N84 21988

OBSERVATIONS OF SOLAR-CELL METALLIZATION CORROSION

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The Engineering Sciences Area of the Jet Propulsion Laboratory (JPL) Flat-Plate Solar Array Project is performing long term environmental tests on photovoltaic modules at Wyle Laboratories in Huntsville, Alabama. Some modules have been exposed to 85°C/85% RH and 40°C/93% RH for up to 280 days. Other modules undergoing temperature-only exposures (<3% RH) at 85°C and 100°C have been tested for more than 180 days. At least two modules of each design type are exposed to each environment--one with, and the other without a 100-mA forward bias.

Degradation is both visually observed and electrically monitored. Visual observations of changes in appearance are recorded at each inspection time. Significant visual observations relating to metallization corrosion (and/or metallization-induced corrosion) include discoloration (yellowing and browning) of grid lines, migration of grid line material into the encapsulation ("blossoming"), the appearance of rainbow-like diffraction patterns on the grid lines, and brown spots on collectors and grid lines. All of these observations were recorded for electrically biased modules in the 280-day tests with humidity.

In the temperature-only tests, discoloration of grid line tips was noted in electrically biased modules. Grid line discoloration was observed in both biased and unbiased modules.

The most important electrical observations are I-V curves taken at each inspection period. Changes in the I-V curve can reveal loss of encapsulation transparency (reduced short-circuit current), loss of cells (reduced open-circuit voltage), junction contamination or short circuiting (reduced shunt resistance), and contact and metallization corrosion (increased series resistance).

Other electrical parameters monitored included insulation resistance (decreased significantly), dissipation or loss factor (increased significantly) and cells-to-frame capacitance (generally unaffected).

In an attempt to quantify metallization corrosion, power reductions resulting from decrease of short-ciruit current (due to changes in the optical properties of the encapsulant) were subtracted from the observed total power reduction after first correcting for losses due to cracked cells and broken interconnects. The remaining power loss was assumed to result from increases in series resistance, a parameter taken to be indicative of contact (metallization) corrosion. Power loss rate ($\Delta P/\Delta t$) data have been compiled for the various metallization systems and the relative power loss rate ($\Delta P/\Delta R$) was found to decrease linearly with time.

Similar tests are in progress at JPL using 85°C/0% RH, 85°C/85% RH, and 85°C/100% RH environments. Driving voltages for metallization migration are as high as 55 volts, compared with Wyle Laboratories driving voltages of about 5 volts maximum.

Following the French, we plot time of observation of metallization migration versus the combined variables t°C + % RH to reveal the effect of voltage acceleration.

We speculate about the mechanism underlying the observed phenomena. Photographic evidence indicates that the migration is along electric-field lines and is thus a form of ionic transport driven by potential differences through the encapsulation which, with the absorption of water, becomes an electrolyte. The observed discoloration peels off with the encapsulant--it is in the encapsulant, not on the cell--and is believed to be due in part to oxide-catalized reactions within the encapsulation, accelerated by elevated temperature. Investigation of these phehomena continues.

Important conclusions from this study relating to metallization corrosion including the following:

(1) Ni-solder metallization is extremely stable in the sense that, unlike systems containing silver, no migration has been observed.

(2) For silver-print metallizations, the power loss observed after 100 hours in an 85°C/85% RH test chamber is equivalent to about 30 years of real-time exposure at 60°C/40% RH daytime conditions.

