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# Low-Cost, Single-Layer Replacement for the Back-Sheet and Encapsulant Layers

## Preprint

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**NOTICE**

# Low Cost, Single Layer Replacement for the Back-Sheet and Encapsulant Layers

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## Abstract

Ethylene propylene diene monomer (EPDM) based polymers have been formulated for specific use in photovoltaic modules to produce better performance and longer term stability at a lower cost than standard materials. EPDM formulations are advantageous over ethylene vinyl-acetate (EVA) because they can use the same lamination/cure cycle as EVA, they do not need a second back-sheet protective material (e.g. PET/Tedlar), they have a lower glass transition temperature, no melting transition, more constant mechanical moduli as a function of temperature, they are less polar than EVA (provides better corrosion protection), and they have excellent damp heat (85ºC/85% relative humidity) resistance against delamination.

Module designs typically use EVA on the back side of cells despite the fact that transparency is not advantageous. We have developed a single encapsulant layer that will replace standard module back-sheet constructions consisting of EVA/PET/Tedlar. Because a single low-cost material layer is used, it will provide a significant materials cost savings of about $6 to $8/m$^2$ as compared to traditional back-sheets. Electrical insulation tests were conducted using 0.85 mm thick stainless steel sheets as a model for a cell. It was found that a polymer layer thickness of about 0.33mm provided better high voltage electrical insulation than a combined film of Tedlar™ (0.038 mm) / PET (0.051 mm) / EVA (0.55 mm). When formulated with a white pigment, reflectivity was comparable to Tedlar$^{TM}$. Upon accelerated exposure to light at 60C and 60% RH it was found that an EVA layer in front of these materials would decompose before significant yellowing and delamination of the back EPDM layer occurs.

## 1. Introduction

Encapsulant materials are used in a variety of applications to isolate components, areas, or other materials from potentially stressful conditions that can adversely affect the performance of a device [1, 2]. For example, the performance of photovoltaic (PV) modules may decrease over time as water penetrates the module and corrodes the metallic components essential for module function [3]. In the absence of water, corrosion occurs relatively slowly because by-products are less able to diffuse away from a surface to allow the corrosion process to progress [4]. Furthermore, water is known to help catalyze some oxidative reactions.

The PV industry has long-recognized the dramatic effect that corrosion has on module performance. PV modules typically include a polymeric encapsulant material to isolate the silicon components from the ever-present potentially adverse conditions created by various sources of water, including rain, snow, and condensation. The isolation created by the encapsulant protects the PV components from the potential for corrosion and provides additional benefits, including mechanical support, electrical insulation and protection from mechanical damage.

Polymeric encapsulants provide the desired isolation by bonding to a surface and limiting access to the protected areas and/or components. For example, encapsulants used in PV modules are typically bonded to one or more glass sheets to isolate the solar cells, or cell strings, from water in the module's environment. The ability of a polymeric material to protect a surface is thus highly dependent on its ability to bond to a

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surface and limit access to corrosion sites. Therefore, a strong correlation exists between corrosion protection and adhesive strength.

The dominant encapsulant used in the PV industry is based on a random copolymer consisting of about 67 wt % polyethylene and 33 wt % poly vinyl acetate. It is typically used on the backside of PV modules despite the fact that good light transmission is not necessary. Some of the drawbacks to EVA include non-ideal mechanical and thermal properties, a high diffusivity for water, acetic acid by-product production [5], and poor electrical insulation properties. Because of this, another layer of polyethylene terepthalate (PET) is typically placed behind the EVA to provide electrical insulation and to slow down moisture ingress. However, PET is not very UV or hydrolytically stable. Because of this, a layer of Poly vinyl Fluoride is commonly used to help protect the PET. Fluoropolymers are typically very expensive so removing them has the potential to provide significant cost savings.

Ethylene Vinyl Acetate (EVA)
X=67 wt%, Y=33 wt%

PolyEthylene Terepthalate (PET)
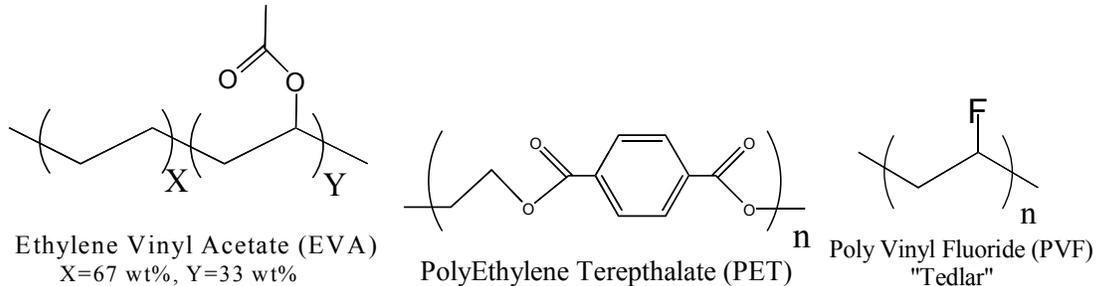
Poly Vinyl Fluoride (PVF) "Tedlar"

Figure 1. Polymers commonly used on the back side of PV modules.

As a more economical solution to this tri-layer back-sheet approach, we propose to use ethylene propylene diene M-class rubber (EPDM) (Fig. 2) to accomplish all the same functions at half the cost. EPDM is very non-polar which provides good corrosion resistance. This also gives EPDM good electrical insulation properties eliminating the need for PET. Through careful selection of pigments, UV absorbers, and stabilizers, EPDM can be formulated to provide UV stability for the life of a module.
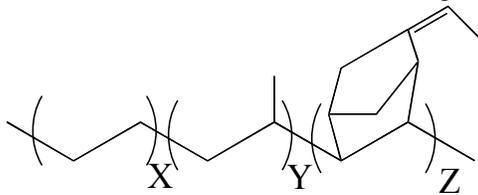
Ethylene Propylene Diene M-class rubber (EPDM)
X=40 to 50%, Y=40 to 50%, Z=5 to 10%

Figure 2. Schematic structure of EPDM.

