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Innovation for Our Energy Future

Types of Encapsulant Materials and Physical Differences Between Them

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This presentation does not contain any proprietary or confidential information.

Purposes of Polymer Materials in PV

- Helps Protect Cell Materials From Environmental Stress
  - Must Provide Good Adhesion.
  - Resistant to Heat, Humidity, UV Radiation, and Thermal Cycling.
- Electrical Isolation
- Control, reduce, or eliminate moisture ingress.
- Optically Couples Glass to Cells
  - High Photon Transmission.
- Cost Must Be Balanced With Performance.

Outline

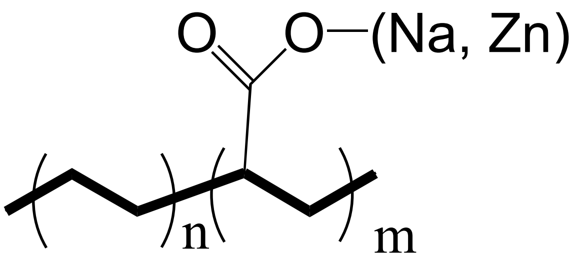
Encapsulant Chemistry

Optical Transmission

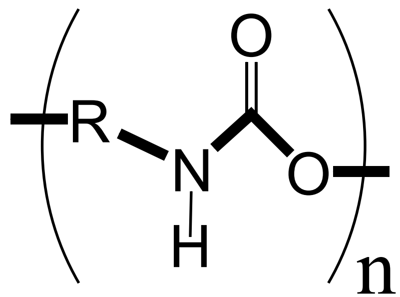
Electrical insulation

Moisture ingress

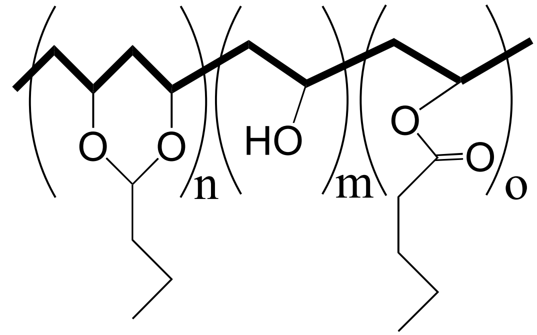
Encapsulant Materials Structures



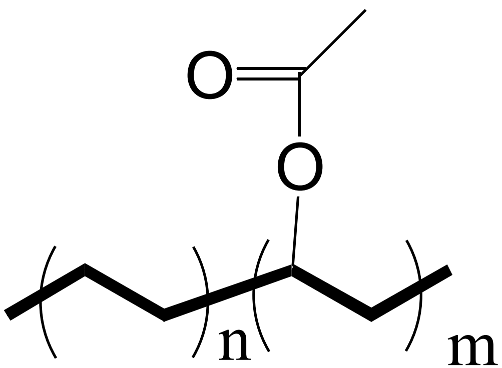
Ionomer



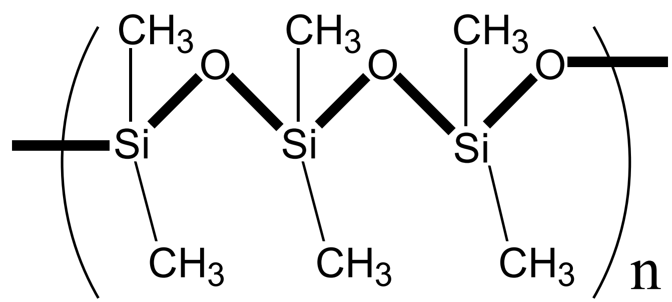
Thermoplastic Polyurethane
(TPU)



Polyvinyl Butyral
(PVB)

