Impacts of Humidity and Temperature on the Performance of Transparent Conducting Zinc Oxide

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ABSTRACT

The impact of humidity and temperature on the performance of a zinc oxide based transparent conducting oxide (TCO) was assessed under accelerated aging conditions. An in situ electroanalytical method was used to monitor the electrical properties for a conducting zinc oxide under controlled atmospheric (humidity, temperature and irradiation) conditions. A review of thin film photovoltaic (PV) literature has shown one major failure mode of cells/modules is associated with the ingress of water. Water contamination has been shown to degrade the performance of the TCO in addition to corroding interconnects and other conductive metals/materials associated with the module. Water ingress is particularly problematic in flexible thin film PV modules since traditional encapsulates such as poly(ethyl vinyl acetate) (EVA) have high water vapor transmission rates. The accelerated aging studies of the zinc oxide based TCOs will allow acceleration factors and kinetic parameters to be determined for reliability purposes.

INTRODUCTION

- Sandia National Laboratories is currently developing predictive models for PV system reliability with the goals of:
  - **Increasing consumer/investor confidence in PV.**
  - **Aid in directing research and development efforts for more reliable PV systems.**
- PV reliability models will incorporate:
  - **Operations and maintenance of large PV systems.1,2**
  - **Accelerated life testing of individual components.3**
- As part of this overall reliability effort, accelerated life tests were performed on aluminum doped zinc oxide (AZO) transparent conducting oxides (TCO) to determine the effects of humidity, temperature and irradiation on sheet resistance over time.
- Characterize degradation of AZO beyond damp heat conditions (85 oC and 85% relative humidity).

Test matrix to study environmental effects on AZO.

Humidity (% RH)	Temperature (°C)	Irradiation (Suns)	TCO Type
0	30, 50, 80	0, 1	AZO[1], *i*-ZO/AZO[2]
25	30, 50, 80	0, 1	AZO, *i*-ZO/AZO
50	30, 50, 80	0, 1	AZO, *i*-ZO/AZO
85	30, 50, 80	0, 1	AZO, *i*-ZO/AZO

[1] 2 wt% Alumina doped zinc oxide
[2] 2 wt% Alumina doped zinc oxide on top of intrinsic zinc oxide

MATERIALS & METHODS

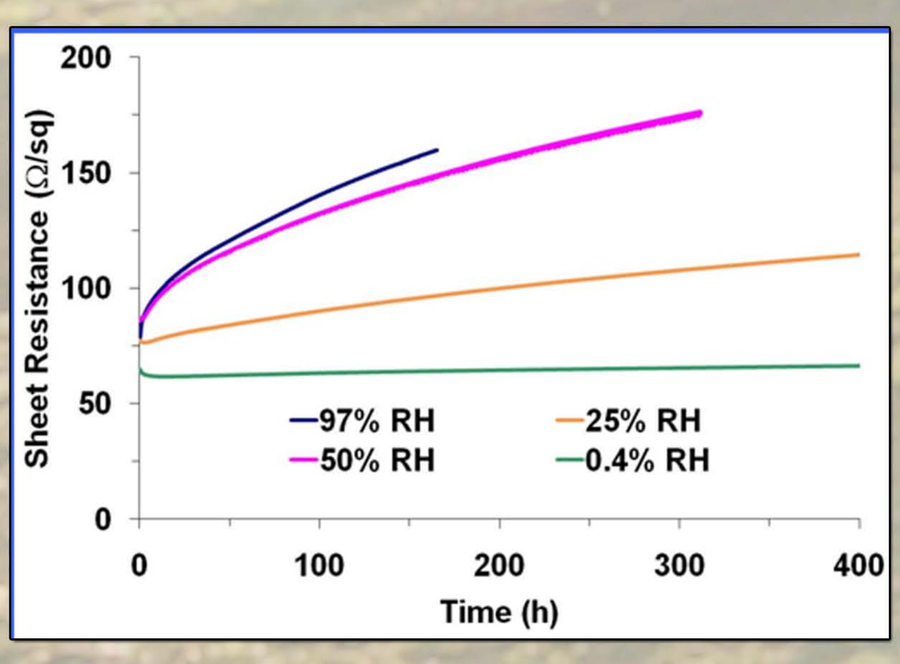
- Custom environmental chamber built for accelerated life testing
- Humidity control (0 to 100% relative humidity)
- Temperature control (25 to 100 °C)

- AZO coatings (200 mm thickness) prepared by DC magnetron sputtering on sputter etched low alkali glass (Corning 1737).
- AZO was monitored via four point resistance measurements for 400 h or until sheet resistance doubled.

