SMALL UNIT COMPOUND MODULES: A NEW APPROACH FOR LIGHT WEIGHT PV MODULES

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ABSTRACT: A new concept for light weight solar modules is presented in this paper. The main difference to the common module type is the replacement of the frame at the laminates fringe by a lattice-like structure at the rear or at the rear and front side. Due to the smaller distances between the mechanical supporting elements the stiffness of the laminate itself can be reduced to a minimum, enabling the use of thin glass or alternative materials like for example polymer foils.

Keywords: PV module, new concept, compound, new material, construction

1 INTRODUCTION

For some PV applications the weight of PV modules is an obstacle. Today's commercial buildings are designed with little to no spare structural capacity due to cost constraints. In fact, most industrial properties built before the 1997 Uniform Building Code (UBC) change are not suitable for conventional rooftop solar installation without costly structural improvement. Therefore light weight modules may address this market segment by achieving weights, which still allow an installation on such roofs. Also for some innovative PV system solutions, e.g. PV elements for parking roofs [1], light weight PV modules may be a prerequisite. In general, a lower module weight may also result in more lightweight and thus cheaper mounting solutions increasing the safety and time-efficiency of installations. Due the tremendous price reduction of PV modules achieved in last couple of years an increasing share of the price for a PV system is related to the mounting of modules, which makes cost reductions in this field more relevant [2]. Innovative concepts based on lightweight modules and mounting structures are thus a suitable means to further reduce the total cost of PV systems.

The segment of light weight modules can be subdivided in thin film and crystalline silicon modules. Light weight thin film modules are mainly flexible structures intended for a flat installation on roof tops. However, a horizontal positioning on the ground is unfavourable with regard to energy harvest, soiling and residual water, which can lead to faster degradation of the modules. There are approaches for light weight c-Si PV modules on the basis of glass/backsheet and glass/glass laminates. The most light weight concepts for c-Si however use alternative materials to glass, e.g. ETFE as transparent medium at the front side, supported by a rigid material such as glass fibre reinforced plastic at the laminates rear.

Standard, 60 cell, crystalline silicon glass/backsheet modules typically have weight in the range of 18- 22 kg, depending on the thickness of the glass and the frame. This results in a specific weight of about 12.5 kg/m^2. The mechanical rigidness is due to the glass and a circumferential aluminium frame.

Glass/glass modules are gaining market share, due to a presumed longer lifetime and other benefits such as the potential bifaciality. Glass/glass modules may be mounted without an additional frame depending on the thicknesses of the glasses and the sub construction used. Light weight glass/glass modules have been reported from Fujipream achieving a weight of 8.2 kg using glass thickness as low as 1.1 mm and an ionomer– based encapsulant [3,4]. The size of the 215 Wp module is not given in the references, therefore a specific weight cannot be calculated.

Modules using alternative materials to glass are commercially available and achieve specific weights of as low as 2.74 kg/m^2 [5]. These semi-flexible modules use a polymeric material as front sheet and glass-fibre reinforced plastics to obtain sufficient mechanical stability.

The basic concept of standard c-Si PV modules has not changed significantly in the last couple of years and has proven its long-term reliability. However, the concept also has some inherent structural drawbacks.

Due to the laminates dimension and weight there are considerable forces which have to be considered in the module design, particularly because of the large open laminate area [6].

For glass/glass modules the glass thickness is the crucial factor which determines the modules stiffness, while for glass/backsheet modules typically also a surrounding frame provides additional stability. The basic structures of both module types cause a considerable weight and material consumption. In order to significantly reduce the weight of a standard crystalline silicon glass/backsheet module one needs to reduce the glass or the frame thickness. Reducing the thickness of the glass or the frame however drastically affects the mechanical rigidness of the module.

Currently heat strengthened solar glass is available with a thickness in the range of 2mm. According to our knowledge at present thinner solar glass is only available in form of chemically strengthened glass, with differing properties compared to the tempered standard. There are however ongoing research activities, which aim at thermally strengthened glass with 1 mm thickness [7].

In present glass/glass modules mostly glass with a thickness $\geq$ 2 mm is used to obtain sufficient stability; some of the modules with 2 mm glass thickness also use an additional frame. For the state of the art glass/glass laminate a significantly reduced glass thickness would therefore be of limited value.

