Robustness of SunPower Cells to Wind Stress via High-Cycle Vibration Testing

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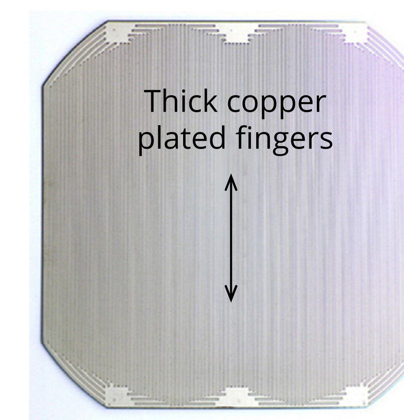
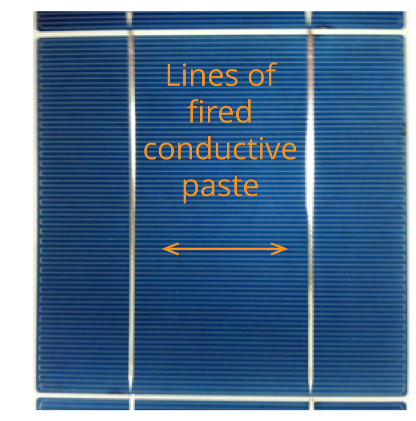
Introduction

It has been previously demonstrated (Degraaff et al 2010) that SunPower's back contact solar cells have low power losses upon cracking due to interdigitated electroplated metallization (a.k.a. "fingers") that retain the cell integrity. In this study it is further demonstrated that the thick SunPower fingers retain cell integrity with long-term fatigue loading. A newly developed vibration test which mechanically fatigues cracked cells in laminated coupons is used to build fatigue (S-N) curves. These are combined with laminate displacement data from fielded modules to generate lifetime estimates for cyclic wind load fatigue. The fatigue test could not be performed on multi-crystalline front contact cells due to their tendency to fall apart when cracked prior to lamination.

Backside of SunPower Cell



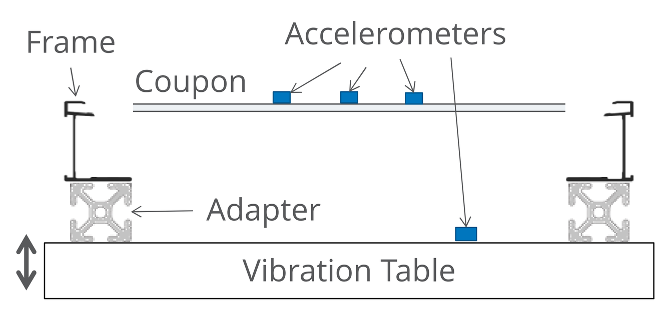
Frontside of Traditional Cell



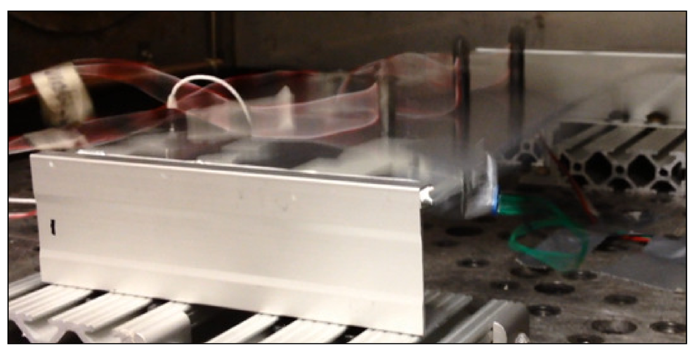
Materials and Methods

Fatigue Testing
Small laminated coupons containing a pre-cracked cell were mounted to a vertical axis vibration system in such a way to allow for flexural bending of the coupon. The vibration test system was configured to dwell at a fixed amplitude at the primary bending resonance of the coupon. The curvature at the cell crack was used as a proxy for the stress level. It was calculated from data collected using accelerometers attached to the coupon.