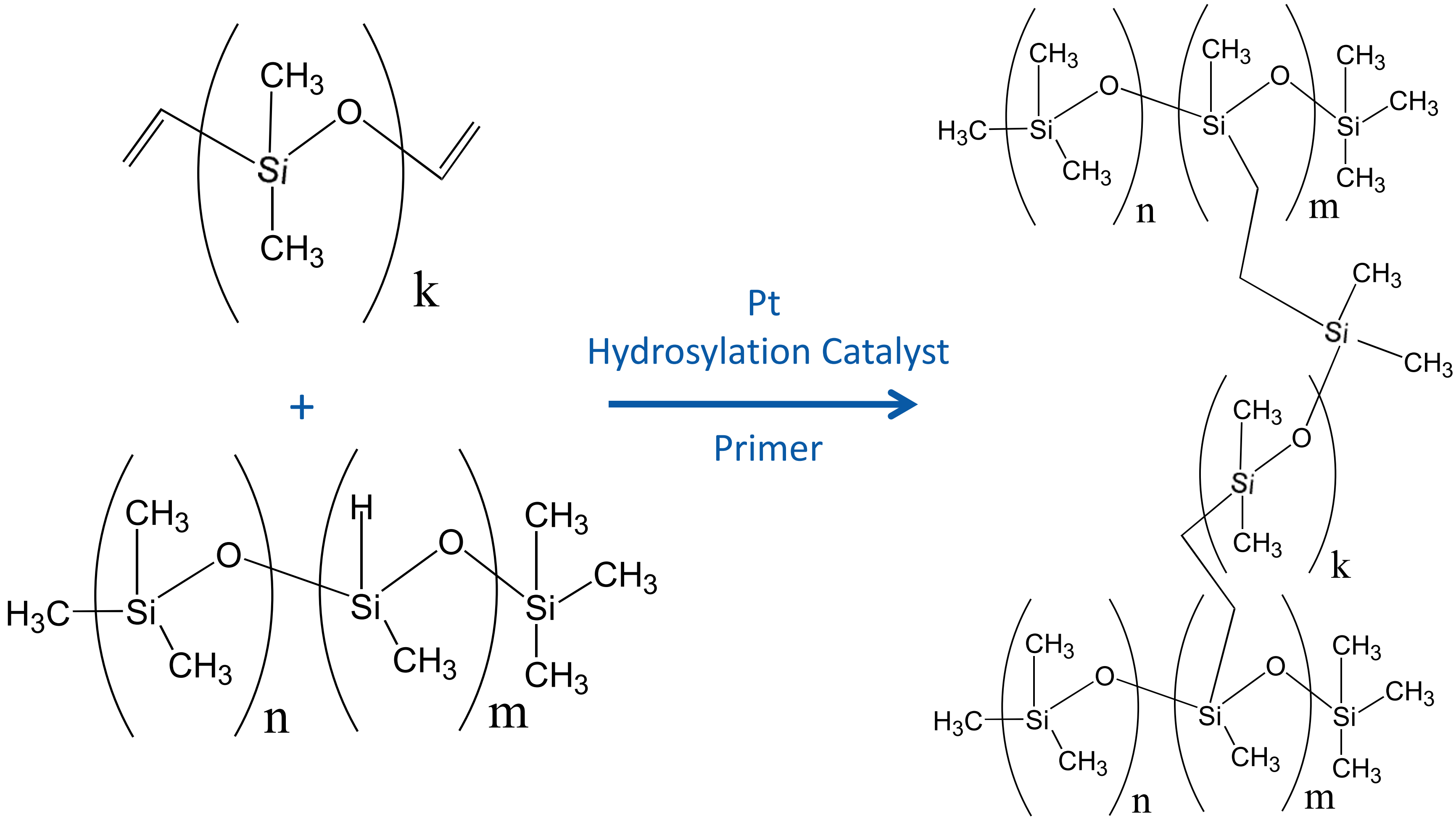


Ethylene Vinyl Acetate
(EVA)



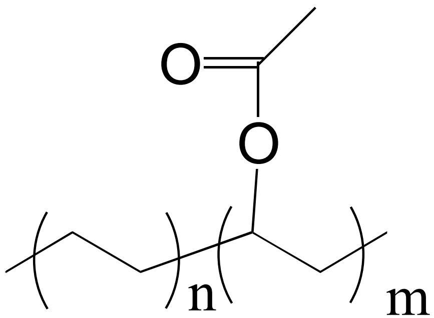
Polydimethyl Silicone
(PDMS)

Early PV Modules Used PDMS

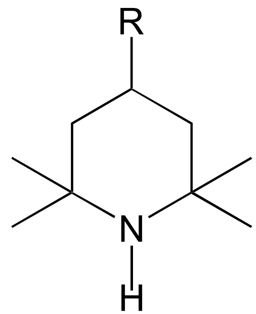


Dow Corning Corporation, "Develop silicone Encapsulation Systems for Terrestrial Silicon Solar Arrays", Doe/JPL954995-2 (1978).
M. A. Green, "Silicon Photovoltaic Modules: A Brief History of the First 50 Years", Prog. Photovolt: Res. Appl. **13,** (2005) 447-455.

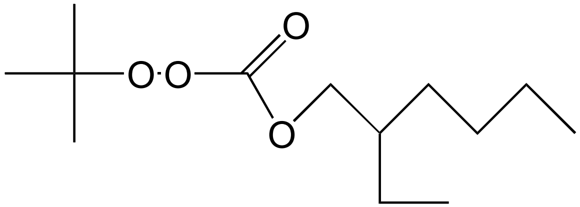
EVA Film Composition



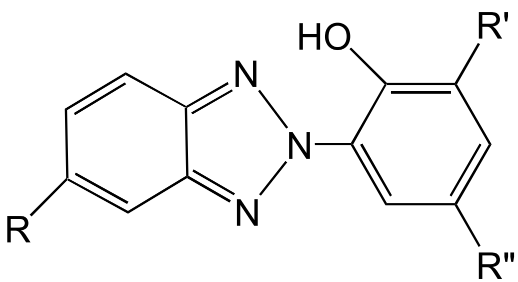
Ethylene Vinyl Acetate
(EVA, 96% to 98%)



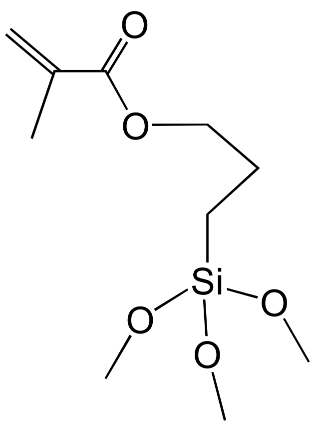
Hinder Amine Light Stabilizer
(HALS, 0.1% to 0.2%)
Decomposes Peroxide Radicals



