

# Light Soaking Measurements of Commercially Available CIGS Modules

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## Summary & Conclusions

- CIGS devices exhibit metastabilities and performance changes with continuous light exposure, or light soaking.
- We used an indoor continuous solar simulator to expose three commercially available CIGS modules to 16 simulated day/night cycles while investigating performance changes in the modules.
- We observed an initial increase in efficiency on the order of ~3-5% during the first 1-2 hours of each illumination cycle in all three modules.
- The time for relaxation to a low-efficiency state in the dark was found to be ~3-16 hours.
- We investigated temperature coefficients of the three modules, and determined that one of the modules would produce ~3-5% less power output at normal operating temperatures than would be expected based on its data sheet  $P_{max}$  temperature coefficient.

## Experimental Details

<b>Modules</b>	Three commercially available CIGS modules from three different manufacturers.
<b>Light Exposure</b>	Atonometrics Continuous Solar Simulator Chamber.
<b>Light Intensity</b>	1000 W/m <sup>2</sup> +/- 10%
<b>I-V</b>	I-V curves recorded every 10 min (& every 1 min during temperature ramps). Modules held at MPP in between I-V.
<b>Experiment 1</b>	Day/night cycle simulation. 8 hours light + 16 hours dark. Repeated cycle 16 times.
<b>Experiment 2</b>	Dark relaxation period investigation. Similar to Exp. 1 but varying dark period from 1 to 9 hours.



Continuous Solar Simulator Chamber  
With Integrated I-V Measurement

## Experiment 1 Results

### Temperature Coefficients Over 16-Day Test

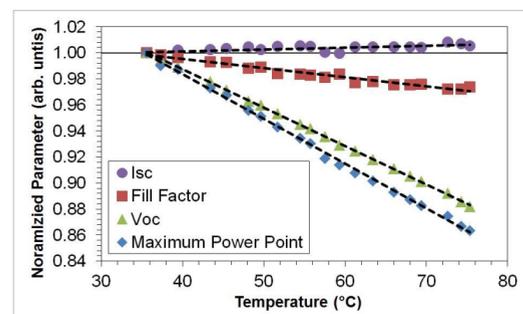


Fig. 1. Example of normalized extracted parameters for a series of I-V curves with the linear fits used to extract the corresponding temperature coefficients.

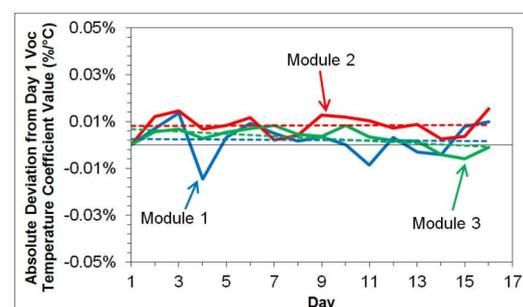


Fig. 2. Absolute deviations, in %/°C, of  $V_{oc}$  temp. coeffs. from the temp. coeffs. measured on Day 1 for each module. Note that the data sheet values of the  $V_{oc}$  temp. coeffs. of each module were on the order of -0.3 %/°C to -0.4 %/°C.

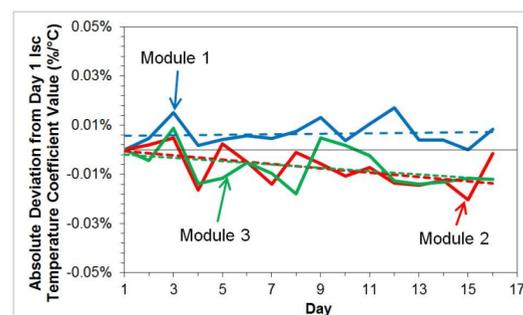


Fig. 3. Absolute deviations, in %/°C, of  $I_{sc}$  temp. coeffs. from the temp. coeffs. measured on Day 1 for each module. Note that the data sheet values of the  $I_{sc}$  temp. coeffs. of each module were on the order of 0.01 %/°C.

