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Metastabilities and their impact on the results of IEC 61646 testing

Tony Sample

European Commission, Joint Research Centre
Ispra, Italy

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

Will not cover

General measurement principles for I-V curve generation and thin-film issues

- *Sweep-speed effects*
- *Direction of measurement* I_{sc} *to* V_{oc} *or* V_{oc} *to* I_{sc}
- *Spectral mismatch correction*

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/µ-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 [2-5]

[1] D. L. Staebler, C. R. Wronski, 1997
[2] J. A. del Cueto, and B. von Roedern 1999.
[3] M. Nikolaeva-Dimitrova et al 2008
[4] D.L. King et al 2000
[5] M. Nikolaeva-Dimitrova et al 2010

Copper Indium Gallium (di)Selenide (CIGS)

CIGS modules are also subject to light-induced change of the module efficiency [6].

Not as clear behaviour pattern for CIGS

- *Some authors have shown that they may degrade [7, 8] with light exposure*
- *but in some cases it has been shown that they remain stable [8] or improve [9].*

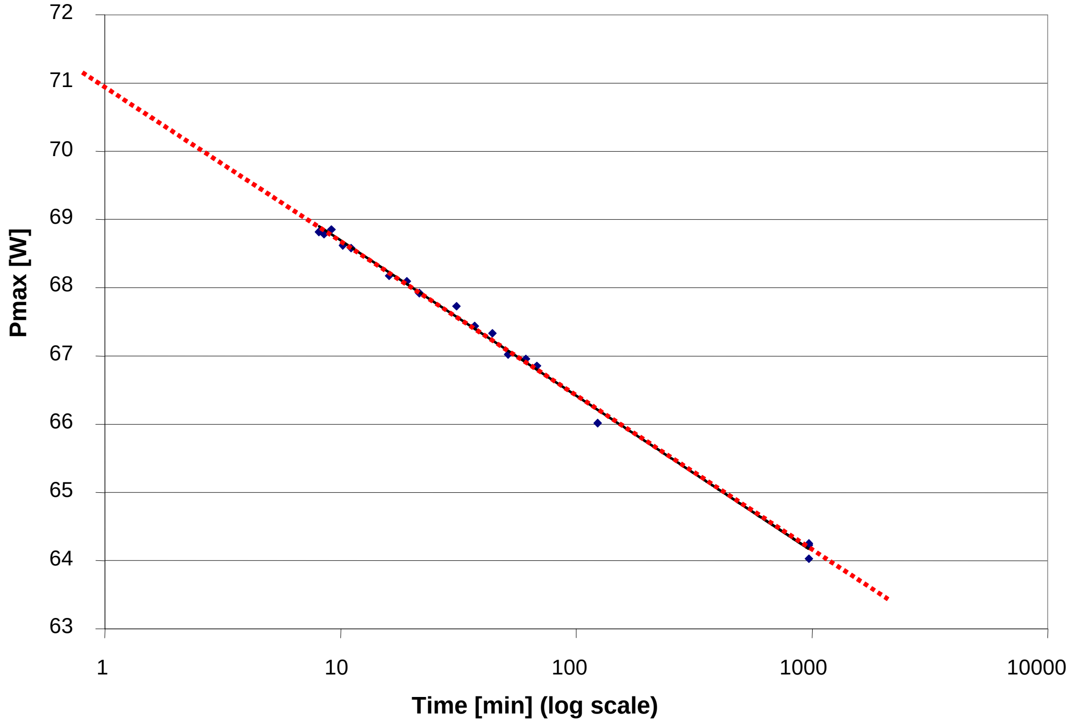
The behaviour is very dependent on the deposition and exact material composition.