Today, the typical glass thickness for standard c-Si glass/backsheet modules is 3.2 mm. Standard modules with circumferential frame have a large unsupported central laminate area. By using readily available front glass with a thickness of 2 mm, a severe dishing of the module is not avoidable with the standard setup and cannot be prevented by a surrounding frame.

Provided that cost-effective thin glass is available also innovative module concepts are needed to exploit the potential advantages.

One approach to achieve sufficient mechanical bending strength is to use a rigid supporting structure on the back of the module. This solution was repeatedly realized with ultra-lightweight honeycomb structures [8], but also repeatedly demonstrated for standard applications [9].

The current paper presents a different approach to prevent dishing for light weight c-Si laminates, by using a lattice instead of a backing plate, as shown in figure 1. This approach subdivides the module into smaller units resulting in reduced lever arms between supporting points and therefore suppressed dishing. Due to the subdivision of the modules in smaller mechanical segments the modules are named Small Unit Compounds (SUC) modules. The concept with a lattice is in-between the above presented standard c-Si module with unsupported laminate and the use of a continuous substrate plate.

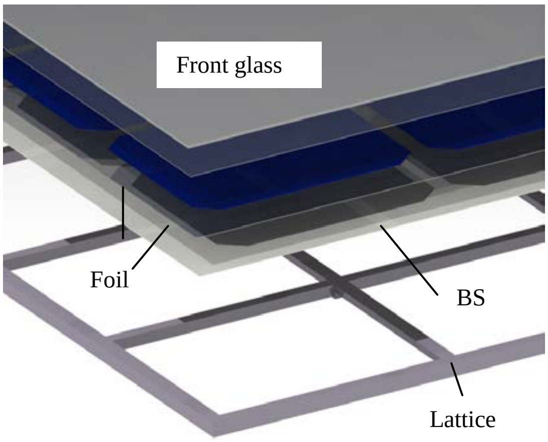

Figure 1: SUC modules with conventional glass/backsheet laminate and lattice structure at the rear.

Because of the smaller distances between the frame elements the laminates stiffness and weight can be reduced. This enables new approaches for the laminate structure, ranging from conventional layouts with reduced weight, for example glass/glass laminates using ultrathin glass, to the implementation of alternative non-glass materials. Besides the laminate also the lattice frame may be made of lightweight materials and components.

2 MECHANICAL STABILITY OF SUC MODULES

In order to get a first appraisal of the mechanical properties some trials with similar lattice-like structures were carried out. Since standard c-Si glass/backsheet modules typically use 3.2 mm glass, we decided to prepare a corresponding laminate, however with thinner 2 mm glass, resulting in lower weight and rigidness.

Several lattice-like structures were tested in combination with the described 2 mm glass/backsheet laminate. The maximum bow of the laminate was respectively measured as a function of the applied mechanical load. The mechanical load varied by using different amounts of sandbags, each weighing 12 kg (see figure 2) to a maximum of 144 kg. In the experiments the modules were supported lengthwise by tables to simulate the sub-construction. The same tests were also performed with a c-Si 60 cell standard module, with glass/backsheet lay-out, frame and 3.2 mm glass.

Figure 2: Laminate with applied mechanical load in form of sandbags on top.

The lattice was simulated by aluminum beams of quadratic shape with side lengths of 10 and 15 mm respectively and a material thickness of 1 mm. The beams were not fixed at the intersections of the perpendicular oriented beams. In figure 3 the set-up of the beams is indicated for clarification.

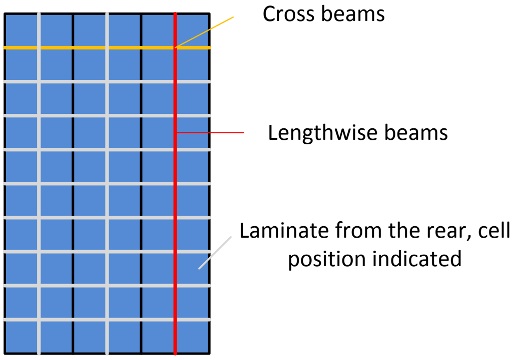

Figure 3: Schematic drawing of the aluminum beams position at the rear of the laminate.

Due to the limited strength of our test rig the maximum applied load was 882 Pa which is considerably lower than the value of 2400 Pa, as required to pass the IEC 61215. However, the results are an indication for the mechanical stiffness and can be compared to the data of a standard module.

