

Bifacial High-Efficiency Panels based on First Solar's *TetraCell* Technology

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Agenda

- The TetraCell: high-efficiency; non-HTJ; bifacial by nature
 - Cell architecture
 - Mass production data
 - Record efficiency
- The bifacial TetraSun module
 - Requirement spec
 - Design solution
 - Electrical data
 - Reliability data
- Outdoor data
- Summary
- Actual Situation

c-Si business within First Solar



First Solar TetraSun PV Module ADVANCED MONO-CRYSTALLINE TECHNOLOGY

TS-300
DATASHEET

HIGH-POWER, HIGH-ENERGY PV MODULES

For years, the industry's most selective customers have turned to First Solar for our commitment to manufacturing excellence, module reliability, and financial stability. But those who require maximum power-density have had to go elsewhere...until now. Introducing the First Solar TetraSun line of high-performance mono-crystalline PV modules. Our proprietary technology offers a step-function improvement in power per cell and more energy per Watt installed versus conventional crystalline offerings because we redesigned the cell architecture and manufacturing process from the ground up for superior performance.



– INDUSTRY LEADING POWER OUTPUT

First Solar's breakthrough, proprietary mono-crystalline technology produces approximately 20% more power per panel versus conventional crystalline offerings making them ideally suited for rooftop, carport and space-constrained applications. More power per panel means less time and money spent on installation and more power and revenue from the same site area. The result is superior returns for installers and system owners.

– INDUSTRY LEADING ENERGY PRODUCTION

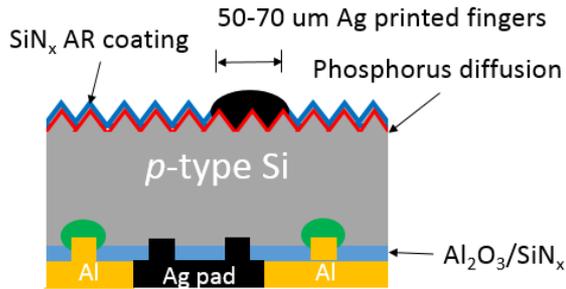
First Solar TetraSun PV modules have one of the lowest temperature co-efficients of any crystalline PV technology and are designed to eliminate effects like LID and PID which degrade module performance of conventional crystalline modules. As a result, TetraSun modules produce up to 10% more energy than standard crystalline modules with the same power rating and 25%+ more energy versus conventional crystalline solutions using the same site area. Greater energy production results in greater system revenue.

– PREMIUM QUALITY AND RELIABILITY

- In 2013 First Solar acquired the US-based company TetraSun which had developed a new high-efficiency new solar cell architecture
- In Q1-2015 the ramp of the first solar cell production line in KLM started. Capacity is 100 MWp p.a.
- Commercial module manufacturing started in July 2015 (60c and 72c standard modules)
- In August 2015 a new c-Si module R&D center got established in Berlin (Germany)
- Development of a bifacial panel got kicked-off in October 2015

TetraCell Architecture

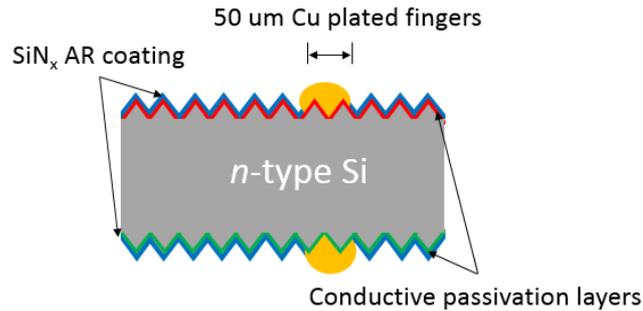
PERC Cell



Ag pad required for soldering, but negatively impacts efficiency by about -0.2% [1,2]

Small metal contact fraction required for low rear surface recombination [3]

TetraCell®



Metal contacts are solderable, no need for extra Ag pads

Surface recombination is not a function of the metal contact fraction [4]

