



# **Preconditioning of Thin-Film PV Modules Through Controlled Light-Soaking**

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# Overview

General introduction to meta-stabilities in Thin-Film devices

- *Some examples of what has been observed in the literature*

Methods used to stabilize Thin-Film devices

- *Light-soaking according to IEC 61646 ed 2 (2008)*

Outline of light-soaking experiments with various Thin-Film modules

- *Modules used in the experiments*
- *Results*
- *Conclusions from the experiments*

Overall Conclusions



## **Amorphous Silicon, including Tandem, micromorph and triple junction**

Exhibit a long-term meta-stable behaviour in which their maximum power decreases with light exposure but improves through thermal annealing, the Staebler-Wronski effect [1]

Micromorph silicon (a-Si/ $\mu$ -Si) materials are also affected because they contain an amorphous layer, but it is more stable than single junction amorphous silicon [2,3]

All exhibit a slow decrease in power due to cold soaking and a much faster recovery through thermal annealing [2,3]

The impact of the different time constants is reflected in the observed seasonal variations [2-4]

[1] D. L. Staebler, C. R. Wronski, 1997  
[2] J. A. del Cueto, and B. von Roedern 1999.

[3] M. Nikolaeva-Dimitrova et al 2010  
[4] D.L. King et al 2000

## Copper Indium Gallium (di)Selenide (CIGS)

CIGS modules are also subject to light-induced change of the module efficiency [5].

Not as clear behaviour pattern for CIGS

- *Some authors have shown that they may degrade [6, 7] with light exposure*
- *but in some cases it has been shown that they remain stable [7] or improve [8].*

The behaviour is very dependent on the deposition and exact material composition.

In general these modules exhibit a short-term meta-stable behaviour modulated by light and for this reason they have to be measured quickly following light exposure [8]

[5] A. G. Aberle, 2009

[6]. E. L. Meyer and E. E. van Dyk, 2003

[7] C. Radue et al 2009

[8] R. P. Kenny et al 2006

## Cadmium Telluride (CdTe)

Early generation CdTe modules exhibited a long-term meta-stable behaviour but modules could either degrade or improve with light exposure [9]

However, recent modules have been shown a more uniform behaviour in that they tend to increase their maximum power with light exposure, especially following storage in the dark [9-11]

[9] J. A. del Cueto and B. von Roedern 2006  
[10] First Solar, Inc. 2009.

[11] Z. Jingquan et al 2009

## Methods used to stabilize Thin-Film devices

Some groups have experimented with the use of current injection to stabilize CIGS devices, in particular to overcome the very fast degradation on dark storage. However, this approach will not be detailed here.

Light-soaking according to IEC 61646 ed 2 (2008) [12]

Stabilization occurs when measurements from two consecutive periods of at least 43kWh/m<sup>2</sup> each integrated over periods when the temperature is between 40°C and 60°C, meet the following criteria:

$$(P_{max} - P_{min}) / P_{average} < 2\%$$

## Light-soaking apparatus

Large climatically controlled chamber containing a class BBB solar simulator (on the limit for spectral match CBB)



*Irradiance: 850-870 W/m<sup>2</sup>*

*Duration per period ~48 Hours*

*Module temperature 45-55°C*

- Stability better than  $\pm 2^{\circ}\text{C}$

*Operation under resistive load*

*Module  $P_{\max}$  determined on class AAA simulator at 25°C*



## Power measurements

The IV characteristics are measured by sweeping the device from  $I_{sc}$  to  $V_{oc}$  using a SpectroLab X25 LAPSS has a light pulse of 2 ms duration with a flat irradiance of 1000 W/m<sup>2</sup>.

- Measured IV characteristics according to IEC 60904-1. It is noted that this standard may be applicable to multi-junction test specimens, if each sub-junction generates the same amount of current as it would under the reference AM1,5 spectrum in IEC 60904-3.
- It is assumed that the spectral mismatch between the various modules and the reference cell remains constant throughout the repeated light exposures.
- It is also assumed that the limiting junction of the multi-junction devices does not switch due to light-soaking when measured using the solar simulator

Relative uncertainties of

$I_{sc} \pm 1.3\%$ ,  $V_{oc} \pm 0.3\%$ ,  $FF \pm 0.72\%$ ,  $P_{max} \pm 1.5\%$  [13]

