

A novel glue-membrane integrated backsheet for PV modules

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ABSTRACT

This paper presents a novel glue-membrane integrated backsheet specifically for PV modules, which has been designed and fabricated by utilizing a flow-tangent cast roll-to-roll coating process combined with a plasma technique. Polyethylene terephthalate (PET) is adopted as a substrate and is surface activated and etched by atmospheric plasma. Then a special coating formulation containing reactive fluoropolymers is applied to both sides of the PET, followed by thermal curing, resulting in a glue-membrane integrated coating layer with a polyurethane structure. Finally, a monolayer of silane molecules is grafted onto the surface via plasma-enhanced deposition to provide a medium level of surface energy, rendering excellent long-term adhesion to ethylene vinyl acetate (EVA). Scanning electron microscope (SEM) images have revealed that plasma etching and activation significantly improves compatibility between the PET and the coating layer, resulting in a tight and strong integration between the two. It has also been confirmed by SEM that the obtained novel backsheet integrates the glue layer and the membrane layer perfectly. There is no clear boundary between the two layers, distinguishing the novel backsheet from the conventional layer-by-layer laminated backsheet. The unique glue-membrane integrated structure has already been demonstrated by many practical applications under harsh environmental conditions to have significant advantages over other backsheets regarding delamination, blistering and discoloration. Furthermore, the novel backsheets showed excellent barrier properties (water vapour transmission rate, WVTR < 0.3g/m².day), weatherability (85°C, 85% RH, 1000h), mechanical properties and electrical isolation properties. Because it is a promising photovoltaic material, the novel backsheet has already been widely used in China for PV module encapsulation and has obtained extensive praise from customers.

Introduction

A PV module consists of many different materials ranging from silicon wafer PV cells to packaging materials, such as protective frontsheets, backsheets, sealants and encapsulants. These account for almost half of the cost of materials in thin-film PV modules and are associated with a significant percentage of the failures experienced in the field [1]. To survive in harsh operating environments, PV modules rely on packaging materials to provide the requisite durability. Generally, PV modules are embedded in soft EVA sheets and encapsulated by either glass/glass or glass/plastics technology. With increasing demand in terms of both quality and quantity, the glass/plastics encapsulation laminate structure has been increasingly promoted [2]. Replacing the glass backsheet with soft cover (polymeric) layers can eliminate glass breakage because of edge pinching and provide a more durable mechanical package. In addition, the lighter weight can result in easier installation and lower cost.

For PV modules a total lifetime of at least 25 years is intended. The modules are exposed to various stresses (e.g. UV radiation, temperature, atmospheric gases and pollutants, and diurnal and annual thermal cycles), which may decrease module stability and performance. Additional losses in performance may be caused by rain, dust, wind, hail, condensation and evaporation of water, and thermal expansion mismatches [3]. It

is therefore necessary that the backsheets provide the following key functions:

- **Physical protection:** offer resistance to puncture and abrasion
- **Moisture protection:** minimize moisture and water vapour ingress
- **Electrical insulation:** isolate the cells and connections from the environment
- **Long-term protection:** demonstrate UV stability and moisture stability over the life of the module, protecting the absorber layer
- **Colour:** provide the colour that helps the modules blend into the environment
- **More power:** improve efficiency, possibly, through optimized internal reflection

To fulfil these requirements, multi-layer (layer-by-layer) laminated backsheets are normally used, while fluoropolymers such as polyvinyl fluoride (PVF) and polyvinylidene fluoride (PVDF) act as a protection layer against weathering influences, and polyester such as PET provides mechanical strength.

The most popular backsheet construction is a tri-laminate 'sandwich' of polyester film between two layers of Tedlar film (DuPont). This is commonly referred to as a Tedlar/polyester/Tedlar

(TPT) structure. To date, multi-layer laminated backsheets have dominated the market because of their excellent strength, weather resistance, UV resistance and moisture-barrier properties. Nevertheless, PV module failures related to multi-layer laminated backsheets are frequently reported. These failures include adhesion loss of EVA as well as delamination. In several publications delamination has been described as an important failure mechanism of PV modules [4–6]. Delamination phenomena of PV modules comprise delamination within the backsheet material and delamination between EVA and backsheet. A lot of research about the delamination of PV modules focuses only on EVA/backsheet interfaces. During applications, adhesive bonds between encapsulants and substrate materials of PV modules can be weakened because of the non-stick property of fluoropolymers (low surface energy), leading to delamination failure and/or moisture ingress.

