

DAILY POWER OUTPUT INCREASE OF OVER 3% WITH THE USE OF STRUCTURED GLASS IN MONOCRYSTALLINE SILICON PV MODULES

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ABSTRACT

Various types of structured glass have been evaluated in terms of module efficiency and total energy yield. A glass with fine round pits has been selected as optimum as a result of our evaluation taking into account efficiency gain, improved energy yield, outdoor performance and material cost. The benefit from such glass with reduced reflectance is observed through a nominal power boost of around 1%.

The largest benefit from this glass, however, is obtained when rays arrive to the front module surface at low incident angles. In this case a power increase of over 15% can be measured, at the early morning and evening hours. Overall, this is translated in an increase in a measured daily energy output of more than 3%, which is a substantial gain in terms of electricity production per module. The benefit can be even larger in installations where the inclination of the module is not optimal as, for instance, on façades.

The long-term performance of modules with structured glass has been evaluated in an outdoor monitoring station, showing no accumulation of dust in the glass features even after long periods with complete absence of rains in southern Spain.

INTRODUCTION

It is well known that a texture such as inverted pyramids, grooves or pits can reduce significantly the reflectance of a surface. This has been done for decades on the front surface of the solar cells and has now been implemented too for the front surface glass of the PV modules [1, 2]. In this way a reflectance reduction can be measured, which is due mostly to the double or triple incidence of rays.

NOMINAL POWER INCREASE AND ANGULAR DEPENDENCE

We have evaluated several kinds of structured glass from different suppliers. Two of the most promising types, glass with inverted pyramids and glass with fine round pits, are shown in Figure 1.

A pre-series of 12 medium-size module prototypes was built, 6 of them with a fine round textured glass (glass S) and 6 with an inverted pyramids glass (glass P), showing a consistent nominal power boost of 1% for glass type S and 1.5% for glass type P. This increase is partly due to the texture and partly to the better infrared response of the glasses under evaluation.

The largest benefit of these types of glass, however, resides on the larger power increase when light rays arrive to the module at lower incidence angles. In this case the reflectance with respect to a flat glass is largely decreased, which produces a boost in the short-circuit current, as shown in Fig. 2. Two monocrystalline silicon cells with almost identical IV curves were encapsulated using a flat glass in one case and a structured glass in the other, as shown in Fig. 3. They were measured indoor in a continuous solar simulator type A, adjusting the incidence angle. The power increase was as high as 8% for inclination rays of 30°.

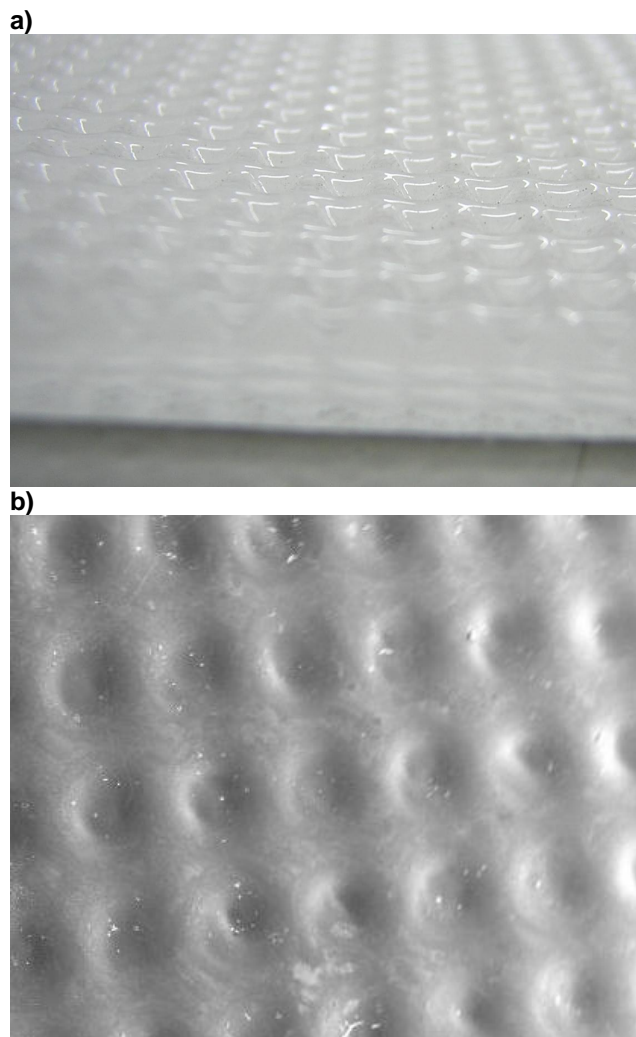


Fig. 1: Two different types of structured glass with (a) inverted pyramids and (b) round pits (optical microscope photograph 10x).

