

# Design criteria for photovoltaic back-sheet and front-sheet materials

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## ABSTRACT

Back-sheet materials for photovoltaic modules serve several purposes such as providing electrical insulation, environmental protection and structural support. These functions are essential for modules to be safe for people working near them and for the structures to which they are attached. To ensure that all modules meet a minimum set of requirement, they must pass qualifications tests such as IEC 61646, 61215, 61730, and 62108. This paper puts forward the design and composition requirements of back- and front-sheet materials for achieving the highest possible quality performance from PV modules.

## Introduction

For PV modules, ethylene vinyl-acetate (EVA) is the dominant encapsulant because it has the best properties possible and is also a very economical solution. Other materials such as silicones have better light transmission and UV stability, but these improved properties come at a cost. However, EVA by itself does not provide adequate electrical insulation and scratch resistance. Because of this, a layer of polyethylene terephthalate (PET) is typically added as a good dielectric and as a mechanical barrier. Most PET films are not resistant to UV radiation and must be further protected as is typically accomplished through the use of a layer of poly vinyl fluoride (PVF, or Tedlar).

For crystalline silicon modules, this trilayer back-sheet laminate of EVA/PET/PVF dominates the industry. Much of this is historical in origin and dates back to work performed at the Jet Propulsion Laboratory (JPL) in the 1980s [1]. Fluoropolymers are known to be very UV resistant and chemically stable, but in many ways much more stable than is necessary for PV modules. Unfortunately it is very difficult to get good adhesion of fluoropolymers to other materials. They are also relatively expensive despite the fact that they are used as very thin films (~0.025mm). For this reason, coupled with supply limitations, there is an opening in the market for other materials to that are less expensive and not so over-engineered.

## Alternatives

One alternative is to replace all three layers (EVA/PET/PVF) with a single encapsulant. To do so requires a very electrically-insulative material that is tough and scratch resistant and can maintain good adhesion to module components. Ethylene propylene M-class monomer (EPDM) is one such material [2]. It is commonly used as wire insulation, roofing material, radiator hoses, and gaskets.

This material is still in the experimental stage but because it would replace both the encapsulant and the back-sheet materials, it may provide a cost saving of approximately US\$6.00/m<sup>2</sup> as compared to typical back-sheet laminates.

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Other PVF replacement materials that have already passed the PV qualification tests and achieved significant market penetration are stabilized PET formulations, which are designed to replace both the PET and PVF films. Stabilization is obtained principally through the addition of inorganic fillers and can be pigmented to a desired colour. This material can save between US\$3 and US\$5/m<sup>2</sup>, depending on the application. Stabilized PET formulations eliminate the issues associated with adhesion of PET to PVF but still feature the more easily managed issues associated with adhesion of PET to EVA. The cost savings of these alternatives, in addition to the supply issues with PVF, provide a strong incentive to change typical manufacturing materials for crystalline silicon modules.

## Thin film module requirements

For thin-film modules, there is a much greater concern regarding moisture ingress. This is especially true of CdTe and Cu(In,Ga)Se (CIGS) technologies, but not so much for thin-film silicon technologies. Semi-hermetic packages are commonly constructed for CdTe-

and CIGS-based thin-film PV through the use of glass front-sheets, aluminum and/or glass back-sheets, in conjunction with desiccant-filled butyl rubber edge seals around the perimeter. However, for CIGS materials constructed on metal foils, there is a desire to use flexible front- and back-sheet materials to make building integrated products more cost-effective. For the front-sheet this presents a unique set of challenges in designing a material that is a flexible moisture barrier but that is also able to transmit light.

## Water vapour transmission rate – sample study

If an initially dry module was exposed to constant environmental conditions then the transient water vapour concentration [ $C(t)$ ] in the encapsulant just on the inside of the vapour barrier can be approximated as [3]:

$$\frac{C(t)}{C(0)} = 1 - e^{-\frac{WVTR_{B,Sat}t}{C_{Sat,EVA}l_{EVA}}} \quad (1)$$

In this case,  $t$  is the exposure time;  $WVTR_{B,Sat}$  is the maximum water vapour transmission rate (WVTR) for the case with liquid water on one side and dry air on the other side of the back-sheet material;  $C_{Sat,E}$  is the concentration of water in the encapsulant at saturation; and  $l_E$  is the encapsulant thickness. This yields a half-time for equilibration of [4].

$$\frac{C(t)}{C(0)} = 1 - e^{-\frac{WVTR_{B,Sat}t}{C_{Sat,EVA}l_{EVA}}} \quad (2)$$