However, delamination within the backsheet material itself can contribute significantly to the initial failure of PV encapsulation and is attributable to the poor integration between layers, i.e. between substrate and fluoropolymer layers. This can allow water vapour to enter the encapsulation at the edge of a PV module, resulting in degradation and oxidation, as well as electrochemical corrosion of the semiconductor, and ultimately device failure. Therefore, there

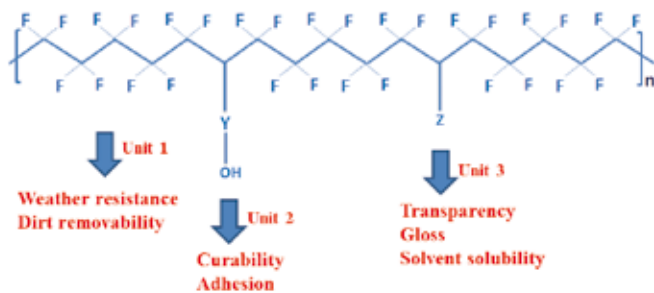


Figure 1. Chemical structure of the reactive fluoropolymer.

is still a strong need for the PV industry to develop a backsheet with excellent properties. This paper presents such a PV backsheet, coined 'glue-membrane integrated backsheet'. It has been extensively characterized and evaluated using many techniques and the test results confirm that it possesses excellent properties required by PV modules.

“PET – a material utilized extensively in the food packaging industry – was used as a substrate: it is attractive for PV module packaging applications because of its good mechanical properties and low cost.”

PV Modules

Design and fabrication of the glue-membrane integrated backsheet

To fabricate a PV backsheet with excellent properties, an intelligent design of the backsheet construction is crucial. In our approach, PET – a material utilized extensively in the food packaging industry – was used as a substrate: it is attractive for PV module packaging applications because

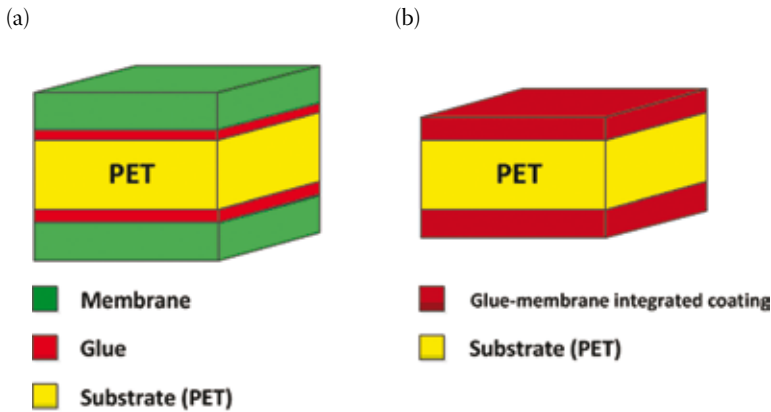


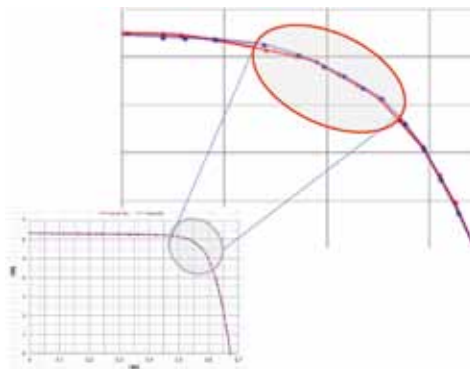
Figure 2. (a) Conventional layer-by-layer backsheet; (b) Glue-membrane integrated backsheet.

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of its good mechanical properties and low cost. However, uncoated (unmodified) PET exhibits high water vapour permeability [7]. PET is also subject to various types of degradation during applications. The main degradations that can occur are hydrolytic and thermal oxidation, which will result in poor performance: therefore, PET cannot be used directly as a PV backsheet material. To coat/modify PET, a coating material has to be identified. Fluorine-containing polymers have been demonstrated to possess many properties that are desirable in coatings, for example excellent hydrophobicity and oleophobicity (stain resistance), low coefficients of friction, excellent chemical resistance and good weatherability [8–12]. Conventional fluoropolymer coatings, such as polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF), besides their high cost, are generally difficult to process because they are chemically inert and not soluble in most of the organic solvents. After a long screening time, a reactive fluoropolymer was identified and used as a main coating component to fabricate the novel glue-membrane integrated PV backsheet. The chemical structure of this reactive fluoropolymer is shown in Fig. 1.

As shown in Fig. 1, the reactive fluoropolymer is a triblock copolymer with tetrafluoroethylene (TFE) as a main monomer. The TFE unit (monomer 1) provides the polymer with excellent weather resistance and dirt removability (anti-fouling) as well as barrier properties; monomer 2 (unit 2) contains the hydroxyl group (–OH) and therefore contributes curability and adhesion of the polymer; and monomer 3 (unit 3) consists of organic groups (mainly ester groups) and contributes solubility as well as transparency. The reactive fluoropolymer was used as the main ingredient, together with other components such as pigments and a cross-linking reagent, to create a special coating formulation. The coating formulation was applied to both sides of the PET substrate and then subsequently cured by thermal heating, resulting in a well-integrated coating layer on both sides of the PET.

