APPLICATION NOTE

FTIR Spectroscopy and Thermal Analysis

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Characterization of Degradation Modes of Ethylene-Vinyl Acetate Encapsulant of Photovoltaic Modules by FTIR and TGA

Scope

Ethylene-vinyl acetate (EVA) has been a material of key importance as an encapsulant of photovoltaic (PV) modules used in the solar energy industry.

EVA has many favorable characteristics as an encapsulant material. It allows good light transmittance, is sufficiently elastic and has excellent melt fluidity and adhesive properties.[1] EVA also has a relatively low price point which has further allowed it to be widely adopted by the solar industry. Given that the encapsulant has such a vital role in maintaining the function of the PV module, it is important to understand and characterize the various failure modes of different material components that could occur in the field. In this application note, EVA samples extracted from mini-PV modules aged under various conditions are characterized using a PerkinElmer Spectrum Two™ FTIR Spectrometer and a PerkinElmer TGA 8000 Thermogravimetric analyzer to investigate the degradation behavior of EVA.

Introduction

The encapsulant of a PV module is of vital importance to improve the operating stability of the PV module (Figure 1). In addition to providing adhesion to the top and bottom layers, the encapsulant effectively seals the cell and contributes to shielding the encapsulated layers by reducing atmospheric related degradation, i.e., as a result of the ingress of moisture and air at operating temperatures and long-term exposure to UV irradiation. The encapsulant is susceptible to photooxidation in its position within the PV module and this can lead to delamination of the module and the resulting exposure of the components to the environment.[2] As such, it is important to understand how the various materials degrade upon the application of such atmospheric stress factors. It is also important to consider changes occurring at the interface between the encapsulant and an adjoining layer within the composite. These interfaces are where different materials within the module interact with each other as well as the ingress of stress factors and are crucial to understanding breakdown modes of the module. Being able to characterize materials extracted from a laminated PV module after ageing allows for better understanding of the material degradation at a specific location within the module. A combined characterization approach is favorable to research encapsulant failure modes as multiple materials characterization techniques can often correlate or provide a more complete result from the analysis of a sample. In this application note, the results of material degradation as a result of ageing at elevated temperature and humidity as well as increased UV exposure is investigated with FTIR spectrometry and TGA. Mini PV modules were aged under different conditions to give a representation of field-based PV module degradation. The EVA encapsulant was then extracted from different locations of the PV module to determine differences in degradation across the whole PV module. Changes in the FTIR spectra of the samples can indicate the formation of or depletion of functional groups within the polymer because of irreversible chemical change whereas the TGA results provides valuable information regarding the encapsulates thermal stability. This data in combination with other materials characterization techniques can give us a good understanding of the degradation modes of an EVA encapsulant.

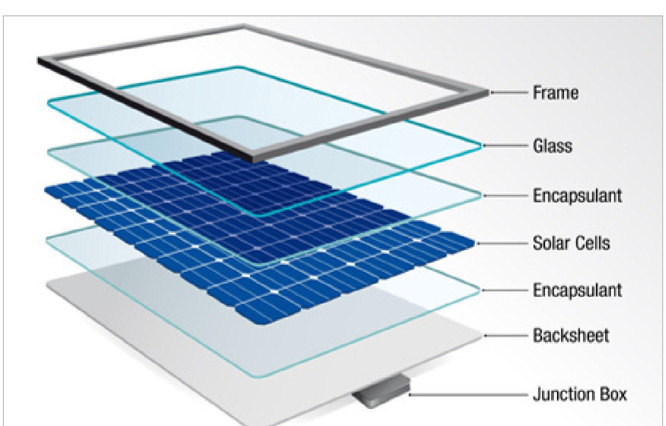

Figure 1. Typical PV module layout.

Experimental

The ageing tests were conducted using mini-PV modules (20 cm x 20 cm). The mini modules were produced in-house at the University of Loughborough, at the Centre for Renewable Energy Systems Technology (CREST) using a vacuum laminator. The mini-modules consisted of commercially available crystalline Silicon (c-Si) solar cells, standard glass, a fast-curing EVA and a multiple layer polymer backsheet composed of PET/PET/Primer (air side/core layer/encapsulant side). The encapsulants and backsheets were cut at a slightly larger size than the glass to prevent delamination from occurring with the intention of characterizing the portions of the EVA encapsulant exposed to the environment. Once completed and laminated the mini-PV modules underwent a series of ageing tests described in Table 1.