In figure 4 the maximum bow as a function of the load for various structures is shown. The standard 60 cell glass/backsheet module with a 3.2 mm front glass and frame shows a maximum bow of about 15.5 mm at a load of 144 kg. The 2mm glass/backsheet laminate without a frame and any supporting element shows extreme bowing already for lowest load values. Therefore this thin laminate itself provides a very small contribution to the mechanical rigidness of the module. As shown in figure 3 the beams were positioned lengthwise or crosswise. Only the crosswise beams were supported by a sub-construction.

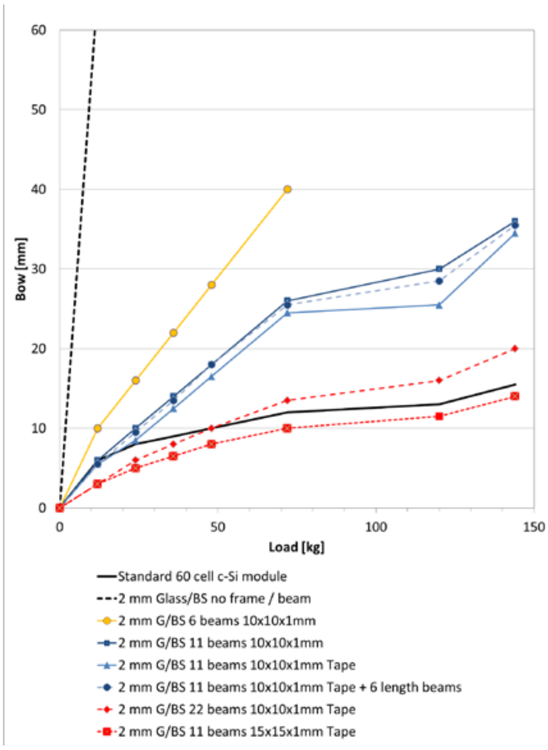

Figure 4: Maximum bow as a function of load for several lattice-like structures and a standard module. Due to the limited strength of our experimental set-up the maximum load is limited to 144 kg, which is considerably lower than the loads according to the IEC 61215.

First 6 lengthwise beams were taped to the backsheet, 11 beams were then positioned crosswise below them without any fixing. This was compared with a composition of 11 crosswise beams with and without fixation to the module. The fixation was done with a double sided adhesive tape.

As shown in figure 2 (blue lines with symbols), there is no significant difference between the three compositions. Therefore one can conclude, that only the cross beams, supported by an appropriate sub-construction have a significant influence on the mechanical rigidness of the structure as a whole. Neither the taping, nor the varied placement in direct contact with the backsheet or below the lengthwise beams showed any significant effect.

In the following experiments we have analyzed how the amount and the dimensions of cross beams affect the measurements. Reducing the amount of cross beams from 11 to 6 has a tremendous effect on the mechanical rigidness of the module as shown in figure 4.

Enhancing the cross-section from 10 x10 to 15 x 15 mm and keeping the number of cross beams constant at 11 resulted in a bow slightly lower as the bow observed for the standard module. This indicates that this structure could be a promising candidate for a light weight SUC module.

As material for the lattice aluminum or glass fibre reinforced plastics may be used, dependent on the specific requirements. First estimations, based on the elasticity module of the aluminum beams, do not indicate that a significant weight reduction can be expected by replacing the aluminum. Using plastics may however be beneficial if not only cross beams but a real lattice structure is chosen.

Based on this lattice-like structure in combination with the 2 mm glass/backsheet laminate we made an estimation concerning the obtainable weight and compared it to a standard c-Si module and the most light weight 60 cell c-Si glass/backsheet module which is currently available on the market. The results are shown in table 1.

Table 1: Weight and specific weight for different types of 60 cell c-Si modules

Type	Weight [kg]	$[kg/m^2]$
Standard c-Si 3.2 mm glass/bs, frame	~20 kg	12
SUC lattice at rear, 2 mm glass/bs	13.65 kg*	8.5
Light-weight c-Si Glass/bs, frame, BenQ	10.5 kg	6.5
SUC lattice at rear 0.8 mm, glass/bs	8.9 kg	5.6

*12 kg laminate + 1.65 kg (11 cross beams 15 x 15 x 1 mm) = 13.65 kg

The lastly described structure with lattice and rear and 11 cross beams (15x15x1 mm) would result in a module with a weight of about 13.7 kg. This is considerably lower than a standard module with a weight from 18 to 22 kg, but still heavier than the best in class type with only 10.5 kg [10]. Alone the laminate which was used by us has a weight of 12 kg. This means that the best in class module type also uses considerably thinner glass than the laminate prepared by us. Since the use of very thin and flexible substrates should be a major advantage of the proposed lattice concept, we estimate a potential module weight with thinner glass. According to our knowledge the thinnest available solar glass presently is chemically strengthened 0.8 mm glass from AGC. Based on this assumption a module weight of 8.9 kg may be obtained with a lattice at rear.