In order to improve adhesion between the coating layer and the PET substrate, atmospheric plasma treatment was carried out prior to coating. It has been demonstrated that plasma treatment can increase the adhesion in the polymer-coating interfaces by positively affecting one or several of the following phenomena: cleaning by ablation of low molecular weight species, dehydrogenation, chain-scissioning combined with cross-linking, generation or incorporation of radicals and reactive species, and structural modifications of the surface topography [13]. The most important feature of the plasma treatment is that

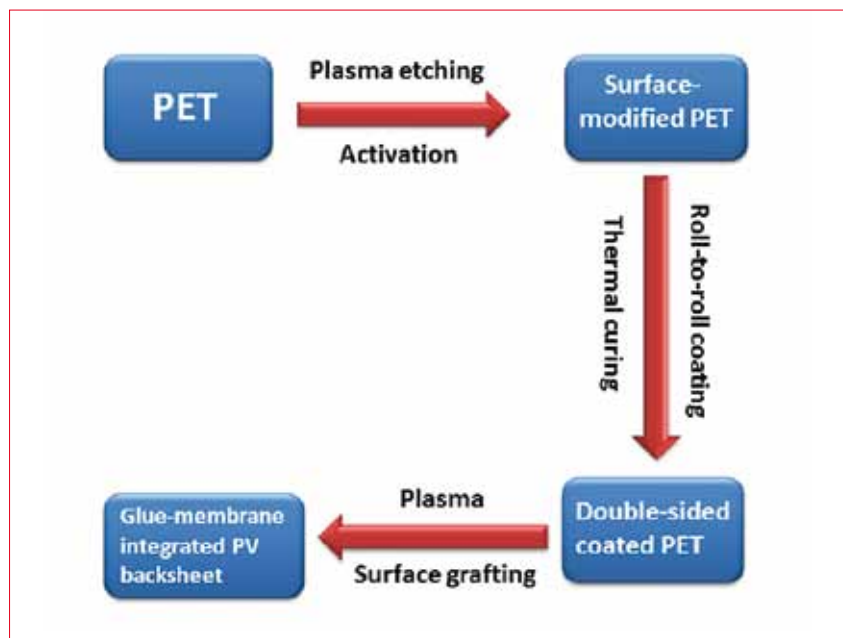


Figure 3. Schematic process diagram of the fabrication of the glue-membrane integrated PV backsheet (FFC-JW30).

Item	Test method (standard)	Value
Total thickness of backsheet [μm]	Microscope	305 \pm 11
Coating thickness (air side) [μm]	Microscope	30 \pm 3
PET thickness [μm]	Microscope	245 \pm 5
Coating thickness (EVA side) [μm]	Microscope	30 \pm 3
Tensile strength (MD) [N/mm^2]	ASTM D 882-2002	≥ 120
Tensile strength (TD) [N/mm^2]	ASTM D 882-2002	≥ 120
Elongation (MD) [%]	ASTM D 882-2002	≥ 100
Elongation (TD) [%]	ASTM D 882-2002	≥ 90
Shrinkage 150°C \times 30min (MD) [%]	ASTM D 1204-2002	≤ 1.0
Shrinkage 150°C \times 30min (TD) [%]	ASTM D 1204-2002	≤ 0.6
Inter-layer adhesion [grade]	ASTM D 3359-2002	5B
Peeling strength with EVA (initial) [$\text{N}/10\text{mm}$]	GB/T 2790-1995	≥ 60
Peeling strength with EVA (85°C, 85% RH, 1000h) [$\text{N}/10\text{mm}$]	GB/T 2790-1995 IEC 61215-2005,10.13	≥ 55
Breakdown voltage [kV/mm]	ASTM D 149-1997	≥ 85
Partial discharge [VDC]	IEC 60664-1-2007 IEC 61730-2-2004	≥ 1010
Water vapour transmission rates (WVTR) [$\text{g}/\text{m}^2\cdot\text{d}$]	ASTM F 1249-2006	≤ 0.3
Weather resistance (85°C, 85% RH, 2000h)	GB/T 13448-2006 IEC 61215-2005,10.13	No delamination, no blistering, no yellowing
Peeling strength with EVA [$\text{N}/10\text{mm}$]		≥ 45
Radiation exposure (QUVB, 4000h) [grade]	GB/T 16422.3-1997	4

MD=machine direction; TD=transverse direction

Table 1. Properties of the FFC-JW30 backsheet.

the surface properties, for example the chemical composition and topological structure of the materials, can be changed simultaneously without altering their intrinsic bulk properties.

