

PET Film Degradation Analysis via Fluorescence Spectroscopy

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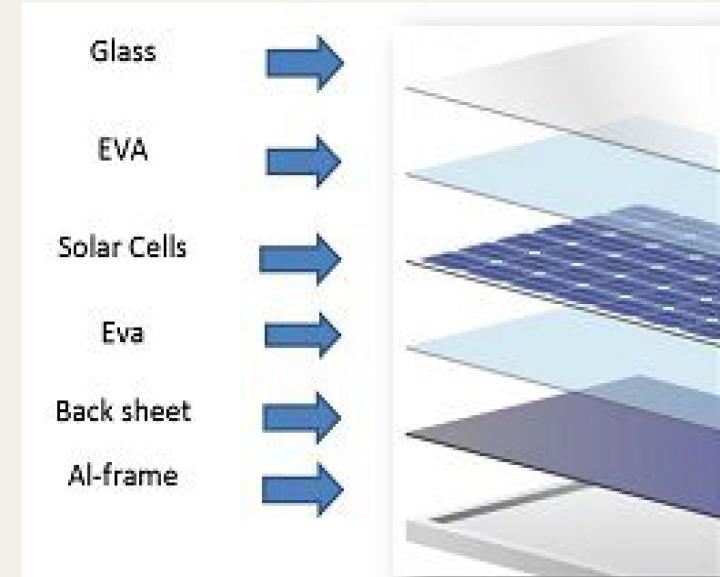
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Overview & Introduction

Understanding the degradation of photovoltaic (PV) materials is necessary in order to predict the lifetime of modules. In the layout of the PV module, poly (ethylene terephthalate) (PET) is a core component of the polymer back sheet. The characteristics of low cost and dielectric made it an ideal material for back sheets that were used as electrical and environmental barriers in the PV System. However, according to the Norrish degradation mechanisms, PET material is influenced by environmental stressors, such as ultraviolet (UV) light, heat, and humidity. Affected by those factors, PET materials could lose its mechanical strength and dielectric properties during the process of degradation. The goal of the project is to analyze PET film degradation during its warranty lifetime via fluorescence spectroscopy. With the simulated real-world outdoor data which were taken from samples exposed to accelerated conditions of temperature, humidity, and UV irradiance, the analysis will provide a 3D excitation-emission spectrum for PET Films after exposures. It will also make several corrections to remove the interference factors, such as Raleigh & Raman scatters and negative values.

The PV Module and PET

PET (ethylene terephthalate) is a condensation polymer of terephthalic acid/dimethyl terephthalate and ethylene glycol. The clear PET films have a specialty application in photovoltaic (PV) backsheets. As the core layer in backsheets, PET has high dielectric breakdown strength, and is used as the electrical and environmental barriers for PV modules. The potential problem of this material is that it is susceptible to degradation by environmental stressors such as heat, humidity, and ultraviolet (UV) light. Based on Norrish degradation mechanisms, the degradation of PET causes changes in its chemical structure that lead to loss of dielectric breakdown strength and mechanical properties.



Exposure & Measurement

Luminescence Spectroscopy:

- An Agilent Cary Eclipse Spectrophotometer is used to measure 3D Excitation Emission spectra with following each exposure step
- Measurements were conducted on the retained sample from the exposure protocol.
- One sample was retained (removed from study) following each exposure step, so the number of samples for a given material under a given exposure will decrease by 1 from step to step.

Hot QUV: 168 hr (one week) time steps

- Continuous exposure to UVA-340 light at 1.55 W/m²/nm and 70 °C

Cyclic QUV: 168 hr (one week) time steps

- 8 hrs of exposure to UVA-340 light at 1.55 W/m²/nm and 70 °C followed by 4 hrs of darkness and condensing humidity at 50 °C

