N86-29360

MOISTURE-TEMPERATURE DEGRADATION IN MODULE ENCAPSULANTS

JET PROPULSION LABORATORY

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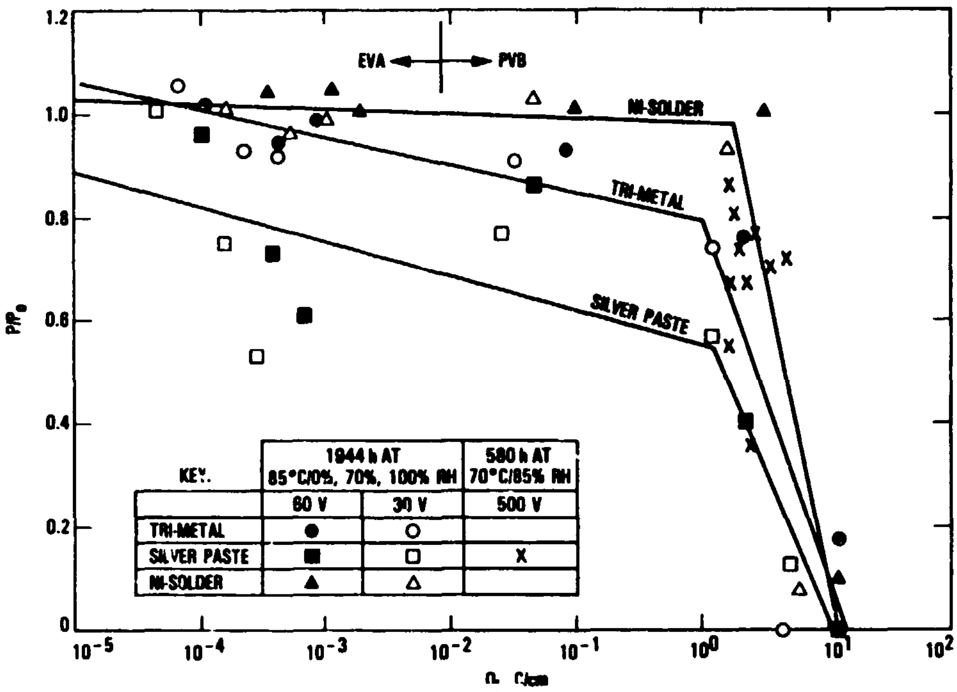
The General Problem of Moisture in Photovoltaic Encapsulants

- **Water transport**
  - **Rain, snow**
  - **Condensation, dew**
  - **Changes in water vapor pressure**
- **Effects of water in photovoltaic modules**
  - **Swelling of polymers and gaskets**
  - **Delamination of encapsulant**
  - **Galvanic (contact) corrosion**
  - **Electrochemical (leakage current) corrosion**
  - **Plays an active role in**
    - **Photo degradation**
    - **Voltage breakdown**

General Research Approach

- **For a given degradation mechanism, establish module performance loss versus level of accumulated degradation**
- **Establish dependence of rate of degradation reaction on moisture and temperature level in module**
- **Establish moisture and temperature level in module versus time in field environment and module construction**
  - **Sealed module**
  - **Partially sealed module**
  - **Unsealed module**