As an example, a module consisting of a back-sheet with a WVTR of 1.13g/m<sup>2</sup>/day @ 25°C (e.g., PVF/PET/EVA) laminated to

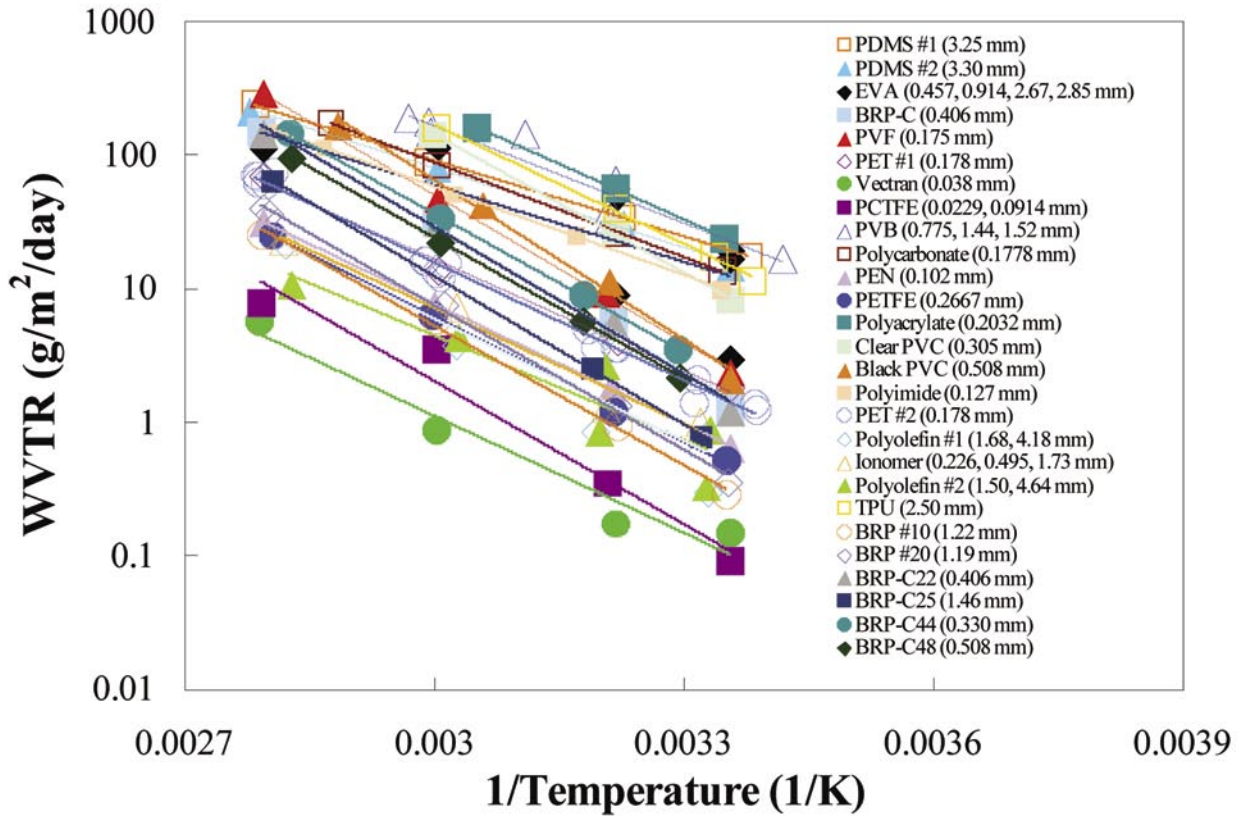


Figure 1. Steady state water vapour transmission rate (WVTR) for various polymeric materials. Polydimethylsiloxane (PDMS), Ethylene Vinyl Acetate (EVA), experimental film from Buckeye Rubber Products (BRP), Polyvinylfluoride (PVF), Polyethylene Terephthalate (PET), Poly chloro trifluoro ethylene (PCTFE), Poly vinyl butral (PVB), Poly Ethylene Napthalate (PEN), Polyvinylchloride (PVC), and Thermoplastic Polyurethane (TPU). These measurements were made using a Mocon Permatran-W 3/31 instrument.

a 0.46mm-thick layer of EVA ( $C_{Sat}=0.0021$  g/cm<sup>3</sup> @ 25°C) would have an equilibration half-time of 14 hours. For a front-sheet to

have an equilibration half-time of the order of 20 years, it would need a WVTR of about  $1 \cdot 10^{-4}$  (g/m<sup>2</sup>/day). This value should

be thought of as a minimum WVTR that will just begin to make a difference for the moisture content of a PV package over the