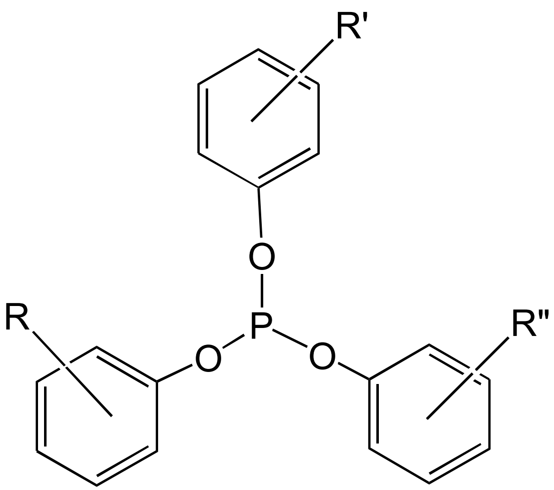
Peroxide
(1% to 2%)
Cross-Linker



Benzoltriazole
(0.2% to 0.35%)
UV Absorber



Trialkoxy Silane
(0.2% to 1%)
Adhesion Promoter



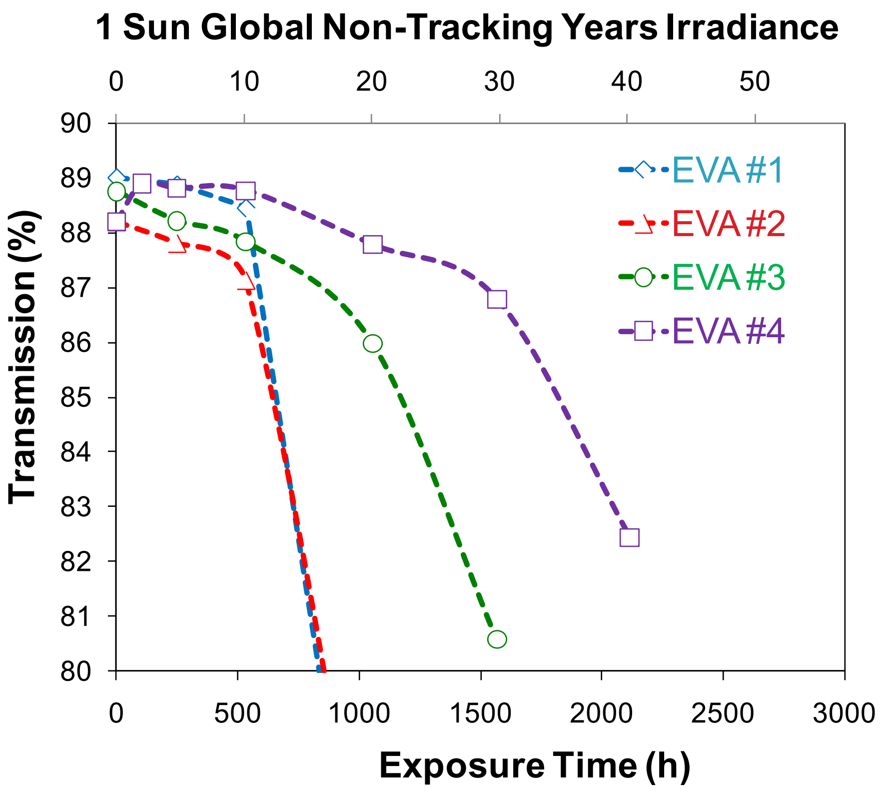
Phenolic Phosphonite
(0.1% to 0.2%)
Peroxide Decomposer/
Radical Scavenger

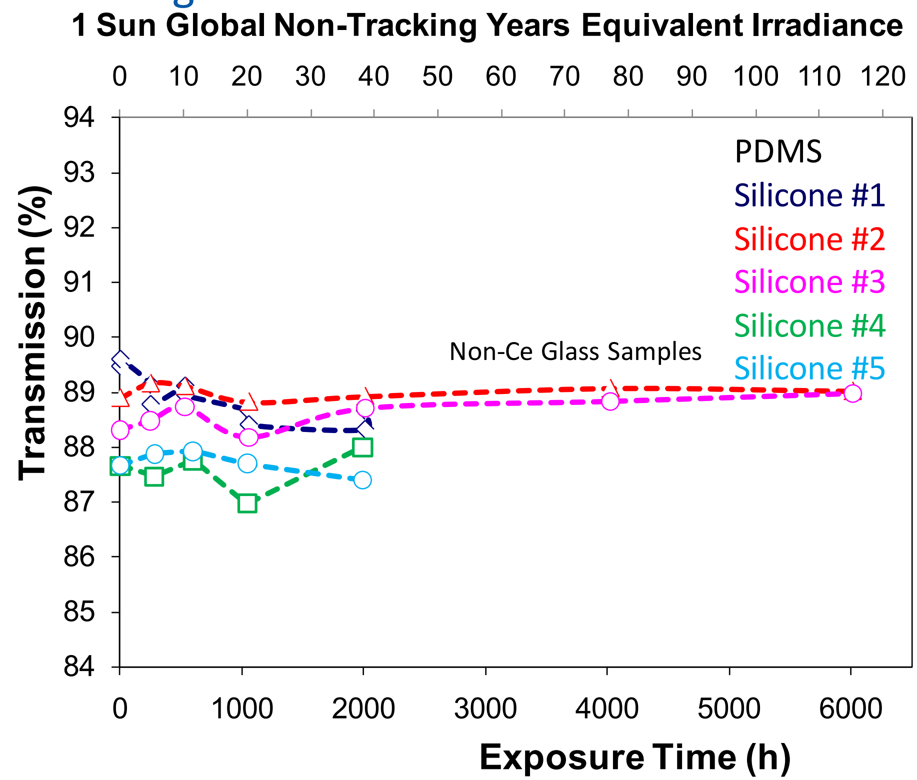
F. J. Pern, “Composition and Method for Encapsulating Photovoltaic Devices”, Patent# 6,093,757, (2000).
P. Klemchuk, M. Ezrin, G. Lavigne, W. Holley, J. Galica, S. Agro, ”Investigation of the Degradation and Stabilization of EVA-Based Encapsulant in Field-Aged Solar Energy

The PDMS Samples Did Not Degrade

Exposure of encapsulant materials to 42 UV suns at 80°C to 95°C.