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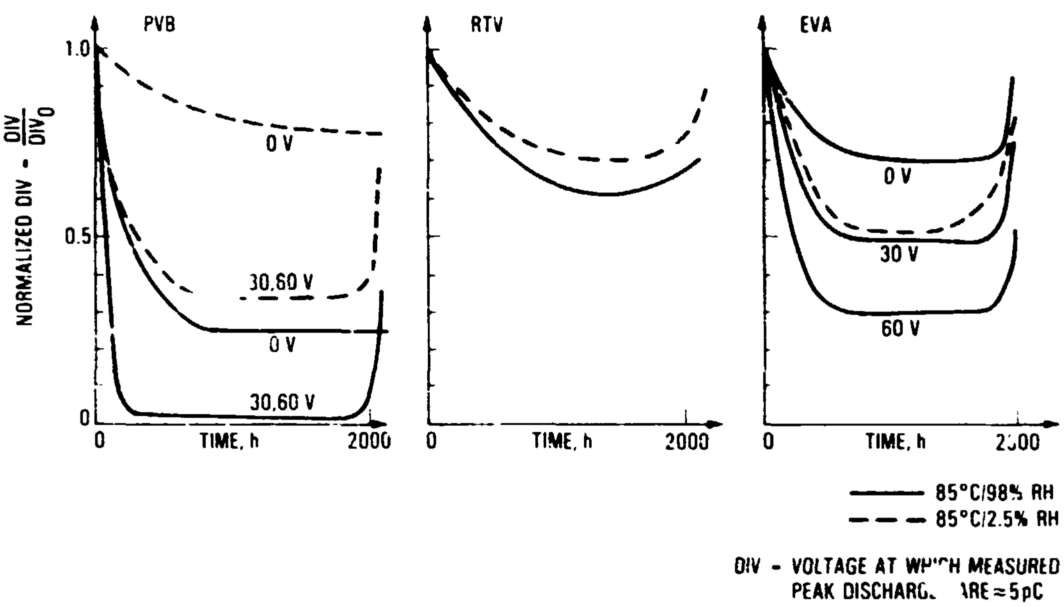
Discharge Inception Voltage Data (General)