Power Output Reduction vs Accumulated Unit Charge Transfer

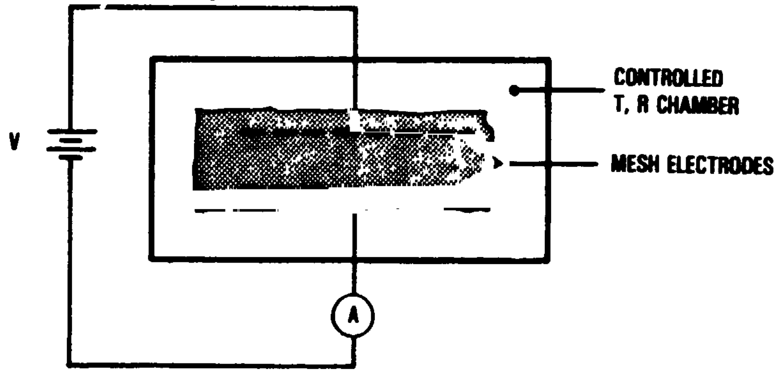


Electrochemical Corrosion: Analysis of Leakage Current

- **Leakage Current**
  - **Leakage current (rate of transfer of charge) is responsible for electrochemical corrosion**
  - **Leakage current magnitude is determined by**
    - **Applied (or generated) voltage V**
    - **Insulation (encapsulant) surface and volume conductivities**
- **Encapsulant conductivity**
  - **Insulation conductivity increases with increasing**
    - **Temperature**
    - **Moisture content**

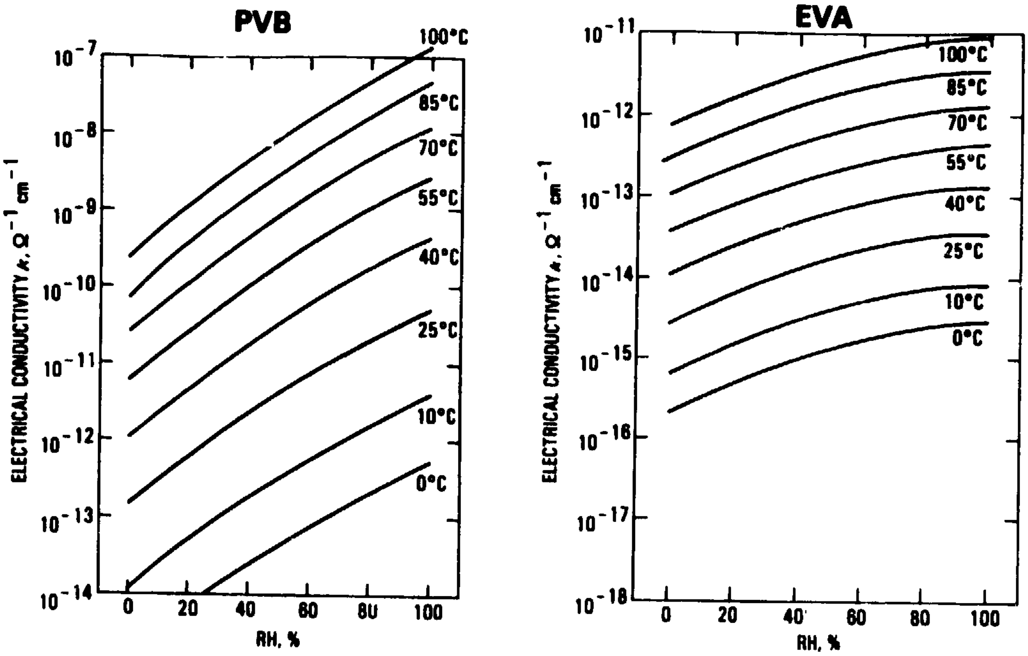
Experimental Determination of the Electrical Conductivity of PVB and EVA

