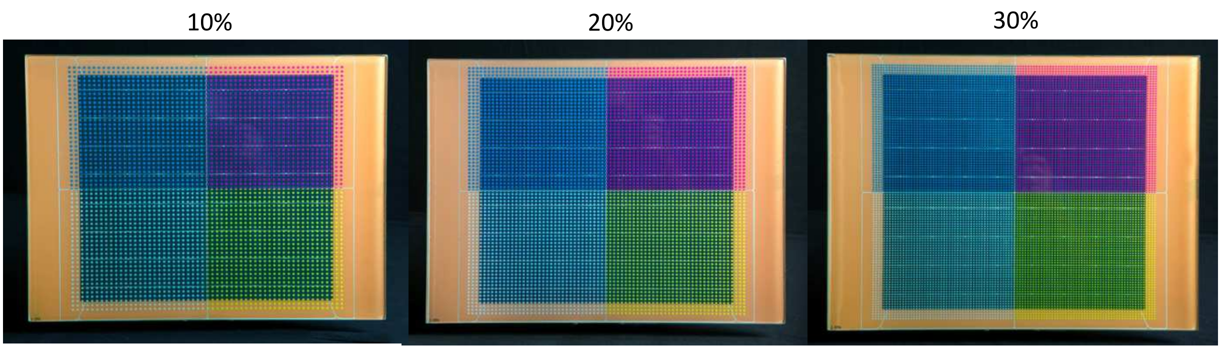

Figure 6: Panels with 4 cells where each cell has a single color print with a specific coverage and dot size.

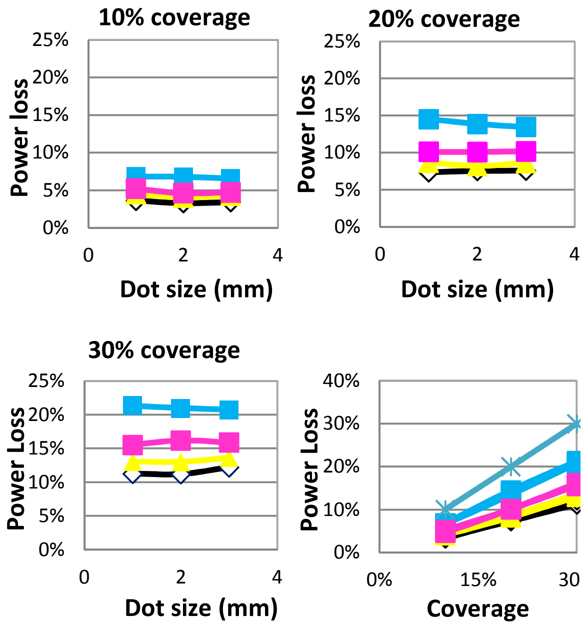

Figure 7: Power loss as function of dot size (1-3 mm) and coverage (10-30%) for the different colors: Cyan, magenta, yellow and white (indicated bij the open black triangles). The bottom right graph shows the average power loss if the 1-3 mm dot sizes as a function of coverage. Also shown in that graph is the 1:1 relation between power loss and coverage (purple dotted line)

use them as façade elements, where the Al back allows for easy mounting of the panels. This was continued in the fabrication of large size, 900x1200cm, façade elements with more artistic design prints. Figure 10 shows a series of these full size façade elements from the front side.

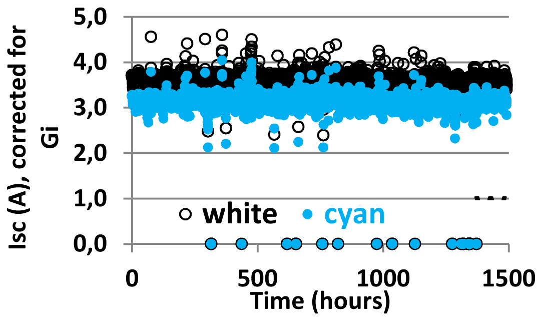

Figure 8: Outdoor stability test on laminates with white or cyan print. Data is selected for an irradiance between 450 and 550 W/m2.

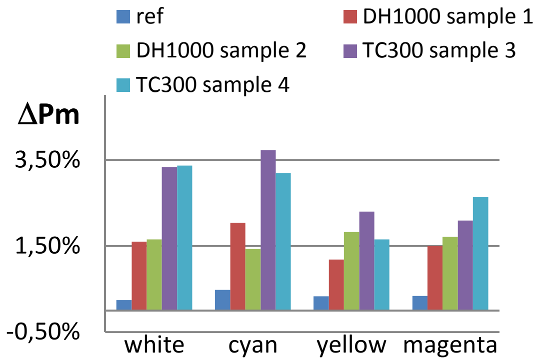

Figure 9: Relative change in power output after thermal cycling tests of 300 hours and damp heat test of 1000 hours. Each test contained two panels with 4 different colors. Also shown is a reference panel that was kept in dark at room temperature.

The output of these modules depends on the actual print, but is between 20 and 25% lower compared to a module without print. The rear of these modules have an Al plate with a special frame, see Fig. 11. This allows easy mounting on a façade.

Figure 11: Rear side of the façade elements showing the Aluminum frame for mounting the modules to façades.

5 CONCLUSIONS

Multi-colored modules have been presented that combine a visually appealing appearance with an efficiency that is better than expected based on the coverage of the print. For a print coverage of 30% the output of the module is about 20% lower than the output of a module without print. The overall efficiency depends mainly on the coverage and the main colors that are used

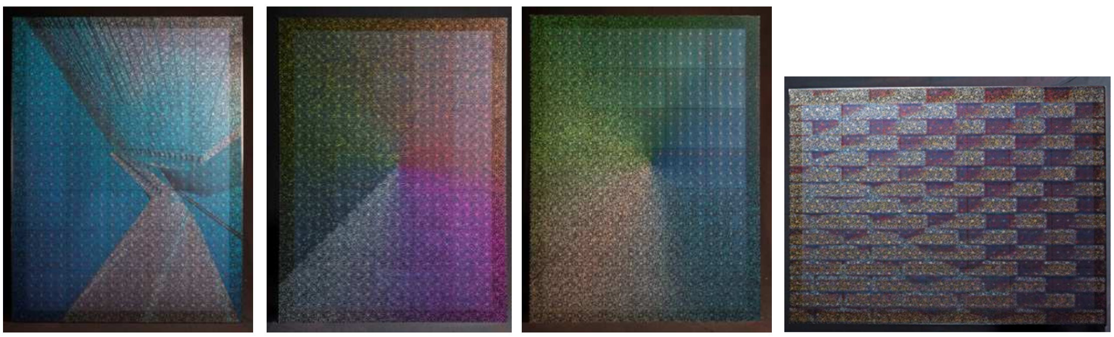

Figure 10: Façade elements with different full color prints.

but hardly on the size of the ink dots. By increasing the transparency of the print, the output could be increased by 7%. Stability tests have shown no sign of degradation after damp heat and thermal cycling tests comparable to the standard IEC test. Also outdoor tests and UV degradation tests show stable results. Large size façade element have been built with a mounting frame to facilitate application. Overall these panels are well suited for building applications and offer an aesthetic alternative to the standard modules.

6 ACKNOWLEDGMENTS

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