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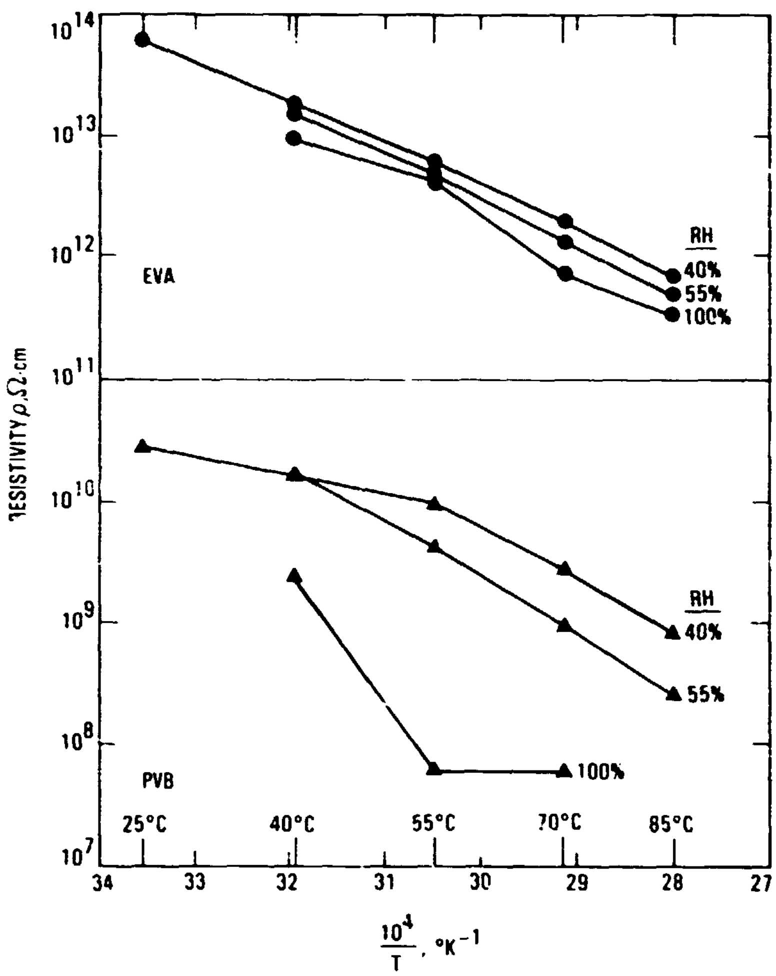
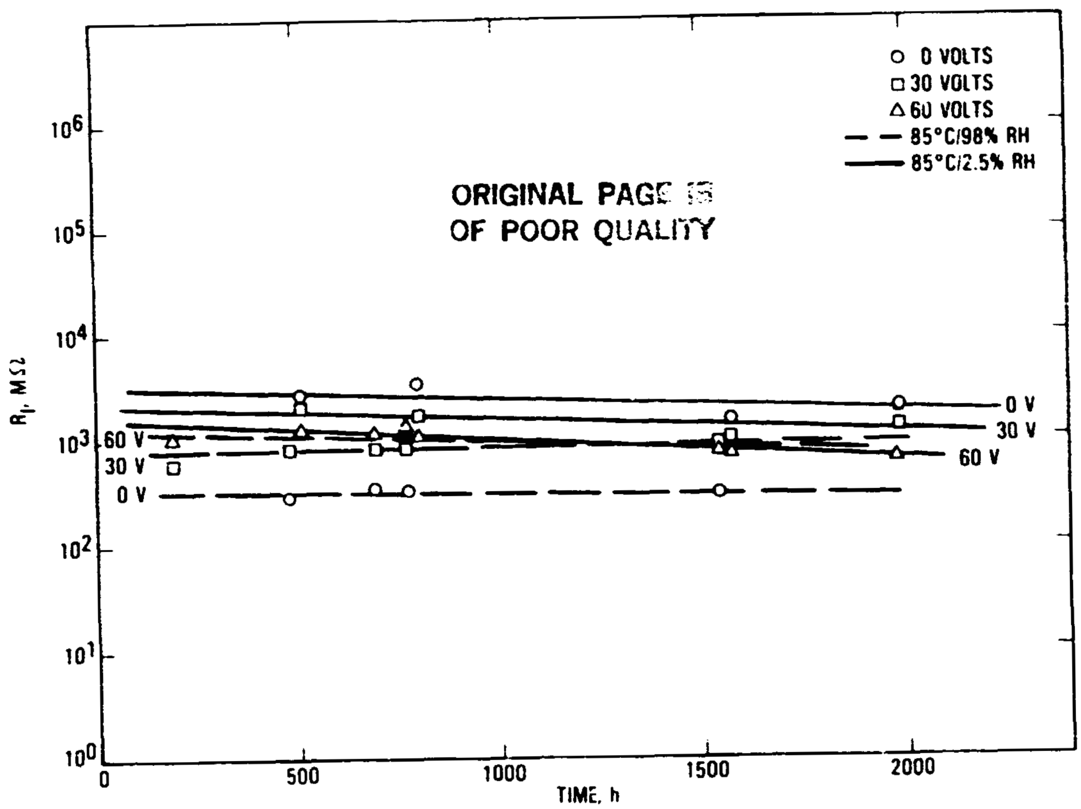
Resistivity vs Temperature With Relative Humidity as Parameter



