New module concept for aesthetic PV integration with better shadow performance

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Abstract

Tessera® is a new Si PV module concept especially developed to improve the integratability of PV. Tessera enables freedom of module size, shape and form and moreover has a high shadow tolerance. Where standard PV systems have a significantly reduced output under partial shading conditions, a shadow of 10% on a module can decrease the output by 30%, the dedicated electrical interconnection of cells in the Tessera® concept gives an almost linear response under shading.

Keywords: PV systems, shade tolerant, annual yield, aesthetics, solar modules, PV modules, size flexibility.

1. Introduction

In order to reach the goal of the Paris climate change agreement, keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels, it is envisaged that the role of solar energy in the energy mix will increase substantially. As a result PV will become more and more visible in Urban areas. The current implementation of PV is often as a building added rooftop system, where only part of the roof is covered (see Fig. 1a, c). The aesthetics of such applications obviously can be improved (see e.g. Fig 1b, d) in order to increase the acceptance of PV. To enhance the integratability of PV modules several aspects need to be addressed around surface appearance, shape and size flexibility and shadow tolerance.

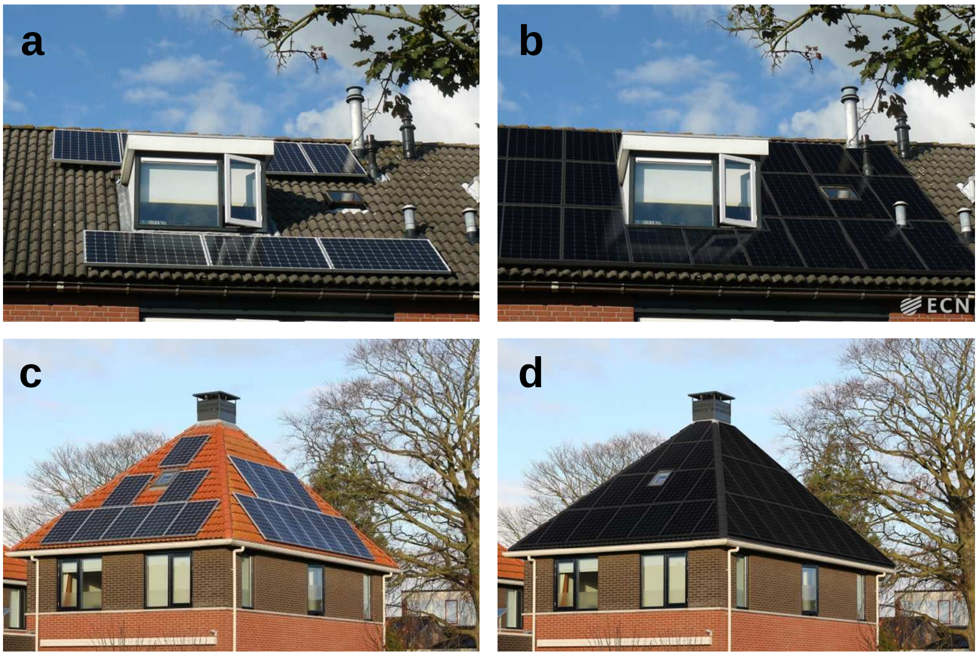


Figure 1: State of the art situation for PV on rooftops (a and c). Mock-up of the same buildings with Tessera modules (b and d).

The improvement in surface appearance by more variation in colour and shape is addressed e.g. in [1], in which various modules have been made with a completely different appearance compared to standard modules. The appearance of the modules can be changed by applying graphics at the inside of the module. References [2-4] report on alternative approaches, using a black back encapsulant to make a fully black module, or by adding nano coatings on the front side of the glass to change the colour of the module. In this paper we will focus on the aspects of size and shape flexibility of back contact foil technology [5-7] and on improved shade tolerance by using a newly developed PV module technology called Tessera® [8,9]. This technology offers the potential of good shade tolerance at a low cost. The Tessera® concept is based on the existing and proven back contact foil technology in which the back contact cells are interconnected via a conducting foil. Not only is back contact technology an enabler for the Tessera® concept, it also allows easy integration of colour and prints and has more form and shape flexibility than normal H-pattern modules [1] without the need for large changes in the module line.

