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Comparison of different microclimate effects on the aging behavior of encapsulation materials used in photovoltaic modules

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The purpose of this work was the investigation of the influence of the microclimate on the ageing behavior of polymeric encapsulants for photovoltaic (PV) modules. Different types of encapsulation films were investigated. Single film and laminated samples were artificially aged under different conditions (with and without irradiation). The results showed that there is a strong influence of the microclimate on the aging behavior of polymeric encapsulant materials on the optical, chemical and morphological properties of the materials. Differences were even detectable in the unaged state between film and module samples after the production process. Not only has the sample set-up (film or laminated module sample) highly influenced the degradation of the encapsulants, but also the type of aging (dark aging or aging with irradiation).

Contents

1. Introduction

Nowadays the demand for alternative energy sources is high and the importance of renewable energy sources is growing. To directly convert sun light into electricity photovoltaic (PV) modules can be utilized. A relatively high lifetime of 25 years and more is necessary to collect radiant flux cheaply by PV modules. Therefore a high quality product standard for the components is required to guarantee this module lifetimes with a limited loss in functionality.

The important part of a PV module is the solar cell, which is covered by an encapsulation material. The encapsulant must provide electrical insulation, structural support, protection against environmental influences and connect all components. Therefore the following properties are required: high transmittance in a selected spectral region of the solar cell and the incident solar

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radiation, good thermal conductivity, good adhesion to organic/inorganic materials, low price, good UV resistance and a long lifetime. Furthermore the encapsulant has to deal with different thermal expansions of the materials used in a PV module in order to avoid over-stressing and breakage. Thus encapsulation films need to be made from a low modulus, elastomeric material [1–4].

The long lifetime (>25 years) is a challenging objective particularly for organic encapsulants. During use with terrestrial sunlight and elevated temperatures the material must retain its properties in order to protect the silicon solar cells. This task gets more challenging when the PV modules are used in regions with high solar irradiance, like deserts. Especially the properties of the encapsulant are critical to the long term behavior of modules [4].

In the PV industry the encapsulation material mainly used is ethylene vinyl acetate (EVA) copolymer due to its good optical and structural properties, the low-cost production and over 20 years of experience [1,2,4,5]. It consists of polar vinyl acetate (VAc) units randomly dispersed in the ethylene backbone. Depending on the VAc content the material properties can be influenced from plastics to elastomers [1]. Nowadays alternative materials, like thermoplastic polyolefins (TPO) are starting to be in the focus of the PV industry [6–8]. Due to the required module lifetimes the quality and the lifetime of the encapsulant is of high importance. The degradation behavior of polar ethylene copolymers and thermoplastic poly olefins is well described in the literature [2–4,9–14]. For example the thermo- and photo-oxidation of cross-linked EVA copolymers can lead to a decrease of the mechanical performance (e.g. enhanced brittleness) and also to yellowing with the consequent loss in performance of the whole PV module [3,15,16]. As the main volatile decomposition product acetic acid is formed, which enhances the oxidation process and can lead to corrosion of the metal parts and to an efficiency loss [2]. A reduction in mechanical performance can cause delamination and consequently the breakdown of the whole PV module [16,17]. These effects are caused by the chain scission mechanism (Norrish type I, II and III reactions) [17]. Typical degradation products are acetic acid, lactones, ketones and acetaldehyde. Additionally, carbonyl groups, hydro peroxides and anhydrides are formed during the oxidation process. TPOs are also sensitive to thermo- and photo-oxidation, due to remaining catalyst and residual molecules of the production process, which can support the degradation processes. Degradation causes the formation of a variety of oxygen containing groups (carbonyl compounds). Photo-degradation of PE comes along with chain scission and crosslinking and leads to molecular weight changes [18]. Of course not only chemical aging processes occur, as described before, but also physical aging processes; this is to say, changes in the morphology of the material, loss of additives due to migrations, etc. [19].

However, the main task in PV material development is the correlation of natural and accelerated aging effects, which is of complex nature. The aim is to reduce the testing time in order to verify the material quality. A simple dependence can rarely be found between artificial and natural weathering results, due to possible synergies or anti-synergies. On the one hand the accelerated degradation stresses, like temperature or humidity, highly impact the property changes of the material, as already described in the literature [2,11,20–22]. But on the other hand also the microclimate due to sample design (single film or laminated module exposure) can influence the aging behavior. The microclimate describes the environment of the sample. It arises from the combination of the surrounding climate conditions and also from the application specifics (e. g. single polymeric film vs. polymeric film incorporated in a PV module) [23].

No investigations have been done yet dealing with the influence of the microclimate on polymeric encapsulants concerning physical and chemical aging processes due to the sample set-up. Additionally, DH is the main test for a fast material selection and quality testing in the PV industry. The influence of radiation on the microclimate has been unconsidered in the industry as well as in research work up until now and should be as well verified. Therefore the main focus in this work was to evaluate the influence of different microclimates on the aging behavior of encapsulation materials used in PV modules, due to different sample set-ups and aging types.

2. Experimental

Three commercially available standard EVA films (EVA 1 and 3 were fast-cure and EVA 2 was an ultra-fast-cure type) and one thermoplastic Polyolefin (TPO) were investigated. Czanderna and Pern, Klemchuk et al. described well the composition of their samples, such as additive systems and curing agents and the influence on the aging behavior [3,4]. The aging behavior depends not only on the class of the material, but also on the manufacturer and consequently on the specific formulation of the material. Unfortunately the exact chemical composition was not known as only the datasheet was available due to confidential issues. Single films and glass/EVA/backsheet (TPT) modules were laminated with a size of approximately 7 × 25 cm. In this research no solar cells were incorporated in the module samples. The same pre-treatment was used for all samples in a vacuum laminator, see Table 1. The backsheet was a commercially available TPT multilayer consisting of poly vinyl fluoride (PVF), poly ethylene terephthalate (PET) and PVF. The samples were artificially aged under damp heat (DH) test conditions and under Xenon (Xe) test conditions up to 2000 h (h), see Table 2. The description “unaged” or “0 h” means pre-treated (laminated) but not aged. For damp heat conditions a Vötsch climate chamber type VC 7020 (Balingen, D) was used. An Atlas Xenotest Beta LM (Linsengericht, D) with the filter system for outdoor irradiation (similar to the sun) was utilized for aging tests under Xenon test conditions. The irradiation was controlled in the wavelength region from 300 to 400 nm. In order to verify physical and chemical degradation effects of ethylene-based PV encapsulants Fourier transform Infrared (FTIR), Ultraviolet (UV)/visual (Vis)/near IR (NIR) and Raman spectroscopy were applied. In addition differential scanning calorimetry (DSC) as the detection method was conducted, in order to verify possible changes in the thermal behavior.

2.1. UV/Vis/NIR spectroscopy

The UV/Vis/NIR measurements were carried out using a Lambda 950 spectrometer from Perkin Elmer (Waltham, USA). Spectra were recorded from 250 to 2500 nm with an integrating sphere from Labsphere (North Sutton, USA) in order to measure hemispherical transmittance and reflectance. The film samples were measured in transmittance mode. The module samples were measured in reflectance mode, including the glass front cover and the backsheet. All spectra were used to calculate b* values according to the CIE L a*

Table 1
Curing conditions in the vacuum laminator.

Process step	Time [min]	Temperature [°C]	Pressure [mbar]
Closing laminator	0.5	144	atmospheric
Evacuation	6.0	144	atmospheric to 850
Pressure	1.0	144	850
Curing	9.3	144	850
Ventilation	0.3	144	850 to atmospheric
Opening laminator	0.5	144	atmospheric