IMPACT OF HUMIDITY AT A CONSTANT TEMPERATURE ON AZO SHEET RESISTANCE

Conditions: Isothermal at 79 °C, humidity varied for individual samples, no irradiation

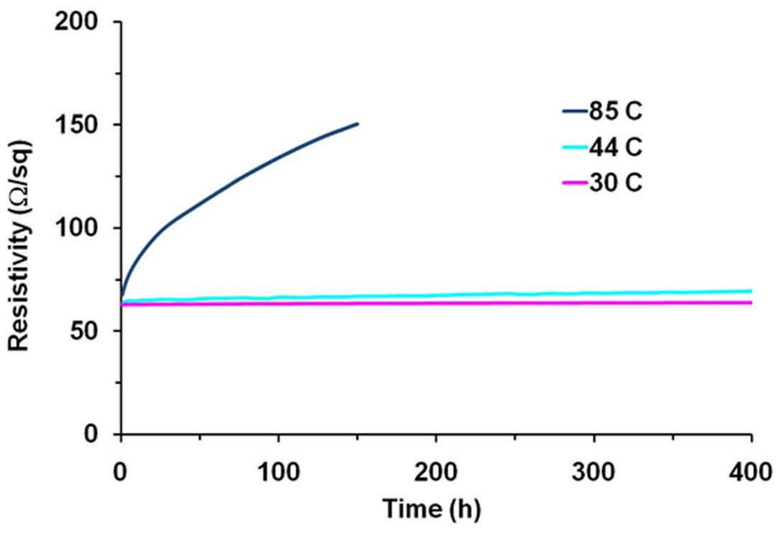
Sample	% RH	Slope after 24 h (W/sq/h)
1	0.4	0.01
2	25	0.10
3	50	0.24
4	97	0.38

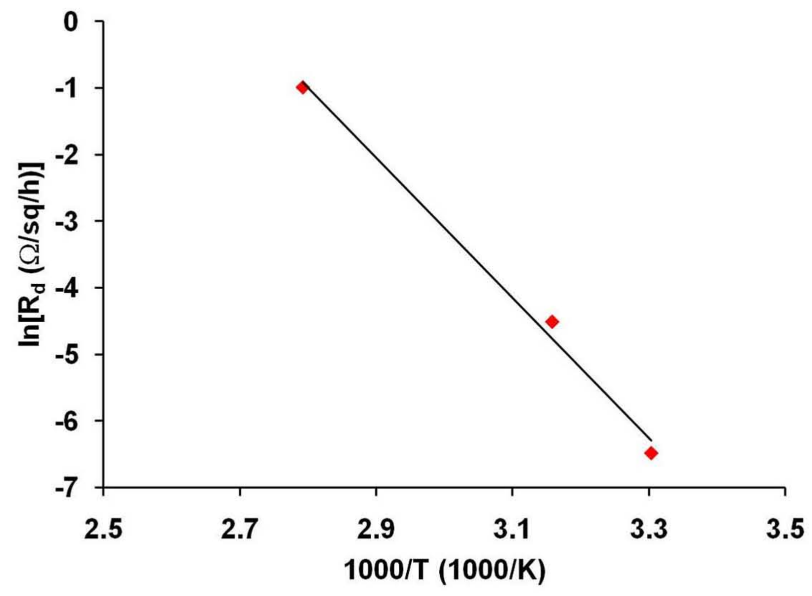


- Nonlinear increase in sheet resistance during first 24h of exposure
- Non-linearity more pronounced at higher humidities
- Multiple degradation pathways
- Accessibility of oxygen vacancies
- After 24 h, degradation rate is constant ($R^2 > 0.98$)

IMPACT OF TEMPERATURE AT A CONSTANT HUMIDITY ON AZO SHEET RESISTANCE

Conditions: Temperature varied for individual samples, constant 85% RH, no irradiation,