Even lower weights might result if the concept of a back lattice is combined with ultra-light weight non-glass laminates. In such laminates the glass would be replaced by transparent layers at the front side. There are several options for suchlike frontsheets based on different materials (ETFE, glass fibre reinforced plastic, polyester,…) which were repeatedly tested and are also used in currently available products. The combination of both approaches would result in light weight mechanically rigid PV modules, which may be used in the same way as standard modules. In addition also larger light weight modules could be an interesting option. Because the cross beams could be also seen as a part of the sub construction, it may be an option to mount them on-site to the appropriate sub construction, e.g. by silicon adhesive.

For very thin and flexible laminates it might be an option to use a lattice at the rear and front of the laminate. This structure would have some advantages for laminates with a symmetrical structure, for example foil/cell/foil as shown in figure 5 or glass/glass laminated with very thin glass.

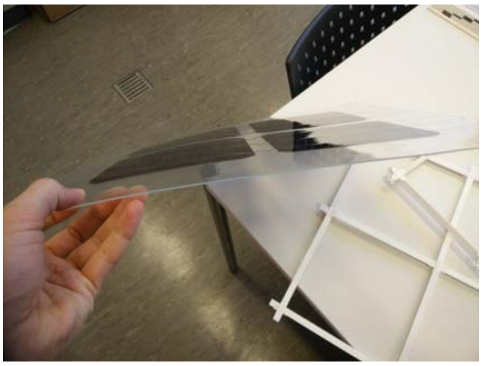

Figure 5: Foil/cell/foil laminate. Both foils are transparent which would enable the use of bifacial solar cells.

If the laminate has a symmetrical structure, a cell in the middle of the symmetric structure does not experience compression- tension forces (neutral fibre) as shown in figure 6.

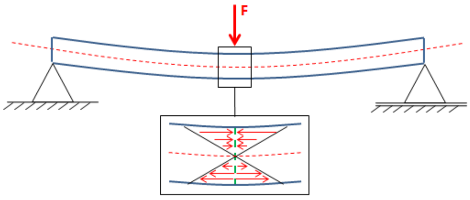

Figure 6: Schematic drawing of a solar cell (dotted red line) in the center of a symmetrical structure resulting in lowest compression- tension forces.

Pursuing the symmetrical approach with regard to the lattice one has to apply a lattice at front and rear. We have designed a demonstrator lattice out of plastic fabricated by the use of a 3D- printer.

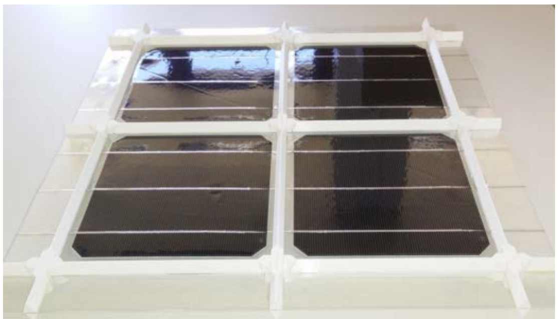

Figure 7: Lattice at front and rear with a foil solar cell/ foil laminate using bifacial solar cells. The cross-section of the upper and lower part of the lattice has a triangular shape to reduce the shading and to enhance the light scattering from the reflective lattice material.

First results concerning the mechanical rigidness of a lattice front and rear structure are included in figure 3. The structure that was tested consisted of 11 front and 11 rear aluminum bars with cross sections of 10 x 10 mm. The maximum bow as a function of the load for this structure is comparable to the bow of a standard module.

Obviously, the front and rear lattice approach has some disadvantages. Besides the shading for low sun positions soiling may be an issue. For very thin and fragile laminates the resistivity to mechanical damage, as caused by hail, is another problem that needs to be addressed. Possibly, the front side grid structure may enable an option to address these issues. A transparent sheet may be used to protect the laminate as indicated in figure 8. At a first glance the use of such a foil seems too fragile and prone to damage. However, there are comparable solutions in architectural and BIPV applications with ETFE foil. This material has a very good transparency and an extremely high resistivity against crack-propagation. Pressure stabilized ETFE structures were also repeatedly used to include PV modules [11]. The feasibility of the proposed concept needs to be verified in experiments.