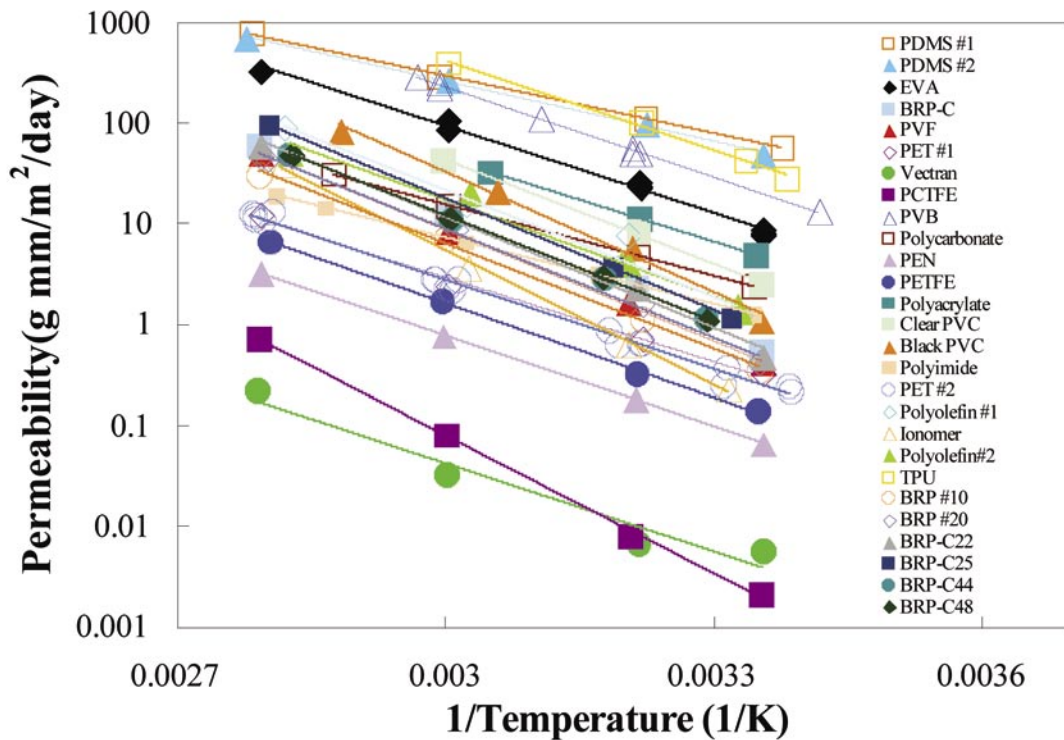
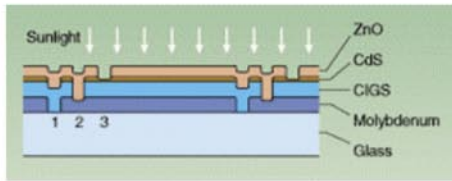
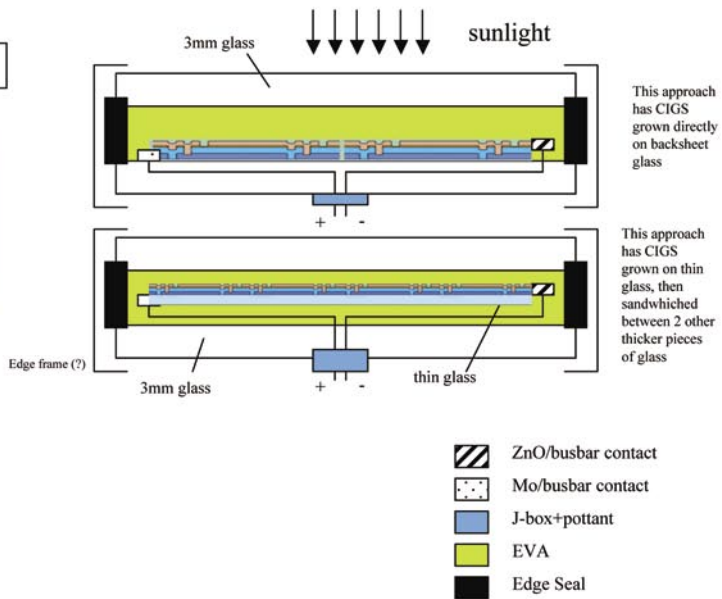


Figure 2. Permeability of various polymeric materials considered for use in PV applications (same definitions as in Figure 1).

monolithic (glass) constructions



Basic design of monolithically-connected series cells:



This approach has CIGS grown directly on backsheet glass

This approach has CIGS grown on thin glass, then sandwiched between 2 other thicker pieces of glass

- ZnO/busbar contact
- Mo/busbar contact
- J-box+pottant
- EVA
- Edge Seal

Figure 3. Cu(InGa)Se Monolithically Integrated on Glass.