After plasma treatment, the PET surface was etched and activated, resulting in a strong bonding between the coating layer and the substrate. This kind of strong bonding will definitely minimize, or even

High-quality connections for PV modules

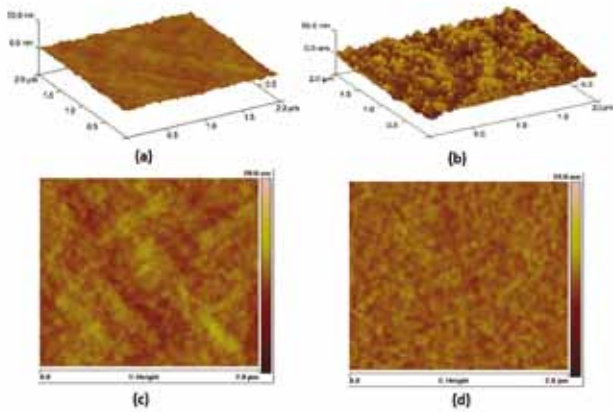


Figure 4. Atomic force microscope (AFM) images of the backsheet: (a) and (c) before; (b) and (d) after plasma grafting of the silane monolayer.

totally eliminate, delamination between the coating layer and the substrate during applications. It can be seen that no glue (adhesive) was used in the fabrication process, which distinguishes this approach from conventional layer-to-layer laminating methods. The coating layer is a glue-membrane integrated system which functions as both a glue and a membrane at the same time. From the polymer chemistry point of view, the coating layer is a kind of polyurethane (PU) because hexamethylene diisocyanate (HDI) was used as a curing agent.

During thermal curing, the isocyanate groups of HDI reacted with -OH groups of the reactive fluoropolymer to form a polymer network containing the urethane linkage. Generally, PU is a unique material that can offer the elasticity of rubber combined with the toughness and durability of metal. The fluorine-containing PU coating will possess the excellent barrier properties and long-term durability that are required by a PV backsheet. It should be emphasized here that a lot of active groups, such as hydroxyl groups and amino groups, were introduced during plasma treatment. These active groups also participate in the curing reaction, resulting in covalent chemical bonding between the coating layer and the substrate, namely the PET. The covalent bonding ensures the tight and dense integration of the coating layer and the substrate, which will minimize the delamination problem suffered by a conventional layer-by-layer laminated backsheet.

It has been widely accepted that a good backsheet must also exhibit excellent adhesion to the encapsulant material, which is typically a formulated EVA film. To achieve this, a surface

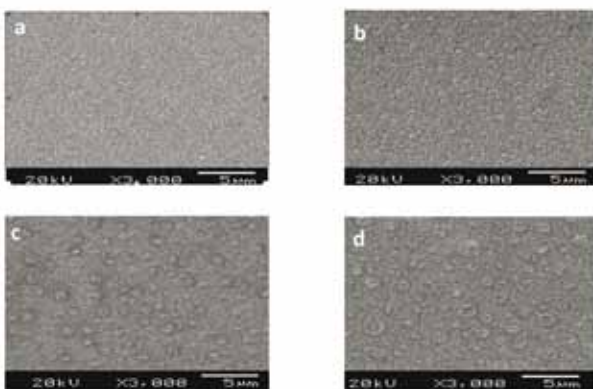
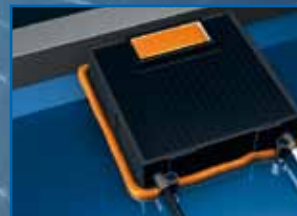


Figure 5. SEM images of the PET surface: (a) before plasma treatment; (b)–(d) after having been treated for 3s, 5s and 10s, respectively.



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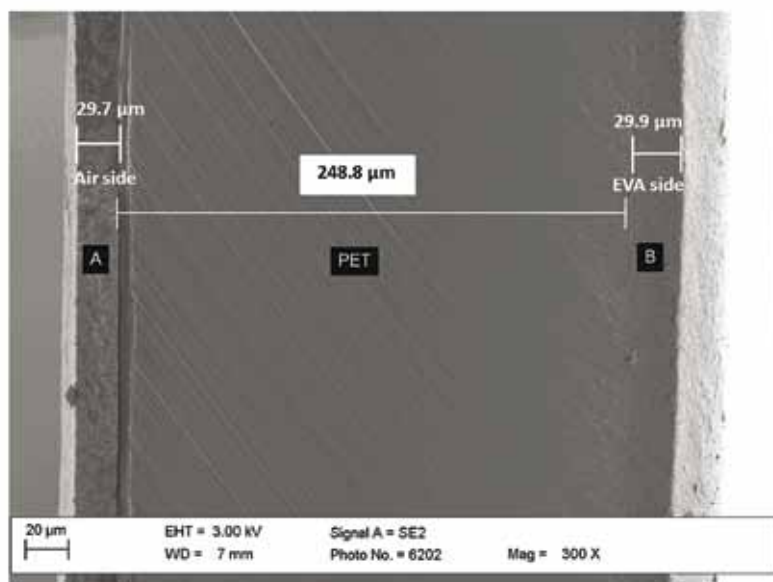


Figure 6. SEM image of a cross section of an FFC-JW30 backsheet.

modification of the coating layer is essential because fluorine-containing polymers normally have low surface energy, rendering them non-stick. The non-stick property of fluoropolymers is actually the main cause of the delamination problem in most conventional layer-by-layer laminated backsheets. To overcome this drawback of fluoropolymers, a monolayer of silane molecules was grafted onto the surface via plasma-enhanced deposition to give the surface a medium level of surface energy. The test results confirmed that the grafted silane molecules increased the surface energy to a medium level and significantly improved adhesion between the backsheet and the

EVA film. Fig. 2 presents a schematic representation of the conventional and novel backsheets; the fabrication process of the novel glue-membrane backsheet (FFC-JW30) is shown in Fig. 3.