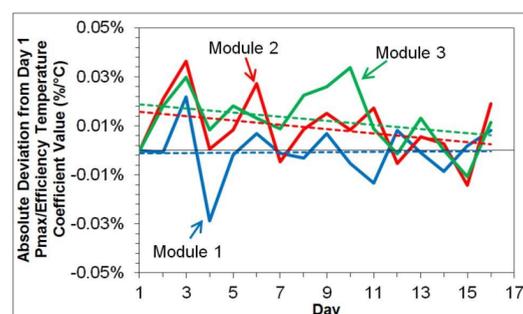


Fig. 4. Absolute deviations, in %/°C, of  $P_{max}/\text{efficiency}$  temp. coeffs. from the temp. coeffs. measured on Day 1 for each module. Note that the data sheet values of the  $P_{max}/\text{efficiency}$  temp. coeffs. of each module were on the order of -0.3 %/°C to -0.45 %/°C.

### Measured Temperature Coefficients Compared to Data Sheet Values

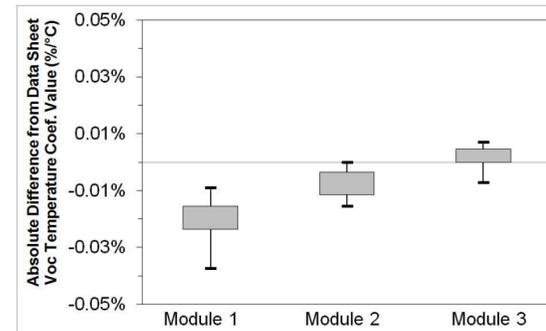


Fig. 5. Whisker-box plot showing the absolute difference between the measured  $V_{oc}$  temp. coeffs. and values from the modules' data sheets. See notes below on plot interpretation.

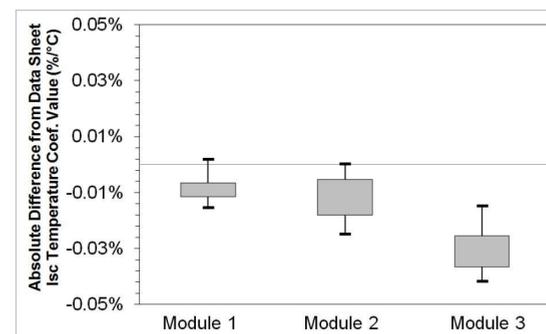


Fig. 6. Whisker-box plot showing the absolute difference between the measured  $I_{sc}$  temp. coeffs. and values from the modules' data sheets. See notes below on plot interpretation.

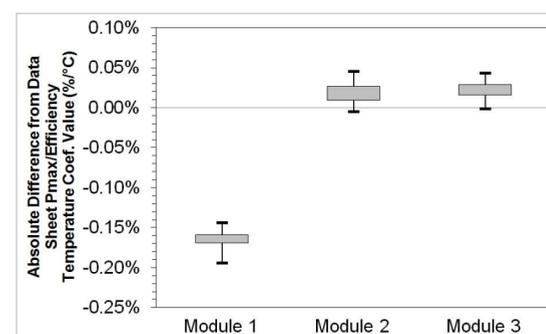


Fig. 7. Whisker-box plot showing the absolute difference between the extracted  $P_{max}/\text{efficiency}$  temp. coeffs. and the data sheet values. See notes below on plot interpretation.

- Note significant discrepancy from data sheet value for  $P_{max}$  temp. coeff. for Module 1 (Fig. 7).

### Whisker-box plot interpretation:

- The upper and lower limits of the boxes shown indicate the upper and lower limits of the second and third quartiles of the measured data, respectively (*i.e.*, 50% of the collected data points lie within each box).
- The center of each box indicates the median value.
- The upper and lower limits of the vertical lines drawn through each box indicate the maximum and minimum measured values, respectively.

