

Introduction

One main challenge for solar cells and all components in a photovoltaic (PV) module is their durability and reliability to weathering. Prior efforts to understand the degradation of ethylene vinyl acetate (EVA) due to ultraviolet (UV) radiation, temperature and moisture have made significant progress. However, a comprehensive framework to describe the effect of oxygen on EVA degradation mechanisms has remained vague. This information is particularly important because in real life applications, due to the laminated structure of the modules, the oxygen diffusion to encapsulant layers in the central part of the panels tends to be more restricted compared to the diffusion to those near the edge. At the early stage of the field exposure, from the center to the edge, the environment of EVA layers changes from "anaerobic-like" to "aerobic-like". The objective of this study is to unravel the underlying degradation mechanisms of EVA in both air and argon conditions in the presence of UV radiation. Furthermore, the effect of wavelength on the EVA degradation in both conditions was studied.

Experimental

Sample preparation

Materials:
EVA: Evatane® (~32% of VA by mass)
Crosslinker(peroxide): **Luperox TBEC®**
UV absorber/Hindered Amine: Chimasorb 81/Tinuvin 770



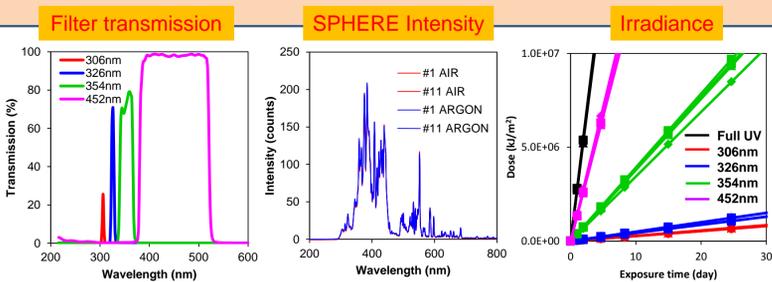
The specimens were prepared by spin casting the EVA solution in CaF₂ substrates and then cured in a vacuum oven at 160°C for 10 min.

Exposure conditions



Temperature : 55°C
Relative Humidity (RH) : 0%
Atmosphere : aerobic (with air)
anaerobic (with argon)
Accelerated UV exposure:
 NIST SPHERE (Simulated Photodegradation via High Energy Radiant Exposure)
 → 4 ranges of wavelengths (band-pass filters) 306nm, 326nm, 354nm and 452nm

Chin et al., Rev. Sci. Instrum. (2004), 75, 4951



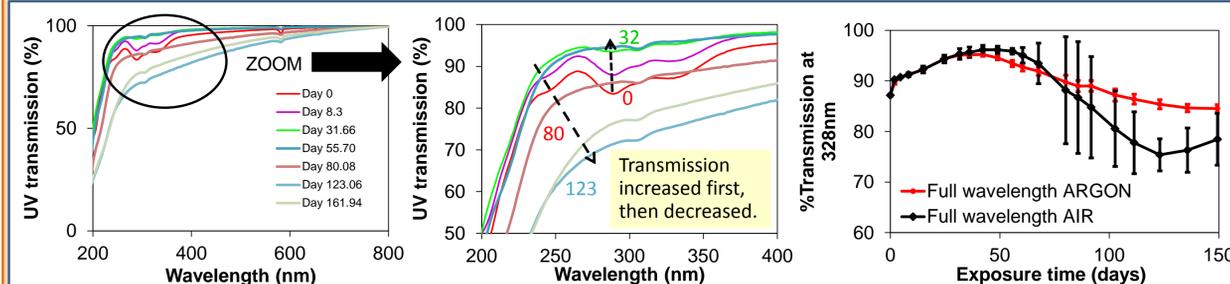
Measurements

Ultraviolet/Visible (UV-vis) spectroscopy: optical degradation
Fourier transform infrared (FTIR) spectroscopy: chemical degradation
Atomic Force Microscopy (AFM): morphological changes