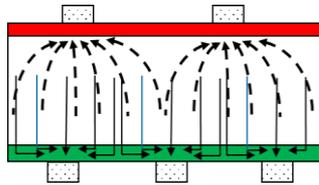
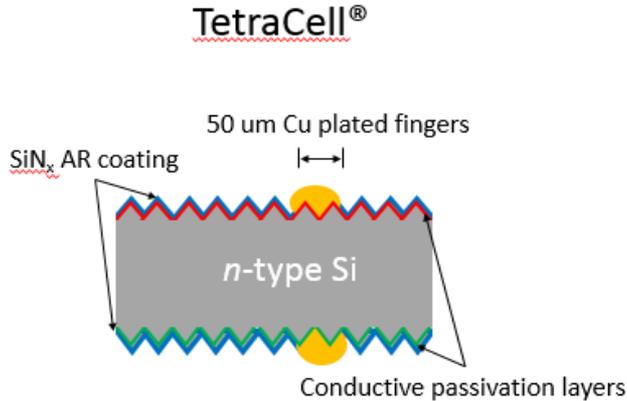
Conductive passivation layers minimize recombination and series resistance

↓
Higher V_{oc} potential

Higher FF potential

[1] H. Schulte-Huxel, [2] T. Urban, [3] W. Deng, all Silicon PV 2016 [4] Glunz, EUPVSC 2015

TetraCell Architecture



Conductive passivation layers minimize recombination and series resistance $\rightarrow V_{oc}$ and FF

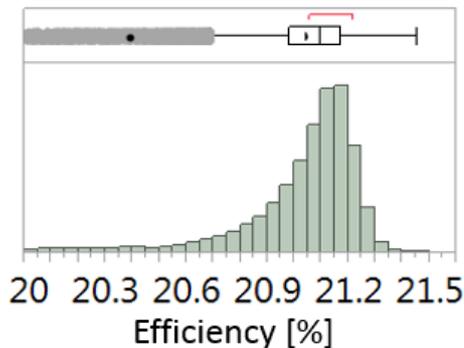
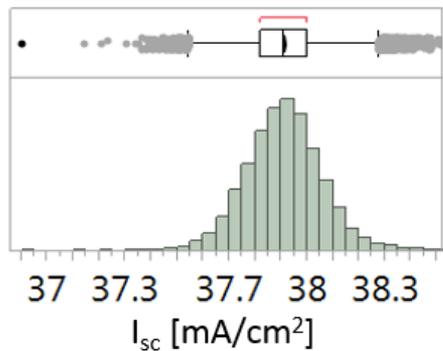
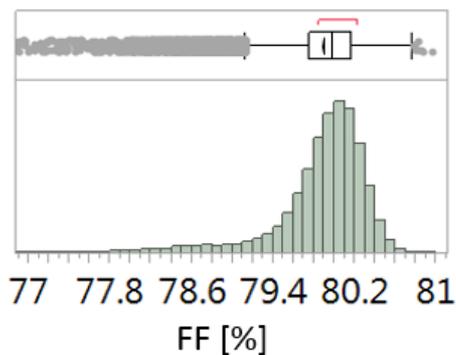
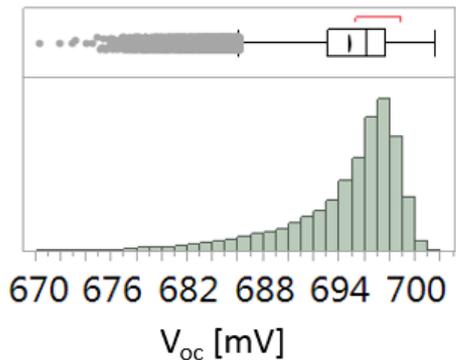
High quality n-type Cz does not need bulk hydrogenation $\rightarrow V_{oc}$

Fine line structuring technology enables very narrow fingers $\rightarrow J_{sc}$

Copper plated metal grid has very high conductivity $\rightarrow FF$

Back junction design allows for lowly doped surfaces maintaining low lateral resistance even without TCO $\rightarrow FF$

Results in Cell Manufacturing (regular HVM)