2. Back contact foil technology

Back contact modules consist of a backsheet (e.g.Tedlar) with Cu foil on top. The solar cells are contacted to the patterned Cu foil via an electrically conductive adhesive. An EVA layer isolates the back of the cells from the Cu foil outside the dots. Transparent EVA is used as the encapsulant between the cells and the front side glass. A schematic representation of the module stack is shown in Fig. 2.

The back contact foil technology offers additional flexibility compared to 3-string modules. The pattern of the foil can be adapted to a different module layout by changing the conducting pathways in the Cu foil. These pathways are defined by the isolation lines in the Cu film and can e.g. be laser scribed, see Fig. 3a. Examples of patterned foils are shown in Fig. 3b-c. The pattern can e.g. be adapted such that cells can be omitted to form transparent areas in the module, see Fig. 4a, or to make different shapes such as a circle see Fig. 4b, and triangular modules to fit the sides of the roof as e.g. in Fig. 1d.

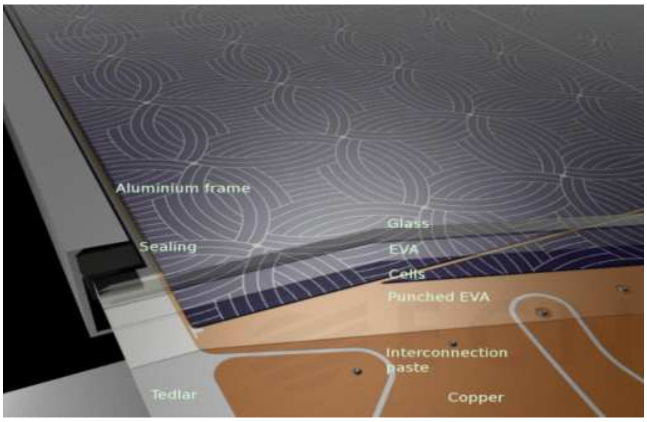


Figure 2: Presentation of the build-up of a back contact module using an interconnecting backsheet.