As mentioned above, the colour of the backsheet is sometimes a concern during practical applications. The right colour can not only help the modules blend into the environment but also meet the specific aesthetic requirements. In our approach, backsheets of different colours can readily be fabricated: it is only necessary to identify the right pigment and blend it with other components during the coating formulation. Currently, the three colours frequently used in our fabrication are

white, black and blue, but other colours can easily be customized.

Properties, surface characterizations and performance of the novel backsheet

Table 1 summarizes the basic properties of the glue-membrane integrated PV backsheet (FFC-JW30). For a good PV backsheet, the primary property of interest was adhesion, especially adhesion as a function of damp-heat exposure, peel strength and water vapour transmission rate (WVTR).

Adhesion

It can be seen from Table 1 that FFC-JW30 with EVA showed excellent peel strength ($\geq 60\text{N}/10\text{mm}$), which was only slightly decreased ($\geq 55\text{N}/10\text{mm}$) after the damp-heat exposure test. The exposure test can simulate specific environmental conditions in order to investigate the properties of a backsheet in service. The samples were subjected to accelerated weathering in laboratory-controlled exposure chambers (damp heat, no light, 85°C , 85% RH). Relevant performance parameters were measured as a function of exposure time to evaluate how well the samples could withstand environmental stresses over time. The samples were allowed to dry out for several hours after damp-heat exposure prior to being tested, since testing too soon after exposure can result in catastrophic adhesive failure and therefore cannot provide an accurate evaluation.

“Fluoropolymers have poor adhesion properties and consequently the surface needs to be modified: a monolayer of short chain silane was grafted onto the surface by plasma-enhanced deposition.”

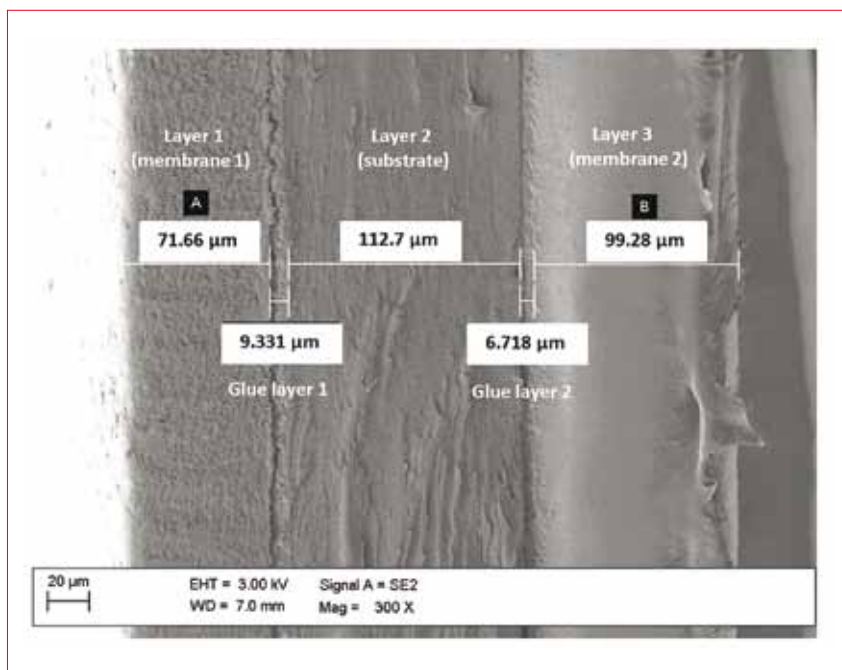
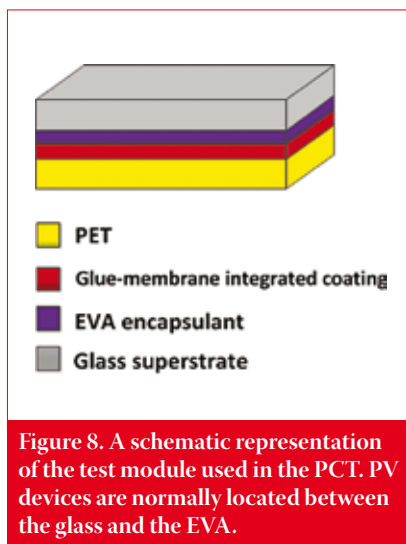


Figure 7. SEM image of a cross section of a conventional layer-by-layer laminated backsheet.