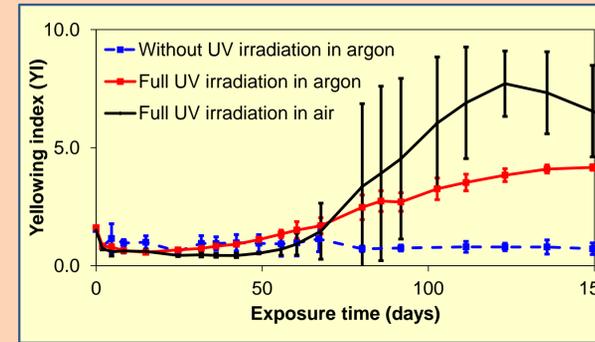
Results and Discussion

Effect of Oxygen on EVA Degradation

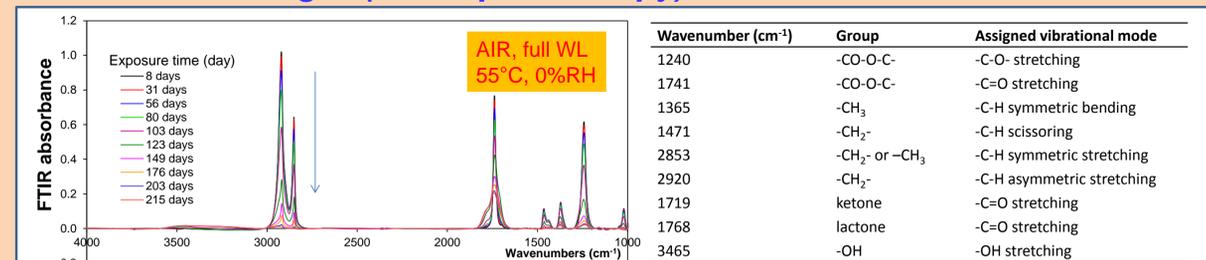
Optical Changes (UV-vis Spectroscopy)



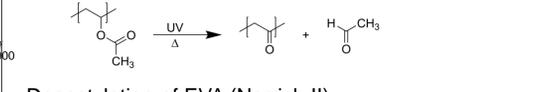
- The transmittance of EVA specimens increased first then decreased with longer exposure. This change is due to the competition between the loss of UV-absorbers and the formation of chromophoric degradation products.
- Initially, the change in transmittance was similar in argon and air. In later stages of exposure, the loss of transmission in argon was much slower than that in air.
- Photodegradation of EVA in oxygen environment caused more yellowing than that in argon, which was consistent with the chemical changes by FTIR (below).
- Specimens exposed in the same condition without UV radiation showed little yellowing, indicating UV is a key factor for yellowing.



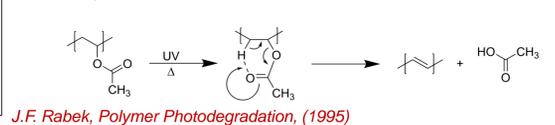
Chemical Changes (FTIR Spectroscopy)



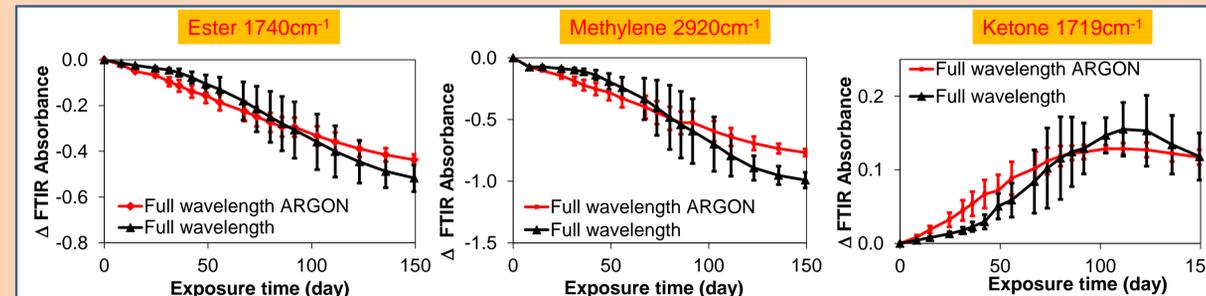
Ketone formation via acetaldehyde formation (Norrish I):



Deacetylation of EVA (Norrish II):



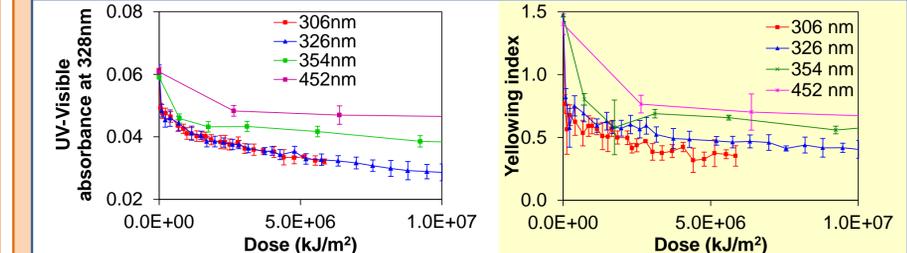
J.F. Rabek, Polymer Photodegradation, (1995)