Median production values of

$$V_{oc} = 696 \text{ mV}$$

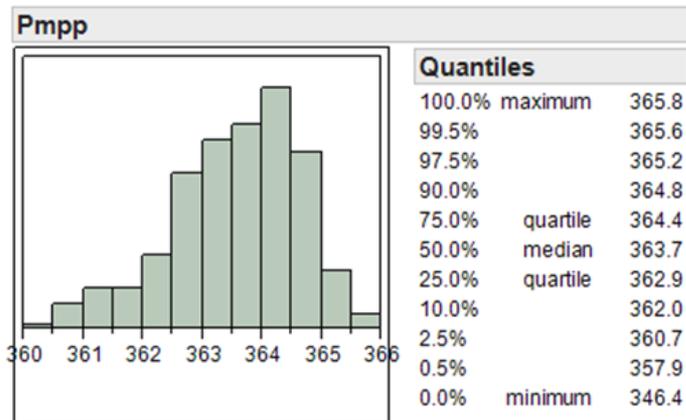
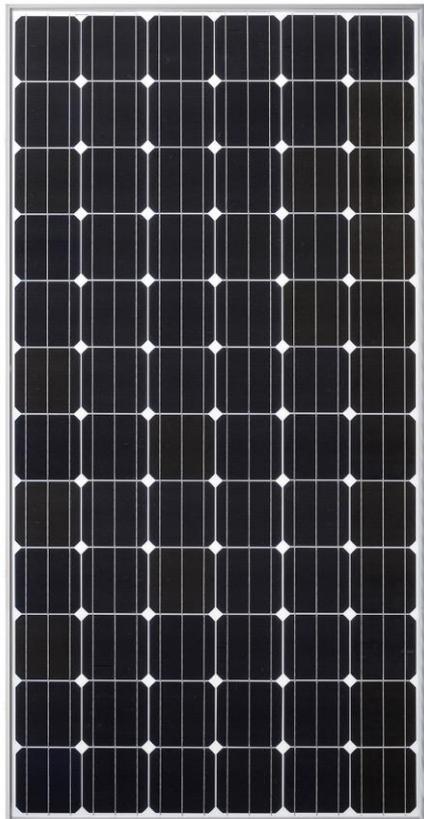
$$J_{sc} = 37.9 \text{ mA/cm}^2$$

$$FF = 80.0\%$$

$$\eta = 21.1\%$$

Distribution shown for 40,000 production cells.

Results in 72c Standard Module Manufacturing (regular HVM)



72-cell module power distribution

3 busbar design

1.00 m x 1.964 m

= 1.964 m² total area

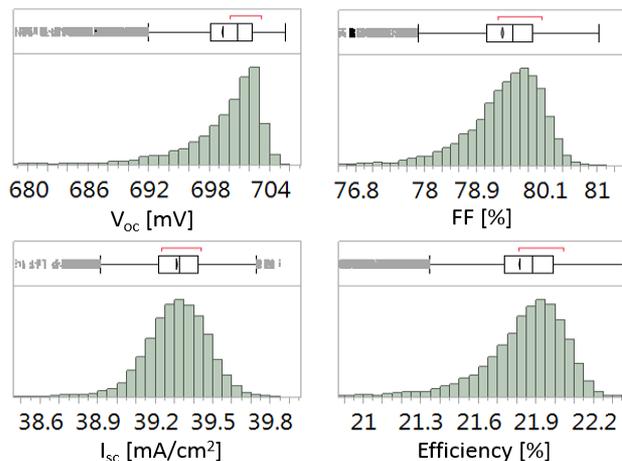
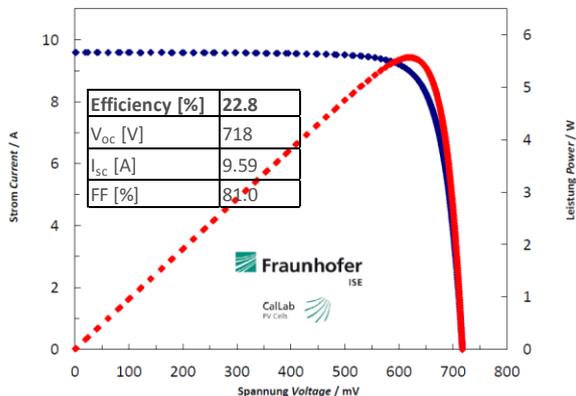
Median Power = 364 W_p

$$CTM = \frac{P_{max,module}}{\sum_1^{72} P_{max,cells}} = 0.980$$

95% of modules within a 5 W_p range

Results in Cell Manufacturing (engineering run)

Latest process optimizations developed in R&D lab got implemented into Malaysian HVM line.



