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Fluoropolymer films in the photovoltaic industry

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Abstract

The unique combinations of properties that fluoropolymer exhibit are ideal for photovoltaic modules. Typical modules take advantage of fluoropolymers' properties in many ways. This brief overview discusses the most common uses of fluoropolymers in the photovoltaic energy industry and some of the reasons behind their popularity.

Keywords: Fluoropolymers; Films; Photovoltaic modules

1. Introduction

To reliably produce electricity from fragile crystalline silicon wafers, a stable packaging system is needed. Much of the development time and energy in the early days of the photovoltaic industry was not only devoted to the wafers themselves but also to the packaging materials. To fully appreciate the task, one needs to consider the requirements. New photovoltaic technologies such as thin film will put even greater demands on the packaging materials. Fluoropolymer films have played and continue to play multiple roles in the photovoltaic module package. This paper will describe the use of fluoropolymer films in present day photovoltaic modules.

2. Discussion

Photovoltaic modules by their nature need to be exposed to as much sunlight as possible. Therefore the materials used to support and protect the modules must be up to the task of such exposure. Let us begin by examining a cross-section of a typical crystalline module. Fig. 1 shows such a cross-section including its primary components. The silicon wafers and associated electrical connections are essentially suspended in a crosslinked ethyl vinyl acetate (EVA) matrix. The side of the module incident to solar radiation is most often glazed with glass. The glass provides durability, rigidity and clarity. The backside of the module is covered with a backing layer most often composed of polymer films and laminates. Functionally the backing layer provides physical protection, electrical insulation, moisture protection and in some circumstances unique color identification all while adhering to the encapsulant over the life of the module [1].

In today's modules fluoropolymers most often appear in the backing layers and to a lesser extent as clear glazing. Clear fluoropolymers as glazing are used with technologies that produce modules that are flexible themselves or require properties unique to clear polymer layers.

In the early years of photovoltaic development when material and development costs were high and durability unproven, fluoropolymers were an obvious material choice [2]. Durability and chemical or environmental resistance are the hallmark of fluoropolymers. Further, when the effect of warranty development in a new industry is evolving the most effective materials are usually considered first. Warranty development involves long term testing and represents a large expense to the module producer. Confidence in raw materials is built over time and is the basis for the value proposition with their customers [3].

Major influences on material choice also come from process considerations. Photovoltaic modules are most often made in a vacuum lamination process. The preponderance of glass as a superstrate leads to batch laminations as the process of choice. Products in film form are ideally suited for these types of processes. Uncured EVA encapsulant, backsheet laminates and polymeric glazings are all typically supplied as rolled goods. There are a variety of fluoropolymers available as films. Table 1 lists commonly available fluoropolymer films.

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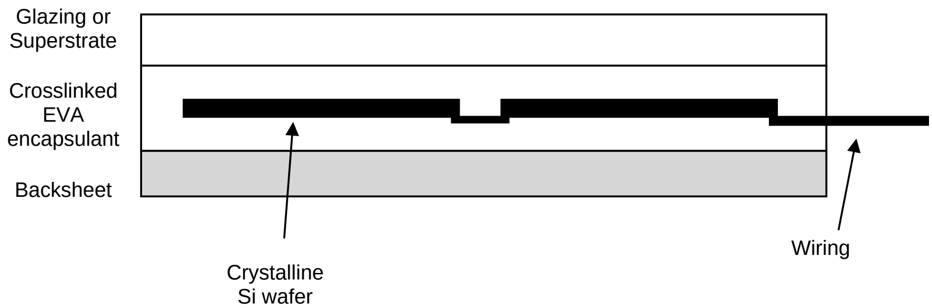

Fig. 1. Cross-section of a crystalline silicon photovoltaic module.

Table 1
Fluoropolymer films[a]

Fluoropolymer	Abbreviation	Structure
Polyvinyl fluoride	PVF	$–[CH_2CFH]–$
Polyvinylidene fluoride	PVDF	$–[CH_2CF_2]–$
Ethylene-terafluoethylene	ETFE	$–[CH_2CH_2]\text{-}[CF_2CF_2]–$
Fluorinated ethylene-propylene	FEP	$–[CF_2CF_2]_{1-x}\text{-}[CF_2CF(CF_3)]_x$
Perfluoroalkoxy	PFA	$–[CF_2CF_2]_{1-y}\text{-}[CF_2CF(OR)_y–$
Polychlorotrifluoroethane	PCTFE	$–[CFClCF_2]–$

[a] For FEP, x is 0.10–0.15. For PFA, R is perfluoalkoxy (OC_nF_{2n+1}) where $n = 1–3$; $y = 0.03–0.10$.

2.1. Backsheets

There are a several different backing layers in common use today and fluoropolymers play a role in the majority of these. Polyvinyl fluoride (PVF) is the most often used fluoropolymer. PVF is commercially available as a film from DuPont and is sold under the Tedlar® brand. PVF's properties are well suited for this application. In its most common available form, PVF is a biaxially oriented film that is tough, photostable, chemically resistant and unaffected by long term moisture exposure. It is one of the few fluoropolymers that can be readily pigmented. The vast majority of backing layers are pigmented and white is the predominant color. Table 2 shows selected properties of PVF.

Table 2
Selected properties of PVF film[a]

Property	Value	Method
Density, cc/cm^3	1.38–1.72	Weighed samples
Tear strength, initial, kJ/m	129–196	ASTM D1004-66
Tensile modulus, Mpa	44–110	ASTM D882
Ultimate elongation, %	115–250	ASTM D882
Continuous use temperature, °C	−70–107	
Solar energy transmittance (359–2500 nm), %	90	ASTM E427-71
Water vapor permeability, g/m^2 day[b]	24.5	ASTM E96E-80
Dielectric strength, short term dc, kV/μm	0.15–0.19	ASTM D150-81

[a] Adapted from [4].
[b] Measured on 1.5 mil white film.

