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THE EFFECT OF METAL FOIL TAPE DEGRADATION ON THE LONG-TERM RELIABILITY OF PV MODULES

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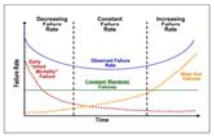
ABSTRACT

A program is underway at Sandia to predict long-term reliability of photovoltaic systems. The vehicle for the reliability predictions is a Reliability Block Diagram (RBD), which is used model system behavior. Because it is based mainly on field failure and repair times, it cannot currently be used to predict end-of-life. In order to be truly predictive, physics-informed degradation processes and failure mechanisms need to be included in the model. This paper describes how tape joint degradation, a possible failure mode, can be incorporated into the model.



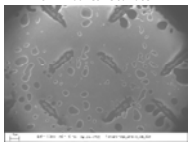
Field data can provide infant mortality and constant failure rate predictions, but cannot address wear out or end of life. That requires "physics informed" data for specific failure mechanisms.

Goal: Use accelerated aging data to predict reliability and end-of-life

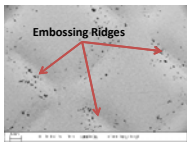
Tape Characterization

SEM analysis of the tape shows points of contact due to embossed nature. Actual contact are is ~2% of nominal area.

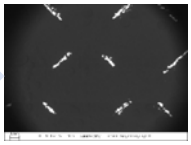
SEM – adhesive surface



SEM – metal surface



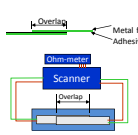
SEM (BSE) – adhesive surface

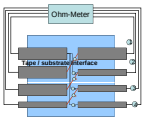


Metal penetration through the adhesive is observed in back-scatter electron images show (contrast depends on atomic number - high z is bright). These results suggest poor electrical contact behavior.

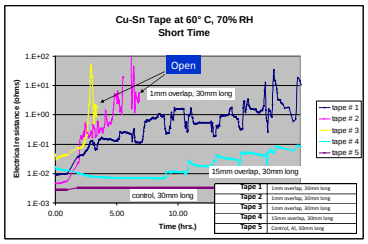
Accelerated Aging Setup

Samples were designed to monitor both tape-substrate and tape-on-tape interfaces.

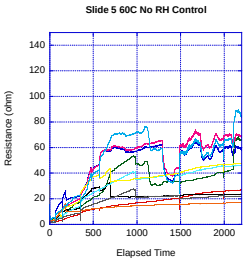




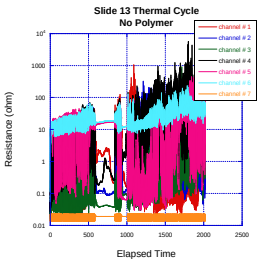
Accelerated Aging Results



Damp heat provides the highest degree of stress for the tape joints, with open circuit being observed at less than 5 hours. These data were not used in reliability calculations.



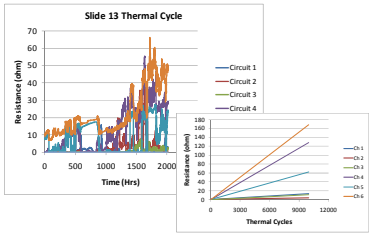
Tape-on-substrate
Constant heating at 60°C results in a systematic increase in resistance. The acceleration factor for this test is unknown at this time, so these data were not used in reliability calculations.



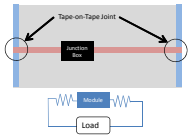
Thermal cycle test were chosen to simulate the stress applied by diurnal heating / cooling. The temperature range was -40C to +60C.

- Gradual increase in mean or nominal resistance with time (cycles).
- Resistance swings with temperature (channel 7 shows results without joint).
- High resistance corresponds to high temperature.

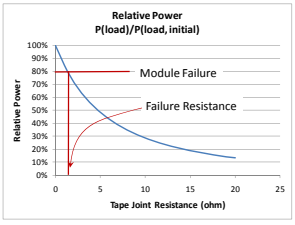
Accelerated Aging Data Analysis



- Apply moving median technique to thermal cycle data.
- Relationship between resistance and thermal cycles was found to be linear.
- Use these data to determine cycles to failure and then convert to time to failure (T_f).

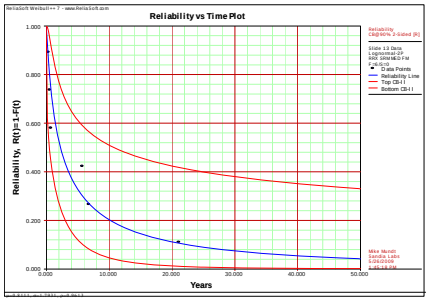


- Assume a "Standard Module" (70 W, 40V, 1.75A).
- Calculate the Load Resistance (E=IR) without tape joint resistance [22.86 Ω].
- Parasitic resistors simulate tape joint degradation (increase with time). Values obtained from thermal cycling data.
- Calculate total resistance (R_{load} +$R_{tape\ joint}$).
- Calculate circuit current assuming constant voltage.
- Calculate relative power and failure resistance.
- T_{fail} is determined from thermal cycling data assuming a power-loss failure criterion.



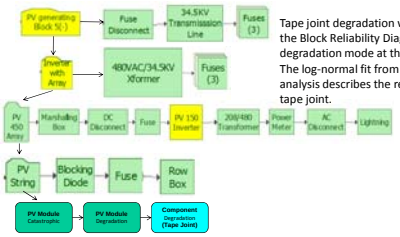
Results of Tape Degradation Tests Used in Reliability Block Diagram Model

Channel	1	2	3	4	5	6
Resistance (ohm)	2.82	0.77	2.39	28.16	21.1	46.15
Slope	0.0012	0.00035	0.00108	0.0128	0.0095	0.02097
T_{fail}	2.9 yrs	11.2 yrs	3.4 yrs	0.3 yrs	0.6 yrs	0.2 yrs



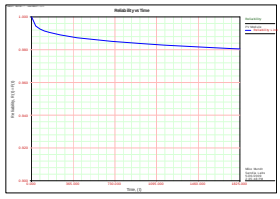
Using Weibull++ to analyze time to failure data, a log-normal fit was established.

Reliability Model

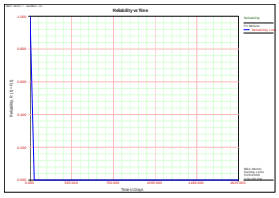


Tape joint degradation was included in the Block Reliability Diagram as a degradation mode at the module level. The log-normal fit from the Weibull analysis describes the reliability of the tape joint.

Reliability Model – no tape joint degradation



Reliability Model – with tape joint degradation



The effect of tape joint degradation on reliability is significant. The reliability prediction (based solely on field data) is above 0.98. Including the accelerated aging data into the prediction results in essentially complete loss of reliability in less than one year.

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