Median values of

$$V_{oc} = 701 \text{ mV}$$

$$J_{sc} = 39.3 \text{ mA/cm}^2$$

$$FF = 79.5 \%$$

$$\eta = 21.9 \%$$

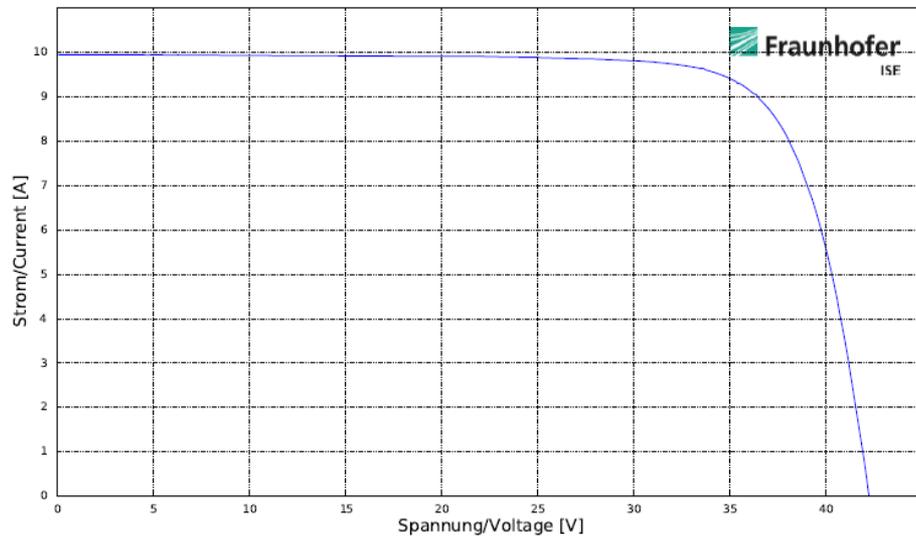
Data for 60,000 cells from our HVM production line.



Best confirmed cell efficiency at 22.8%
made on HVM production line.

Result of 60c Record Module (engineering run)

CTM increased to 1.027 by various module design optimizations.



$$P_{STC} = 330 \text{ Wp}$$

$$V_{oc} = 42.2 \text{ V}$$

$$J_{sc} = 9.94 \text{ A}$$

$$FF = 78.6 \%$$

$$\eta_{total\ area} = 20.1 \%$$

60 full size cells
3 busbars
1.64 m² total area

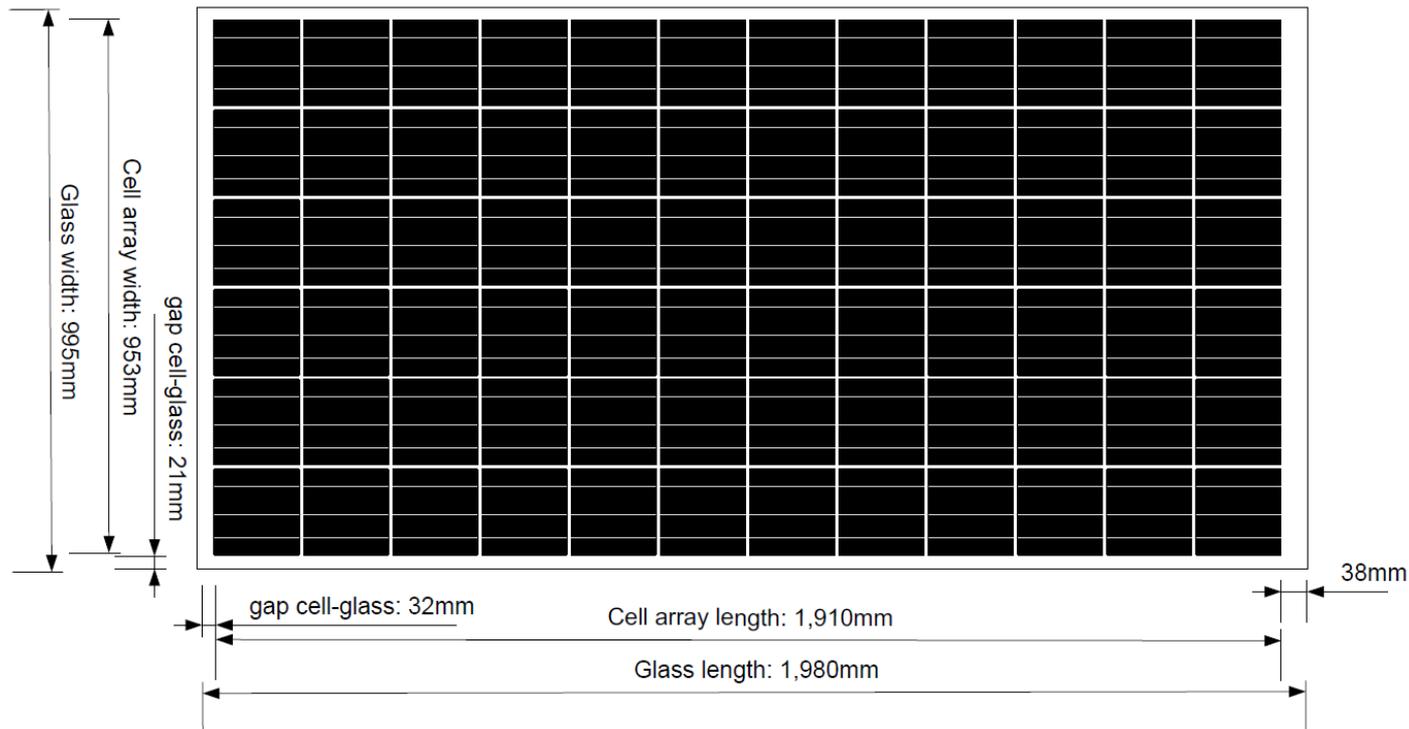
330W_p 60-cell module (1.64m²) =
20.1% total area efficiency
independently measured