Samples between 3.18mm low Fe non-Ce glass.





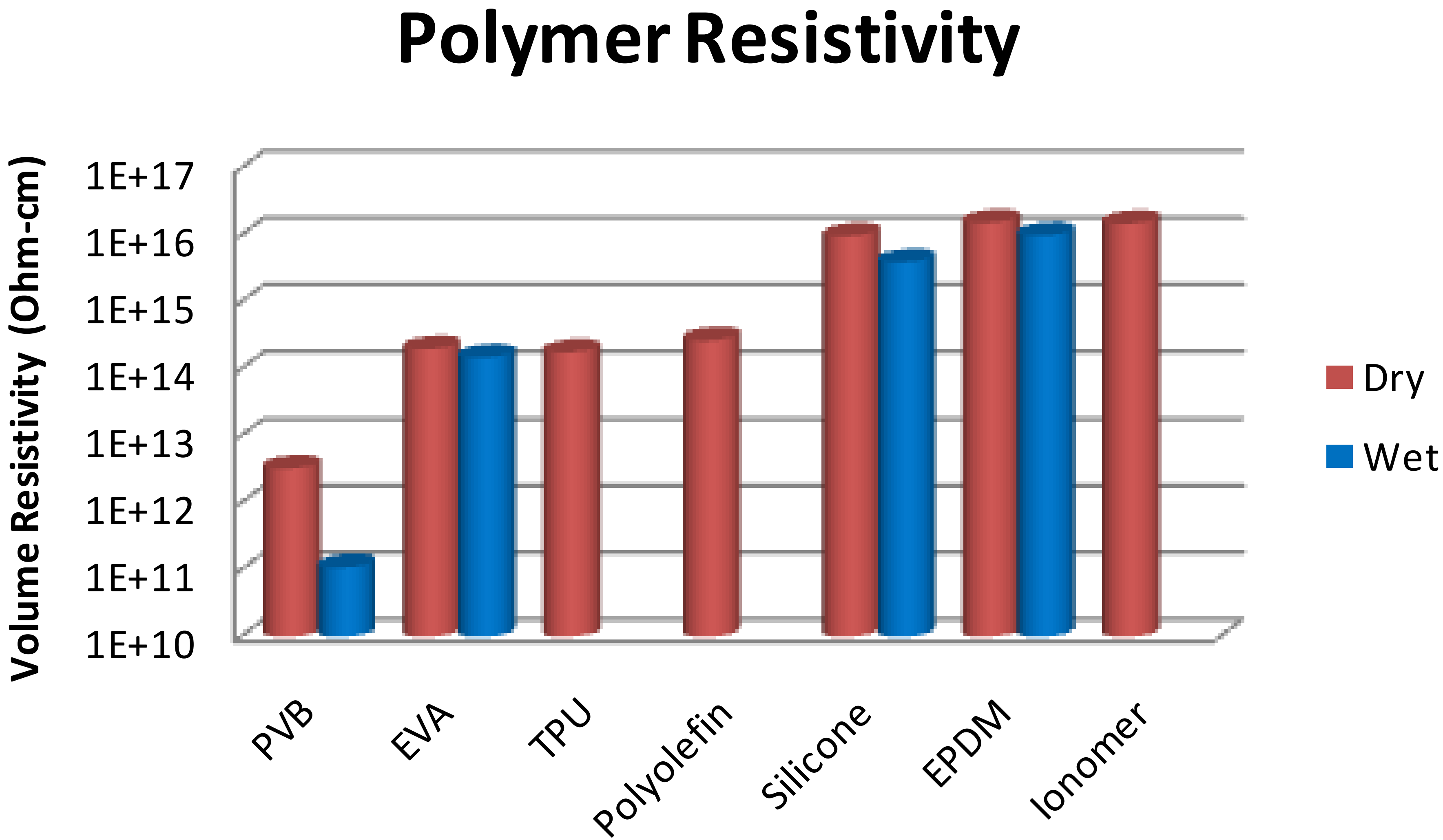
M. D. Kempe, T. Moricone, M. Kilkenny, "Effects of Cerium Removal from Glass on Photovoltaic Module Performance and Stability", *SPIE,* San Diego, Ca, August 2-7, 2009.

EVA Has Good Optical Transmittance

Encapsulant	Transmission to Cells through 3.18 mm glass and 0.45 mm Encapsulant	Comments
	%	
Momentive RTV615	94.5 ± 0.3	PDMS, Addition Cure
Dow Corning Sylgard 184	94.4 ± 0.3	PDMS, Addition Cure
Dow Corning 527	94.4 ± 0.3	PDMS, Addition Cure
Polyvinyl Butyral	93.9 ± 0.4	
EVA	93.9 ± 0.4	
NREL Experimental	93.4 ± 0.4	Poly-α-olefin
Thermoplastic Polyurethane	93.3 ± 0.3	
Thermoplastic Ionomer #1	92.3 ± 0.4	Copolymer of Ethylene and Methacrylic acid
Dow Corning 700	91.7 ± 0.3	PDMS, Acetic Acid Condensation Cure
Thermoplastic Ionomer #2	88.4 ± 0.4	Copolymer of Ethylene and Methacrylic acid

Solar photon-weighted average optical density determined from transmittance measurements through polymer samples of various thickness (1.5 to 5.5 mm) between two pieces of 3.18 mm thick Ce doped low Fe glass.