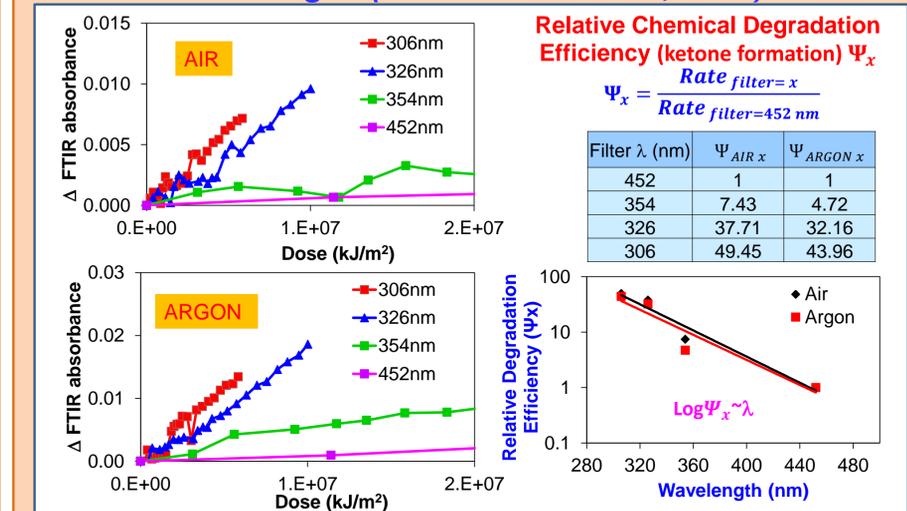
- In argon, the chemical degradation of EVA was approximately linear to irradiation time, which is different from air condition.
- The chemical degradation was inhibited at the early stage in air, then markedly increased and surpassed that in argon. The effect of oxygen on the chemical change of EVA showed similar trend as that on the yellowing.

Effect of Wavelengths on EVA Degradation

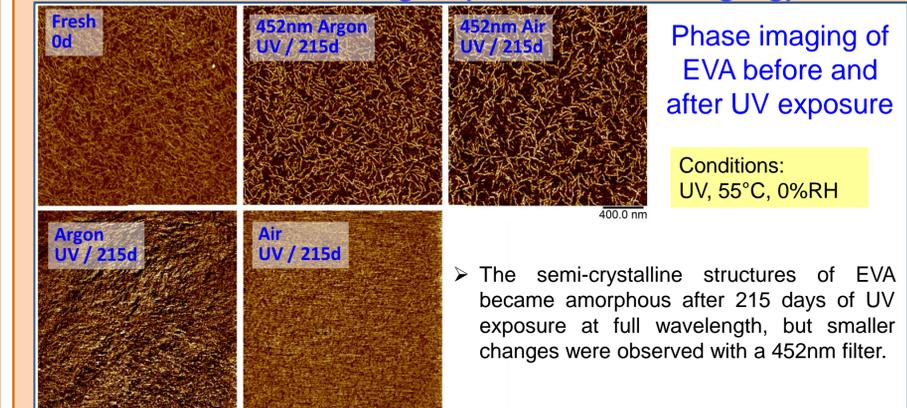
Optical Changes (UV-vis Spectroscopy)



Chemical Changes (Ketone Formation, FTIR)



Microstructural Changes (AFM Phase Imaging)



- The semi-crystalline structures of EVA became amorphous after 215 days of UV exposure at full wavelength, but smaller changes were observed with a 452nm filter.

Summary

- Effect of oxygen on chemical and optical changes of EVA was observed during UV exposure. The degradation of EVA at early stages appeared to be inhibited in comparison to those in the argon. However, after prolonged exposure, the rates of EVA degradation in oxygen substantially increased and surpassed those under the anaerobic counterpart.
- The depletion of UV absorber/hindered amine was observed during UV exposure of EVA. Dramatical degradation of EVA took place after substantial loss of UVA, especially in the oxygen environment.
- The shorter the UV wavelength, the faster is the degradation for EVA in both aerobic and anaerobic conditions.