Damp heat: 304 hr (two week) time steps

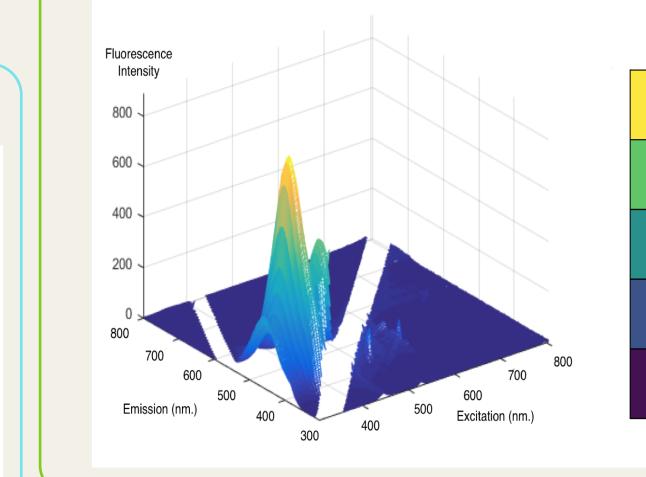
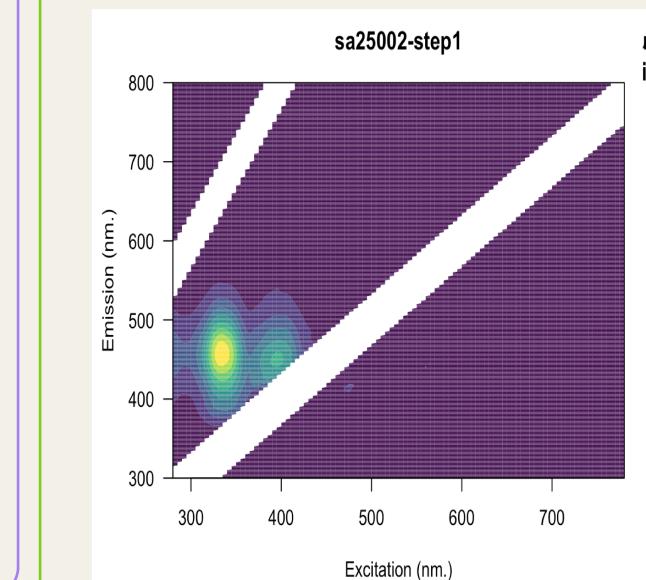
- Continuous exposure at 85 °C and at 85 °C relative humidity

The PARAFAC Analysis

According to the seminal paper of (C. A. Stedmon, Markager, and Bro 2003), the use of parallel factor analysis (PARAFAC) can aid the characterization of fluorescent DOM.

The multi-way technique can process the excitation-emission matrix and convert the decomposition of complex DOM fluorescence signals into a set of individual chemical components and provides estimations of their relative contribution to the total fluorescence (Bro 1997; Fellman, Hood, and Spencer 2010; C. A. Stedmon, Markager, and Bro 2003). [1]

After the removal of the first and second order scatterings, the PARAFAC is performed on a group of data taken from one sample material in different steps during a certain exposure to monitor the degradation progress. The increases in the fluorescence intensity and the signal area means the material is being more degraded.



Fluorescence Spectroscopy

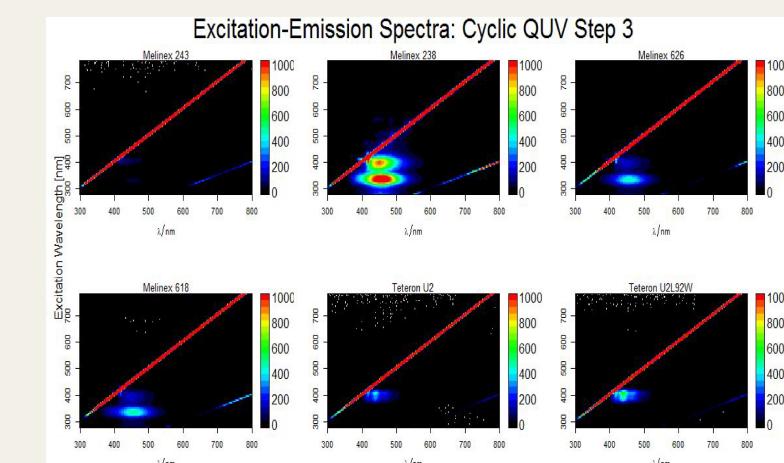
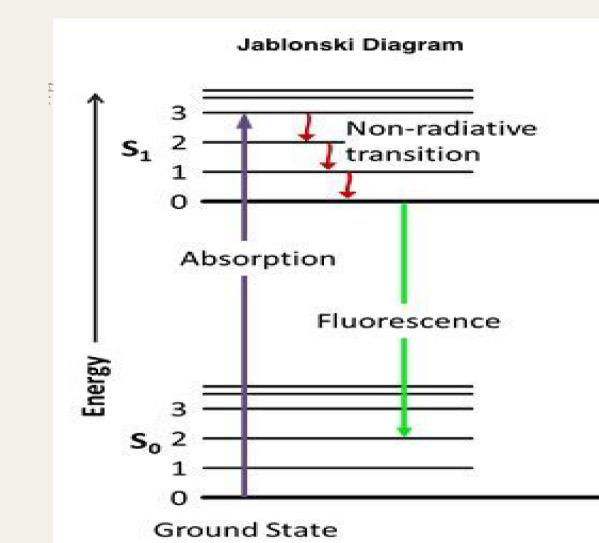
Environmental stressors' effects on PET:

- UV and humidity exposure cause degradation through chain scission mechanisms.
- Increases in temperature cause acceleration of degradation processes.