A good backsheet should adhere well to the encapsulant before, during and after damp-heat exposure. In one of our tests, the initial peel strength with EVA was as high as $135\text{N}/\text{cm}$; after 2000h damp-heat exposure, the peel strength was at $45\text{N}/\text{cm}$, and was still at $31\text{N}/\text{cm}$ after 3000h. The excellent adhesion with EVA was attributed to plasma surface modification. As mentioned earlier, fluoropolymers have poor adhesion properties and consequently the surface needs to be modified: a monolayer of short chain silane was grafted onto the surface by plasma-enhanced deposition. The grafted silane monolayer significantly increases surface

Samples/measured position (Fig. 6)	C [%]	O [%]	N [%]	F [%]	Si [%]	Cl [%]
A	83.9±0.4	10.8±0.2	0.9±0.1	2.2±0.2	1.4±0.3	0.8±0.0
B	82.9±0.3	11.1±0.4	0.9±0.0	2.5±0.1	1.7±0.3	0.8±0.0
Coating materials (before curing)	76.0±0.2	16.2±0.1	–	7.8±0.2	–	–
Uncoated PET	73.6±0.5	24.7±0.3	–	–	0.5±0.0	–

Table 2. Atomic composition of the surface of an FFC-JW30 backsheet.



energy and the topological structure of the backsheet, resulting in excellent adhesion with EVA. Fig. 4 shows clearly the difference in topological structure of the backsheet before and after plasma grafting. It can also be seen that the surface becomes much rougher after plasma grafting. The rough surface facilitates good contact and compatibility between the backsheet and the EVA, leading to a strong adhesion between the two surfaces.

The inter-layer adhesion of the backsheet was evaluated in accordance with ASTM D3359-2002. A lattice pattern with 11 cuts in each direction was made in the coating film of the PET substrate; pressure-sensitive tape was applied over the lattice and then peeled off. The adhesion was evaluated by calculating the percentage of detached area at the intersections. Grade 5B was achieved, indicating that the edges of the cuts were completely smooth and none of the coating (the squares of the lattice) became detached. The inter-layer adhesion confirmed that the coating layers had extremely strong adhesion to the PET substrate; this favourable result was attributed to plasma etching and activation of the PET prior to coating.

It is well known that surface etching and activation by plasma pretreatment is an effective way to improve adhesion of the coating to the polymeric substrates [14]. Plasma treatment of a PET surface dramatically increases its wettability,

which was confirmed by contact-angle measurement. The plasma-treated PET surface showed a lower contact angle compared with an untreated surface. In general, the lower the contact angle, the higher the surface energy. The increase of energy and decrease of contact angle usually correlates directly with improved adhesion since organic contaminants have been removed during the plasma treatment, and the free radicals and polar function groups are formed on the surface, allowing for a better interface between the surface and the typically polar fluid, i.e. the coating material.

Plasma treatment can also increase surface roughness. It can be seen from Fig. 5 that surface roughness increases as the duration of the plasma treatment increases. Fig. 5 also indicates that a relatively short treating time such as 3 to 10s is enough to significantly increase surface roughness. This is crucial for roll-to-roll fabrication because it allows a high rolling speed of, for example, between 15m/min and 30m/min to be used. The rough surface induced by plasma treatment will promote the diffusion of coating materials into the substrate, leading to better compatibility between them. Importantly, the active functional groups (such as hydroxyl and amino) on the rough surface obtained from plasma treatment will participate in a cross-linking reaction during thermal curing, resulting in a covalent chemical bonding between the coating layer and the PET substrate. SEM imaging of a cross section of the backsheet was used to investigate the well-integrated interfaces (Fig. 6).

Prior to SEM investigation, the sample was fast frozen in liquid nitrogen (−180°C) and then broken in order to keep the original structure of the interface. The cross section was coated with gold and the SEM images were then immediately recorded. Fig. 6 shows clearly the three-layer structure of the backsheet. The layer thicknesses of the air side (the side which contacts air), PET substrate and EVA side (the side which contacts the EVA) were 29.7µm, 248.8µm and 29.9µm, respectively. The coating layer thickness agrees quite well with the parameter setting of the coating process. As can be seen from Fig. 6, the interfaces between the three layers

are unclear; in particular the interface between the EVA side and the PET almost disappears, indicating satisfactory integration between the coating layer and the PET substrate.

To evaluate the differences between the novel backsheet and the conventional one, the same SEM investigation was carried out on a conventional layer-by-layer laminated backsheet; the resulting SEM image is shown in Fig. 7. Surprisingly, the sandwich structure that people usually refer to as tri-laminate is actually composed of five layers: three polymer (membrane) layers and two glue (adhesive) layers. It can be seen that the interfaces between two of the layers are quite noticeable, indicating bad integration between them. The clear interfaces are normally the weak points of the backsheet and will lead to delamination during practical applications.