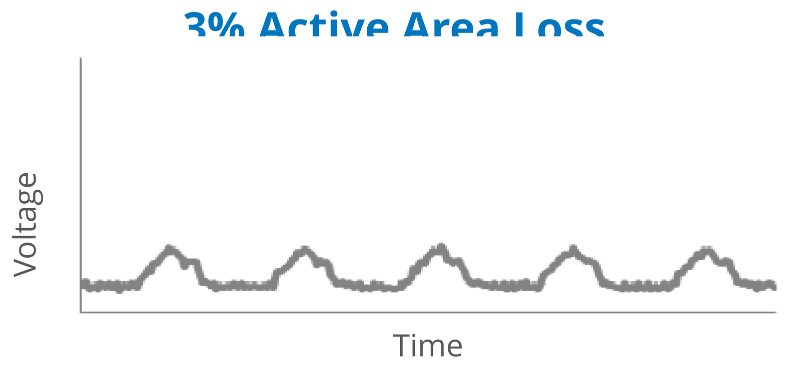
Diagram of test setup



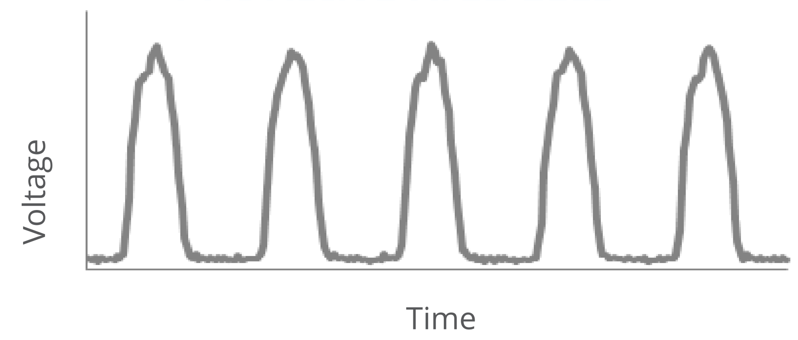
Vibration Test in Progress



3% Active Area Loss



14% Active Area Loss



In-Situ Monitoring
During fatigue testing a fixed current was applied to the cell and the resulting voltage waveform was captured. The amplitude of the signal correlates with the amount of lost active area in the cell due to finger breakage. The failure threshold was chosen to be 10% loss in active area.

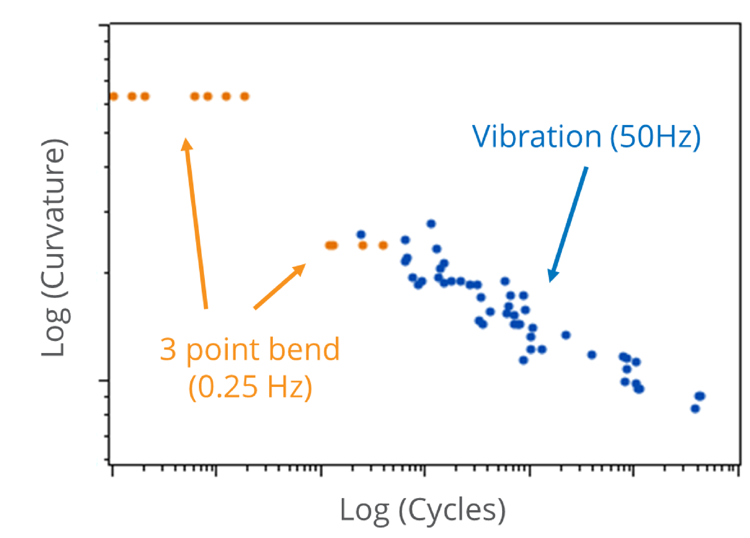
Mission Profiling
Two SunPower modules on the windward corner of a single axis tracker in a windy location were instrumented with displacement sensors. Two weeks of data were collected at a sampling rate of 10 Hz. Included in the dataset are two separate wind events with gusts over 65mph. This dataset was assumed to be very aggressive when extrapolated and the resulting lifetime estimates were expected to be conservative.