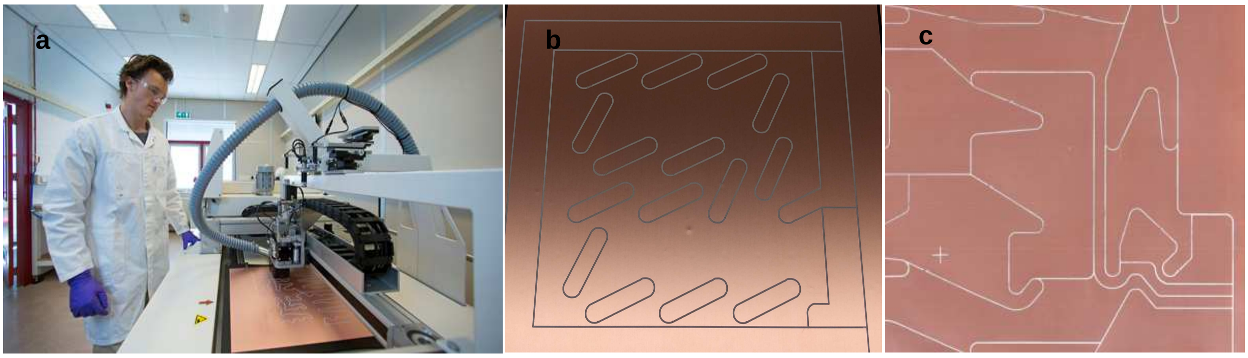
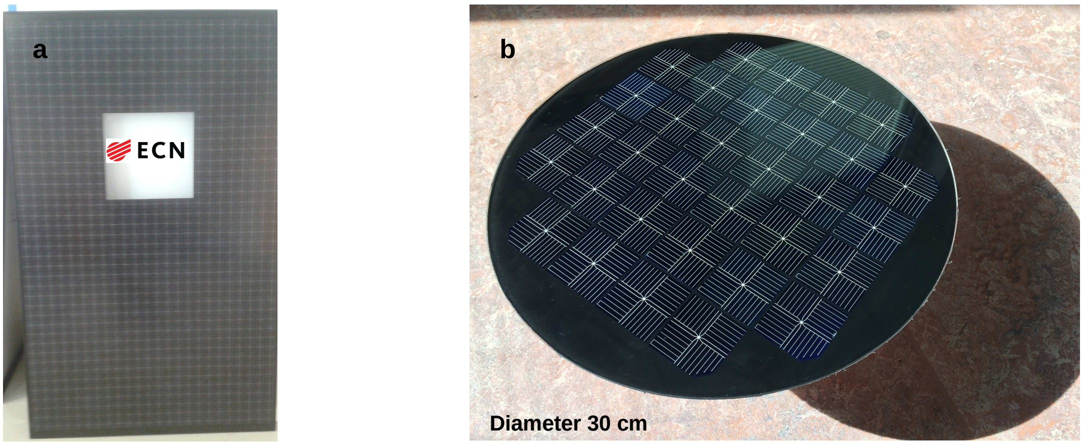


Figure 3: a) Cu foil patterning equipment. b-c) examples of different foil patterns for different cell configurations in the module.



Size: 1.6x1 m

Figure 4: Examples of module shapes and options possible due to Cu backsheet technology.

3. TESSERA module concept

Standard PV modules consist of 3 series connections of each 20 cells. In a series connection, all cells have to carry the same electrical current. As a result, a shaded cell in the series connection will decrease the current, and thus the power output of the whole series connection of cells. A shadow of a few % can thus decrease the output by 30%. This hampers application in the built environment, where shade is often present. By adding electronics to the system (power optimizers or micro-inverters) [10-16] or by re-designing the cells such that they have a softer breakdown characteristics [17-23], the modules become less sensitive to shade [24], but it also adds cost to the system. The Tessera® concept, is a module concept that is based on back contact foil technology. For Tessera®, the 6 inch cells have been cut to produce 16 mini cells. The mini cells are connected in series and protected with an in-laminate low current by-pass diode. In total 64 mini cells are connected in series, forming a maximum power point (MPP) voltage of around 31V at standard test conditions (STC). Blocks of 64 mini cells are then connected in parallel. These blocks can be seen as the strings of the module. The smaller blocks of the concept are the basis for the improved shade linearity. A full size Tessera® module contains 15 building blocks.

Only a minor upgrade of a standard back contact module line is needed to implement manufacturing of Tessera® modules using the smaller cells. Hence, the modules can be manufactured without adding manufacturing complexity. A full size Tessera® shade tolerant module has been made and is shown in Fig. 5.

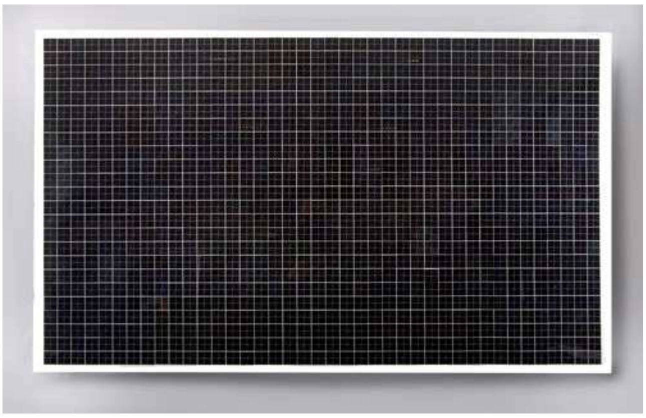


Figure 5: a full size Tessera® module.