Electrical Conductivty Varies Greatly



Resistivity measured at 22°C using alternating polarity DC current a +/- 700V.
"Wet" samples were soaked in water at 40°C.

PVB, 1000 Times more Conductive than EVA

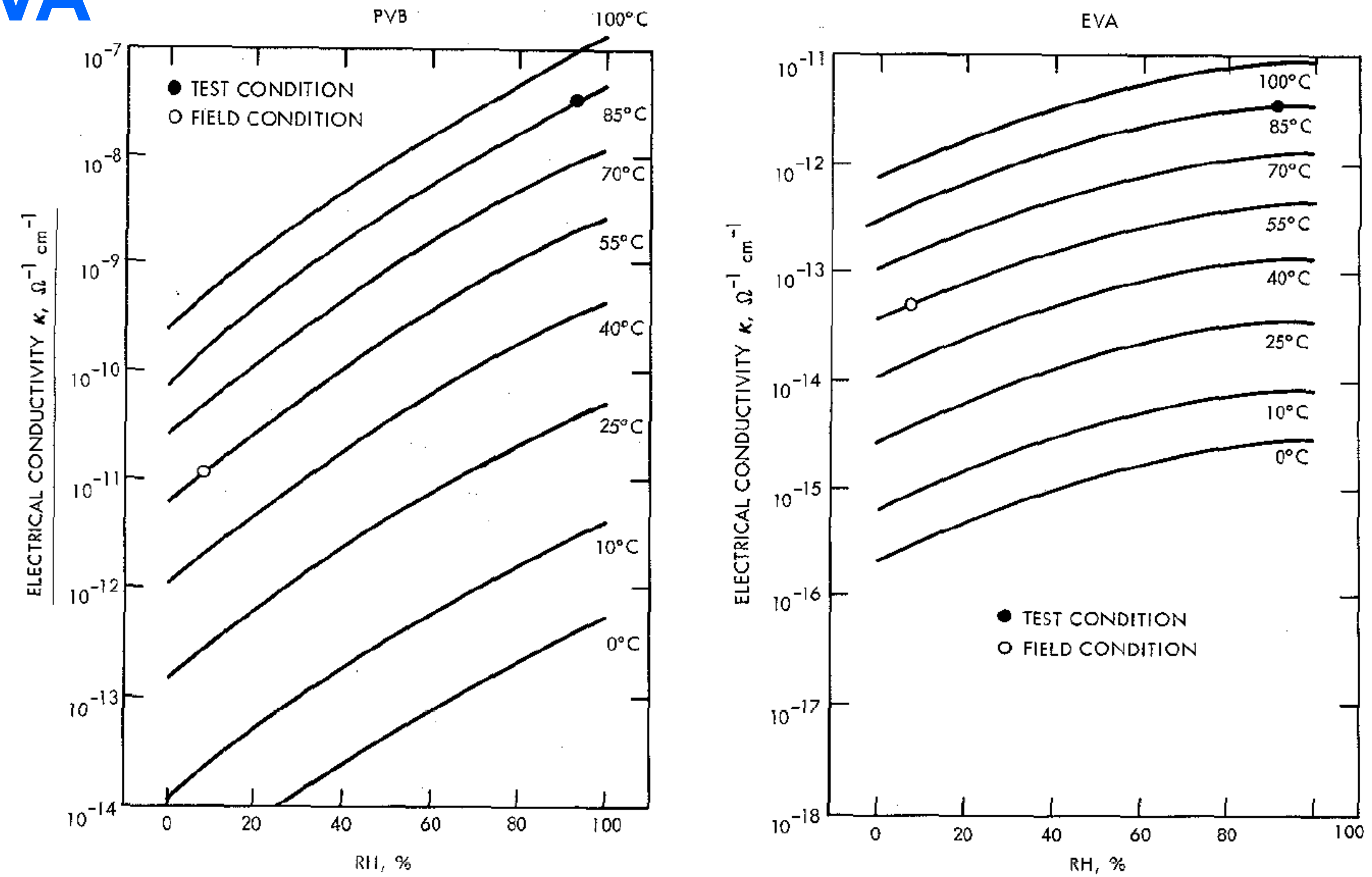


Figure 2. Bulk Electrical Conductivity of PVB and EVA

G. R. Mon, R. G. Ross, "Electrochemical degradation of amorphous-silicon photovoltaic modules", 18th PVSC, Las Vegas, NV, October 21-25, (1985) p. 1142-1149.