The PV industry is under significant pressure to reduce the cost of manufacturing PV modules. Before PV modules and the renewable energy they deliver can enjoy widespread adoption, the manufacturing process must be refined to a point at which the product, PV modules, have desirable costs as compared to conventional energy sources. In this current environment, there is great interest in new technologies that realize efficiencies in the module manufacturing process. Encapsulants, as a component in PV modules, provide an opportunity to realize greater efficiencies in the module manufacturing process and overall module cost.

## 2. Experimental Methods
### 2.1 Rheology

Dynamic mechanical analysis was performed on a TA Instruments Ares Rheometer equipped with an IGC Polycold Systems Inc. cryogenic refrigeration unit model #PGC-100, that is capable of producing temperatures of -60ºC when used with the Ares forced-convection oven. A rectangular torsional testing fixture was used because the encapsulants tested were cross-linked elastomers. Samples were about 3 mm thick, 12 mm wide, and 25 mm long, with about 12 mm of the length covered by the clamps holding the sample in place.

## 2.2 Lap Shear Measurement

Lap shear measurements were performed as described by Kempe et. al. [5] using an Instron Test Unit (model 1122/5500R). The adhesive was applied to an approximately 19-mm-square area at a thickness of about 0.5 mm (Fig. 3).
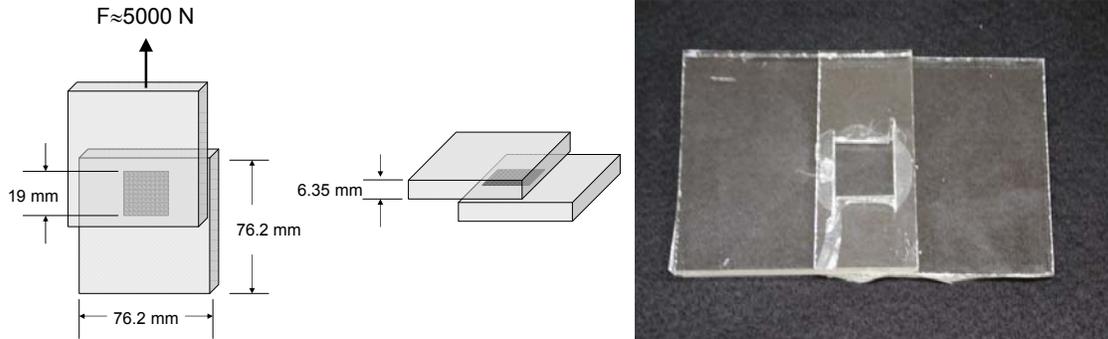


Figure 3. Schematic and photo of the lap shear design.

After accelerated environmental exposure, samples were removed from the test chamber, allowed to come to room temperature, and immediately tested using the Instron. Because there is a small strain-rate dependence of the maximum shear stress [6], a pull rate of 10 mm/min was chosen for EVA because it produced consistently high values. A pull rate of 1000 mm/min was chosen for the EPDM formulations to maximize the applied stress. The maximum shear stress is computed as

Equation 1. $\sigma_{max} = \dfrac{F_{max}}{Area}$ .

## 2.3 Aluminum Film Deposition

Aluminum mirrors were produced as described by Kempe et. al [5] in the sputtering chamber of a Pernicka multichamber vacuum deposition system. The substrates used were 2-mm-thick, 10.2-cm-square soda-lime glass. The Al thickness was about $800 \pm 25$ Å, sputtered with an instantaneous deposition rate of 4.8 Å/s.

## 2.4. Lamination

A well-formulated, commercially available EVA was encapsulated using a Model LM-404 Solar Module Laminator manufactured by AstroPower Inc. The laminator was programmed to hold the temperature at 60ºC for loading, apply a vacuum (~400 Pa) while heating to 120ºC in 10 min, hold the temperature at 120ºC for 10 min, apply atmospheric pressure to a diaphragm on top of the samples, heat to 145ºC, hold at 145ºC for 6.25 min, and then cool down to 100ºC and vent to atmospheric pressure.

## 2.5. Environmental Stress Testing

Test samples were exposed to a variety of stressed environmental conditions using several different chambers. Damp-heat [85ºC/85% relative humidity (RH)] exposure was obtained using a Blue M environmental chamber. UV exposure, 60ºC, 60% RH and 114 W/m$^2$ between 300 and 400 nm (2.5 AM 1.5 [7] UV suns), was obtained using an Atlas Ci4000 Weather-Ometer with Type S borosilicate inner and outer filters while controlling the light intensity by monitoring irradiance between 300 and 400 nm. The black-panel resistance temperature detector thermometer typically measured between 95ºC and 105ºC. A thermocouple placed directly on the samples typically read about 70º±3ºC. At this temperature, the samples will actually be exposed to about 38% RH.

## 3. Results and Discussion

The mechanical characteristics of an encapsulant material are important to ensure PV materials are protected form mechanical and thermal stresses. Typically, modules are tested and designed to operate at temperatures between 85ºC and -40ºC. In Fig. 4, EVA is shown to go through both a melting transition

