Investigation of Field Aged Photovoltaic Modules for Encapsulant Discoloration Mechanisms

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Introduction

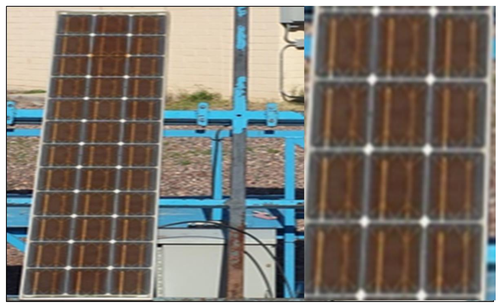
- The power output of PV modules is affected by the deterioration of one or more of the following three I-V parameters (response variables): short circuit current, open circuit voltage, and fill factor(due to series resistance increase and/or shunt resistance decrease). These response parameters are typically affected by several degradation modes.
- This investigation deals the encapsulant discoloration mechanisms related to the loss of short circuit current of field aged modules with identical construction and manufacturer from two diverse climatic conditions (California and Arizona).

Methods

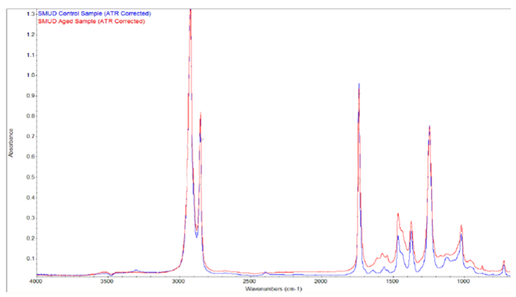
The techniques utilized in this work are: current-voltage measurement (I-V), visual inspection (VI), nondestructive cell-module quantum efficiency (C-M-QE), and module level reflectance spectroscopy (M-RS), Differential scanning calorimetry (DSC), and Fourier transform infrared spectroscopy (FTIR).

Results

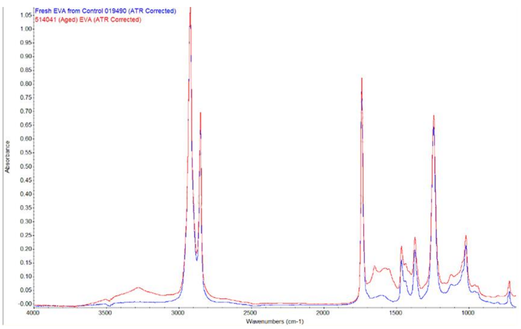
Visual Image of AZ
18 Years Old Aged Module



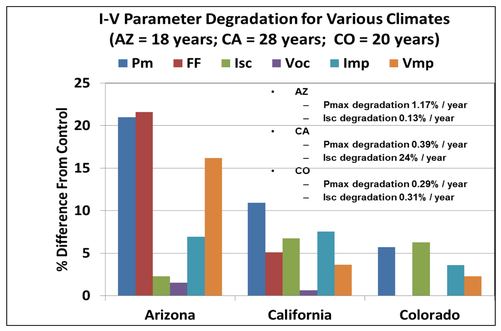
Visual Image of CA
28 Years Old Aged Module



FTIR of CA Aged and Control Modules



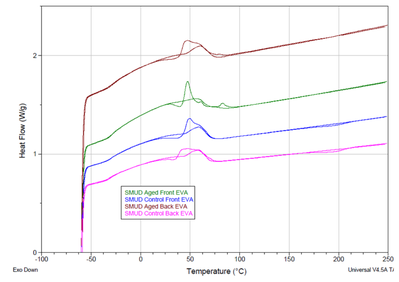
FTIR of AZ Aged and Control Modules



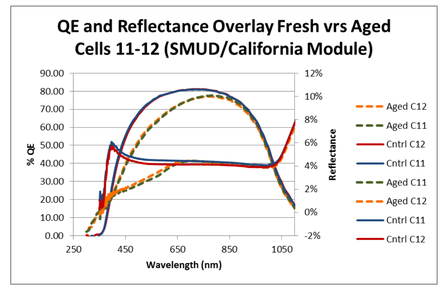
I-V Parameter Degradation Values

- The CO and CA modules showed higher Isc degradation rates than the AZ modules – primarily attributed to encapsulant discoloration
- FTIR spectra indicated the presence / formation of polyenic chromophores (1641 cm^{-1}, 1545 cm^{-1}) in both CA and AZ modules
- FTIR spectra showed the hydrolysis peaks in the CA module but strangely not in the AZ module

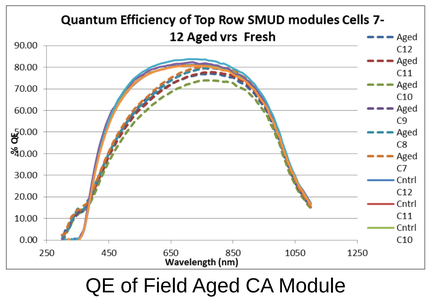
Results



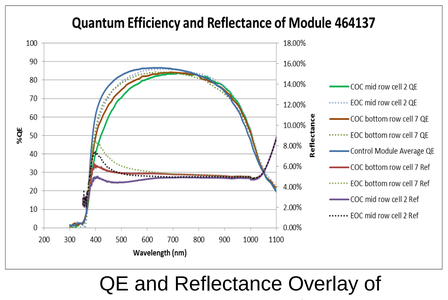
DSC Thermograms of
Aged and Control CA Modules



QE and Reflectance Overlay of
Aged CA Module



QE of Field Aged CA Module



QE and Reflectance Overlay of
Aged AZ Module

- Browning appears to affect performance below 650nm as shown in the QE plot
- Browning leads to a 10% drop in QE in the 400-650nm range for AZ modules and 15% drop in CA modules
- Increased spectral response in the UV region of the QE graph for the aged CA module is a result of UV absorber additive depletion over its lifetime
- DSC shows both irreversible and reversible reactions in melting transitions and the loss of lubersol 101, a slow curing additive, in aged modules when compared to control modules

Conclusions

- Aged AZ module: The most dominant degradation mode is the increase of series resistance leading to FF drop; the second most dominant mode is the discoloration (browning) of EVA leading to Isc drop.
- Aged CA module: The most dominant degradation mode is the discoloration (browning) of EVA leading to Isc drop; the second most dominant mode is the increase of series resistance leading to FF drop
- Strong correlation is observed between loss of additives (QE), polyene formation (FTIR) and the browning (visual)
- DSC shows both irreversible and reversible reactions in melting transitions and the loss of lubersol 101, a slow curing additive, in aged modules when compared to control modules
- QE loss: Above 650 nm, primarily due to series resistance increase; below 650 nm, due to series resistance increase and encapsulant browning
- Increased spectral response in the UV region of the QE graph for the aged CA module is a result of UV absorber additive depletion over its lifetime
- These findings need to be further confirmed with additional samples

Acknowledgements

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