Fluorescence Behavior

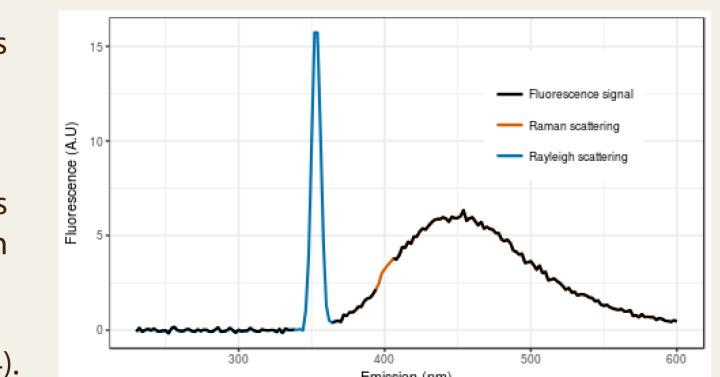
The degradation of PET can be monitored via fluorescence/luminescence spectroscopy. The analysis of the fluorescence involves using light to electronically excite a material and subsequent detection and analysis of the light emitted by the material upon relaxation. The material structure determines the range of wavelength absorbed by the material and features of the emitted light.

In the experiment and measurement steps, 3-Dimensional excitation emission matrix plots were generated for each exposure step to observe changes in the fluorescence behavior of the material after time in exposure.



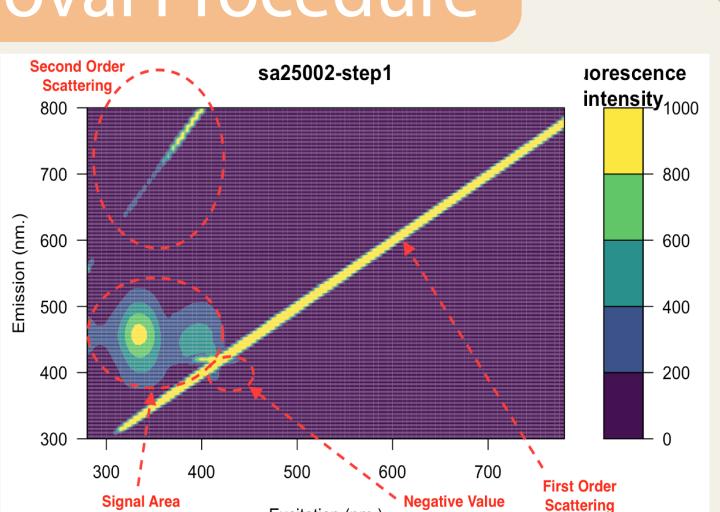
Raleigh & Raman Scattering

Rayleigh and Raman scattering are optical processes by which some of the incident energy can be absorbed and converted into vibrational and rotational energy (Lakowicz 2006). The resulting scattered energy produce the so-called scattering bands which are visually easily identifiable. Given that both types of scattering are repeated across EEMs, it is important to remove such artifacts prior to analysis (Bahrami et al. 2006; Zepp, Sheldon, and Moran 2004).



Scattering Removal Procedure

Scattering removal: Remove the so-called scattering bands caused by first and second order of Raman and Rayleigh scattering and retain the signal area. Different interpolation techniques have been proposed to eliminate scattering and negative values (Zepp, Sheldon, and Moran 2004; Bahrami et al. 2006). However, it is a common practice to simply remove the scattering-bands by inserting missing values at the corresponding positions (Murphy et al. 2013; C. A. Stedmon and Bro 2008).



Conclusion & Future Work

The weathering study data from indoor exposure of clear poly(ethylene terephthalate) films have been successfully cleaned. And the first order and the second order Raleigh & Raman scatterings have been removed from the fluorescence spectra. After the PARAFAC analysis being performed, the researchers can get the insights from trends in the results/factors with increasing exposure time/steps. The degradation progress of sample materials can be identified with the increments in the fluorescence intensity and the signal area. Nevertheless, since PARAFAC emphasizes on data visualization, there are works needed to quantify the statistical data of the fluorescence spectra and give a more comprehensive insight about the degradation of PET in the future.

Reference

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