(~55ºC) and a glass transition (~ -25ºC) both of which are in the range of temperatures a PV module might be exposed to.  This makes design of a module to withstand mechanical stress more difficult.  Testing at room temperature should not be extrapolated to high or low temperatures.  Similarly, polyvinyl butral (PVB) suffers from the presence of a glass transition (~40ºC) making the material less able to absorb the mechanical energy and protect the cells.  The other materials (polydimethyl silicone PDMS, thermoplastic polyurethane TPU and BRP-C) have good mechanical properties over a wide range of temperatures.  With these materials, tests conducted at room temperature are applicable for a wide range of use conditions.
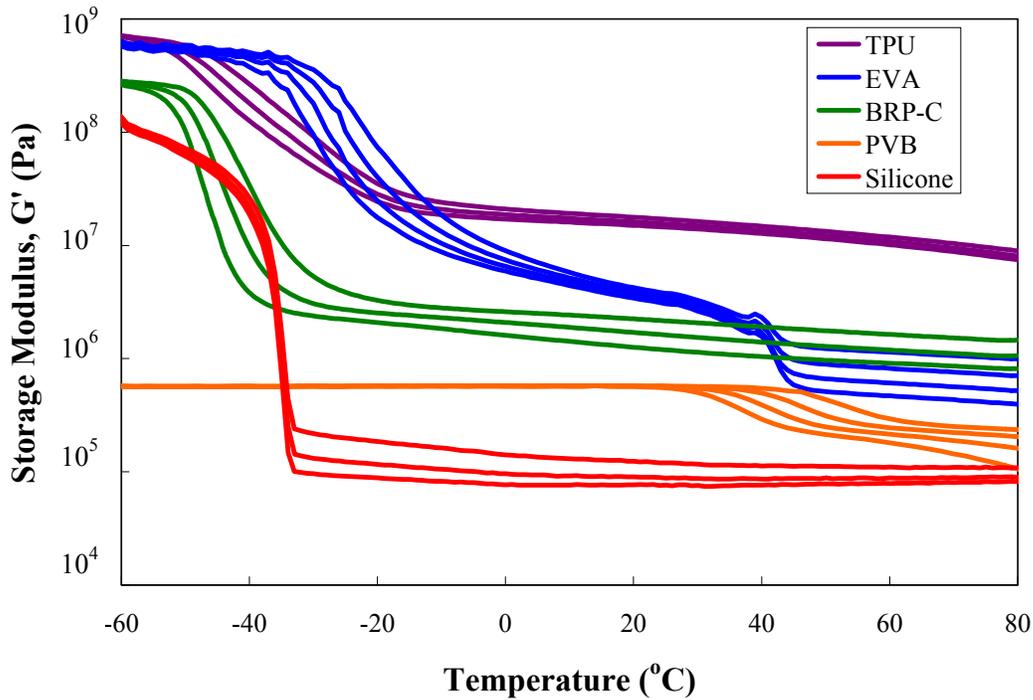


Figure 4.  Dynamic storage moduli (G') for PV encapsulant materials: a thermoplastic polyurethane (TPU), ethylene vinyl acetate (EVA), an experimental material from BRP Manufacturing, polyvinyl butral (PVB), and polydimethylsilicone.  The curves represent measurements at frequencies of 100 rad/s, 10 rad/s, 1 rad/s and  0.1 rad/s.

The EPDM resin in Fig, 4 was selected to have 7.5±1 wt % diene monomer which results in a copolymer without a melting transition.  This is beneficial for the processing and lamination of PV modules.  The absence of a melt transition reduces the magnitude of the drop in viscosity during lamination.  This helps to reduce the problems with edge pinch when laminating modules with a glass front-sheet and a glass back-sheet.  Furthermore, this slightly reduced flow will help to prevent thinning of the encapsulant around cell edges and busbars when EPDM is used as the only material on the backside. This is beneficial for an encapsulant layer to maintain adequate electrical insulation.

To evaluate the ability of encapsulant materials to reduce corrosion, 800Å aluminum films were deposited on glass (using magnetron sputtering) and laminated to another piece of glass using a variety of encapsulant materials as adhesives (Fig. 5).  The glass plates were laminated using an encapsulant material around the perimeter and in the center with an air gap in between.  This allowed for comparison of the effects of humidity on bare aluminum to an encapsulated film within the same specimen.  Samples were exposed to 1000 h of 85ºC and 85% RH.
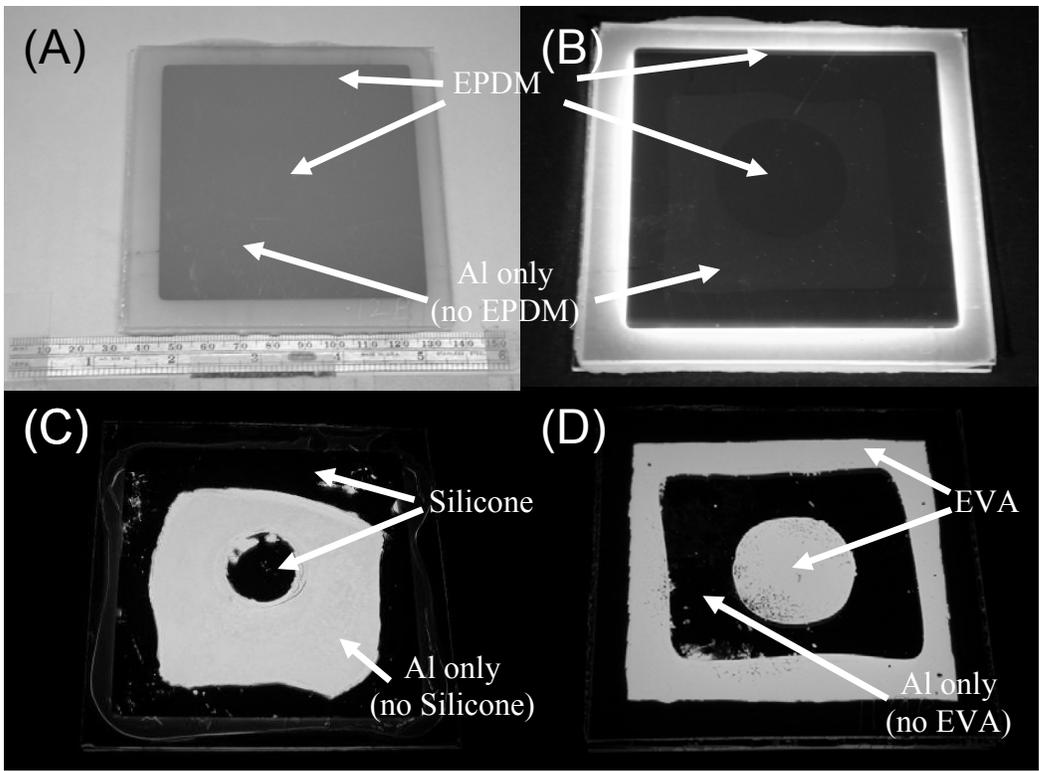
Figure 5.  Aluminum film on glass laminated with EVA located only in the center and in the outer ~25 mm using a glass back-sheet.  Photos were taken after 1000 h exposure to 85ºC and 85% RH.  (A) Back-lit EPDM (B) front-lit EPDM (C) Back-lit Dow Corning 700 acetic acid condensation cure polydimethylsiloxane (D) Back-lit EVA.