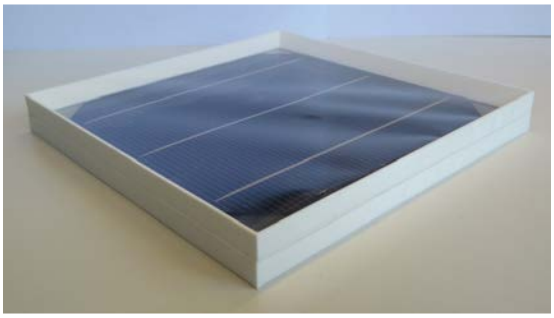

Figure 8: Lattice at front and rear with a foil/ solar cell/ foil laminate covered on both sides with an ETFE foil resulting in an ultra-light weight SUC module. The ETFE foil acts as soiling protection and may also act as a protector against hail impact (to be verified). The triangular shaped frame is the bearing for the ETFE foil.

The lattice structure may possibly also be used to generate small unit compound elements in a way that the lattice also includes electrical elements such as cables or bypass diodes. These small elements would be mounted then on an appropriate sub-construction with mechanical and electrical connectors as indicated in figure 9.

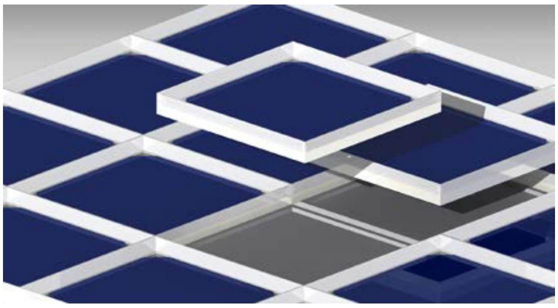

Figure 9: Small units, here a single solar cell, may be placed on an appropriate designed sub-construction hosting mechanical and electrical joints.

4 DISCUSSION, CONCLUSION AND OUTLOOK

The replacement of the frame by a lattice like structure opens the path towards the use of glass with thickness below 2 mm or the use of very thin and flexible non-glass laminates. The simplest approach is to use cross bars with sufficient stiffness, as indicated in figure 10. The cross beams can either be a part of the module or of the sub-construction. The cross beams have to be fixed on a supporting element, e.g. a perpendicular oriented bar.

This concept is an evolutionary approach towards more light weight structures. Conventional glass/backsheet and glass/glass laminate lay-outs can be used with lower glass thicknesses than the currently used ones. For standard glass/backsheet laminates the glass thickness could be lowered to readily available 2 mm as a first step. Chemically strengthened thin solar glass with 0.8 mm thickness is already available. Heat strengthened solar glass with 1 mm thickness is subject to recent research. The concept should however also be suitable for even thinner and more flexible non-glass laminates. With the lattice at rear concept specific weights of <6.5 kg/m^2 and sufficient mechanical stiffness should be feasible.

Applying the lattice-like structure not to the laminate but to the sub-construction would further lower the laminates transport weight and the transport volume. Also considerably larger modules may possibly be realized with this approach.

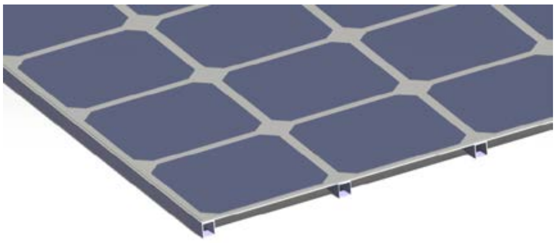

Figure 10: Type 2 SUC module with the subjacent supporting structure in form of cross bars.

A lattice at the rear and the front might be a suitable approach for laminates with symmetrical lay-out. Keeping the symmetrical structure of the laminate is beneficial in order to suppress tension-compression stress. Obviously, the front and rear lattice approach has some disadvantages. Besides the shading for low sun positions soiling may be an issue. For very thin and fragile laminates the resistivity to mechanical damage, as caused by hail, is another problem that needs to be addressed. Possibly, the front side grid structure may enable an option to address these issues. A transparent ETFE sheet may be used to protect the laminate, but the feasibility of the proposed concept has to be verified in experiments first.

5 ACKNOWLEDGEMENT

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