Often 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 [9]

[6] A. G. Aberle, 2009
[7]. E. L. Meyer and E. E. van Dyk, 2003
[8] C. Radue et al 2009
[9] R. P. Kenny et al 2006

Copper Indium Gallium (di)Selenide (CIGS)

One example of the short-term light soaking [9]



[9] 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 [10]

However, more recent module production has generally shown a more uniform behaviour in that they tend to increase their maximum power with light exposure, especially following storage in the dark [10-12]

[10] J. A. del Cueto and B. von Roedern 2006
[11] First Solar, Inc. 2009.
[12] 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) [13]

Stabilization occurs when measurements from two consecutive periods of at least 43kWh/m² each integrated over periods when the temperature is between 40℃ and 60℃, meet the following criteria:

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

[13] IEC 61646 2008

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^2

Duration per period ~48 Hours

Module temperature 45-55^oC

- Stability better than ±2^oC

Operation under resistive load

Module P_{max} determined on class AAA simulator at 25^oC

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^2.

- 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} ±1.3%, V_{oc} ±0.3%, FF ±0.72%, P_{max} ±1.5% [14]

[14] H. Muellejans et al 2009

Modules used in the study

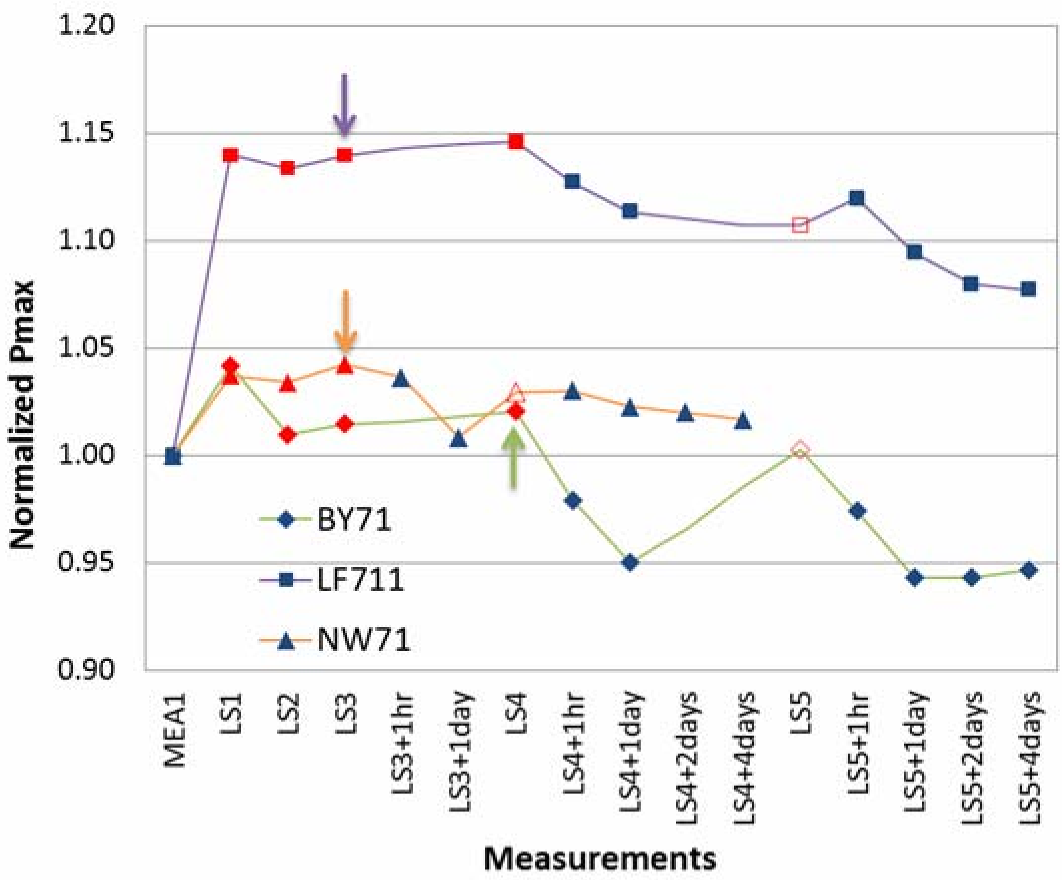
ESTI CODE	TECHNOLOGY
BY71	*CIGS* (Copper-Indium-Gallium-diselenide)
LF711	*CIGS* (Copper-Indium-Gallium-diselenide)
NW71	*CIGS* (Copper-Indium-Gallium-diselenide)
KX711	*CdTe*
NW73	*CdTe*
LK711	*Triple junction a-Si*
LK712	*Triple junction a-Si*
KW711	*a-Si/ μ -Si*
KW712	*a-Si/ μ -Si*
HJ410	*a-Si/ μ -Si*