Figures 5A and 5B show front-lit and back-lit photographs of a sample constructed using BRP-C.  One can see that there are essentially no signs of corrosion.  Figure 5C shows a sample constructed using Dow Corning 700, an acetic acid condensation cure silicone elastomer.  Here, after exposure to humidity, the aluminum mirror is completely corroded where it is not contacted by the encapsulant.  The dramatic difference in these results is presumably attributable to significantly lower moisture ingress rates that kept the water concentration very low in the air space of the BRP-C sample [8].

Figure 5D shows a sample constructed using EVA as the encapsulant.  Here the greatest amount of corrosion is found where EVA is in direct contact with the aluminum film highlighting the corrosive nature of EVA [5].  These results demonstrate the excellent corrosion protection capacity of these EPDM based films.

The encapsulant used in a PV application serves several purposes such as reducing corrosion and mechanically holding module components together.  Good adhesion is correlated with corrosion resistance and is also necessary for mechanical integrity.  Fig. 6 indicates that these EPDM based materials can have excellent adhesive properties under damp heat (85ºC and 85% RH) for long periods of time.  EVA starts out with a high adhesive strength and slowly degrades to much lower values over the course of 1.5 y.  The EPDM based materials however fail in a cohesive manner; therefore, despite the generally lower values it is possible that the adhesion to glass is actually better than with EVA.  With the EPDM formulation, BRP-C, no loss in adhesion was detectable for the first 2 y.  Then the last sample tested at 3 y exposure time failed adhesively.   This indicates that the EPDM formulations are well suited to withstand extremes of temperature and humidity while maintaining good adhesion.
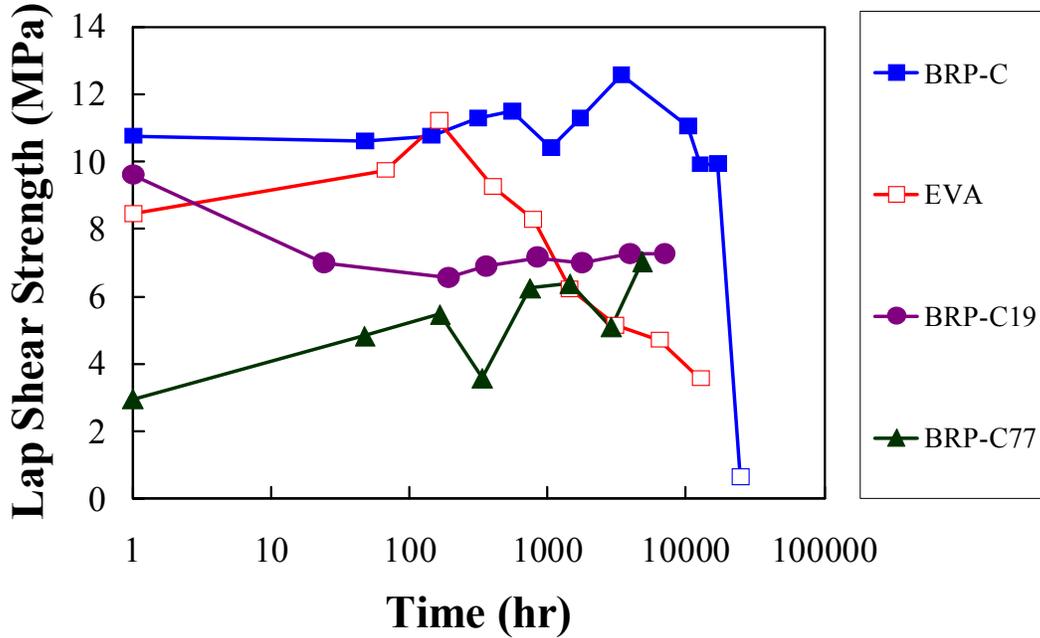
Figure 6. Lap shear adhesion results for several EPDM compositions and an EVA encapsulant after exposure to 85ºC and 85% RH. Open symbols indicate adhesive (glass to polymer) failure and filled symbols indicate cohesive failure.

PV encapsulant materials are also required to provide good adhesion under exposure to UV radiation. Lap shear samples were thus exposed to 60ºC, 60% RH and 2.5 AM 1.5 [7] UV suns (Fig. 7). EVA quickly lost about 70% of its adhesive to the UV exposed side of the glass in about 2000 h and then maintained a lower adhesive value between about 2 MPa and 4 MPa for the next two years of exposure. EPDM formulation number BRP-C107 initially had good adhesive strength failing in a cohesive manner. Then after about 1000 h exposure the failure mode changed to glass to EPDM adhesive failure. This test is still ongoing, but these preliminary results indicate comparable adhesion with that of EVA.
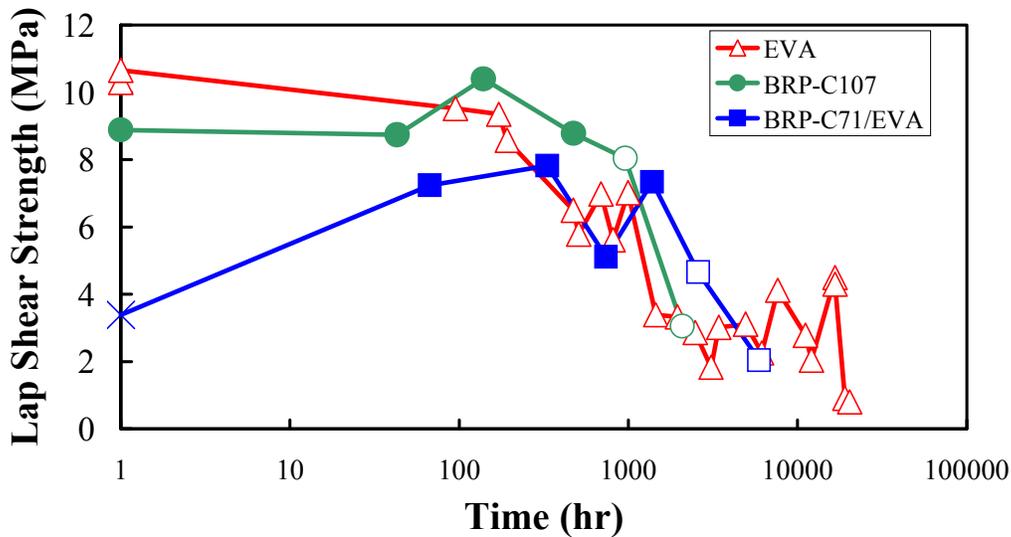


Figure 7. Adhesion strength retention after exposure to 60ºC, 60% RH, and 2.5 AM 1.5 UV suns behind low iron non-ceriated glass [9]. Open symbols indicate adhesive (glass to polymer) failure, filled symbols indicate cohesive failure and "×" indicates EVA to EPDM interfacial adhesive failure.