20-year lifetime of a module. To really keep a module dry, values in the  $1 \cdot 10^{-5}$  ( $\text{g}/\text{m}^2/\text{day}$ ) to  $1 \cdot 10^{-6}$  ( $\text{g}/\text{m}^2/\text{day}$ ) must be obtained [3].

The WVTR for a number of potential PV packaging materials was measured, as shown in Figure 1. Because the WVTR is dependent on the thickness of the film, it is useful to consider the permeability ( $P = \text{WVTR} \cdot \text{thickness}$ ), as shown in Figure 2. The lowest permeability materials were the liquid crystal polymer Vectran and poly chloro trifluoro ethylene (PCTFE) with permeabilities around  $5 \cdot 10^{-2}$  ( $\text{g} \cdot \text{mm}/\text{m}^2/\text{day}$ ). A thickness of 50cm would be required to achieve a WVTR of  $1 \cdot 10^{-4}$  ( $\text{g}/\text{m}^2/\text{day}$ ).

This 50cm estimate neglects transient effects but indicates the inability of simple polymeric materials to significantly reduce the exposure to moisture. Modules with polymer front- or back-sheets will quickly equilibrate with the environment. Using materials with lower permeation rates will

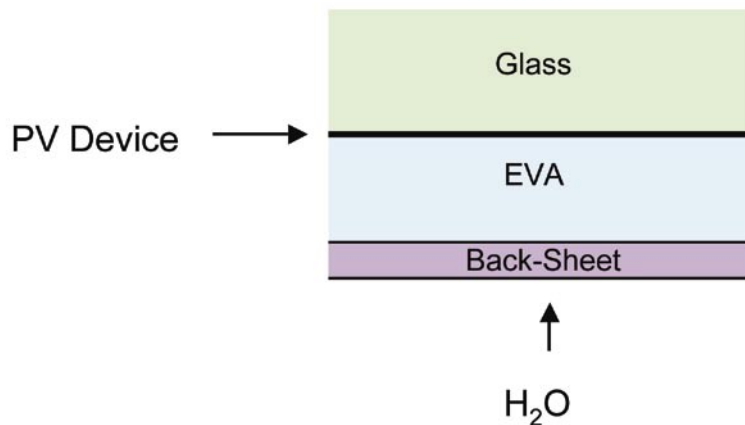
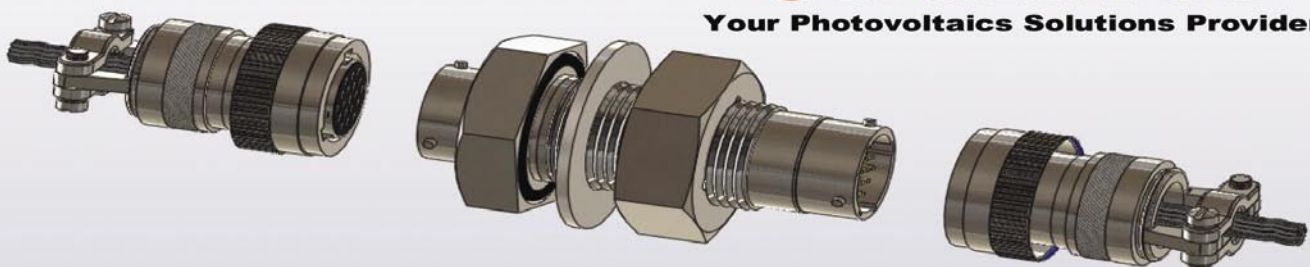


Figure 4. Schematic of model used for a module with a breathable back-sheet. For a crystalline silicon module this could also represent the conditions on the backside of the cells.