### Efficiency Changes with Light Soaking

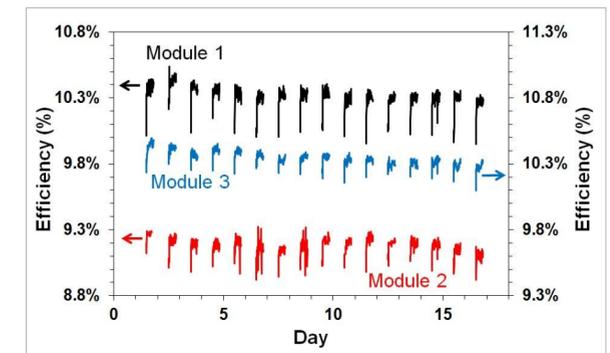


Fig. 8. Efficiency plotted as a function of time. The spaces between data indicate the time the modules were kept in the dark. Note that two y-axes have been used for clarity. Data for Modules 1 and 2 correspond to the left y-axis. Data for Module 3 correspond to the right y-axis.

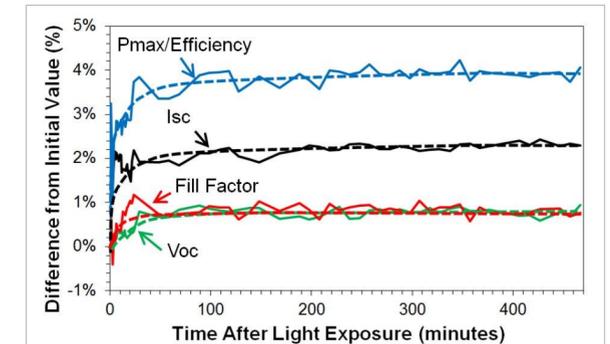


Fig. 9. Relative response of Module 3 to light exposure on the 8<sup>th</sup> day of Experiment 1. Dashed lines have been added here to the  $P_{max}/\text{efficiency}$ ,  $I_{sc}$ ,  $V_{oc}$ , and  $FF$  data to guide the eye.

## Experiment 2 Results

### Dark Relaxation Time

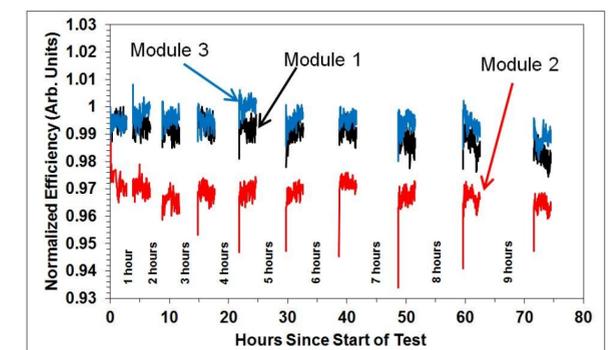


Fig. 10. Efficiency plotted as a function of time. The spaces between data indicate the time the modules were kept in the dark. The amount of time of each period in the dark is indicated by the text on the graph. Note that Module 2 begins exhibiting a pronounced increase in efficiency with initial light exposure after 3 hours in the dark.

## References

- [1] M. Gostein and L. Dunn, "Light Soaking Effects on Photovoltaic Modules: Overview and Literature Review," in 37th IEEE Photovoltaic Specialists Conference, Seattle, WA, 2011.
- [2] J. A. del Cueto, S. Rummel, B. Kroposki, C. Osterwald, and A. Anderberg, "Stability of CIS/CIGS Modules at the Outdoor Test Facility over Two Decades," in 33rd IEEE Photovoltaic Specialists Conference (PVSC), 2008.
- [3] T. Yamagisawa and T. Kojima, "Behavior of a CuInSe<sub>2</sub> solar module under light irradiation in light/dark cycle tests," *Solar Energy Materials and Solar Cells*, vol. 77, no. 1, pp. 43-47, Apr. 2003.
- [4] T. Yamagisawa and T. Kojima, "The stability of the CuInSe<sub>2</sub> solar mini-module I-V characteristics under continuous and light/dark irradiation cycle tests," *Microelectronics Reliability*, vol. 43, no. 3, pp. 503-507, Mar. 2003.