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When used with crystalline silicon or with thin film PV on metal foils, EPDM will be required to maintain good adhesion to EVA. To test this, another lap shear sample set was constructed with using both an EVA and an EPDM layer (Fig. 7). Initially failure was between the EVA and EPDM layers. But after exposure to heat and humidity the adhesion of EPDM "set" and the failure mode changed to cohesive within the EPDM. The need for some samples to take some time to achieve good adhesion is not unusual. When one considers that PV modules will not immediately be exposed to harsh environmental conditions, this delay in the acquisition of strong adhesion should not be a concern.

After 2500 h of UV exposure the EPDM/EVA samples began to fail adhesively on the UV exposed EVA to glass interface. This indicates that the EVA to glass adhesion is the weakest interface for modules constructed using both EVA and EPDM. This is expected because this interface gets a full dose of UV radiation whereas the EVA screens out most of the UV radiation for the EPDM film.

Because water is known to accelerate corrosion, the ability of a back-sheet material to keep moisture out is related to its ability to protect a PV device. When used as a back-sheet material, the EPDM has moisture permeation properties similar to composite laminate films comprising EVA/PET/Tedlar commonly used in the PV industry. When PET is used as a back-sheet material it is typically used at a thickness of between 0.1 mm and 0.18 mm as compared with about 0.5 mm for an encapsulant. Therefore even though PET has a lower permeability than the EPDM formulations (Fig. 8), they should have similar water vapor transmission rates (WVTR=Permeability·thickness). If impermeable front- and back-sheets are used limiting moisture ingress to the sides, the lower permeation rates of EPDM materials will dramatically outperform EVA.
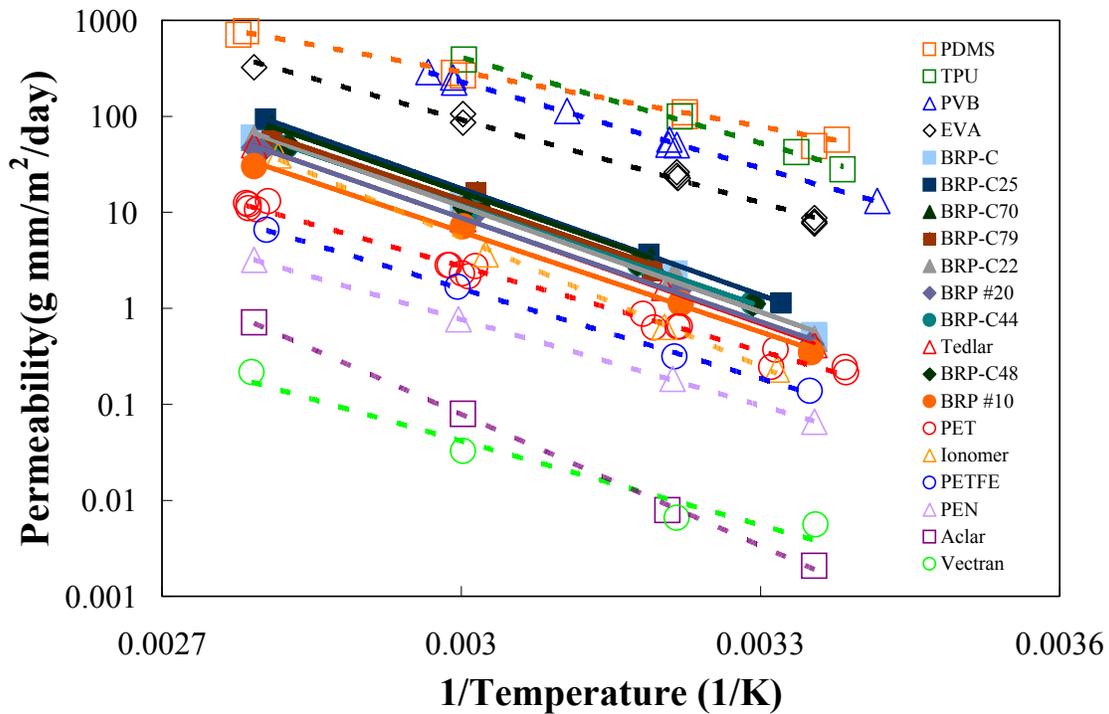


Figure 8. Permeability of materials used in PV modules. Solid lines and filled symbols are used for the different EPDM formulations. Polydimethylsiloxane (PDMS), Polyvinylfluoride (PVF), Polyethylene Terepthalate (PET), Poly chloro trifluoro ethylene (PCTFE), Poly vinyl butral (PVB), Poly Ethylene Napthalate (PEN), Polyvinylchloride (PVC), and Thermoplastic Polyurethane (TPU).