Table 1. Mini PV cell artificial ageing tests.

Artificial Ageing Test	Main Parameters	Maximum Time/ UV Dose
(DH) Damp Heat (IEC 61215-2:2016 MQT 13)	85°C, 85% Relative Humidity (RH)	2000 h
(UV) Dry UV (IEC 61215-2:2016 MQT 11)	250 W m^{-2} (280 nm – 400 nm). 60°C	500 kWh m^{-2}
(UVDH) UV and DH Tests Combined	180 W m, 60°C, 85% RH	250 kWh m^{-2}

After the ageing tests were completed, samples of EVA were destructively extracted from the mini-PV modules from three separate locations. The three extraction locations were as follows: at the interface between the solar cell and the glass above it ("above cell"), at the interface between the solar cell and the backsheet ("above backsheet") and the extra encapsulant directly exposed to the environment ("external"). An additional mini-module was kept in the dark for the duration of the ageing tests to act as a reference sample ("REF").

Instrumental

To characterize molecular changes in the EVA samples a PerkinElmer Spectrum Two FTIR Spectrometer fitted with a PIKE MIRacle attenuated total reflectance (ATR) accessory with a ZnSe crystal and diamond tip. A small piece of EVA from the relevant sampling area on the mini-PV module was cut and applied to the ATR, thereafter sufficient force was applied to the sample to ensure good contact with the ATR crystal. The instrument parameters for the FTIR are shown in Table 2. The thermal stability of the EVA samples was characterized with a PerkinElmer TGA 8000. Approximately 10 mg of EVA sample was weighed and added to a ceramic pan before measuring under the instrument parameters in Table 3.

Table 2. FTIR Scanning Parameters.

Spectral Range	4000 cm^{-1} – 650 cm^{-1}
Resolution	4 cm^{-1}
Number of Scans	4
Ordinate	% Transmittance

Table 3. TGA instrument parameters

Temperature Program	30 – 600 °C @ 20 °C/min
Purge Gas	Nitrogen (Sample: 50 mL/min; Balance: 60 mL/min)
Sample Weight	10 mg

Figure 2. PerkinElmer Spectrum Two FTIR with MIRacle ATR accessory.

Figure 3. PerkinElmer TGA 8000 Thermogravimetric analyzer.

Results and Discussion

FTIR:

For the EVA samples extracted from the 'above the cell' and 'above the backsheet' sampling positions no obvious signs of material degradation could be observed from the FTIR spectra. This indicates that the glass layer on top of the mini-PV module as well as the lamination process were sufficient to shield the encapsulant from the stresses exerted on it by the ageing tests. Figures 4 and 5 show the spectra of the extracted samples overlayed with the reference sample for these two sampling locations. The EVA samples tested from the 'external' sampling location showed strong signs of molecular degradation for the samples aged under UV and UVDH conditions. Figure 6 shows an overlay of the FTIR spectra obtained from samples from the 'external' sampling location on the mini-PV module, this sampling location was completely exposed to the stresses exerted by the ageing tests. The C=O peak observed at 1736 cm^{-1} for the reference sample is shown to have increased in intensity and shifted to approx. 1720 cm^{-1} for the samples exposed to UV and to approx. 1709 cm^{-1} for the samples exposed to UVDH. This is likely due to the formation of ketones in these samples upon oxidation. Increased absorbance in the region of 3500 cm^{-1} - 3000 cm^{-1} and 1300 cm^{-1} - 825 cm^{-1} for these samples corresponds to the formation of photo-oxidation products such as hydroxyl groups, aldehydes, vinylene, vinyl and vinyl dienes. Without the shielding of the external layers of the mini-PV module, the EVA encapsulant became heavily degraded under the UV and UVDH ageing test conditions.

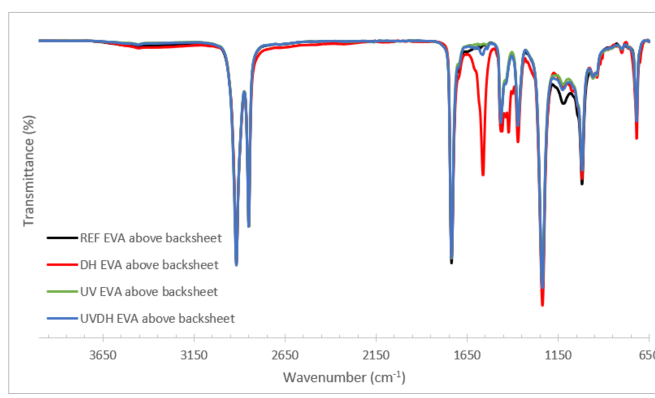

Figure 4. Overlaid FTIR spectra of EVA "above backsheet" sample after different ageing tests.