Though some module manufacturers use PVF alone as the backing sheet, most use laminates of PVF with polyester film (polyethylene terephthalate, PET). The most common laminate is a trilayer structure of PVF/PET/PVF. This structure allows the fluoropolymer to protect both sides of the polyester from photodegradation. Laminates of this type combine the best properties of both materials into a synergistic balance of the desired attributes. Electrical isolation is increased, moisture permeation is decreased and cost is minimized. The expensive fluoropolymer is limited to the outer surfaces where its properties are most useful [5].

For demanding high moisture applications, laminates of PVF/aluminum foil/PVF can be used. While this structure is impermeable to moisture it is not as effective an electrical insulator as the corresponding PET analogue. The breakdown voltage of the aluminum foil laminate is about half that of the analogous PET laminate [5]. When minimum moisture permeation and maximum electrical insulation is desired, a four-ply PVF/Al/PET/PVF is available.

The photovoltaic industry has experienced accelerated growth over the last few years. During this period costs of components and manufacturing have reduced. Backsheets have not escaped this trend. Newer materials are being introduced as backsheet components including polyvinylidene fluoride (PVDF) laminates and vapor deposited silica coated films for enhanced moisture vapor permeation resistance [5].

2.2. Superstrate

Glass is the most common superstrate or glazing used in commercial photovoltaic modules. It is clear, photostable, rigid, impermeable, moderately impact resistant and provides excellent electrical isolation [6]. For most photovoltaic applications glass is a good choice. The negatives for a glass superstrate are primarily weight and the potential for breakage. Lowering overall weight is becoming more important as time goes on. There is an increasing trend to make larger photovoltaic arrays that provide for higher energy densities and lower cost. As weight of these arrays increase, installation becomes more difficult. Thinner and lighter polymeric

Table 3
Selected properties of ETFE[a]

Property	Value	Method
Density, cc/cm^3	1.7	ASTM D792
Melting point, °C	270	
Tensile modulus, MPa	827	ASTM D638
Ultimate elongation, %	200	ASTM D887-64T
Maximum continuous use temperature, °C	150	
Visible light transmittance, %	91–95	

[a] Adapted from [8], values are for Tefzel® 200.

superstrates can facilitate the drive to larger module arrays. When searching for substitutes for glass, most common polymers are inadequate because of the extreme requirements of clarity with long outdoor life. Fluoropolymer films can provide useful alternatives to glass where the properties of flexibility and low weight are desired. The copolymer of ethylene and tetrafluoethylene (ETFE) is the most popular fluoropolymer glazing used today. Table 3 shows some selected properties. Another advantage of using fluoropolymers as glazing is their tendency to self-clean due to their low surface energy [7].

2.3. Thin film photovoltaics

Thin film photovoltaic modules depend on technologies other than thick crystalline silicon. Thin film cells use micron thick layers of semiconductor bonded directly to a backing of glass, plastic or metal. These semiconductor technologies include amorphous silica (a-Si), Copper indium diselenide (CIS) and cadmium telluride (CdTe). These technologies represent a small volume of today's market space but offer some intriguing product advantages such as low cost due to the small amounts of expensive semiconductor needed, flexibility because the thin active layer tolerates bending, and efficient manufacturing processes. Thin film technologies also present packaging requirements that challenge today's materials. The photoactive components of thin film modules are more moisture sensitive than crystalline silicon based systems and therefore the water vapor barrier requirements for these technologies are more demanding.

The flexibility of thin film modules allow for modules to conform to shapes to increase utility and lower costs. These concepts allow modules to be part of integrated systems such as roofing shingles and tiles. In these circumstances polymeric glazings such as ETFE are critical to product design.

3. Conclusion

The properties of fluoropolymers are uniquely suited for the needs of photovoltaic modules. A portion of the photovoltaic industry's success is due to the confidence that these properties instill in manufacturers and consumers.

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References

[1] G. Jorgensen, K. Terwilliger, S. Glick, J. Pern, T. McMahon, in: National Center for Photovoltaics and Solar Program Review Meeting, May 2003, NREL/CP-520-33578.
[2] R. Ross, in: Proceedings of the Flat-Plate Solar Array Project, June 1983, DOE/JPL-1012-89, pp. 3–13.
[3] J.H. Wohlgemuth, in: Proceedings of the Photovoltaic Performance and Reliability Workshop, September 1993.
[4] S. Ebnesajjad, L.G. Snow, Poly(vinyl fluoride), in: J.I. Kroschwitz (Ed.), Encyclopedia of Chemical Technology, 4th ed., vol. 11, Wiley, New York, 1994, pp. 683–694.
[5] S. von Aichberger, Photon International, Solar Verlag GmbH, August 2003, pp. 40–53.
[6] D.L. King, M.A. Quintana, J.A. Kratochvil, D.E. Ellibee, B.R. Hansen, Prog. Photovoltaics 8 (2000) 241–256.
[7] E.F. Cuddihy, in: Proceedings of the Flat-Plate Solar Array Project, June 1983, DOE/JPL-1012-89, pp. 379–396.
[8] S.V. Gangal, Tetrafluoroethylene-ethylene copolymers, in: J.I. Kroschwitz (Ed.), Encyclopedia of Chemical Technology, 4th ed., vol. 11, Wiley, New York, 1994, pp. 657–671.