In Figure 9, the breakthrough time is defined as the time necessary for a film experiencing a step change in water concentration on one side to achieve 10% of the change toward the new equilibrium water vapor transmission rate. This breakthrough time is related to the square of the characteristic distance. For large PV modules with impermeable front- and back-sheets this corresponds to the distance to which moisture will penetrate laterally in a specific time. Figure 9 estimates the penetration depth for different

materials as a function of temperature for a variety of potential PV encapsulants (assuming one dimensional diffusion). A typical time averaged (day and night) module temperature will be between 15ºC and 35ºC (depending on mounting conditions and the local environment) [8]. In Figure 9, this corresponds to 1/K between 0.00347 K$^{-1}$ and 0.00324 K$^{-1}$ and penetration depths of 3 to 10 cm after 20 years of field exposure for EPDM based materials. For comparison, moisture would penetrate distances greater than 1 m if EVA was used as the encapsulant. If moisture penetration can be significantly reduced, better PV performance and longevity should be achieved.
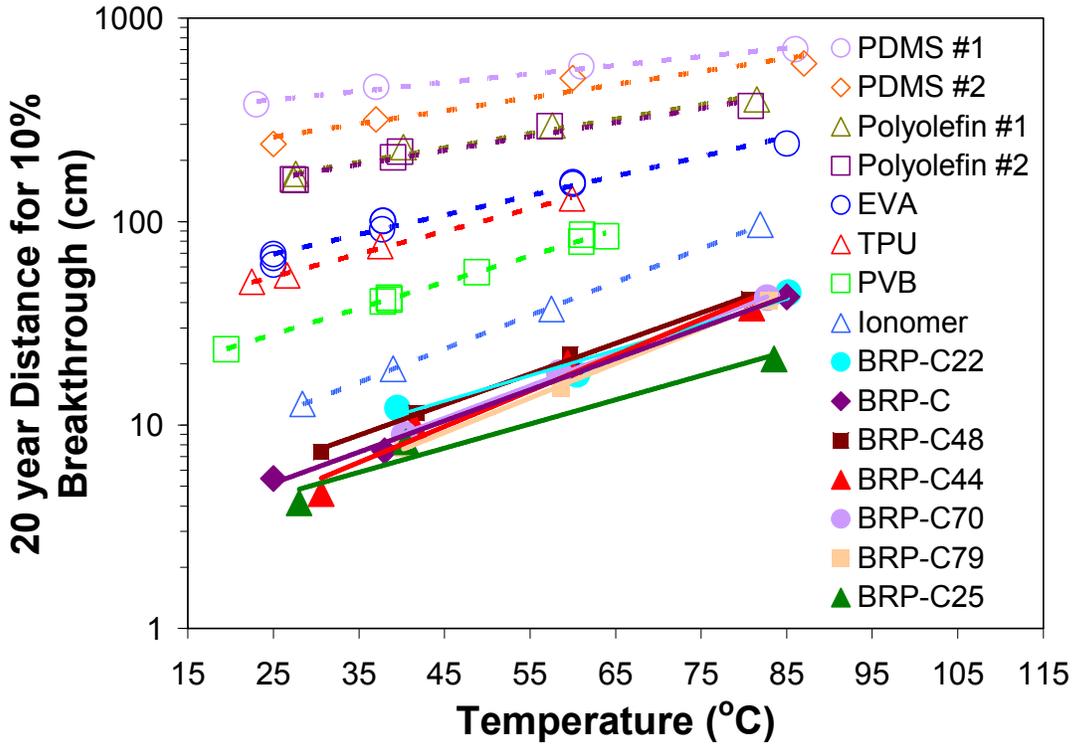


Figure 9. The moisture breakthrough distance is the depth to where significant moisture will penetrate a PV module after 20 y of exposure.

A test representative of the wet high pot test (section 10.15 of IEC 61215) was conducted on several example compositions. According to IEC 61215, after 1000 hr of exposure to 85ºC and 85% RH, modules must be immersed in a surfactant containing water bath with an applied voltage of 500V. The measured resistance from the cell to the bath must be greater than 40 MΩ·m$^2$ for modules >0.1 m$^2$. To simulate this test, 12.7 cm square steel plates were laminated to glass using commercially available PV EVA between the glass and the steel plate with different back-sheets. For this construction, the resistance must be greater than 2.4 GΩ to pass. The steel sheets used were either 0.85 mm or 0.64 mm, glass was 2.26 mm, and the EVA had a nominal 0.46 mm thickness per sheet. "Failed" indicates the ohm meter could not reach 500V because of high current and >10 GΩ indicates the current was too low to measure (Table 1).

| Back-Sheet Material | Back-sheet Thickness (mm) | Initial Resistance | Resistance After 1000 h 85C/85%RH Exposure |
|---|---|---|---|
| EVA | 0.50 | 1 MΩ | Failed |
| EVA/TPE | 0.69 | 6.6 GΩ | 9.1 GΩ |
| BRP-C33 | 0.43 | 8.6 GΩ | >10 GΩ |
| BRP-C34 | 0.30 | 9.6 GΩ | >10 GΩ |
| BRP-C31 | 0.33 | 8.4 GΩ | >10 GΩ |
| BRP-C40 | 0.33 | 8.14 GΩ | >10 GΩ |
| BRP-C32 | 0.33 | 8.63 GΩ | >10 GΩ |

Table 1. Wet high pot test according to IEC 61215. After 1000 hr of exposure to 85ºC and 85% RH, resistance must be greater than 2.48 GW to pass. The sample construction labeled "EVA/TPE" represents a composite back-sheet with layers of EVA/Polyethylene-Terepthalate/Tedlar.

As expected, samples laminated with only EVA on the backside failed the wet high pot test. This is attributable to both the higher polarity of EVA relative to EPDM and to greater flow in the melt state. Higher polarity enables greater ionic movement and more leakage current. The presence of a melt transition in EVA causes increased flow prior to curing which allows it to thin out near the corners of the steel plates. In contrast, when EVA is laminated with a PET back-sheet good dielectric properties are obtained and any thinning of the EVA is irrelevant because the PET layer does not get hot enough to melt. All the EPDM materials passed the wet high pot test even at thicknesses as small at 0.30 mm. After damp heat exposure these materials out performed TPE back-sheets commonly used in PV modules.

EPDM formulations were also tested for compliance to the partial discharge test (IEC60664-1 and IEC61730) [10]. It was found that a back-sheet thickness of 0.50 mm were rated for use at 1221 V. These results indicate that EPDM based back-sheets can be used as a single layer capable of providing adequate electrical insulation.