- **Experimental setup:**

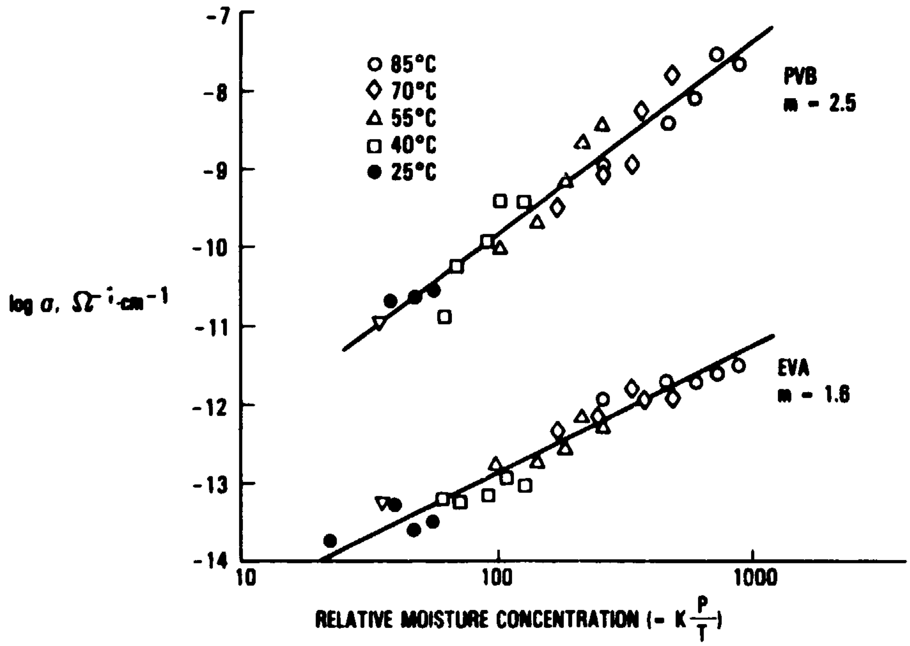


- **Equilibrium values measured by Professor J. Orehotsky**
- **Experimental equilibri‹ n values were processed, yielding sets of "best-fit" data curves**

Electrical Conductivity of PVB and EVA

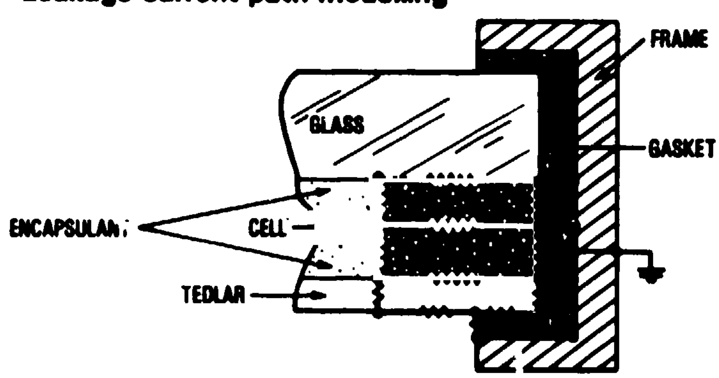


Bulk Conductivity vs Moisture Concentration (From Orehotsky Data and Ideal Gas Law)



Module Performance Analysis

- **Life prediction requires calculation of charge transfer in a real module**
  - **Through the bulk pottant**
  - **Along material interfaces**
  - **On free surfaces**
- **Leakage current path modelling**

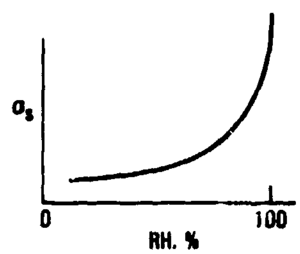


Research Questions About Module Conductivity

- **Over what ranges of temperature and relative humidity do the various conductivities dominate overall module conductivity?**
- **In what ways do the various forms of water in polymers contribute to overall module conductivity?**
  - **Bound water**
  - **Free water**
  - **Clustered water**
- **Does exposure to liquid water result in same measured conductivity values as exposure to saturated water vapor?**

General Dependencies Involving Insulation Electrical Conductivities

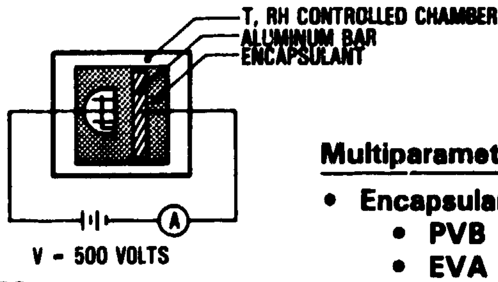
- **Surface conductivity values are strongly affected by contaminants**
- **Surface conductivity responds rapidly to changes in relative humidity and surface-water films**