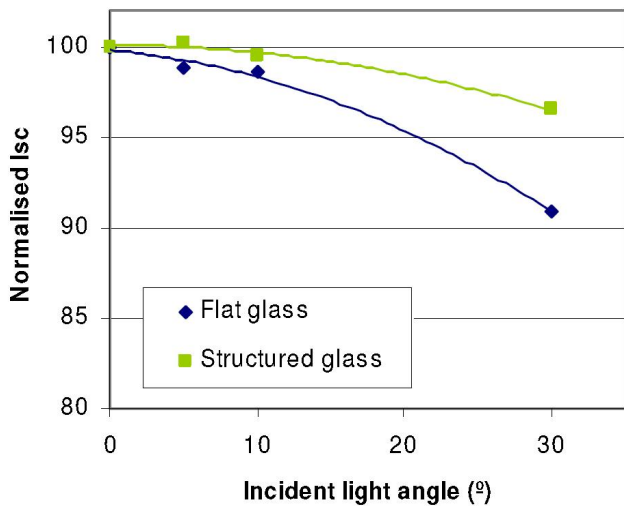


Fig. 2: Angular dependance of the short-circuit current of two almost identical cells, encapsulated with a flat glass and a structured glass, measured indoor with a type A continuous solar simulator.

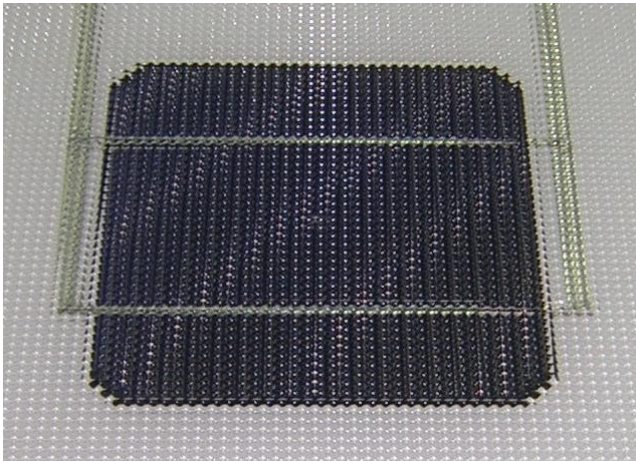


Fig. 3: One-cell module prototype with structured front glass type P used for indoor measurement of angular dependence of I_{sc} .

POTENTIAL ISSUES ASSOCIATED WITH THE USE OF STRUCTURED GLASS

One of the potential issues associated with this new type of glass are the changes required on the quality control of the modules, as visual inspection can no longer be used as a tool for detection of possible broken cells or defects. This is however a minor issue if electrical or thermographic quality control is performed prior to lamination, as it is the case today for most module manufacturers.

Other disadvantages that have been associated with the different visual aspect of the glass are the modification of the module code bar reading procedures and the change of aesthetics in the module.

The most important potential problem associated with these types of glass is, however, the possible accumulation of dust in the structure of the glass, which

could hamper the self-cleaning properties of the PV module and cause a power degradation in time. We have investigated this issue in depth by performing longterm outdoor tests.

OUTDOOR TEST SET-UP

An outdoor monitoring test has been set-up to investigate the performance of textured glass modules with two objectives: i) measure the gain in total energy yield compared to a standard flat glass and ii) evaluate the potential degradation in the module due to the accumulation of dust in the structure.

The monitoring station consists of:

- Optional sun-tracker or fixed supporter at inclination angle of 45° or 60°.
- Pyranometer for measurement of global radiation.
- Pyrheliometer for measurement of direct radiation.
- Temperature control through PT100 on back surface of modules
- Meteorological station for monitoring of ambient temperature, relative humidity, and wind speed and direction.
- Multi-channel data-logger, electronic load with monitoring software, database and simultaneous web access.

Two large-size modules built with monocrystalline solar cells of very close IV characteristics, one of them with a standard flat glass and the other with a structured glass of type S. They have been monitored for a period of 9 months.

The two modules were calibrated initially in the laboratory, giving the S-glass module a short-circuit current 1.05% higher than the flat surface module. This percentage includes possible small variations in the cell or interconnects quality, as well as the influence of the glass material and the round pits texture.



Fig. 4: Facility set-up for monitoring outdoor performance of structured glass modules compared to flat surface modules.

Global and direct radiation over the modules plane, wind speed, relative humidity, ambient and module temperatures, and full IV curves of the two modules were measured almost simultaneously at 5 minute intervals.

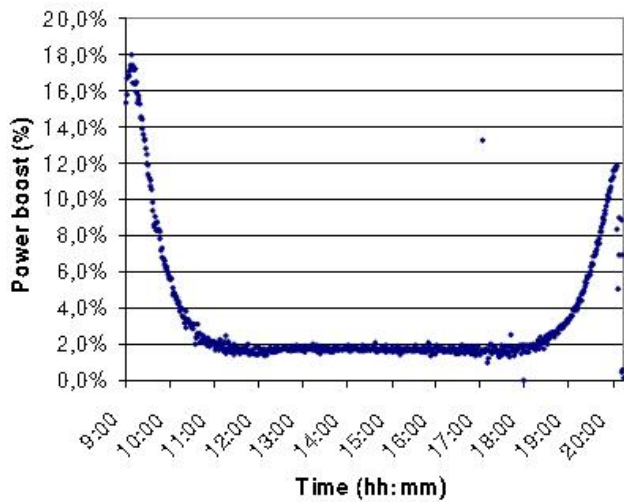


Fig. 5: Power boost of structured glass with respect to flat glass module over a full day.

