Electroluminescence Analysis of PV Module under Accelerated Lifecycle Testing

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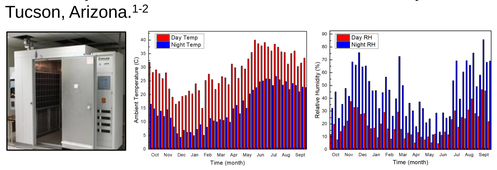
Introduction and Motivation

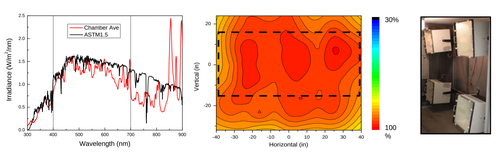
- Degradation in power conversion efficiency undermines long-term reliability of photovoltaic (PV) modules and hence return on investment (R.O.I.).[1-2]
- Electroluminescence (EL) is often applied to qualitatively identify the presence of physical flaws (e.g. cracking) and, less commonly, to quantitatively evaluate module or cell robustness.[3-9]
- Pixel intensity can not only locate the presence of damaged segments, but also reveals the characteristics of slowly degrading cells.
- Chamber-based accelerated lifecycle (ALC) testing enables in-situ observations of EL under desired environmental conditions.[1-2]

Experimental Methods

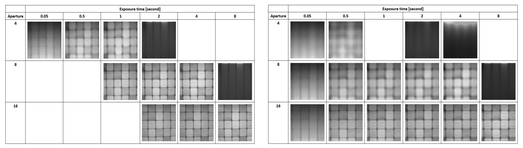
- Environmental chamber replicates accurate climate profile obtained by a weather station situated at the TEP test yard in Tucson, Arizona.[1-2]



- UV-visible-IR metal-halide lamps enable accelerated lifecycle (ALC) testing: spectral distribution ~AM1.5; irradiance distribution ~95% uniformity; solar insolation of 1 full sun (1kW/m^2).[1-2]



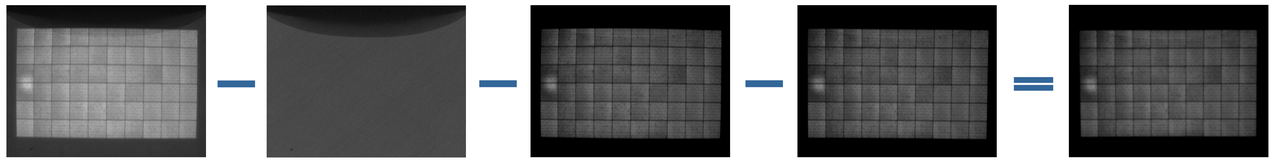
- EL images (Andor iKon-M) were obtained by applying a forward bias, I_{SC}, to the module. Optimized data acquisition conditions (5mm tube length, aperture size of 16, exposure time of 4-8 seconds) were determined via a series of image comparisons.



- EL images are captured during nighttime (dark soak) portions of the chamber test cycle in each simulated month for a simulated year.

Results

Image Preparation: Image Correction



EL images exhibited background noise and image distortion. Image correction included:

- Initial noise removal through acquisition of background image with no energizing source.
- Optical barrel distortion (seen as bend towards each corner of the image) correction.
- Repositioning displacement (rotation) correction.

Image Dimension: Module Cropping

- Enhanced image allows frame edge detection so that the full module can be extracted from the full EL image.

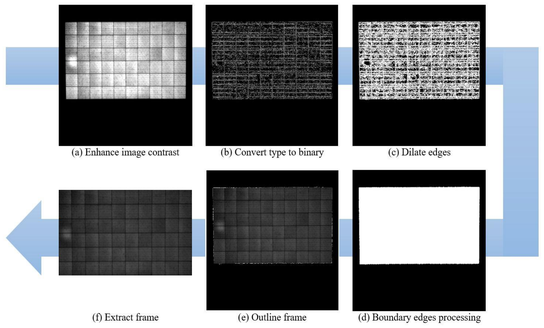
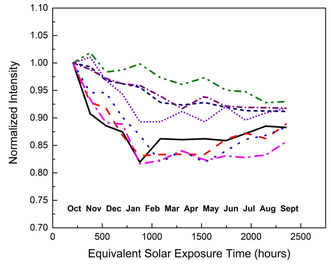
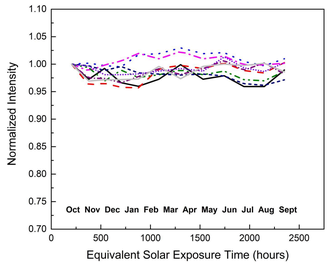
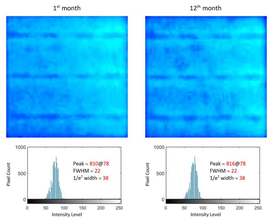


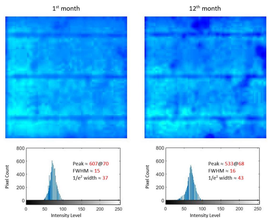
Image Analysis: Intensity Histogram Approach

- Smoother decline in mean and unchanging standard deviation indicate a slowly degrading or undegraded cell.
- Sudden drop in pixel mean and rapid increase in standard deviation suggest potential cracks or significant defects.
- Two observed trends in mean variation of cell intensity over the course of a year-equivalent ALC test:
  - ❑ Relatively constant pixel distribution (left figures) for 2/3 of cells in module;
  - ❑ Significant decrease in normalized intensity (right figures) among 1/3 of 60 cells.