Moisture barrier

In the PV industry, durability and maintaining performance over the lifetime of a module are crucial, and the encapsulant used will influence these key requirements. One major concern for durability is the corrosion of metallic components within a module because this can reduce the power output by increasing resistance at the electrical interconnects. Therefore, the backsheet material must prevent moisture ingress and this is the generally accepted mode of failure for devices that do not pass the IEEE qualification test [15]. High moisture transfer rates would result in more water being available for corrosion, leading to hydrolytic degradation of the PV device.

Water permeation through a barrier film involves a multi-step process. The water vapour adsorbs at the high concentration side of the barrier surface, dissolves into the bulk, diffuses through the bulk, and desorbs from the low-concentration surface. Obviously, the surface should be water-repellent or hydrophobic in order to minimize moisture permeation. Fluorinated polymers can provide a surface with very low surface energy and demonstrate excellent hydrophobicity and oleophobicity [16,17].

The coating formulation applied to the PET substrate was a special material

containing reactive fluoropolymers (Fig. 1) [18,19]. The fluorine element renders the coating layer hydrophobic. Surface analyses such as contact angle and XPS (X-ray photoelectron spectroscopy) were carried out to confirm the hydrophobicity and elemental compositions of the coating. The contact angle of the coated surface was as high as 92 degrees, which was approximately 20 degrees higher than that of uncoated PET. Uncoated PET normally has a very wide-ranging WVTR (between 3 and 20g/m².day), depending on its quality and grade. For PV applications, the typical value is around 4g/m².day (in our case). Table 1 shows clearly that the WVTR of the backsheet was less than 0.3g/m².day, which is more than 10 times lower than uncoated PET. The atomic percentage composition of the surface of the substrate (uncoated PET) and the backsheet was determined by XPS (Table 2).

Table 2 shows that there is a substantial incorporation of fluorine atoms in the backsheet surface, indicating that the reactive fluoropolymers were successfully coated on the PET substrate. Nitrogen atoms were also detected in the surface and this was attributed to the cross-linking reagent, i.e. curing agent (HDI). A tiny amount of silicon was detected on the uncoated PET surface and probably came from organic contamination during PET fabrication. However, a significant quantity of silicon atoms was detected on the surface of the backsheet, indicating that the plasma-enhanced grafting of the silane monolayer was successful. XPS is a surface chemical analysis technique that can be used to determine the quantitative amount of atoms as well as their in-depth distribution within the outermost ~10nm of a surface [20]. A large amount of fluorine was detected after plasma grafting of the silane monolayer, signifying that the thickness of the silane monolayer was less than 10nm. Table 2 also reveals that the atomic composition measured in the two different positions A and B on the backsheet surface was quite similar,

which indicates that the coating was very homogeneous.

Pressure cooker test (PCT)

It is interesting to see how well the novel PV backsheet retained its desired properties under PCT – a more severe exposure test (high pressure, high temperature and high humidity). The backsheet was vacuum laminated to EVA and a front glass superstrate to replicate the backsheet in a module construction (Fig. 8).

The test module was then subjected to accelerated weathering in a laboratory-controlled chamber, i.e. a pressure cooker (121°C, 2 atm, 100% RH). To investigate any changes at the interfaces of the laminates as a function of accelerated exposure, peel tests were conducted on strips of the samples in accordance with GB/T 2790-1995 and IEC 61215:2005(10.13). The coating was sometimes found to exhibit cracking during and/or after laminating. The cracking was attributed to a higher cross-linking degree of the coating. To totally avoid backsheet cracking and ensure good coating quality, a small batch (test batch) of coating formulation was always prepared and applied to the PET and then tested. In the test batch, the amount of cross-linking reagent had to be optimized to ensure a satisfactory coating that was flexible enough to prevent cracking. Once an optimized formulation was identified, it was then adopted to the roll-to-roll process.

During the peeling test, special attention was paid to the peel strength with EVA and to the delamination behaviour within the backsheet. Two EVAs from different suppliers were used in order to check the reproducibility of the test. To obtain a fair evaluation, several commercially available backsheets were used as references and treated and tested under the same conditions as the FFC-JW30 backsheet; the results for two of the commercial backsheets are summarized in Table 3.

As can be seen in Table 3, even the same backsheet shows different peeling strength

with different EVAs used for lamination, indicating that the EVA properties might be slightly different. EVA is the copolymer of ethylene and vinyl acetate. The weight percentage of vinyl acetate might vary (usually from 10 to 40%) from manufacturer to manufacturer, and the cross-linking degree of EVA might also be different because of the manufacturing process. These differences have the potential to influence the peeling strength with backsheets. Generally, the FFC-JW30 backsheet showed high peeling strength with different EVAs. For example, the initial values of peeling strength were 82N/cm for EVA from Mitsui and 103N/cm for EVA from Hanwha (initial value data not shown in Table 3). After 24h, the values were slightly lower – 63.6N/cm and 81.3N/cm, respectively.

