BAPVC Annual Project Report

Project Title: PV Module performance & Lifetime Prediction: Inserting New Technologies Without Lifetime Penalty
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Summary:

A data science approach is being developed for the performance and lifetime prediction (PLP) tool for real-world exposed modules and mini-modules exposed to accelerated exposures to elucidate key degradation modes including corrosion of screen printed silver. The PLP tool is being developed using semi-supervised generalized structural equation modeling (semi-gSEM) for statistical analytics, which generates visual representation of the strength of relationships between stress and responses.[1]

Key Accomplishments:

The PLP tool has been developed to include automated diagraming of degradation pathways and relationships between stress, mechanisms/modes, and responses. The semi-gSEM methodology has been published on Git as an open source package (1C). PyCRADLE GUI was developed to ingest data into E-CRADLE. Nagios was developed to monitor real-world data streams and a databook to keep metadata in Hadoop.

A statistical model was developed using 60 modules of 20 different brands exposed in Cleveland, OH using time series data. Data cleaning procedure was developed and data was integrated into E-CRADLE. Hierarchal clustering showed that the brand effect had less of an impact than the mounting configuration of the model. A mixed effect model was developed to understand the relationship between variables, which include power produced, temperature, irradiance, and model brand. The pairwise plot for this model is shown in Figure 1.[2]

Screen printed corrosion is being investigated to understand the mechanism of degradation and its relationship to overall power loss.[3] This accelerated study protocol includes multi-factor exposures to relate the stress to the degradation mechanism. Mini-modules fabricated by the DuPont Silicon Valley Technology Center. These mini-module samples were finished at the SDLE center and were prepared for testing by adding junction boxes and modifying cable lengths. The prepared modules were used to develop and establish three lab instruments and measurement techniques (EL Imaging, I-V Curves, and Confocal Raman Microscopy) for the non-destructive characterization of electrical and chemical properties of mini-modules. Electroluminescence image of a mini-module exposed to

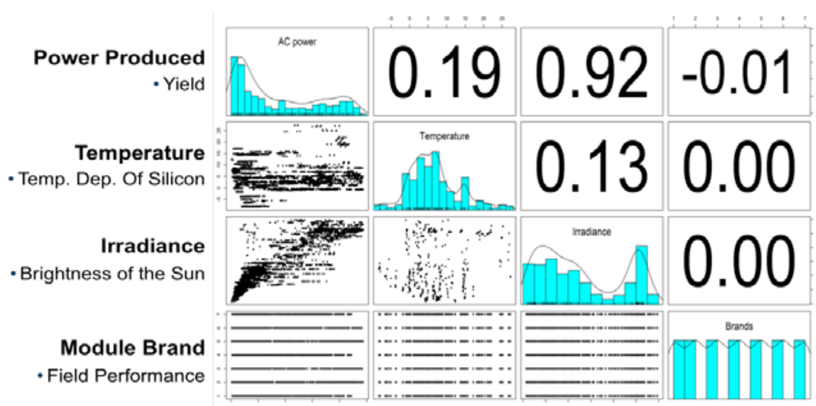

Figure 1: Pairwise plot for the mixed effect module for real-world exposed modules.

damp heat accelerated exposure shows degradation attributed to silver corrosion in Figure 2. Raman spectra are shown in Figure 3 for different segments of the module. R code was developed to facilitate data handling of the three file types produced by the measurement techniques (jpg, xml, spc), and additional code was developed to automate ANOVA modeling of Gage R&R experimental results. Sources of variation being contributed by the measurement techniques themselves were investigated with several rounds of these experiments and corrective measures were designed and implemented.

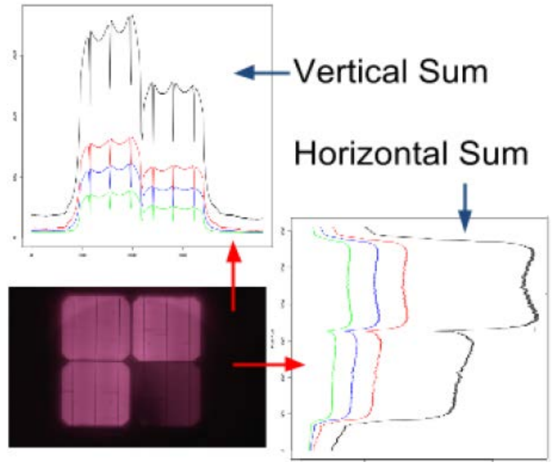

Figure 2: Quantitative image analytics applied to electroluminescence of a mini-module exposed to 1000 hrs of damp heat.

Degradation of transparent conductive oxides (ITO, AZO, FTO) was studied subjecting them to environmental and material stressors. Optical, electrical and surface sensitive TCO property metrics were analyzed and different degradation mechanisms observed.[4]

Future Work:

The next iteration of the semi-gSEM methodology (sgSEM v 0.5) will be able to understand the contribution of multiple stressors and stress levels on the performance loss

In time series analysis additional data will be analyzed to further refine the mixed effects model of real-world PV module degradation. Additionally, the time series data analysis will begin to elucidate information within the dataset to help predict module performance.

Future work on the Screen Printed Silver Corrosion in PV Modules project begins with applying the developed measurement techniques to baseline the mini-module samples prior to beginning environmental exposures. While the dataset is being generated, figures of merit that summarize each datatype will be identified through a combination of literature and observed results, and automatically extracted from the accumulating raw data files. The distilled dataframe of these variables will be analyzed with the semi-gSEM technique to create statistical models describing the rates and functional forms of the observed mechanistic degradation modes and pathways in the two styles of mini-module due to the various stressors present in the exposure conditions, which is the overall goal of this project.

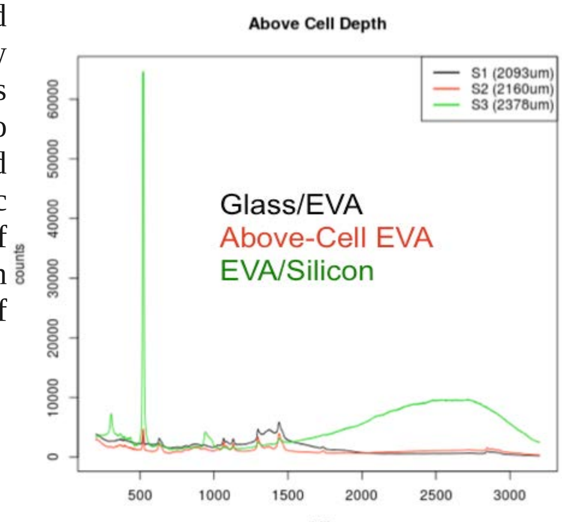

Figure 3: Confocal Raman spectra at various depths in a mini-module, demonstrating the ability to non-destructively probe chemical degradation.

References

1. French, Roger H., et. al, "Degradation Science: Mesoscopic Evolution and Temporal Analytics of Photovoltaic Energy Materials," Current Opinion in Solid State and Materials Science, 2015.
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3. Wheeler, N. R. et. al, SPIE 9563-32, 2015.
4. Mirletz, H. M, et al. Sol. En. Mat, & Cells, 2015.