The yellowness index (YI) is a measure of the perceived color of an object by a human observer. Changes in YI serve as an indication of the degree of degradation of a material. Samples were exposed to 60ºC, 60% RH and 2.5 UV suns for varying amounts of time in an Atlas Ci4000 weatherometer. Table 2 presents results of this evaluation. The Glass/EVA/TPE sample construction represents a common construction used with PV modules. Under these conditions, samples receive a highly accelerated dose of UV radiation [9]. It was found that the PET layer in these laminate films begins to degrade very rapidly and delaminated from the Tedlar film after 4300 h. In Contrast BRP-C27 maintained a low YI of 0.22 after 9024 h exposure. BRP-C42 had reduced amounts of titania compared to BRP-C27 and had a slightly higher YI of 2.8 after 6207 h. BRP-C24 was similar to BRP-C27 but it did not have any hindered amine light stabilizers (HALS) in its formulation. Being protected from the UV radiation by the EVA layer, it only degraded moderately in color, but was observed to crack and shrink around the edges where the EVA layer was much thinner. This demonstrates the need for HALS in the formulations.

| Sample\Time 60ºC/60%RH/2.5 UV Suns | 0 h | 65 h | 682 h | 5137 h | 6207 h | 9024 h |
|---|---|---|---|---|---|---|
| Glass/EVA/TPE | Front 0.34 Back 0.27 | Front 26.7 | Front 30.6 | Front 71.0 Back 4.31 Delaminated | | |
| Glass/EVA/BRP-C24 | Front 1.32 Back -0.47 | Front 0.89 | Front 2.37 | Front 3.0 Back 1.72 | | |
| Glass/EVA/BRP-C27 | | | | | | Front 0.22 Back 0.19 |
| Glass/EVA/BRP-C42 | | | | | Front 2.8 Back 1.4 | |

Table 2. Yellowness index after exposure to 60ºC, 60% RH, and 2.5 suns. The glass was low iron and non-ceriated to allow transmission of most of the UV portion of the spectrum. All BRP samples used titania filler to produce a white, highly reflecting material.

## 4. Applications

For thin film PV superstrate structures on glass (e.g. Cd/Te based devices), the lower diffusivity of water, excellent adhesion, and absence of corrosive by-products (such as acetic acid in EVA) makes EPDM based encapsulants better at protecting against corrosion. The small amount of water that enters the space between glass plates through the junction box or through the edge seal will not penetrate as deeply as it would with EVA (Fig. 10). This will help to reduce the extent of moisture induced corrosion making the module package more reliable.
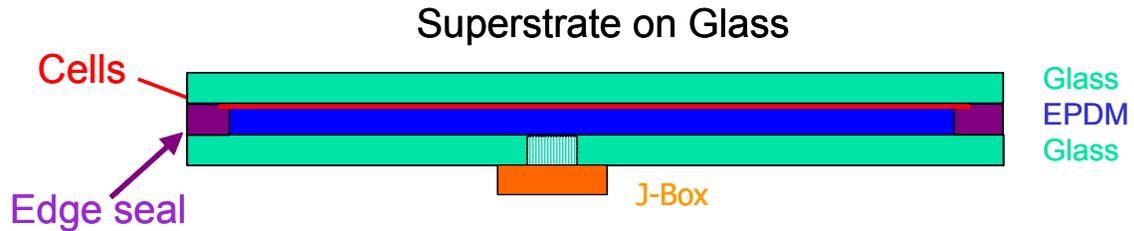


Figure 10. Schematic of a superstrate thin film module laminated with EPDM.

Alternatively, thin film PV cells can be constructed on metal foils. Construction schemes requiring a hermitic package may use a glass front sheet, edge seals, and a back-sheet made of either glass or an aluminum foil containing composite (Fig. 11). Using EPDM with aluminum foil can provide the same electrical insulation in a more robust package at a significant cost savings.
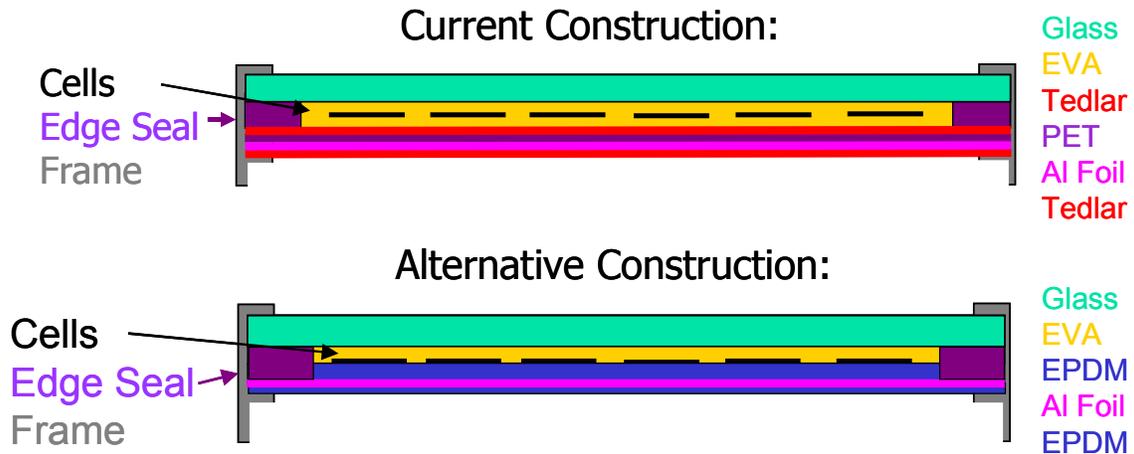


Figure 11. Schematic construction of PV module made using thin film on metal foil cells design to provide a hermitic package.