First Solar Bifacial Module – Requirement Spec from Customers

- a panel optimized for ground-mount power fields
- 72 cells; for fixed-tilt and tracking systems
- „heavy-duty“; extreme robust; weight not critical
- Width < 1,000mm – but edge spacings > 20mm
- outstanding long-term reliability
- IEC 1500V
- Bifaciality coefficient: better than competition

First Solar TS-350DG Module - Module Design and Specs

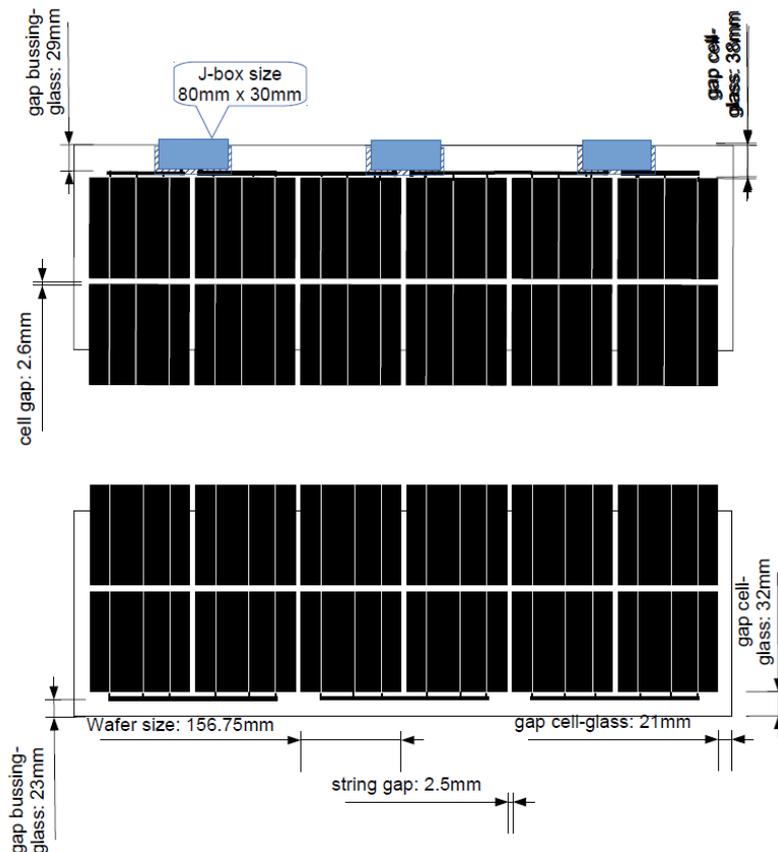
The panel is designed for mostly ground-mount application. It is a frameless double-glass panel with 72 pcs. of solar cells and a nominal STC power of 350 Wp.



First Solar TS-350DG Module - Module Design and Specs

Main data and specs

- 1,980mm x 995mm; 2 x 3.2mm glass; laminate thickness 7.5mm; weight 35kg
- Large edge areas for mounting of the panel w/o covering cells from the rear.
- 5,400Pa mechanical load tested (4-point fixation)
- 350-355 Wp STC power (front); bifi coeff. > 90%
- 1,500 VDC (IEC) rating
- 3 small j-boxes w/o cables for optimal cable management in the field.