## Modules used in the study

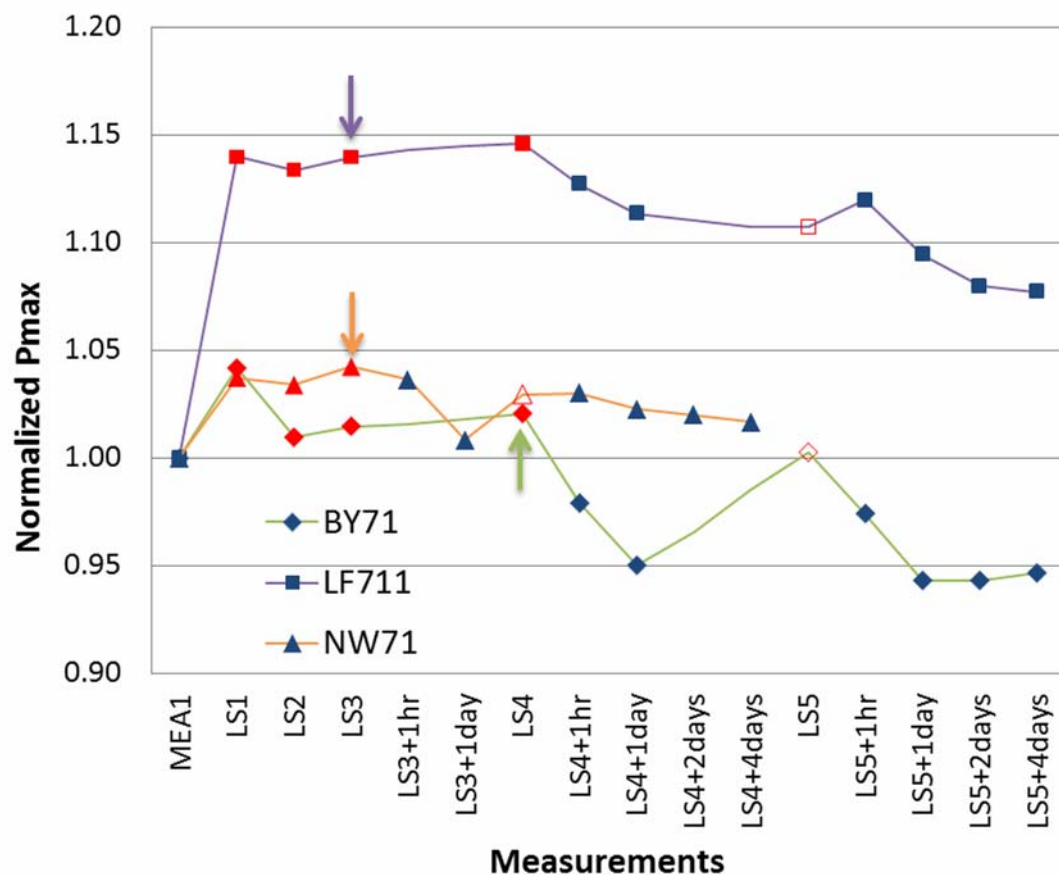
| ESTI CODE | TECHNOLOGY                                       |
|-----------|--------------------------------------------------|
| BY71      | CIGS ( <i>Copper-Indium-Gallium-diselenide</i> ) |
| LF711     | CIGS ( <i>Copper-Indium-Gallium-diselenide</i> ) |
| NW71      | CIGS ( <i>Copper-Indium-Gallium-diselenide</i> ) |
| KX711     | CdTe                                             |
| NW73      | CdTe                                             |
| LK711     | Triple junction a-Si                             |
| LK712     | Triple junction a-Si                             |
| KW711     | a-Si/ $\mu$ -Si                                  |
| KW712     | a-Si/ $\mu$ -Si                                  |
| HJ410     | a-Si/ $\mu$ -Si                                  |
| NW74      | Crystalline Silicon on Glass (CSG)               |

### Note:

Modules with the same two letter code are from the same manufacturer and batch.

The modules had taken part in different projects in the past and have therefore had varying histories of light and temperature exposure. After the end of these previous projects they were stored in the dark, near to 25°C. The length of storage is different for each one of them and varies from several weeks to several months.