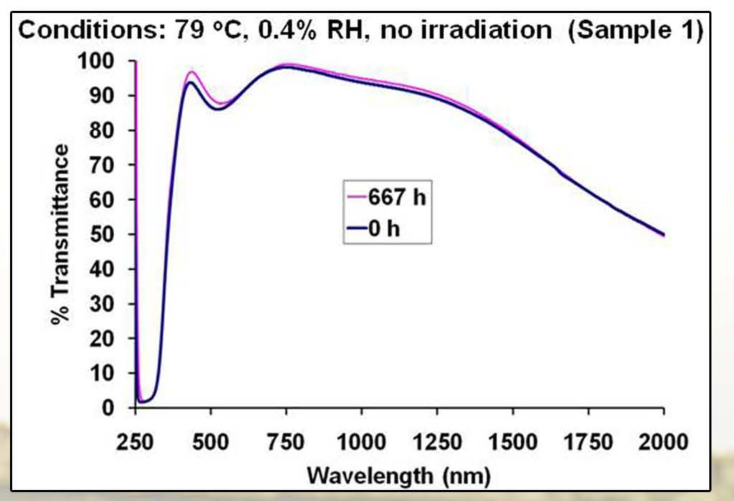
Sample	Temperature (°C)	Slope after 24 h (Ω/sq/h)
5	30	0.002
6	44	0.011
7	85	0.37

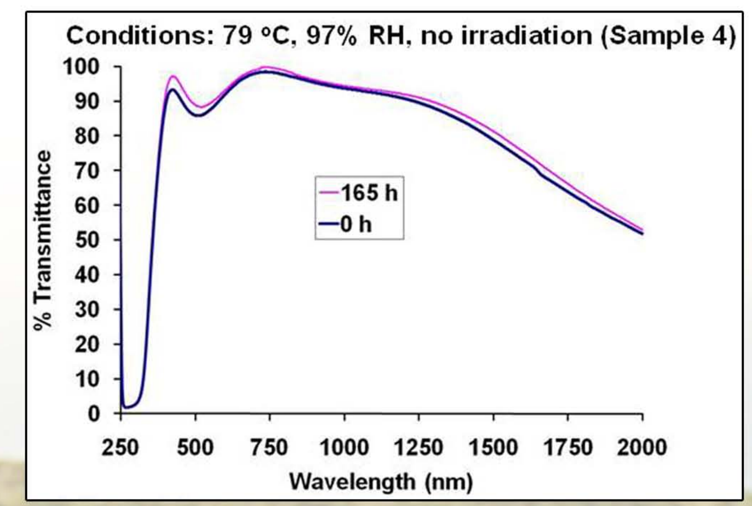
- Nonlinear increase in sheet resistance during first 24h of exposure
- Non-linearity more pronounced at higher temperature
- After 24 h, degradation rates are constant ($R^2 > 0.98$) and can be fitted to Arrhenius equation:

$$R_d = Ae^{\left(-\frac{E_a}{kT}\right)} \quad E_a = 0.91\ \text{eV},\ A = 2.34 \times 10^{12}$$

IMPACT OF TEMPERATURE AND HUMIDITY ON AZO OPTICAL PROPERTIES

Conditions: 79 °C, 0.4% RH, no irradiation (Sample 1)
Conditions: 79 °C, 97% RH, no irradiation (Sample 4)





- **Transmittance of samples after exposure to humidity and temperature increases slightly**
  ~3% increase at wavelengths ranging from 400 to 550 nm

CONCLUSION

Humidity increased the degradation of sheet resistance up to 38 x relative to low humidity exposure at the same temperature.

A nonlinear increase in sheet resistance was noted during the initial exposure of AZO to environmental conditions
The nonlinearity was more pronounced at higher humidities and higher temperatures
After 24 h of exposure, the degradation of AZO sheet resistance was constant .

Where degradation of AZO sheet resistance was constant (> 24 h exposure), degradation rates could be fit to the Arrhenius equation.

Completion of the test matrix will allow us to fully describe the acceleration factors and kinetic parameters of this critical thin film PV cell component .

REFERENCES

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