Insulation Resistance vs Time: EVA-Ag Paste



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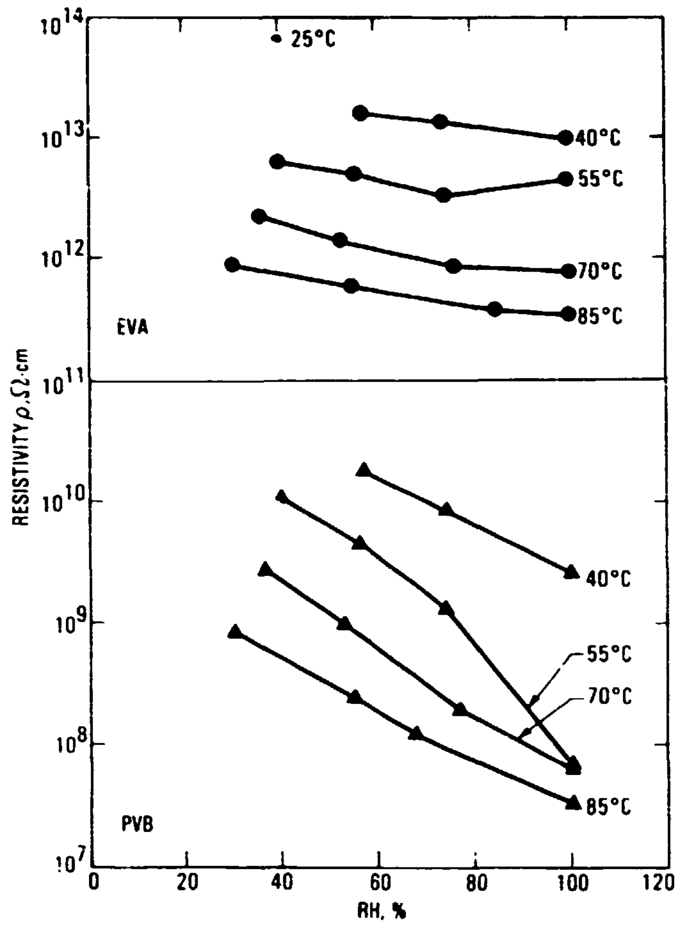
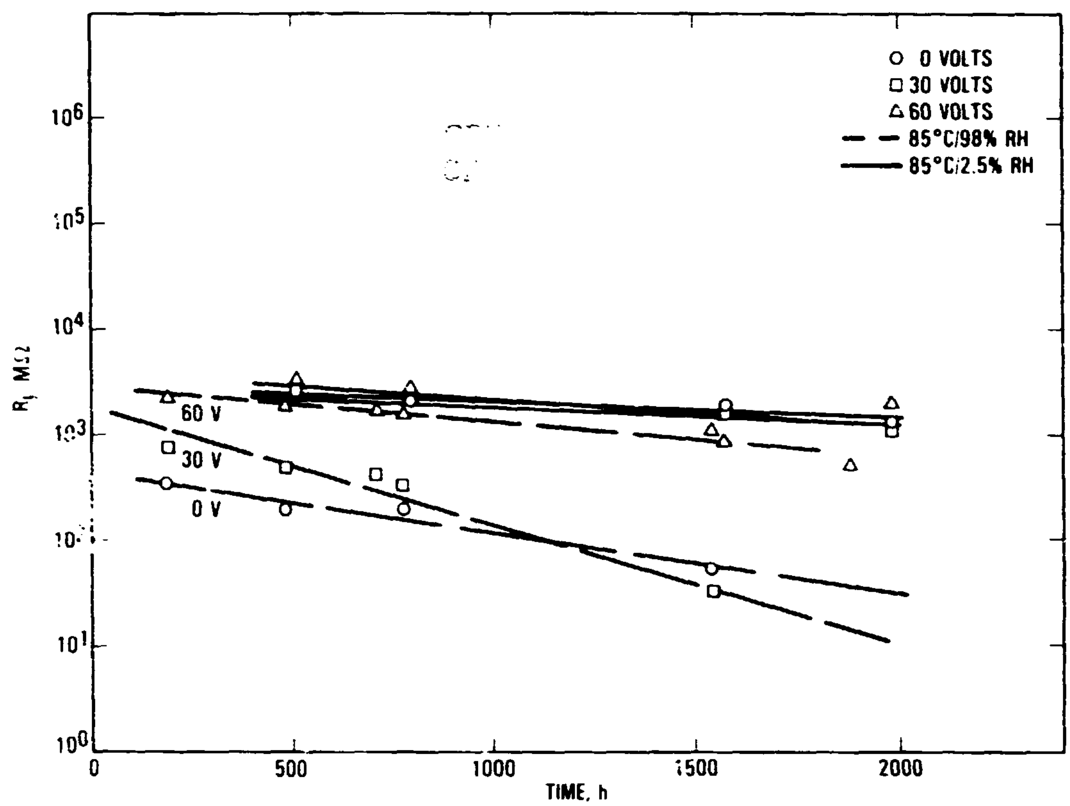
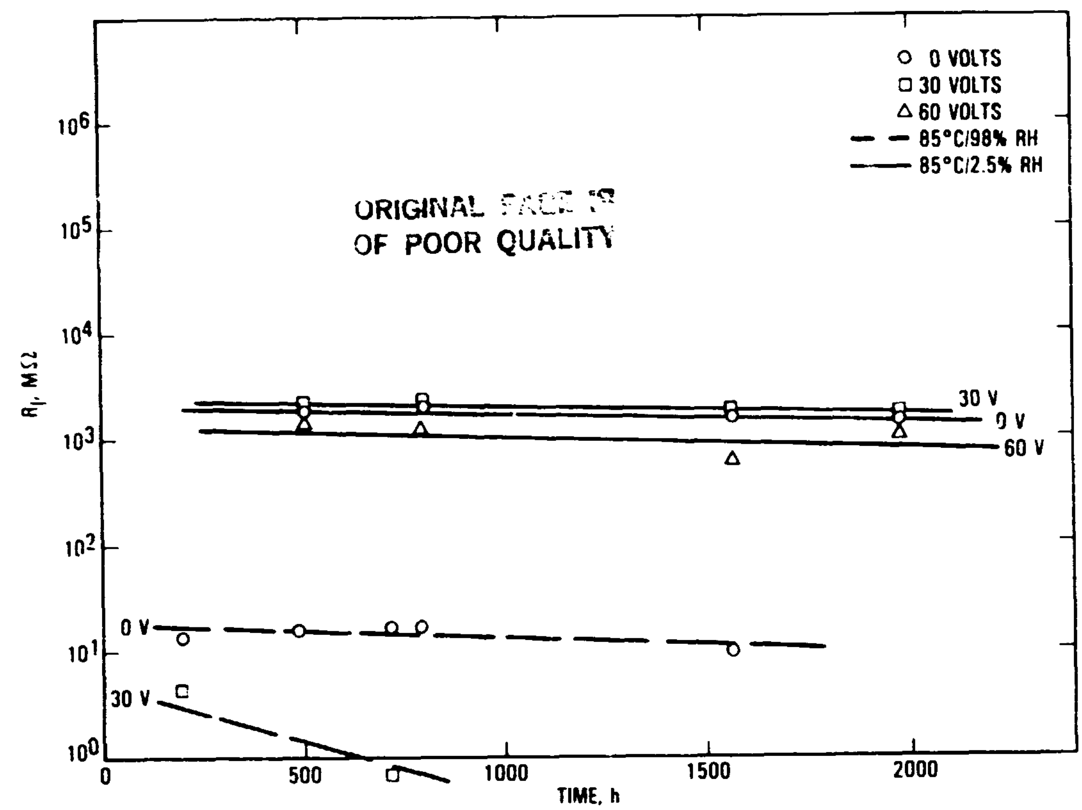
Resistivity vs Relative Humidity With Temperature as Parameter