Leakage Current Correlates With Performance loss

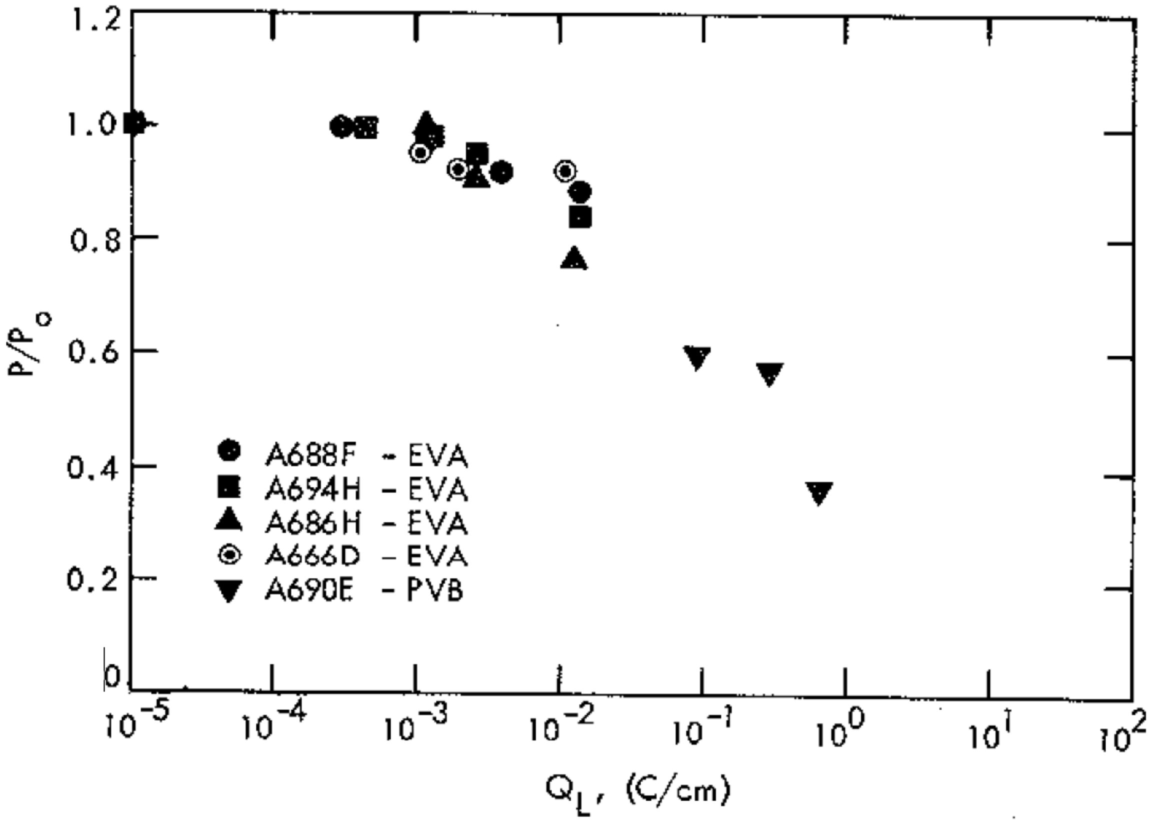


Figure 8. Power Output Reductions Versus Accumulated Unit Charge Transfer for α-Si Cells

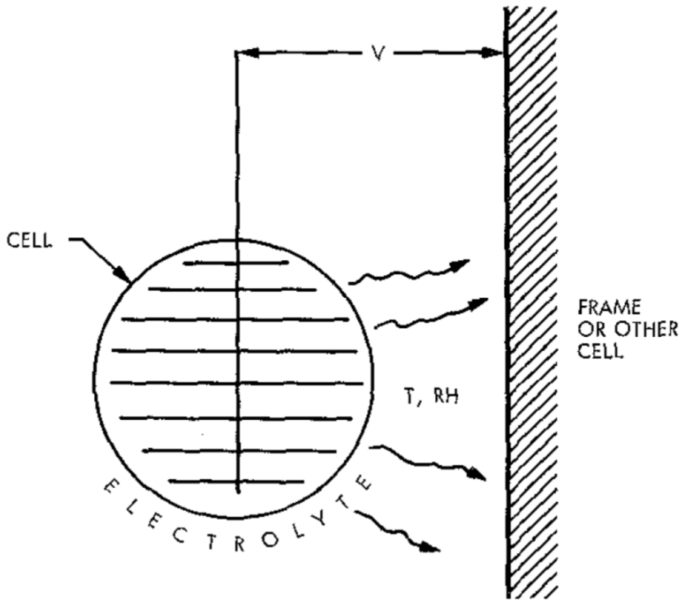
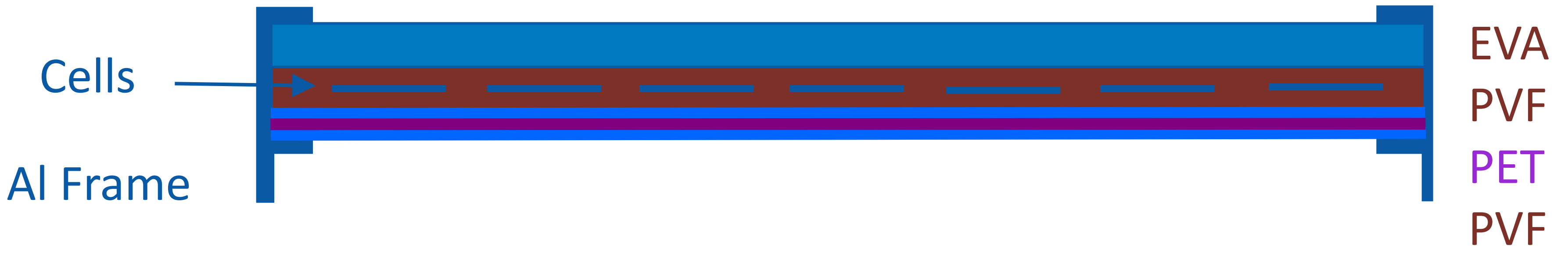