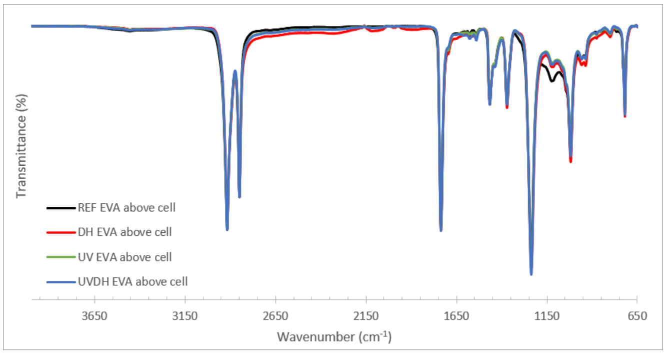

Figure 5. Overlaid FTIR spectra of EVA "above cell" sample after different ageing tests.

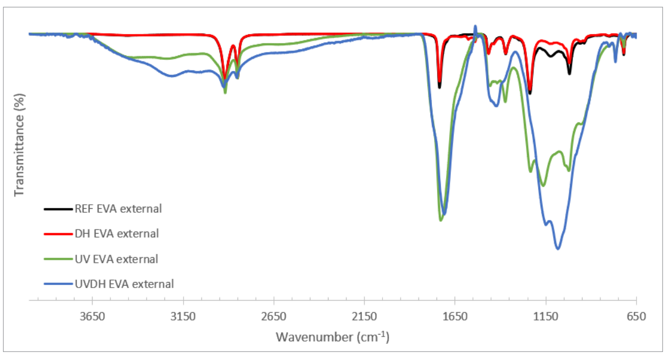

Figure 6. Overlaid FTIR spectra of EVA "external" sample after different ageing tests.

TGA

The TGA thermogram of EVA shows two primary weight losses starting at approximately 330 °C and 430 °C. The first weight loss is a result of the cleavage of the vinyl acetate groups through a deacetylation reaction followed by the thermal decomposition of the primary polyethylene backbone.[3] Figures 7 - 9 show overlays of the thermograms of EVA samples extracted from different sampling positions (above backsheet, above cell and external) and subjected to the different ageing tests. The samples extracted from the 'above cell' sampling position show no obvious changes in thermal stability, again confirming the shielding ability of glass layer of the PV module when completely and properly laminated. Similarly, the samples extracted from the 'above backsheet' position show consistent results despite the different ageing tests. The samples taken from the 'external' sampling position however showed notable changes, specifically those aged under UVDH conditions. The thermogram of the sample extracted from the 'external' sampling position shows a significant decrease in thermal stability with the initial weight loss starting at approximately 250 °C.

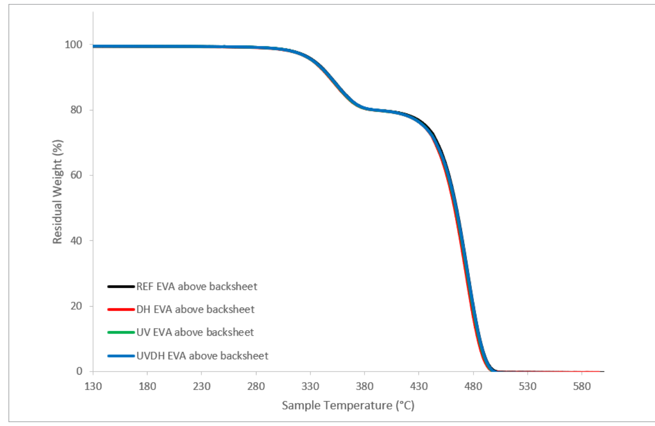

Figure 7. Overlaid TGA thermograms of EVA "above backsheet" sample after different ageing tests.