- **Volume conductivity responds rapidly to changes in temperature, less rapidly to changes in relative humidity**
- $\sigma_v = Ae^{-E/T}$ **(ASTM D257-78)**
- **Generally,** $\sigma_s > \sigma_v$

Experiments to Determine Module Equilibrium Leakage Current Levels and Response to Parameter Variation

Test setup



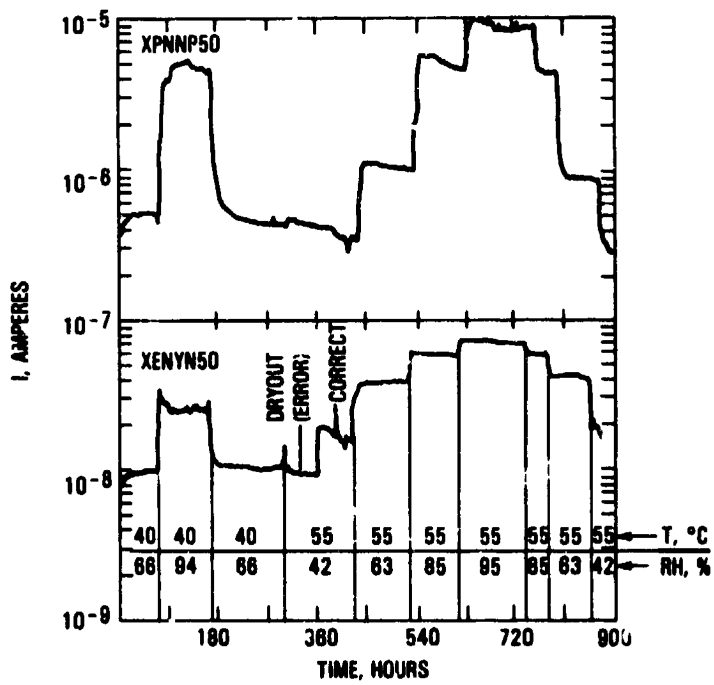
Test sequence

T, °C	RH, %					
40	66	94				
55	42	63	85	95		
70	<10	50	71	85	95	
85	<10	30	50	70	85	95

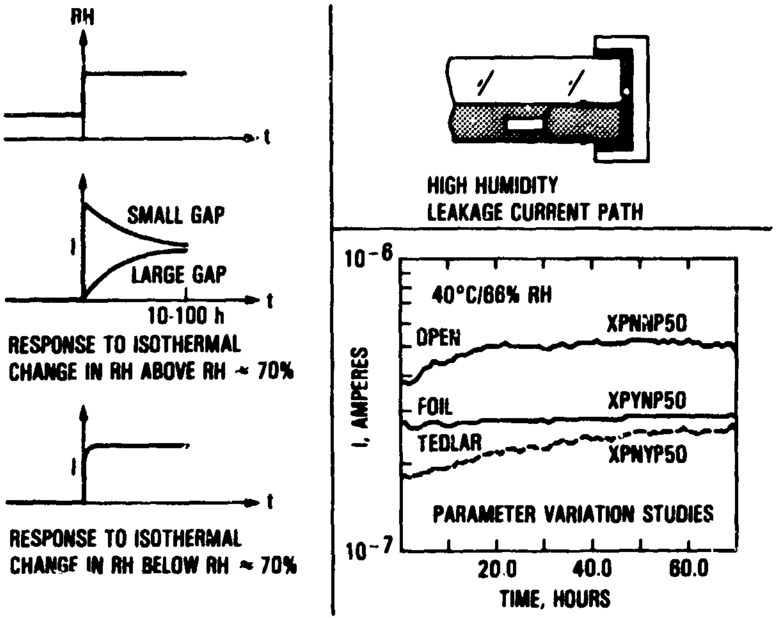
Multiparameter testing

- Encapsulants
  - PVB
  - EVA
- Polarity
  - Positive
  - Negative
- Electrode spacing
- Rear-surface barriers
  - Polymers
  - Metal foils
  - None
- Cell metallizations

