NATIONAL RENEWABLE ENERGY LABORATORY

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Effects of PV Module Soiling on Glass Surface Resistance and Potential-Induced Degradation

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1. Goals

- *Determine applicability of transmission line method (TLM) to evaluate sheet resistance of soils on module glass*
- *Evaluate various soils on glass for changes in surface resistance and their ability to promote potential-induced degradation with humidity (PID)*
- *Evaluate PID characteristics, rate, and leakage current increases on full-size mc-Si modules associated with a conductive soil on the surface*

2. Introduction & Background

- *PID is a critical degradation mode sometimes observed in crystalline silicon PV modules*
- *Factors promoting PID include increased conduction paths from the active cell circuit to ground*
- *Conductive soiling on glass may act as a conductive path from the glass face to the grounded metal module frame or edge clips*
- *Soiling may further trap or react with moisture and increase conductivity on the module face, promoting ionic conduction and PID*
- *TLM is commonly used to determine sheet resistance of semiconductor films independent of film lateral dimensions*
- *TLM is hence applied to evaluate the resistivity of soil films on module glass as function of relative humidity*

3. Apparatus

- *Multi-probe board, 4 wire measurements*
- *Voltage power supply, current sense circuits*
- *Resolution of the apparatus: 5×10^{-9} A, but surface conductivity of the probe holder board at 95% RH led to a background current of 1.5×10^{-8} A*
- *Multi-probe board connected to sample and placed in an environmental chamber*

4. Experiment

A) 162-cm² Square Starphire (low-iron) untextured glass TLM samples

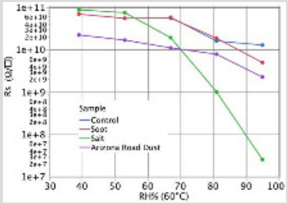
- *Conductor stripes: 3M Electrically Conductive Aluminum Tape #3302, 15.25 cm x 1 cm, 0.25, 0.50, 1.5, and 2.0 cm edge-to-edge*
- *Glass coupons weighed prior and post soil deposition to determine the mass loading*
- *Simulants of common soils applied:*
  - *Arizona road dust:A2 fine grade, Powder Technology, Inc.*
  - *Sea salt: ASTM D-1141-52, Lake Products Co., Inc.*
  - *Soot: in-house formulation, consisting of 92% carbon black [Vulcan XC-723], 5.3% diesel particulate matter [NIST Catalog No. 2975], 2.8% unused 10W30 motor oil, 0.1% β-pinene [Catalog No. AC13127-2500, Acros Organics]) suspended in deionized H_2O*
- *Mass loading: 2.75 ($\sigma = 0.87$) g/m²*
- *60° C, 100 V, step stress of relative humidity: 39% to 95%*
- *Samples used just once due to ion migration and Al corrosion*

B) 60 cell mc-Si modules

- *Sea salt mass loading: 25 g/m²*
- *60° C, -1000 V, step stress of relative humidity 25% 65%, 85%, and 95%*

5. Results

A) Sheet resistance of various soils on glass and an unsoiled control as a function of relative humidity at 60° C



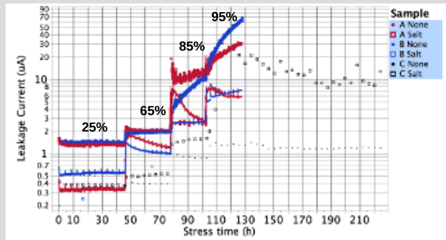
Dwell time at each level: 1.25 h

Arizona road dust:
• Lower sheet resistance compared to the control
• humidity-independent but elevated leakage current suggest increased PID in a low-humidity environment

Soot:
• Did not show significant conductivity over the unsoiled control
• Different soot and other carbon-containing compounds may have differing results

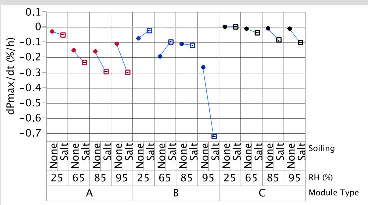
Sea Salt:
• 3.5 order of magnitude decrease in resistance with relative humidity increase from 39% to 95%.

B) Leakage current measured from three pairs of module types, one in each pair with sea salt on the surface, as a function of RH



- *Leakage current measured on the modules with salt were a factor of two to ten times higher than the modules without sea salt*
- *At the 85% and 95% RH levels, the modules with sea salt applied show relatively unstable leakage current as a function of time, usually increasing*
- *Type C module package is more resistive*

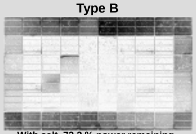
PID rate at P_{max} for three module types at 60° C with and without sea salt applied as a function of relative humidity (determined at end of RH dwell)



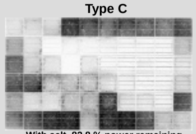
- *Increased conductivity of sea salt induces greater PID rate at higher humidity*
- *Most resistive module package (Type C) degraded the least*

Post-stress test electroluminescence images

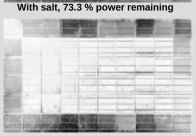
Type B / **Type C**



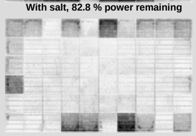
With salt, 73.3 % power remaining



With salt, 82.8 % power remaining



No salt, 84.7 % power remaining



No salt, 96.5% power remaining

- *Low bulk resistivity in the front face (Type B): current preferentially flows to the cells at the module edges, with or without sea salt–consistent with calculations for a wide range of front-surface lateral resistances [1,2]*
- *Higher bulk resistivity (Type C): higher surface conductivity from salt leads to wider distribution of leakage current and PID over the face, but lower magnitude*

6. Summary & Conclusions

- *Soiling determined to be a factor promoting PID.*
- *Arizona road dust showed a decreased resistivity at low relative humidity, but relatively little humidity dependence.*
- *Sea salt showed an important decrease in resistivity and 3.5 orders of magnitude lower sheet resistance at 95% RH. PID risk due to soiling that causes increased module surface conductivity.*
- *Sea salt on 60-cell mc-Si commercial modules promoted increases in leakage current, especially at 85% and 95% RH, leading to increased PID.*
- *Distribution of leakage current and PID depends on module front bulk resistance.*
- *Because of these results, examination of other soil types and further investigation into time-dependent effects are indicated.*

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[1] S. Pingel, et.al "The local potential distribution as driver of PID & 'Live PID Monitoring' method," in 29th European PV Solar Energy Conference and Exhibition, p. 2335, 2014.
[2] N. Shiradkara, E. Schneller, and N.G. Dhere, "Finite element analysis based model to study the electric field distribution and leakage current in PV modules under high voltage bias," Proc. of SPIE, Vol. 8825, 8250G-2, 2013.

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