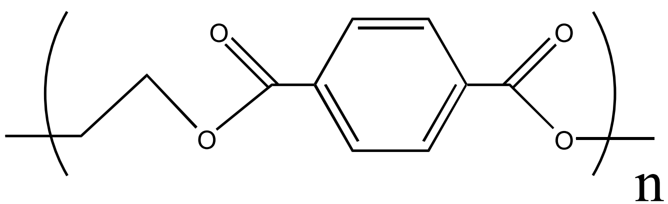
Figure 1. Corrosion Mechanism Overview

G. R. Mon, R. G. Ross, "Electrochemical degradation of amorphous-silicon photovoltaic modules", 18th PVSC, Las Vegas, NV, October 21-25, (1985) p. 1142-1149.

Backsheets Protect Against Electrical Shock

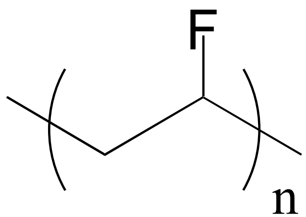
Framed Silicon Wafer Module





PolyEthylene Terepthalate (PET)

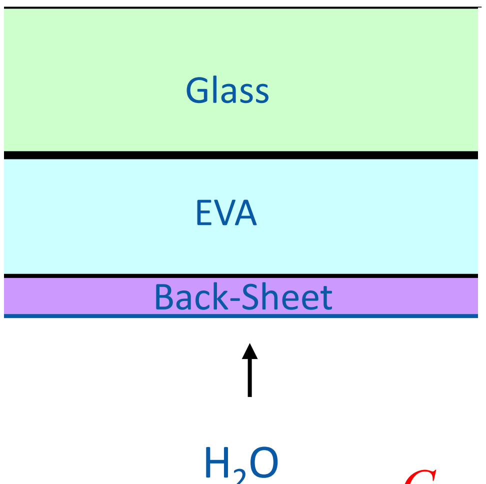
PET
provides Electrical insulation.



Poly Vinyl Floride (PVF)

PVF
provides UV stability

Time Constant for Water Ingress



$$C(t) = C_O\left(1 - e^{-\frac{WVTR_{B,Sat}\,t}{C_{Sat,EVA}\,l_{EVA}}}\right)$$

$$\tau_{1/2} = 0.693\frac{C_{Sat,EVA}\,l_{EVA}}{WVTR_{B,Sat}} = 0.693\frac{Amount\ of\ water\ EVA\ can\ hold}{Rate\ of\ moisture\ ingress}$$

l_{EVA}=18 mil, T=27 °C, $C_{Sat,EVA}$=0.0022 g/cm^3

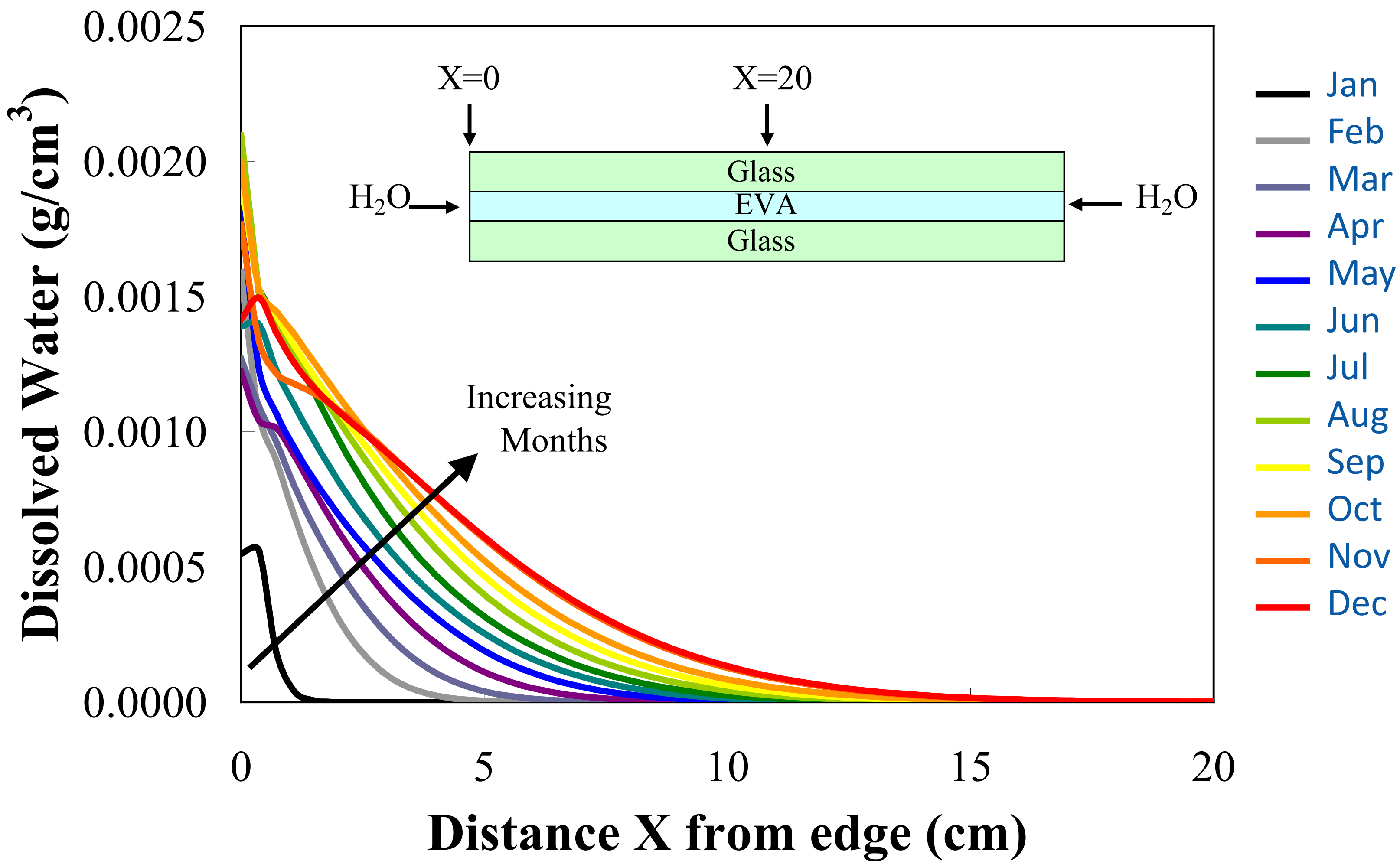
	PVF	ETFE	PVF/PET	PET	PCTFE	
$\tau_{1/2}$ =	0.0741	0.223	0.457	1.78	6.87	(day)