## Results for CIGS modules



Modules measured within 30 minutes of leaving the light-soaking chamber

All modules exhibit an increase of  $P_{max}$  with light-soaking

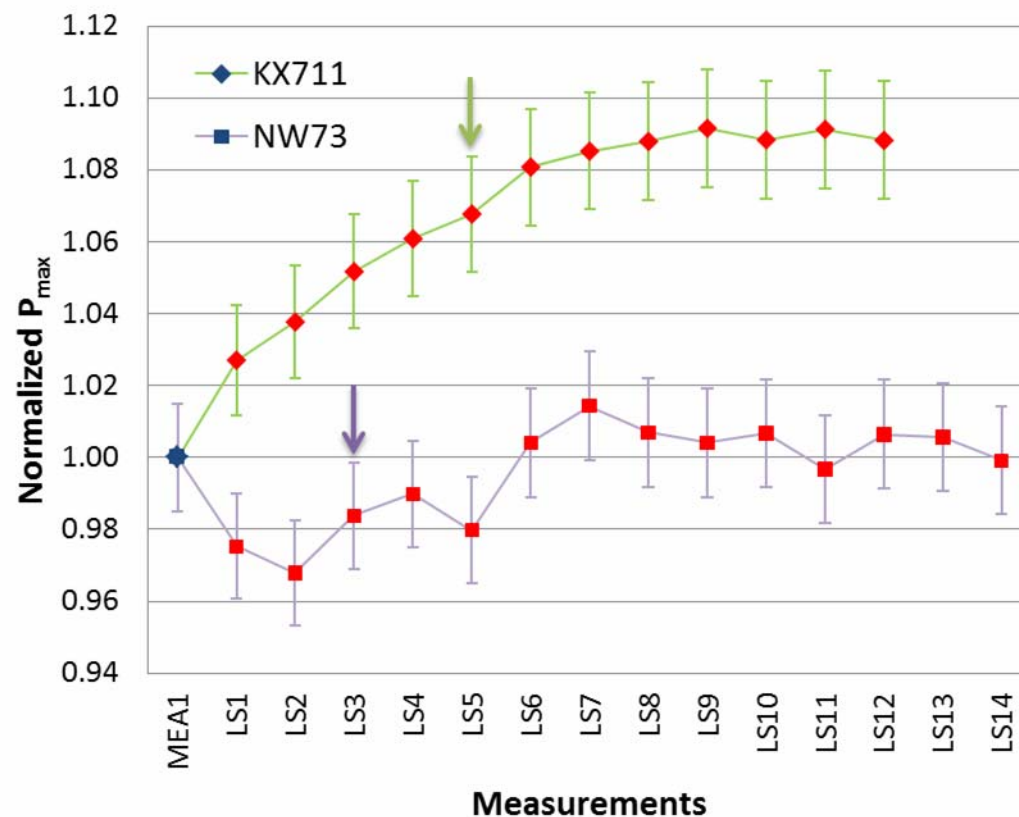
Stabilised after 3-4 exposure cycles

Dark storage leads to a decrease in  $P_{max}$

Note:

Open symbols indicate a faulty connection leading to a lower than expected power

## Results for CdTe modules

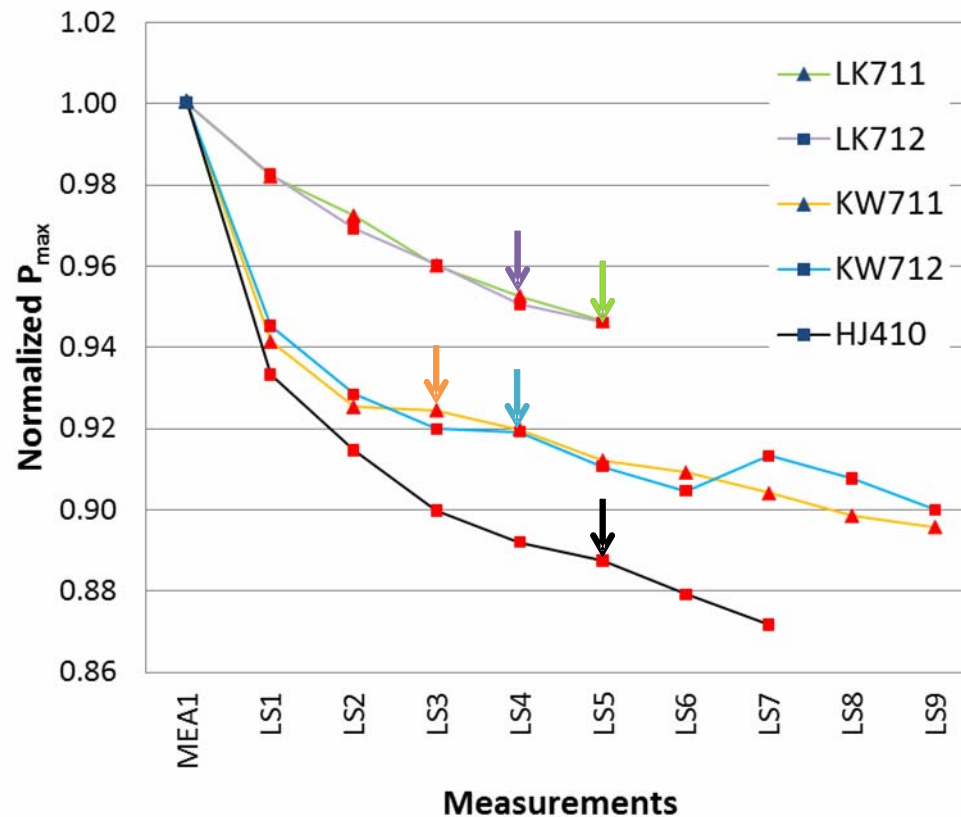


Light-soaking has improved the maximum power

Difference between the two modules due to their prior history

Continued to improve following point of stabilisation

## Results for a-Si/ $\mu$ -Si and Triple junction

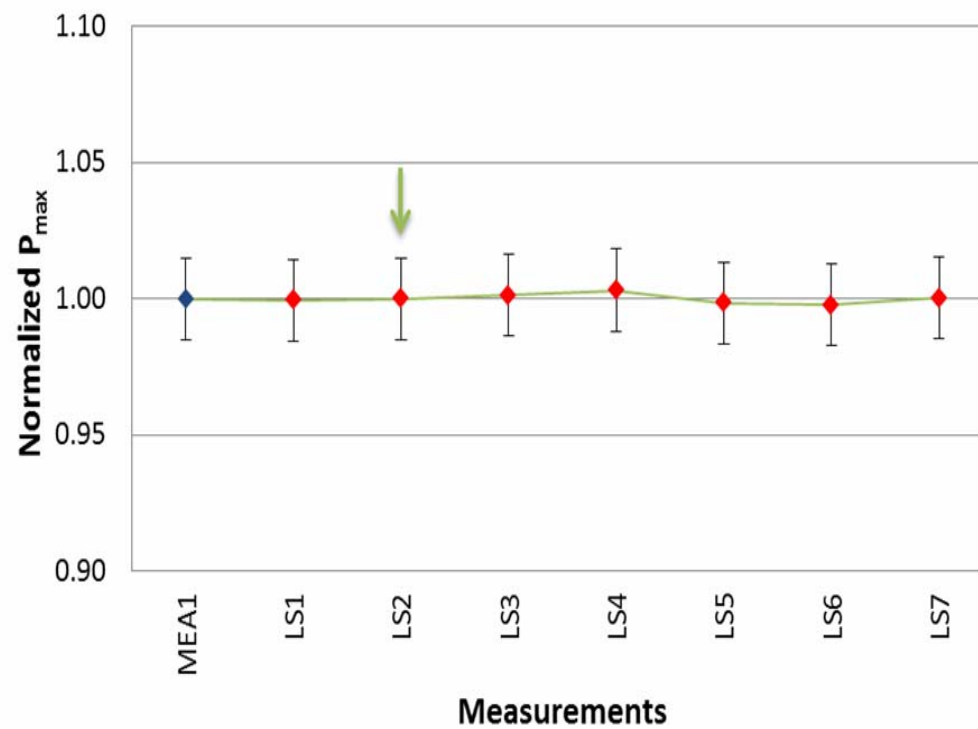


Light-soaking has improved the maximum power

The two triple junction modules exhibited a smaller decrease in power than the a-Si/ $\mu$ -Si modules

Continued to decrease following point of stabilisation

## Results for CSG



CSG material clearly not  
meta-stable

No need to be subjected to  
light-soaking

## Conclusions

**For the purposes of module qualification, the stability procedure of IEC 61646 ed 2 is probably satisfactory, given the need to stay “within reasonable constraints of cost and time”.**

- For a-Si containing modules this will tend to lead to an over estimation of the power output
- For CdTe modules this would tend to lead to an underestimation
- Valid for CIGS
- not required for CSG