With a module constructed as in Fig. 11, a hole would most likely be cut through the aluminum foil back-sheet to get electrical leads to the junction box. This has the disadvantage of providing a moisture ingress pathway to the sensitive thin film PV material. However, if the hole for the junction box was strategically placed directly behind the center of a PV cell (Fig. 12), it would take a significant amount of time for moisture to diffuse around the side of the cell to the more sensitive front side of the cell. The large breakthrough time for moisture of EPDM relative to EVA (Fig. 9) is what makes this a viable option. With EVA, moisture would be able to get around the cells in a timeframe on the order of 1 year, whereas with EPDM it will take 10 to 20 years for significant moisture to reach the front side of the cells.
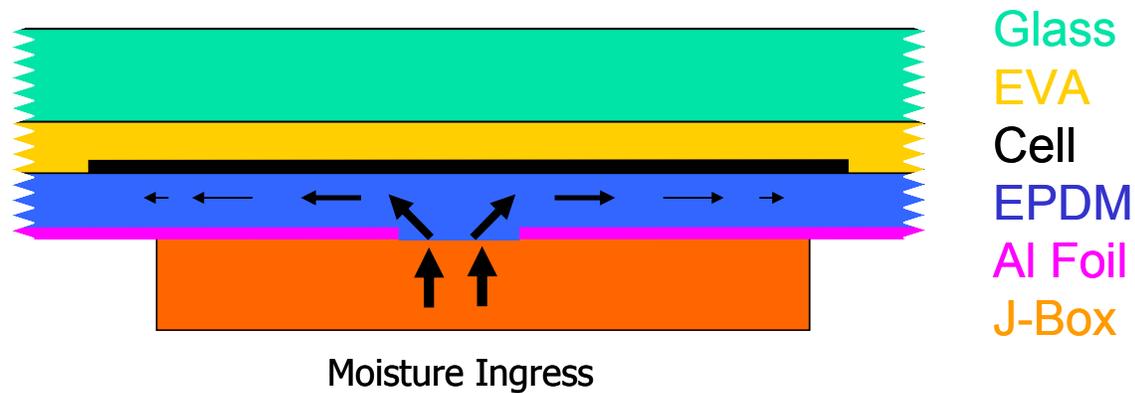
**Moisture Ingress**

Figure 12.  Schematic drawing of moisture ingress pathways through the junction box of a PV module with an aluminum foil back-sheet as shown in Fig. 11.

The EPDM encapsulant films have good UV stability and good electrical insulation properties enabling expensive composite film laminates to be replaced by a single low-cost layer.  Typical silicon wafer cells use an EVA layer behind the cells even though transparency is not a requirement.  The poor electrical properties EVA require a dielectric layer such as PET, to provide electrical insulation.  Then to overcome issues with poor UV and hydrolytic stability of PET an expensive PVF (Tedlar) layer is commonly used on the backside.  EPDM is UV stable and electrically insulating which allows this expensive laminate structure to be replaced by a single layer.  Furthermore the use of a single layer will also reduce the module assemble costs.  This will reduce the materials cost by $8 or more per square meter.
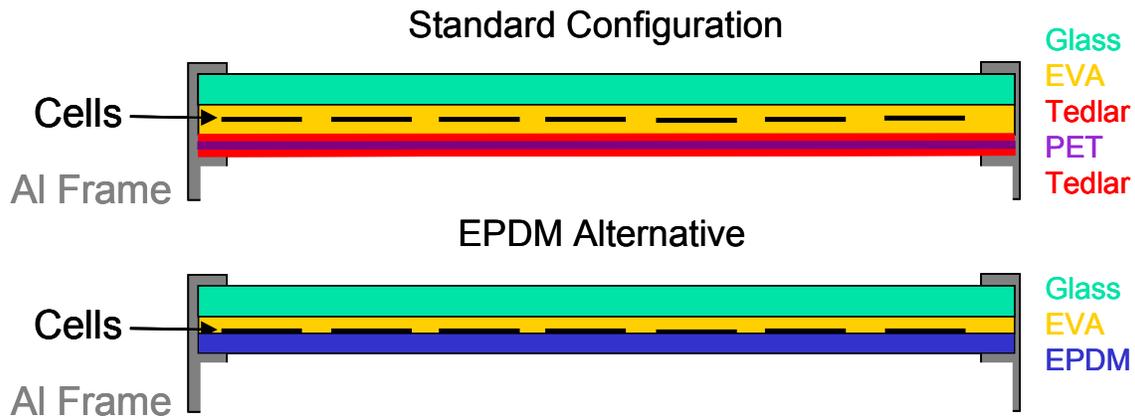


Figure 13.  Schematic of PV module configurations for use with wafered silicon cells.

**5.  Conclusions**

The use of an EPDM based encapsulant material has many advantages over EVA formulations. EPDM is less polar giving it better corrosion protection, good electrical insulation, and low moisture permeability.  The absence of a melt transition and the low glass transition temperature (-50ºC) give it more consistent properties over a wide temperature range.  This allows mechanical tests conducted at room temperature to be relevant over the actual operating conditions and it also reduces mechanical stresses induced by phase changes.  The use of peroxide cure chemistry allows EPDM films be cured using the same cycle as standard EVA formulations.  Its adhesion to EVA and to glass has been shown to be highly resistant to damp heat.

The unique properties of EPDM allow it to be used in PV applications without the need for expensive PVF and PET composite laminates.  This directly reduces the materials cost compared to standard PV module constructions by about $10/m$^2$ (depending on the structure).  It also saves money by reducing the number of polymers films required in the assembly process making a more manufacturable process.

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[10] The partial discharge test was generously conducted by Tamizh-Mani at ASU.

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Ethylene propylene diene monomer (EPDM) based polymers have been formulated for specific use in photovoltaic modules to produce better performance and longer term stability at a lower cost than standard materials. EPDM formulations are advantageous over ethylene vinyl-acetate (EVA) because they can use the same lamination/cure cycle as EVA, they do not need a second back-sheet protective material (e.g. PET/Tedlar), they have a lower glass transition temperature, no melting transition, more constant mechanical moduli as a function of temperature, they are less polar than EVA (provides better corrosion protection), and they have excellent damp heat (85ºC/85% relative humidity) resistance against delamination. Module designs typically use EVA on the back side of cells despite the fact that transparency is not advantageous. We have developed a single encapsulant layer that will replace standard module back-sheet constructions consisting of EVA/PET/Tedlar. Because a single low-cost material layer is used, it will provide a significant materials cost savings of about $6 to $8/m2 as compared to traditional back-sheets. Electrical insulation tests were conducted using 0.85 mm thick stainless steel sheets as a model for a cell.

**15. SUBJECT TERMS**
PV; encapsulant layers; low-cost; single layer replacement; back-sheet; ethylene propylene diene monomer; ethylene vinyl-acetate; polymers;

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