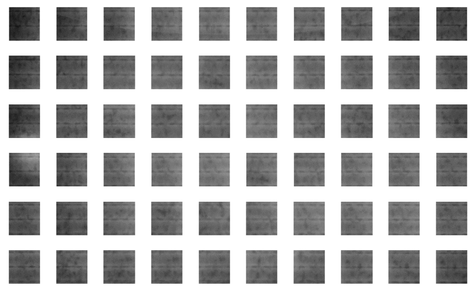


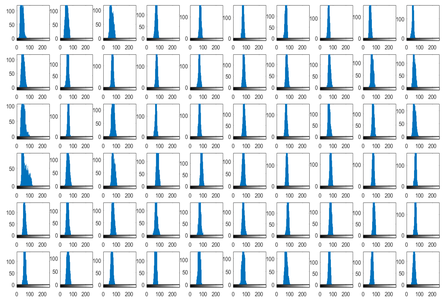


- Left representative figures show little variation in EL intensity histograms over the course of a twelve-month equivalent ALC test: pixel count of 810-816 at intensity level of 78 out of 255, and width (FWHM = 22, and 1/e^2 width = 38).
- By contrast, right representative figures show a clear decay in normalized EL intensity, with losses ranging from 5% to nearly 20%: decrease in pixel counts from 607 to 533, a shift in intensity level from 70 down to 68, and an increase in 1/e^2 width (37 increasing to 43 out of 255 with a notable asymmetry on the low intensity side of the distribution.
- In contrast to other studies using EL assessment of PV modules, no evidence for significant macroscale crack evolution was observed under these more field-relevant, early lifetime environmental test conditions.

Image Processing: Cell Extraction

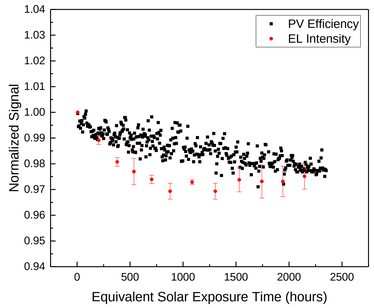
- Given numbers of columns and rows, individual cells are identified and extracted based on their positions in the full module image.
- Intensity histograms of individual cells are monitored monthly to enable degradation analysis using statistical parameters (mean, standard deviation).





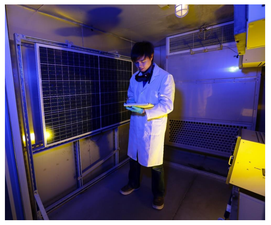
Performance Analysis: Power Efficiency and EL Intensity

- Rapid degradation in EL intensity experienced by 1/3 of the cells in PV module contributed to full PV module degradation behavior.
- Examination of data shows a 0.35% reduction in actual power conversion efficiency (or 2.3% decrease in relative efficiency as plotted in the figure) during the 1-year accelerated lifecycle test.
- A normalized decrease of approximately 2.5% in normalized EL intensity across the module exhibits good agreement with the measured normalized PV efficiency decrease of 2.3%.
- While the form of the normalized efficiency degradation and the normalized EL intensity decay are not identical, within the error bars, the similarity in the behaviors of the two curves is unmistakable and confirms a correlation between these two measurement trends.



Conclusions and Future Research

- Full-scale, controlled environmental chamber enabled EL measurements during accelerated lifecycle testing whose weather profile resembles the climate in Tucson, AZ.
- An analysis method for processing the electroluminescence images was presented that enabled a cell-by-cell evaluation of both mean EL intensity and of the width of the EL intensity distribution
- Series of intensity histograms showed: 60% cells < 5% variation, and 40% beyond 5%, leading to a total normalized loss in EL intensity across the full PV module of approximately 2.5%.
- Comparison of panel efficiency degradation behavior with the observed EL intensity degradation suggests good correlation between the overall module performance with a loss of electrical connectivity, possibly due to the formation of microcracks or other small-scale defects in the cell structure.
- Calibration source has been introduced to the environmental chamber to supply a repeatable calibrated peak intensity for image normalization.
- Finer pixel-to-pixel line scan image analysis will be pursued in future research.



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Acknowledgements

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