Insulation Resistance vs Time: RTV-Ag Paste



Insulation Resistance vs Time: PVB-Ag Paste



Observations on Corrosion of Unencapsulated Ag-Metallization Cells in Aqueous Electrolytes

	0.1 Molar HCl, 0.5 h	C.1 Molar NAOH, 0.5 h
Anode Front	• Ag dissolution proportional to voltage magnitude • AR coat attacked at 9.0 V $Ag \rightarrow Ag^+ + e^-$	• Ag dissolution proportional to voltage magnitude • Evolution of gas bubbles $Ag \rightarrow Ag^+ + e^-$ $4OH^- \rightarrow O_2(g) + 2H_2O + 4e^-$
Anode Back	• Dissolution of back-surface metallization proportional to applied voltage	• Same as above
Cathode Front	• No observed metallization corrosion • Evolution of gas bubbles $H^+ + e^- \rightarrow \frac{1}{2} H_2(g)$ $H_2O + \frac{1}{2}O_2 + 2e^- \rightarrow 2OH^-$	• Severe attack on AR coat • Metallization-silicon bond undermined • Evolution of gas bubbles $4e^- + 4H_2O \rightarrow 2H_2 + 4OH^-$ $SiO + 2OH^- \rightarrow SiO_2 + 2H_2O + 2e^-$
Cathode Back	• Metallization-silicon bond undermined	• No observed corrosion
Control	• No observed corrosion	• No observed corrosion

