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Modeling of rates of moisture ingress into photovoltaic modules

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Abstract

Encapsulant materials are used in photovoltaic devices for mechanical support, electrical isolation, and protection against corrosion. During long-term exposure of photovoltaic modules to environmental stress, the ingress of water into the module is correlated with decreased performance. By using diffusivity measurements for water through ethylene vinyl acetate (EVA), we have modeled moisture ingress using finite-element analysis with atmospheric data from various locations such as Miami, Florida. This analysis shows that because of the high diffusivity of EVA, even an impermeable glass back-sheet is incapable of preventing significant moisture ingress from the edges for a 20–30-year lifetime. Once moisture penetrates a module, it can condense and increase corrosion rates. Significantly reducing moisture ingress requires a true hermetic seal, the use of an encapsulant loaded with a desiccant, or the use of an encapsulant with a very low diffusivity.

Keywords: EVA; Encapsulant; Diffusivity; Solubility; Humidity

1. Introduction

The ingress of moisture into photovoltaic (PV) modules has been correlated with increased failure rates, especially in hot and humid climates such as in Miami, Florida [1]. Therefore, the effects of water are important for failure analysis [2,3]. Materials must be evaluated to determine how much water is present and whether they protect a device against this moisture. The processes that contribute to module failure must be

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understood to obtain the goal of producing modules that will perform reliably for 20–30 years [1,4,5].

Currently, ethylene vinyl acetate (EVA) is the dominant encapsulant used in the PV industry. It is relatively inexpensive and was one of the first encapsulant materials investigated [6]; hence, it has been well formulated for exposure to direct sunlight [7,8] and is known to be adequate for most crystalline silicon PV devices. Some of the newer thin-film PV technologies have the potential to be much less expensive than silicon wafer-based PV modules, but they can require greater protection from environmental exposure.

Modules fail by many different mechanisms that vary with the type of PV technology used. Crystalline silicon modules often fail at the cell interconnections or because of cracked cells [1], and thin-film devices (where small amounts of corrosion can harm micrometer-thick layers) often fail at the scribe lines [9,10] or experience degradation of the cell itself. Because of this, crystalline silicon cells can be sensitive to the embrittlement of an encapsulant as it ages, and thin films are sensitive to moisture that can corrode the module. Both of these degradation processes are accelerated by exposure to hot and humid environmental conditions.

Modules can be constructed with impermeable front- and back-sheets where moisture can diffuse in from the sides, or they may be constructed with a permeable sheet where they will equilibrate more quickly with the environment. Even with impermeable front- and back-sheets, water can permeate in as little as 2 cm and condense to cause corrosion that can cause failure within a cell. With some technologies, a ‘‘breathable’’ construction may be desirable, to allow decomposition products from the encapsulant to escape or to allow the module to dry out on hot, sunny days. It has also been found that by permitting oxygen to enter more quickly, the rate of EVA discoloration can be reduced [7].

The time a module takes to approach equilibrium with the water in the external environment must be determined to understand some failure mechanisms. To do this, the diffusivity and water absorption capacity of EVA were measured to obtain the necessary data to model water ingress rates. This allowed a one-dimensional (1-D) finite-element analysis to be performed using meteorological data, to determine the transient water content within the module for the case of a breathable back-sheet and for a double-glass laminate. The results of these finite-element analyses allowed analytical equations to be used to determine the timescales for moisture ingress.

2. Experimental

2.1. Diffusivity and solubility measurement

Determining how long water takes to enter a module requires knowledge of the diffusivity and solubility of the packaging materials. Films of EVA were made using Specialized Technology Resources' Photocap® 15420P EVA, which was cured according to the manufacturer's specifications. Because manufacturers of PV-EVA encapsulants typically use about 67 wt% ethylene and 33 wt% vinyl acetate [11], it is expected that the results of this study should apply equally well to materials from other manufacturers. Several 12-cm-diameter films between 0.46 and 2.84 mm thick were made to allow the transient water vapor transmission rate (WVTR) through these films to be measured using a Mocon Permatran-W® 3/31 instrument. Such thick films were necessitated by the high diffusivity of EVA, which, for the 50-cm^2 cross-sectional area of the Mocon test cell, was