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

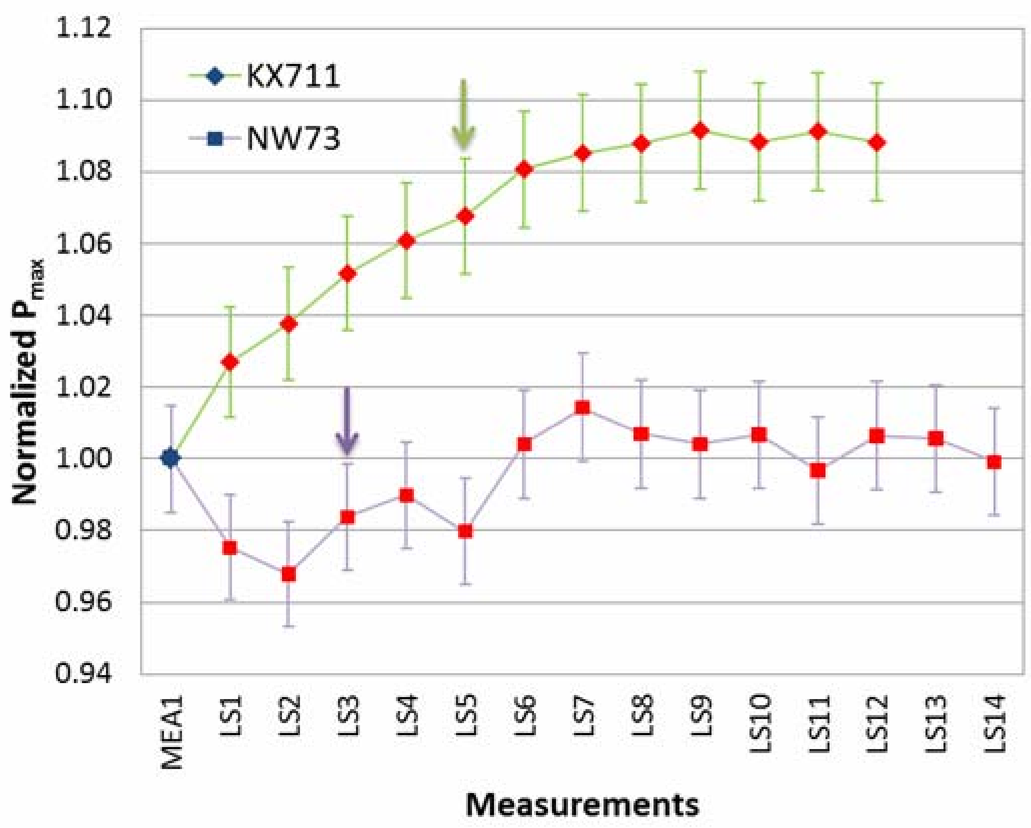
Stabilised after 3-4 exposure cycles

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

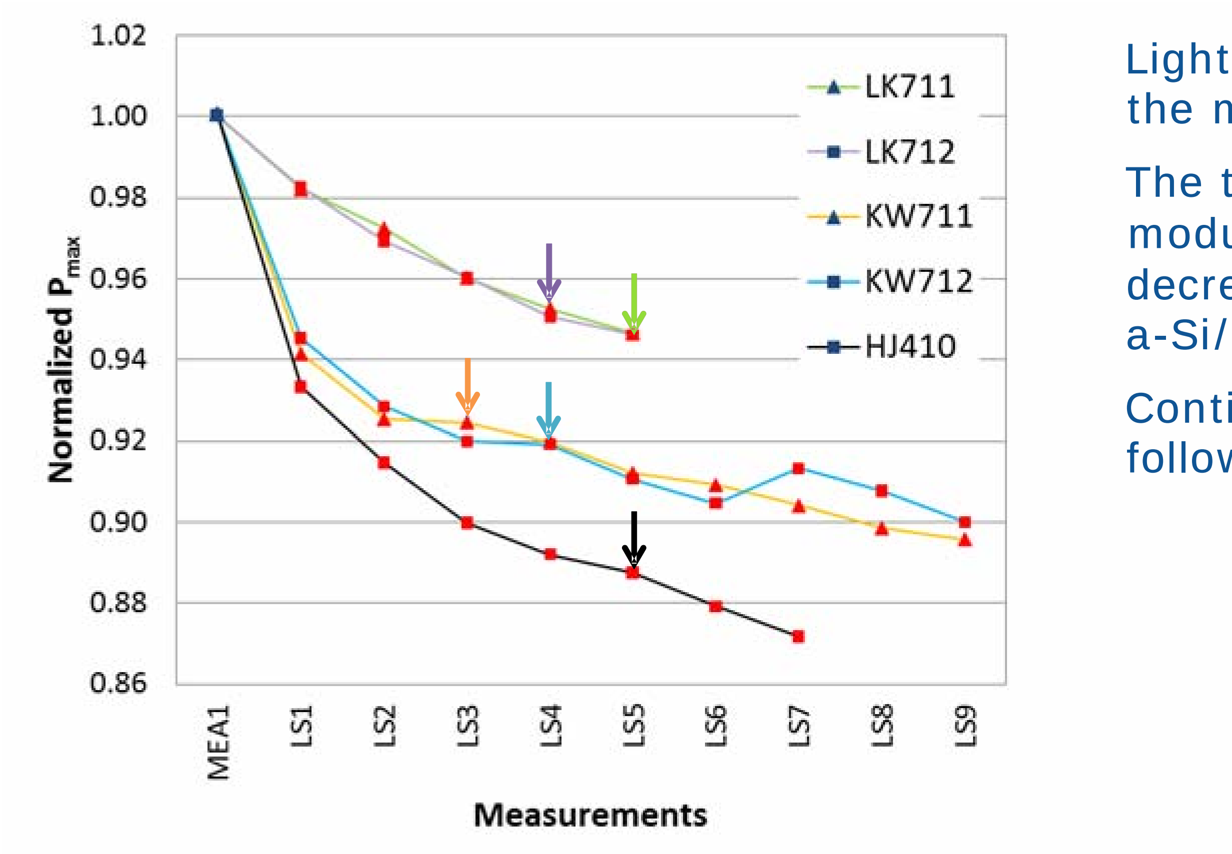


Light-soaking has improved the maximum power

Difference between the two modules could be due to their prior history, or it could also be attributed to batch to batch variation

Continued to improve following point of stabilisation

Results for a-Si / µ-Si and Triple junction



Light-soaking has decreased the maximum power

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

Continued to decrease following point of stabilisation

Conclusions

For the purposes of module qualification, the stability procedure of IEC 61646 ed 2 is probably satisfactory [15], 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

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

[15] R. P. Kenny et al 2012

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 kWh·m^{-2} each integrated over periods when the temperature is between 40°C and 60°C, meet the following criteria: $(P_{max} – P_{min})/P_{average} < 2\ \%$.

If using controlled indoor light-soaking you could choose a target temperature from 40 to 60ºC

- 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 60ºC ?

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