DAILY ENERGY YIELD BOOST

The results of the measurements for a typical spring clear day in Málaga (Spain) are shown in Figure 5. It shows the ratio of the I_{sc} of the structured glass with respect to the I_{sc} of the standard glass throughout the whole day. A significant power boost during the early and late hours of the day is observed, which can be as high as 18%. The increase of 1,7% measured at the central hours of the day is larger than the ratio measured indoors at the start of the test. This could be originated partly by the influence of the diffuse radiation in the outdoor measurement, which the textured surface can collect much more efficiently than the flat surface.

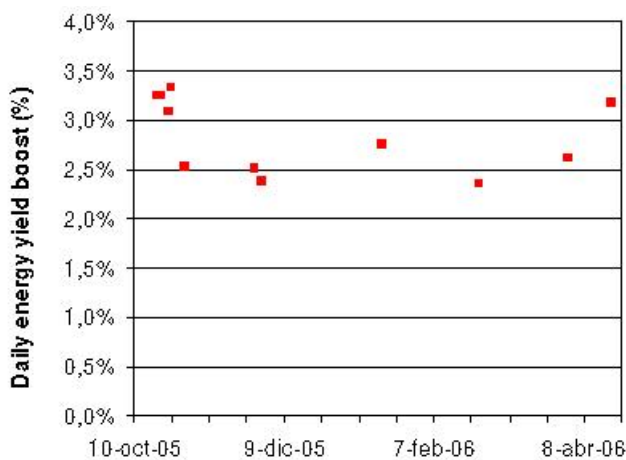


Fig. 6: Daily energy yield boost of the structure glass module, calculated as the ratio of the integrated power throughout the day for a module with a structured glass and a flat surface module.

This is translated in an integrated total daily output energy boost of more than 3%, which is similar to the software simulated energy yield boost calculated in [3] for another type of structured glass. This demonstrates experimentally that with the use of structured glasses, a significant gain in terms of electricity production per Wp of module produced can be achieved. In modules incorporated to façades or installations where the inclination angle of the module is not optimum, the potential gain of this type of glasses is even larger. The same would happen in locations with a higher contribution of the diffuse radiation.

The integrated daily energy yield has been measured at different times for a period of 9 months giving always values in the range 2,5-3,5% as shown in Fig. 6.

DUST ACCUMULATION

The potential accumulation of dust over the structured glass, which could diminish the power boost of the glass, has been investigated by comparing the IV characteristics of the modules before and after a 3 month summer period with almost complete absence of rains.

The results are shown in Fig. 7, where it is observed that the relative changes for both types of modules are very similar and the differences within the measuring tolerances. There has been therefore no additional accumulation of dust in the structured glass during this test. In more rainy seasons or regions the test would be less stringent as the modules would be self-cleaned with more frequency.

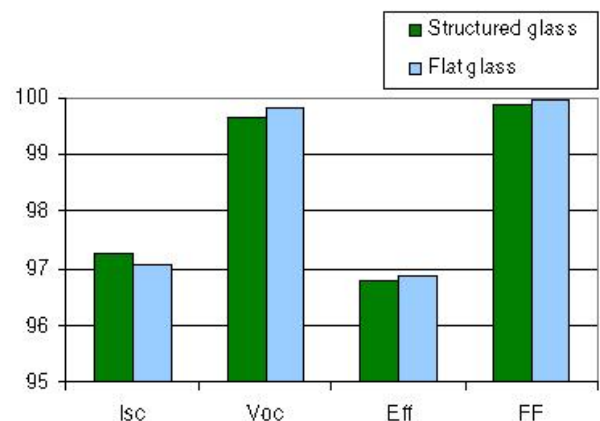


Fig. 7: Relative variation of the different electrical parameters of the module with flat glass and with structured glass, before and after an exposure of 3 months with absence of rain.

CONCLUSIONS

A new type of glass has been evaluated and shown to produce an overall energy output gain of around 3%. This is a significant boost in terms of electricity production, and could be even larger in systems where the inclination angle of the system cannot be optimised, as in building integration systems. Also, it has been observed that an increased proportion of the diffused radiation would enhance further the energy output boost.

Some potential issues associated with structured glass as the accumulation of dust have been investigated in an outdoor monitoring station. The IV characteristics of the structured and flat modules showed no significant differences within the error limits of the measuring system. This shows that there is no additional accumulation of dust in the structured glass.

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