Displacement Sensor Under Module

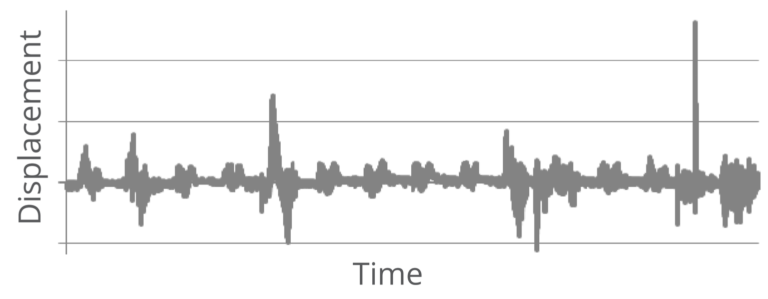
Data Treatment and Results

Test Data
Vibration testing was conducted over a range of stress levels to generate S-N curves. These curves have reasonable agreement with low frequency mechanical testing in a three point bend configuration. The shape, slope, and variance observed in the data is consistent with fatigue testing of metals as reported in the literature.

S-N Curve



Laminate Displacement Time History



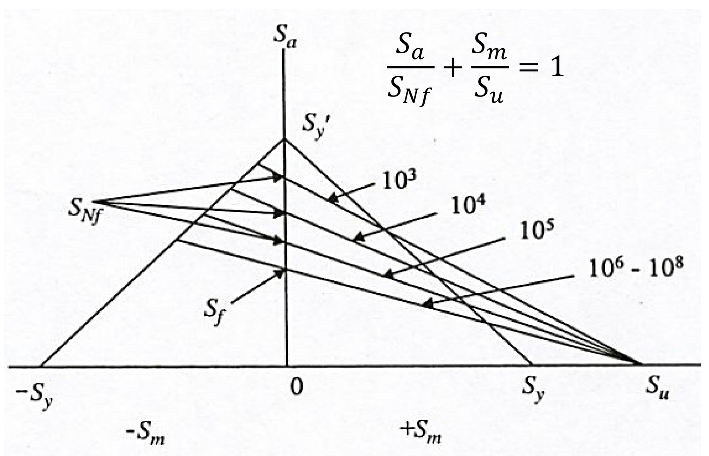
Simplified Rainflow Counting Output

Range	Mean -4	-2	0	2	4	6	8
1	-	4376	3.7e5	12935	276	40	9
3	-	470	1849	780	44	14	3
5	-	11	8	40	10	3	-
7	-	-	1	7	2	2	-
9	-	-	-	2	-	-	-
11	-	-	-	-	-	-	-
13	-	-	-	1	-	-	-

Field Data
The entire mission profile dataset was converted to a list of cycles through the use of a rainflow counting algorithm (ASTM E1049-85). Cycles with less than 0.25mm range were considered insignificant and discarded. Displacement was converted to curvature using a correlation from a previous experiment mapping the surface of a module under mechanical load.

Lifetime Calculation
Since almost all of the cycles in the mission profile had a non-zero mean the Goodman correction was applied to convert the data into equivalent fully reversed curvature cycles which were directly compared to the test data. Finally, Miner's rule was used to generate lifetime estimates with the S-N curve. Even when using the lower 95% confidence band of the fitted S-N data, the predicted lifetime was over 500 years.

The Goodman correction



https://www.efatigue.com/training/Chapter_4.pdf

Conclusions

Based on the findings in this study, SunPower's cell metallization can survive mechanical fatigue damage due to wind loading over the standard 25 year warranty period with a comfortable margin, even when the underlying cell is cracked. Future development could include: application of the same technique to the cell interconnect fatigue, addition of shipping loads to the mission profile, and creation of a standard vibration fatigue test spectrum with 25 year equivalence.

Literature Cited

D. DeGraaff, et al., "Qualification, Manufacturing, and Reliability Testing Methodologies for Deploying High-Reliability Solar Modules", PVSEC 2010 (Valencia, Spain)

ASTM E1049-85 (1997), "Standard Practices for Cycle Counting in Fatigue Analysis", ASTM International, West Conshohocken, PA, 2011, www.astm.org

Acknowledgements

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