For $\tau_{1/2}$=20 years need 10^{-4} g/m^2/day

M. D. Kempe, "Modeling of rates of moisture ingress into photovoltaic modules," *Solar Energy Materials and Solar Cells,* vol. 90, pp. 2720-2738, 2006.

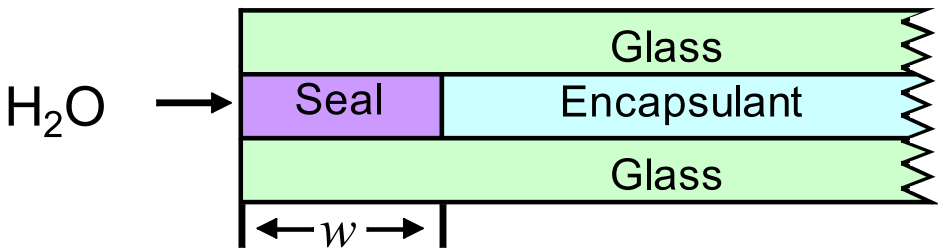
Even a Glass/Glass Module Will Let in Moisture

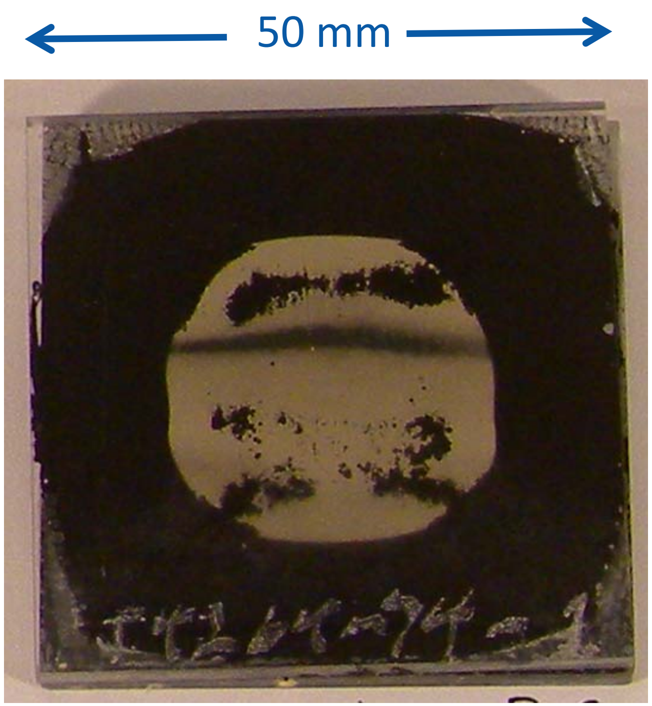
Finite element analysis using meteorological data from Miami Florida 2001



Edge Seals Can Keep Moisture Out

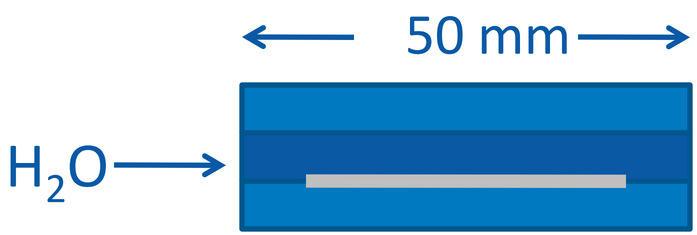
Schematic of module edge





PIB test sample after 3500 h
85^{o}C and 85% RH

Schematic of Test sample



Glass (3.18 mm)
Butyl Rubber (0.3 mm)
Ca (100 nm)
Glass (3.18 mm)

Conclusions

Packaging materials are formulated to:

- Resist to Heat, Humidity, UV Radiation, and Thermal Cycling.
- Provide Good Adhesion.
- Optically Couples Glass to Cells
- Electrically isolate components
- Control, reduce, or eliminate moisture ingress.

Choices made by Balancing cost With Performance.