First Solar TS-350DG Module - Module Design and Specs



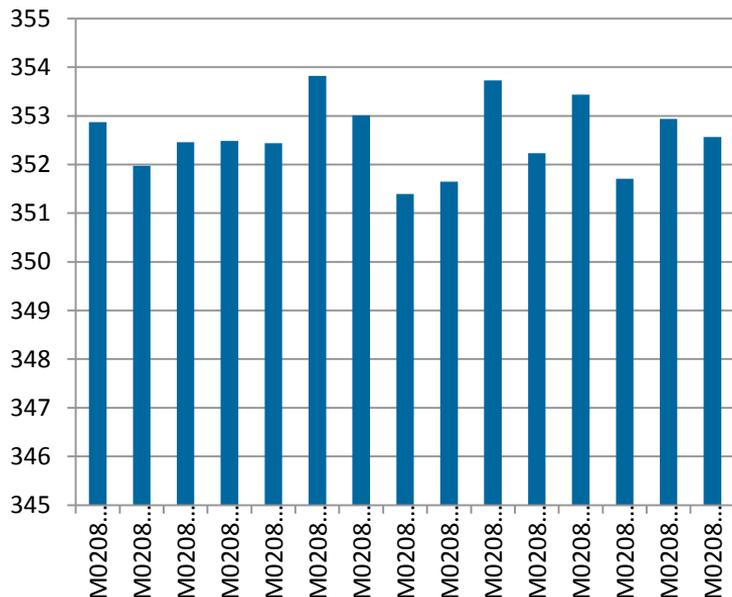
*Image 1 (left): full view.
The 72 pcs. of solar cells look dark blue/black from the front.*



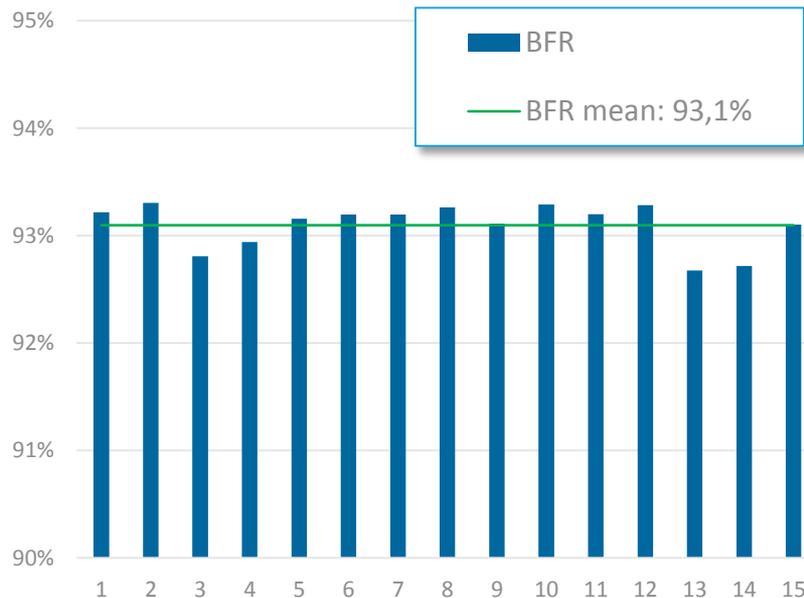
*Image 2: rear side view of the j-box area.
Clearly the the 3 pcs of j-boxes can be seen.*

First Solar TS-350DG Module – STC Power and Bifaciality

Production data from first prototype series (Dec 2015)



The front side STC power is 350 – 355Wp.



The bifaciality coefficient amounts to 93%.

First Solar TS-350DG Module – STC Power and Bifaciality

Bifaciality factor got independently verified by CFV.

Front side power spread of the 500-pieces pre-series run



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Albuquerque, NM 87106
505-998-0100
www.cfv-solar.com