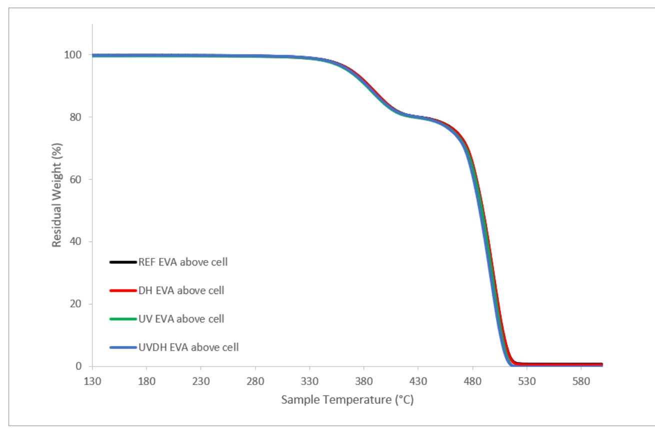

Figure 8. Overlaid TGA thermograms of EVA "above cell" sample after different ageing tests.

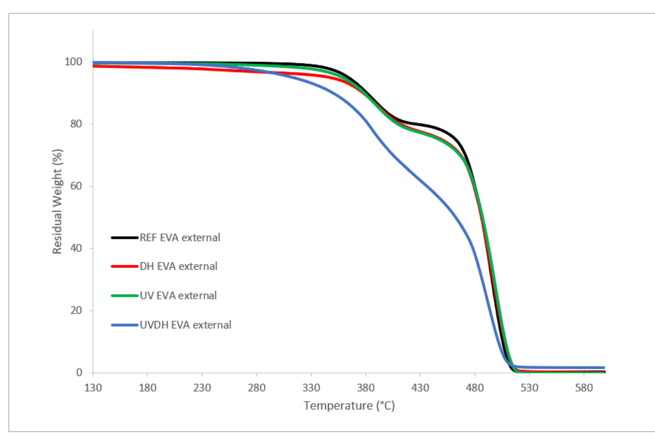

Figure 9. Overlaid TGA thermograms of EVA "external" sample after different ageing tests.

Conclusion

EVA encapsulant samples were extracted from aged mini-PV modules and characterized by FTIR and TGA after being subjected to ageing under DH, UV and UVDH conditions. The EVA samples were extracted from above the cell, above the backsheet and from a section of encapsulant external to the module and directly exposed to the ageing conditions. Only the 'external' EVA showed relevant changes from the FTIR spectra and TGA thermograms, indicating successful shielding of the EVA encapsulant by the external layers of the PV module multilayer composite. The FTIR spectra of the 'external' EVA show clear signs of degradation by means of photo-oxidation due to increase in peak areas in regions associated with oxidation products. The TGA results of the 'external' EVA sample also showed decreased thermal stability. The PerkinElmer Spectrum Two and TGA 8000 are well suited to characterizing molecular and thermal degradation modes of EVA encapsulant and contributing to a broader materials characterization suite of analyses to predict failure modes and perform quality control analysis of the multiple materials that make up a PV module.

Acknowledgements

All data presented in this application note were captured by Dr. Gernot Oreski and his team at the Polymer Competence Center Leoben GmbH (PCCL). The PCCL is the leading Austrian "Center of Excellence" for cooperative research in the area of polymer engineering and sciences. Together with the polymer industry and in close cooperation with its scientific partners (e.g., Montanuniversität Leoben), 100 highly qualified employees of PCCL are active in the R&D-projects in a wide field of applications for plastics ranging from automotive and aircraft, to packaging, and solar and photovoltaic industries.

By incorporating and combining the scientific, engineering and methodological competence of leading Austrian polymer research institutions on the one hand, and the technology, application and market-development expertise of the polymer industry and the service sector on the other, the PCCL acts as a link that interconnects the science-based approach of existing academic institutions with the applied research and product development approach of the polymer industry.

Gernot Oreski holds a PhD in Polymer Engineering and Science Degree at Montanuniversität Leoben. Dr. Oreski is Division Manager at PCCL and heads the »Smart Material Testing« division. He has over 18 years of expertise in polymers for photovoltaics. His main fields of research are ageing behavior and long-term reliability of polymeric materials and components for demanding applications such as PV modules. He finished his habilitation in polymer physics, with "Polymers in Photovoltaics" being the topic of his habilitation thesis. He is also teaching at the Department of Polymer Science and Engineering of the Montanuniversität Leoben.

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