**For thin-film module calibration, in general applying the stability procedure of IEC 61646 is not sufficient, therefore:**

- More stringent stability criteria are suggested, such as more periods of light soaking and/or tighter stability limits.
- The a-Si community has tended to use 1000 hours @ 1 Sun

## Conclusions

**One aspect of the stabilization process not explicitly studied here, but worthy of further examination is the choice of irradiance level and temperature. The standard calls for;**

- A class CCC solar simulator, in accordance with the IEC 60904-9, or natural sunlight
- ..consecutive periods of at least  $43 \text{ kWh} \cdot \text{m}^{-2}$  each integrated over periods when the temperature is between  $40^{\circ}\text{C}$  and  $60^{\circ}\text{C}$ , meet the following criteria:  $(P_{\text{max}} - P_{\text{min}})/P_{\text{average}} < 2 \%$ .

**If using controlled indoor light-soaking you could choose a target temperature from  $40$  to  $60^{\circ}\text{C}$**

- Amorphous silicon devices will have the greatest maximum output at the highest temperature

**For outdoor light-soaking under natural sunlight**

- No control of temperature
- The integrated exposure can be calculated, but what happens if the module exceeds  $60^{\circ}\text{C}$  ?





## References

- [1] D. L. Staebler, C. R. Wronski, "Reversible conductivity changes in discharge-produced amorphous Si", Appl. Phys. Lett. 31, pp 292-294
- [2] J. A. del Cueto, and B. von Roedern "Temperature-induced Changes in the Performance of Amorphous Silicon Multi-junction Modules in Controlled Light- soaking" Prog. Photovolt: Res. Appl. **7**, 101-112 (1999)
- [3] M. Nikolaeva-Dimitrova, R. P. Kenny, E. D. Dunlop, "Controlled Conditioning of a-Si:H Thin Film Modules for efficiency prediction", Thin Solid Films, Vol. 516/20, 2008, pp. 6902-6906.
- [4] D.L. King, J. A. Kratochvil, and W. E. Boyson "Stabilization and Performance Characteristics of Commercial Amorphous-Silicon PV Modules" Proceeding of the 28th IEEE PVSC Anchorage USA, September 2000, pp. 1446-1449
- [5] A. G. Aberle, "Thin-film solar cells", Thin Solid Films, Vol. 517, No. 17, July 2009, pp. 4706-4710.
- [6] E. L. Meyer and E. E. van Dyk, "Characterization of degradation in thin-film photovoltaic module performance parameters", Renewable Energy, Vol. 28, No. 9, July 2003, pp. 1455-1469.
- [7] C. Radue, E. E. van Dyk, E. Q. Macabebe, "Analysis of performance and device parameters of CIGS PV modules deployed outside", Thin Solid Films, Vol. 517, No. 7, February 2009, pp. 2383-2385.
- [8] R. P. Kenny, M. Nikolaeva-Dimitrova, E. D. Dunlop, "Performance Measurements of CIS Modules: Outdoor and pulsed simulator Comparison for Power and Energy Rating", Proceedings of the 4th WCPEC, Hawaii, May 2006. pp. 2058-2061.
- [9] J. A. del Cueto and B. von Roedern "Long-term Transient and Metastable Effects in Cadmium Telluride Photovoltaic Modules" Prog. Photovolt: Res. Appl. 2006; 14:615-628
- [10] First Solar, Inc., "Application Note: Best Practise for Power Characterization", PD-5-434, Rev 1.0, downloaded from [www.firstsolar.com](http://www.firstsolar.com), 2009.
- [11] Z. Jingquan F. Lianghuan, L. Zhi, C. Yaping, L. Wei, W. Lili, L. Bing, C. Wei, Z. Jiagui, "Preparation and performance of thin film CdTe mini-module", Solar Energy Materials and Solar Cells, Vol. 93, No. 6-7, June 2009, pp. 966-969.
- [12] IEC 61646. Thin-film terrestrial photovoltaic (PV) modules - Design, qualification and type approval (2nd ed.). IEC Central Office: 2008.
- [13] H. Muellejans, W. Zaaiman, R. Galleano, "Analysis and mitigation of measurement uncertainties in the traceability chain for the calibration of photovoltaic devices", Meas. Sci. Technol., 20, (2009): 075101 (12pp).



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