4. Tessera® shadow response

A Tessera® module and a standard 3 string module, (H-pattern 60 cell module made by GPPV, GPM230P-B-60), were subjected to various shadow configurations in which 1-12 cells were shaded by black paper. I-V measurements under these shadow configurations were done using a PASAN flash tester at 1000 W/m2 irradiance, which is comparable to the irradiance on a module on a sunny day if the module is facing the sun. Fig. 6 shows the measured power loss versus shade fraction and number of affected strings. Measurements are indicated by the black dots. The standard module has 3 strings and the Tessera® module has an equivalent of 15 strings (building blocks). At a shade fraction of 0.017, 1 shaded 6 inch cell, the Tessera®

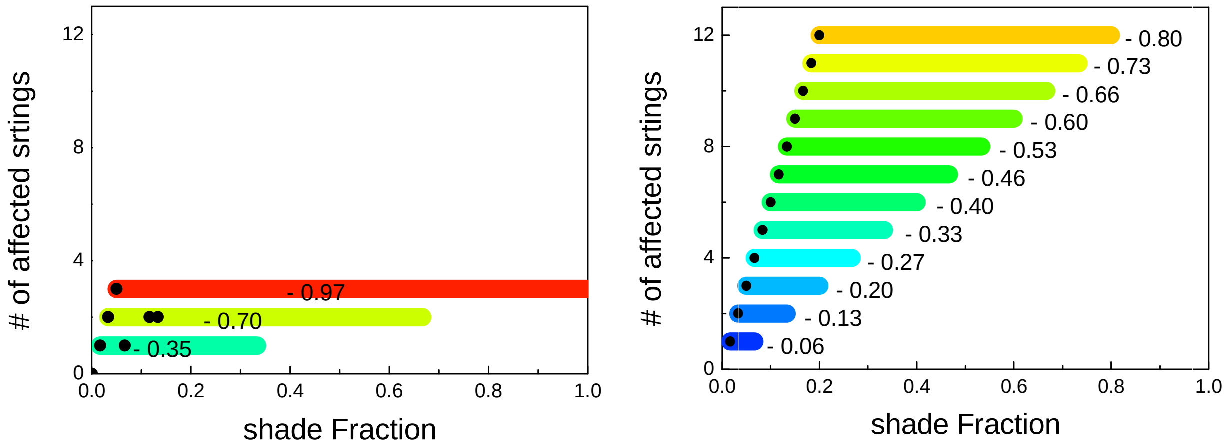


Figure 6: Expected relative power loss, based on number of shaded strings and shade fraction. Left for a standard 3 string module and right for the Tessera® *module. The colours and numbers indicate the height of the power loss, blue=low, red=high. The black dots show the measured data points.*

module has a power loss of 6%, indicated by the number next to the colored bar, which is much smaller compared to the power loss of 35% in the standard module. More shaded cells within 1 string will not affect the output further because the current, and thus the power, is already reduced to zero if one cell is fully shaded. This is seen in Fig. 6 as a constant color for increasing shade fractions along the x-axis. When an additional shaded cell lies in another string, than the output will drop further, indicated by the changing colors along the y-axis. Clearly the standard module has a much larger loss for small shadows across multiple strings.

The benefit of the Tessera® concept is especially seen when a pole like shade falls on the module, see Fig. 7. In a standard module such a shade will affect most of the time all three strings, thereby reducing the output almost completely, whereas in this example 5 building blocks of the Tessera® module will be affected, reducing the output to about 70% of the unshaded output.