First Solar TetraSun Module Test Report

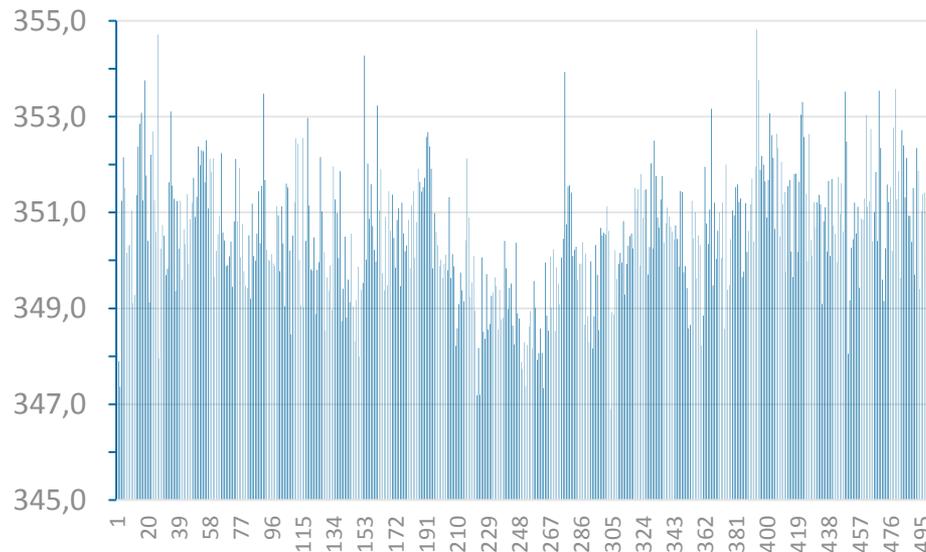
Report Date: August 2, 2016

CFV Project ID: 16063

2 Executive Summary of Results

The TS-345-R11-10-A modules showed an average front-side Pmp of 349.9W (17.7% module efficiency; 10 modules tested) and an average back-side Pmp of 324.5W (14.4%;

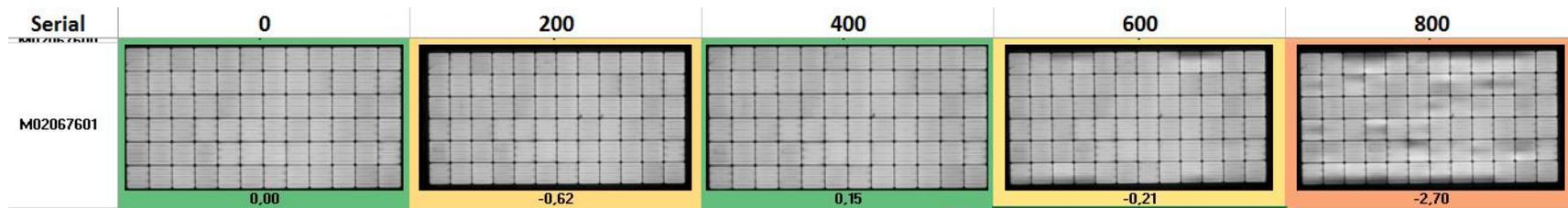
$$\frac{\text{back side } 324.5\text{Wp}}{\text{front side } 349.9\text{Wp}} = 92.7\%$$



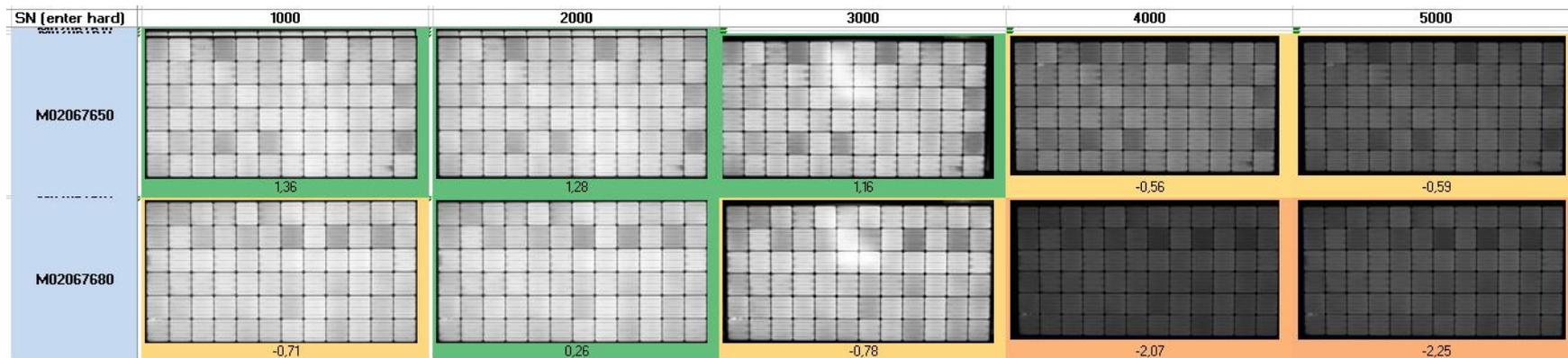
First Solar TS-350DG Module - Reliability and Robustness

The TS-350DG shows an exceptional long-term reliability. Very low degradation up to TC800 and DH5000.