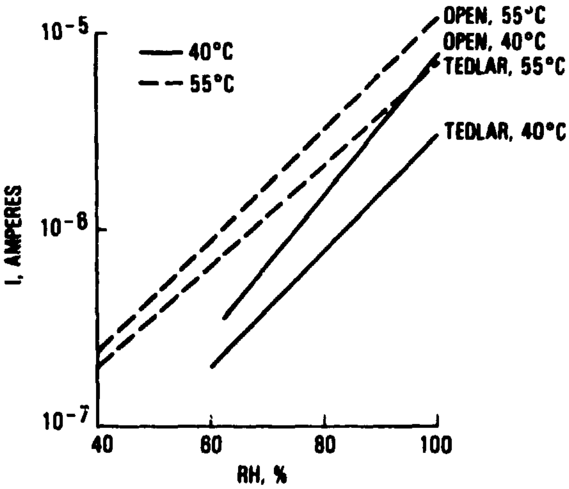
Current vs Time



Some General Observations



Leakage Current Sensitivity to Relative Humidity at 40°C and 55°C: PVB, Positive Polarity, 50-Mil Gap



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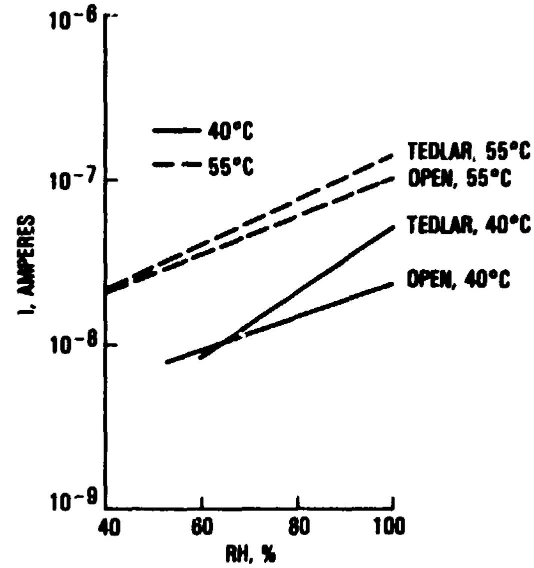
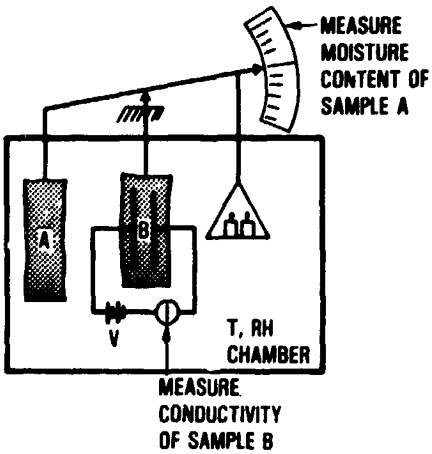


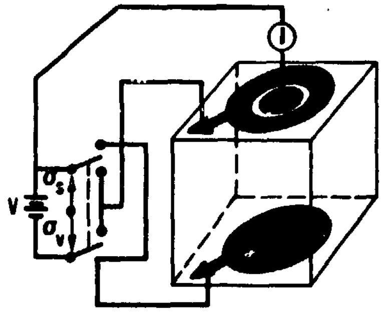
Conclusion

- **Because of the importance of bulk, interfacial, and free-surface conductivities, additional experiments are necessary to separate the relative contributions of these to overall module conductivity**

Direct Conductivity Measurements



- **Cahn balance sorption test**
  - **$c = S(T)\ RH$**
  - **$\sigma = \sigma(V; T, c\ (T, RH))$**
    $= \sigma(V; T, RH)$



- **Guarded electrode measurements**
  - **Surface and volume conductivities**
    - **PVB**
    - **EVA**
  - **Interfacial conductivity**
    - **Glass/polymer**
    - **Polymer/Tedlar**