It is quite interesting to compare FFC-JW30 with S-4 and S-5. Both S-4 and S-5 showed higher peeling strength than FFC-JW30 after 24h exposure when EVA from Mitsui was used. However, when the exposure increased from 24 to 48h, the peeling strength of S-4 was dramatically reduced to 47.1N/cm, degrading by 65.4%. Similarly, the peeling strength of S-5 decreased to 38.7N/cm, degrading by 42.5%. In contrast, the peeling strength of FFC-JW30 with EVA degraded by only 27.5% when the exposure increased from 24 to 48h. The peeling strength of the FFC-JW30 with EVA was still at a higher level (43.4N/cm) than that of S-5 even after 60h exposure. However, S-4 became very brittle after 60h exposure, and no peeling strength could be measured.

Similar results were obtained when EVA from Hanwha was used. The FFC-JW30 showed higher peeling strength than all the reference samples after 24h, 48h and 60h exposures. No lamination was observed after the 48h exposure.

The PCT results confirmed that the bonds between the backsheet and the EVA would generally be weakened because of water ingress under harsh

Samples	Manufacturing process	EVA used for test											
		Mitsui Chemicals Tohcello, Inc						Hanwha SolarOne					
		Peeling strength [N/cm]			Interfaces			Peeling strength [N/cm]			Interfaces		
		24h	48h	60h	24h	48h	60h	24h	48h	60h	24h	48h	60h
S-1	L-b-L	37.5	31.5	BT	NL	LM	BT	48.1	22.8	–	NL	LM	BT
S-2	L-b-L	56.9	34.3	BT	NL	BK	BT	47.3	42.1	–	NL	BK	BT
S-3	L-b-L	47.4	35.7	BT	NL	LM	BT	45.2	39.3	–	NL	LM	BT
S-4	L-b-L	136.1	47.1	BT	NL	BK	BT	50.8	37.8	–	NL	BK	BT
S-5	L-b-L	67.3	38.7	33.2	NL	NL	BK	66.8	40.3	34.9	NL	NL	BK
FFC-JW30	G-M	63.6	46.1	43.4	NL	NL	BK	81.3	56.1	50.2	NL	NL	BK

L-b-L=layer-by-layer laminated; BT=brittle; NL=no laminating; G-M=glue-membrane integrated; BK=broken; LM=laminated

Table 3. PCT results (121°C, 2 atm, 100% RH) for backsheets laminated to EVA.

exposure conditions. For a test module, the dominant path of moisture ingress is inwards from the edges and through the EVA due to the very large WVTR of EVA even at ambient temperature. When a sample module is placed in damp heat, the WVTR through the EVA is about 50 to 100 times higher than at room temperature, and water vapour more easily permeates the EVA. Water vapour rapidly diffuses throughout the EVA and reaches its equilibrium value at the glass/EVA interface, as well as the EVA/backsheet interface, as it progresses in from the edges.

“For the FFC-JW30 backsheet, the reduction in peeling strength was approximately 25%, which is lower than most commercially available PV backsheets.”

Investigations reported in the literature have shown that for most of the commercially available backsheets, there is a reduction in the peeling strength of at least 30% after 24h exposure [21]. For the FFC-JW30 backsheet, the reduction in peeling strength was approximately 25%, which is lower than most commercially available PV backsheets. The better performance of the FFC-JW30 under exposure conditions indicated that it was more difficult to destroy or weaken the bonding between the FFC-JW30 and the EVA, or there might be a different type of adhesive bonding or a reaction such as covalent chemical bonding taking place between the two. More detailed experiments and investigations are being carried out to understand the mechanism of adhesion between the backsheet and EVA. Ways to further improve the properties of the novel backsheet are also currently being pursued with our collaborators.

Conclusions

A novel PV backsheet design, coined ‘glue-membrane integrated backsheet’, has been presented. This backsheet was fabricated by utilizing a flow-tangent cast roll-to-roll coating process combined with a plasma technique, and, unlike a conventional layer-by-layer lamination process, no glue (adhesive) was used in the fabrication. In this new approach, a special coating formulation containing reactive fluoropolymers was adopted as a coating material and applied to a PET substrate. This was followed by thermal curing to create the glue-membrane integrated backsheet. The fluoropolymer contributed all the necessary properties – weatherability, UV resistance, moisture

barrier, durability and electrical insulation – required by a PV backsheet. The use of a plasma technique dramatically improves the surface properties of the PET substrate, resulting in better wettability and compatibility with coating materials, and eventually stronger adhesion between the coating layer and the substrate. After coating the PET substrate, a monolayer of silane molecules was grafted onto the surface via plasma-enhanced deposition in order to increase the adhesion between the backsheet and EVA.

The novel backsheet was extensively characterized and tested using different techniques, namely SEM, AFM, contact-angle measurement and XPS, and compared with other commercially available PV backsheets. A PCT experiment demonstrated that it was superior to most of the commercially available PV backsheets in terms of adhesion to EVA and delamination. The novel backsheet promises to be a suitable candidate as a replacement for the conventional layer-by-layer laminated backsheets currently used for PV module encapsulation.

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