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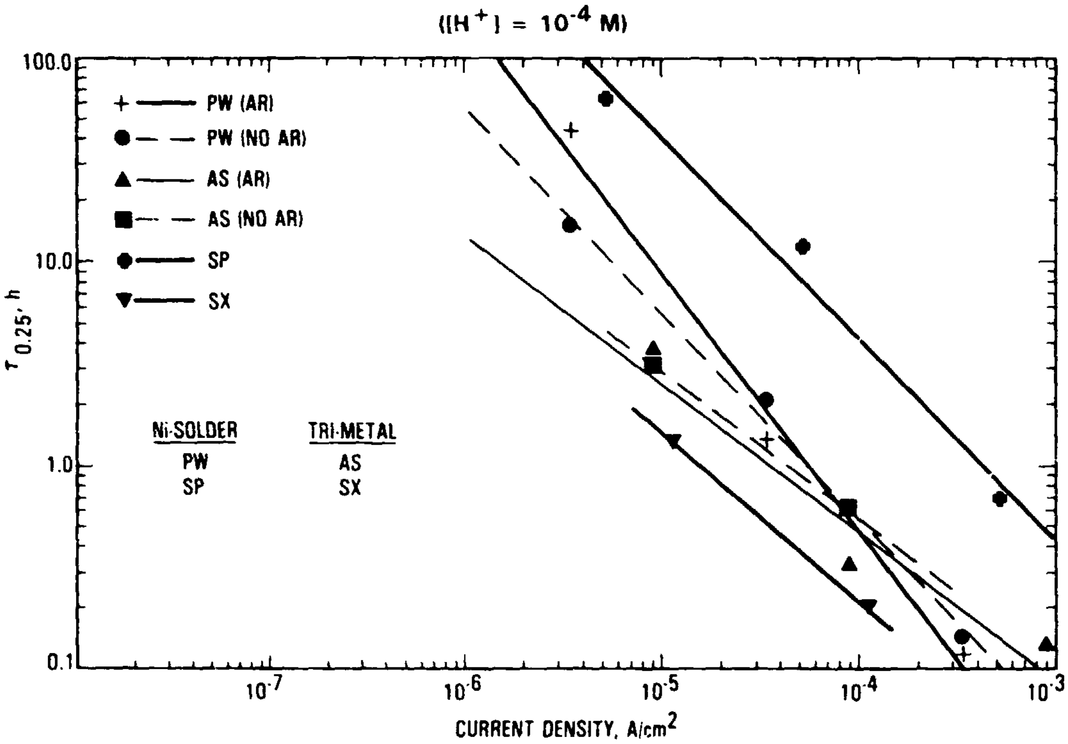
Time to 25% Maximum Power Degradation vs Current Density



Summary: Failure Mechanisms—Causes and Effects

Parameter Monitored	Parameter Variation	Observed Degradation	Probable Mechanism
Series resistance	$R_S \uparrow$	Metallization Dissolution	Electrochemical electrode-electrolyte reactions between metallization and pottant
Short-circuit current	$I_{sc} \downarrow$	Discoloration of encapsulation; reduced optical transmission	Diffusion of metallization into encapsulation resulting in metallization-encapsulant interactions catalyzed by high temperature and moisture levels
Insulation resistance and capacitance	$R_I \downarrow$ $C_I \uparrow$	–	Absorption of moisture
Discharge inception voltage	DIV $\downarrow$	Condu..ng paths between high-voltage cell and ground, electrical breakdown	Diffusion of metallization from cell to cell or from cell to frame