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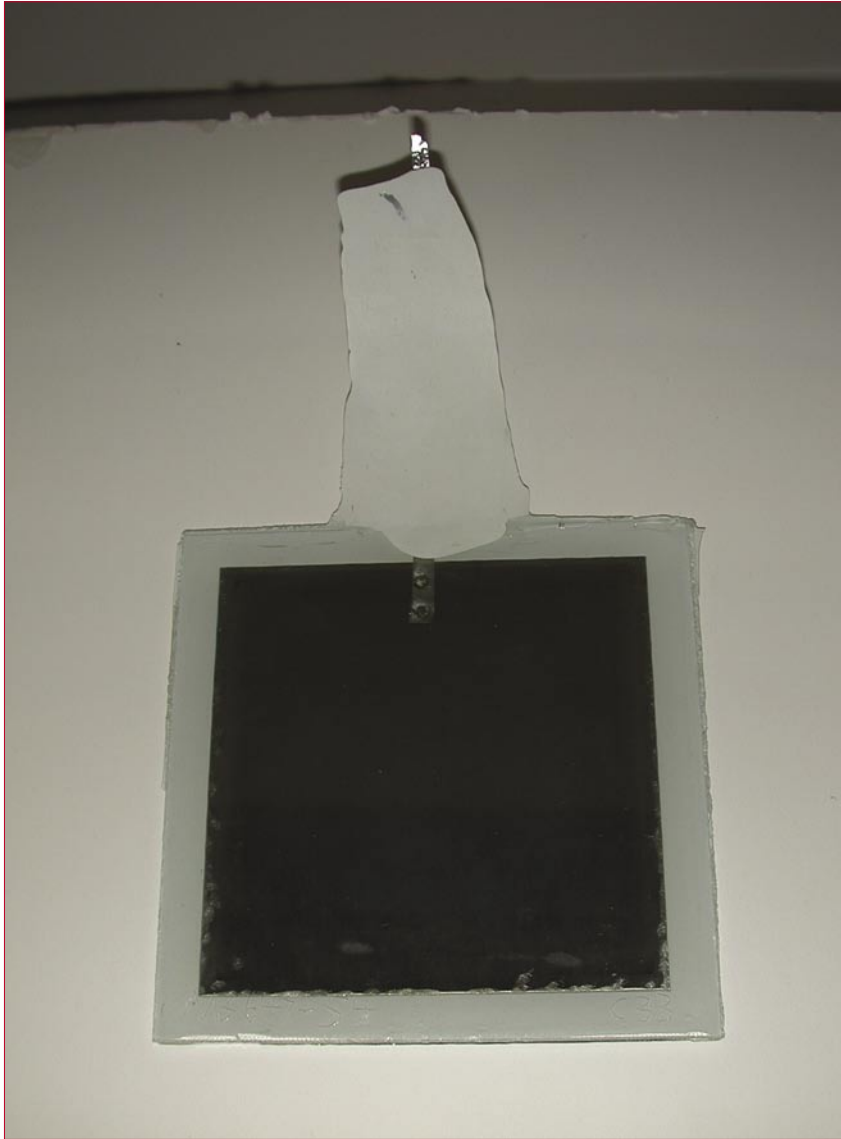


Figure 5. Sample cell used in electrical tests. Cell is encapsulated with EVA, a stainless steel plate, and EPDM-33.

only serve to reduce the time a module is exposed to conditions of supersaturation of moisture [3].

**“Modules with polymer front- or back-sheets will quickly equilibrate with the environment.”**

Oxide barriers with extremely low permeation rates are necessary to achieve low WVTR [5] to prevent moisture ingress. In these systems, the WVTR of  $1 \cdot 10^{-4}$  (g/m<sup>2</sup>/day) is about two orders of magnitude lower than what would be practically achieved by a polymeric-only barrier. Application of the ideal laminate theory [6] indicates that contribution to the resistance to permeation from the polymer is insignificant. Therefore, the choice of polymer film for oxide deposition is not directly relevant when trying to achieve a WVTR of  $1 \cdot 10^{-4}$  (g/m<sup>2</sup>/day).

These calculations have been conducted for the case of an encapsulant layer between PV cells and a barrier film. The effects of moisture ingress for the case of a barrier deposited directly on the PV cell would be different and characterized by degradation occurring at pinholes in the barrier and spreading out from those points [7]. Because moisture barriers deposited directly on materials have the ability to limit the extent of degradation, this approach is more likely to yield environmentally-stable flexible PV products.

### Summary

Back-sheet and front-sheet materials serve many purposes such as providing mechanical integrity, electrical insulation, UV stability, and environmental protection. PV module technology works but there are still many ways to improve designs to make them more economical. Flexible CIGS designs, however, are in need of the development of cost-effective and environmentally resilient

transparent barriers to achieve large-scale production. For crystalline silicon modules, new back-sheet materials are beginning to displace more expensive PVF films thus helping to reduce the cost of solar energy.

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### About the Author



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