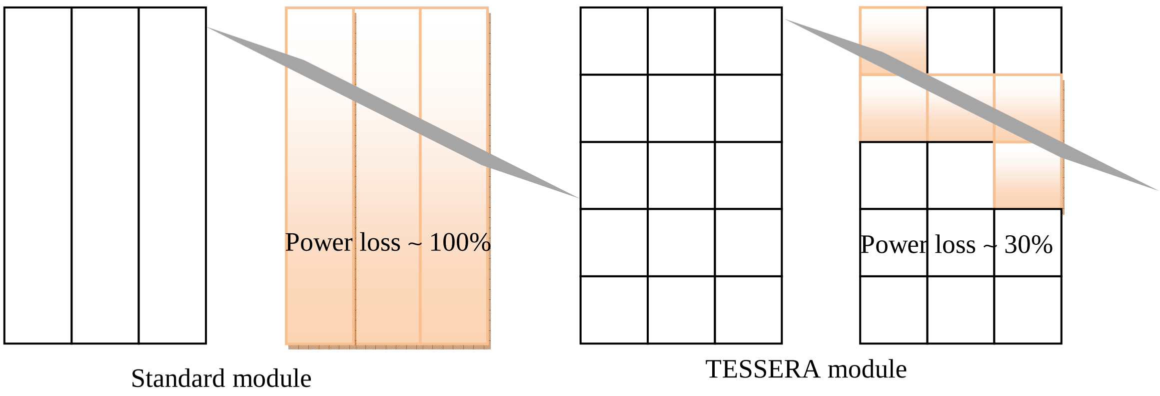


Figure 7: Effect of a pole like shadow on a standard 3-string module (left) and a Tessera® module (right).The blocks in the Tessera® module represent the building blocks.

The Tessera® module connected to a micro-inverter from Heliox was measured outdoor together with a standard module, see Fig. 8. The normalized data versus irradiance, are shown in Fig. 9, is somewhat lower compared to the standard module. Both non-shaded and shaded results as presented. The white paper is semi-transparent and blocks only 1 string of the standard module, resulting in a drop of already 36% at roughly 1000 W/m2 irradiance (noon on a sunny day). The Tessera® module drops only 14% when subjected to the same shade.

Figure 8: Outdoor setup with on the left a standard module and on the right the Tessera® *module*

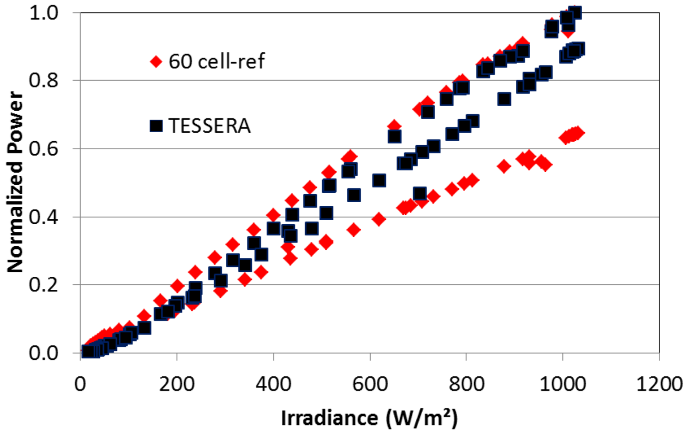


Figure 9: Power output versus solar irradiance for a standard and Tessera® *module with and without the shadow as shown in Fig. 6*

5. Conclusions

A module technology has been shown that is much more shadow tolerant than the current state-of-the-art PV technologies. The Tessera® concept is based on the back contact technology and can be produced on a standard back contact module line with some adaptions for the handling of the small cells. It allows variations in shape and appearance, which offers much more flexibility for applications in urban areas. It is shown that for a shadow with an area on the order of one 6 inch cell, the Tessera® concept has an almost 6 times higher output than a standard 3 string module with 3 bypass diodes. The Tessera® concept and the back foil technology can also be combined with the graphics layer to improve the appearance even further. This palette of options opens a toolbox for integration of PV.

6. Acknowledgements

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