TC800



DH5000



First Solar TS-350DG Module - Reliability and Robustness

The TS-350DG consists out of two sheets of 3.2mm tempered glass. This leads to an outstanding mechanical stability.



The panel can be held by 4 clamps of appropriate design (here: clamps by NEXTracker) and got tested at 5400Pa w/o significant power loss.

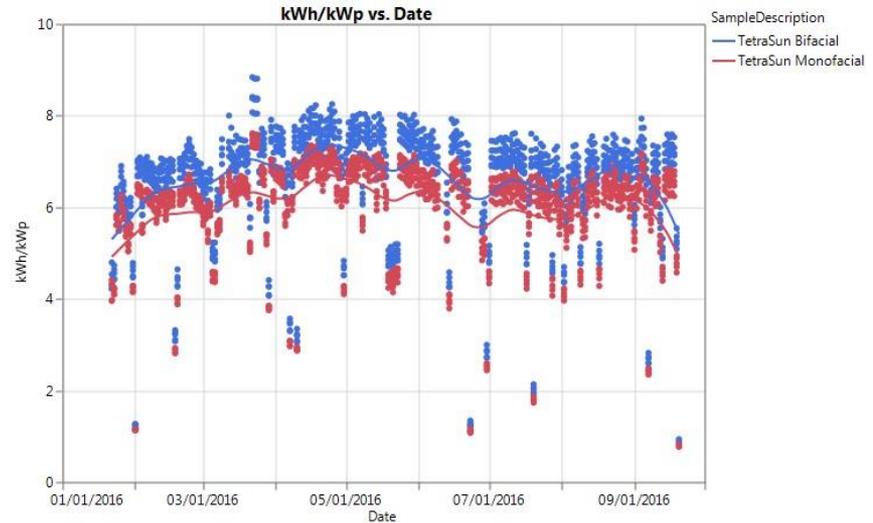


In case of fixation along the long sides (here: by Creotecc/Baywa) the panel can withstand extreme mechanical loads (tested at 8100 Pa w/o significant power loss).

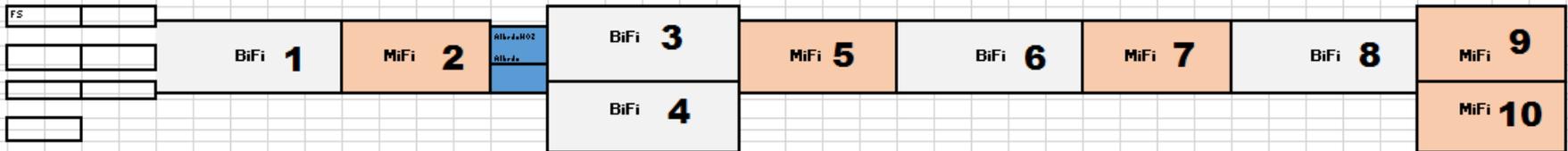
Outdoor Test Field Data



Module testing fixed-tilt array comparing mono- and bifacial modules



Delivers 10% extra energy (measured from 6th of February to 15th of September) at “worst case” conditions (brown soil; racking behind the panels; very high ratio of direct sunlight).



Summary

- First Solar has developed a bifacial solar panel based on its *TetraCell* high-efficiency c-Si technology
- the TS-350DG is a 72c frameless double glass module; 1,980mm x 995mm
- outstanding reliability got proven
- production data: 345 – 355 Wp (frontside only); bifaciality coefficient > 90%
- > 380 Wp would have been reached in Q4-2016
- probably the highest performing product of all bifacial panels (front side efficiency; bifaciality; mechanical stability; Tc; zero PID; TC and DH reliability; ...)
- fixed-tilt and tracker racking solutions available
- 500 pcs. pre-series was built. UL/IEC certifications was about to start - but then the program got stopped

Actual Situation

- Due to difficult mid-term industry perspective First Solar has decided to concentrate on its core business i.e. CdTe product
- production of the TetraSun product line ceased on 08/31
- several investors have expressed willingness to take over – but First Solar is very picky about potential buyer
- currently we are in an advanced stage of negotiations with one particular group – but no final decision yet.

Maybe it will continue – maybe it will get closed and disappear.

Contact

Whatever the future will bring for the *TetraCell* technology, this email will work:

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