# Depth Profiling of Chemical and Mechanical Degradation of PV Backsheets after Exposure to Simultaneous UV, Temperature and Moisture


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## Introduction

The backsheet provides electrical insulation and physical support, and acts as a barrier against the moisture and weathering to the photovoltaic (PV) module. The degradation of the backsheets can be detrimental to the safety and performance of the modules. This is a costly problem for industry due to the lack of comprehensive knowledge of multilayer system during weathering.

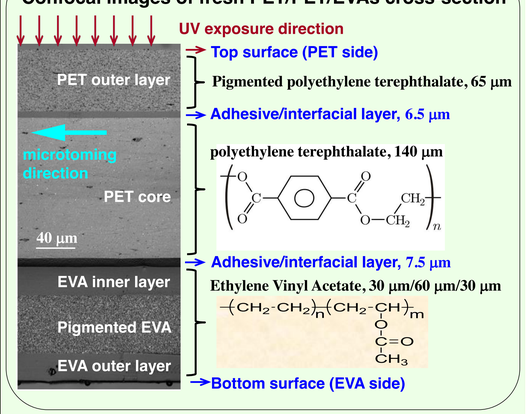
In this study, a new depth-profiling technique, combining cross-sectional nanoindentation, atomic force microscopic quantitative nanomechanical mapping (AFM-QNM) and Raman imaging, was used to measure mechanical and chemical properties of a multilayered PET/PET/EVA backsheet before and after exposure to accelerated laboratory conditions under simultaneous UV, temperature and moisture. New insights into the degradation mechanisms of individual layers and interlayer structures of the backsheets during accelerated testing will be presented.

## Experiments

### PET/PET/EVA Backsheet

- Cross-sectional samples were prepared by cryo-microtomy
- Epoxy was used to mount the samples

Confocal images of fresh PET/PET/EVAs cross-section




### Accelerated Laboratory Exposure

- Samples: Free-standing films of PET/PET/EVA backsheet before and after SPHERE exposure for 67 days
- Exposure conditions: UV irradiance (300 nm-400 nm): 170 W/m²; T = 85 °C; RH = 5% (dry) and 60% (wet)

NIST 2-meter SPHERE*

* Chin et al, Review of Scientific Instruments (2004), 75, 4951; Martin and Chin, U.S. Patent 6626053.

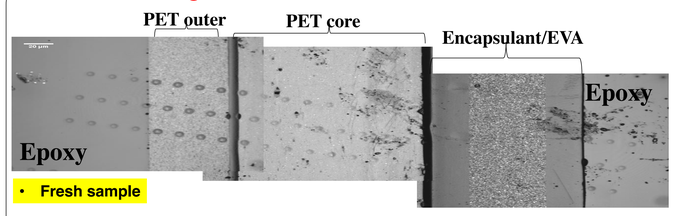
### Characterization

- Nanoindentation (cross-sectional),
- Atomic force microscopy with QNM (cross-sectional),
- Raman microscopy with laser l = 785 nm (cross-sectional)
- UV-Visible reflection mode (top/bottom-surface)
- ATR-FTIR (top/bottom-surface)
- Laser scanning confocal microscopy (both)

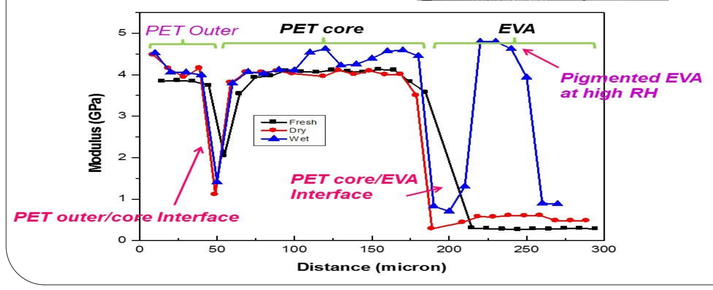
## Cross-Sectional Chemical and Mechanical Characterization

### Mechanical Depth profiling by Nanoindentation

Confocal image of residual indents after nanoindentation




- Fresh sample



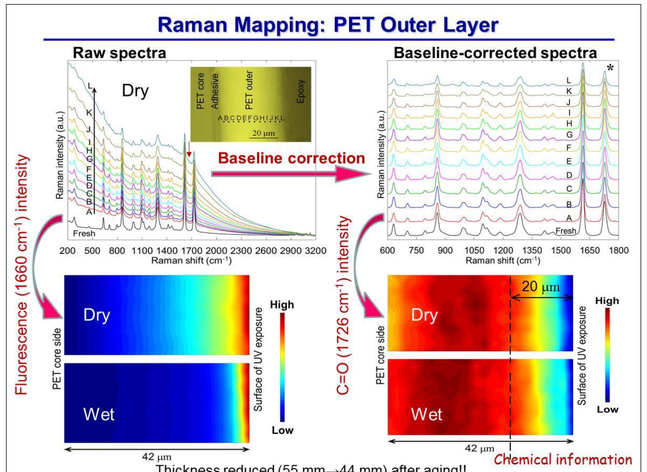

| Modulus (GPa) by Nanoindentation | | | |
|---|---|---|---|
| Layer | Fresh | Exposed to UV/85°C/5% RH for 67 d | Exposed to UV/85°C/60% RH for 67 d |
| PET Outer Layer | 3.81±0.23 | 4.13±0.16 | 4.29±0.41 |
| PET Core Layer | 4.01±0.44 | 4.00±0.12 | 4.33±0.43 |
| EVA (All) | 0.28±0.02 | 0.48±0.13 | 2.72±1.92 |

- The PET outer/core and PET core/EVA interfaces have the lowest moduli.
- The moduli of PET outer-most layer, part of PET core layer and EVA pigmented layer were increased after exposure to UV, particularly at high RH.
- The effect of relative humidity on the change of modulus was observed.

### Chemical Depth Profiling by Raman Imaging

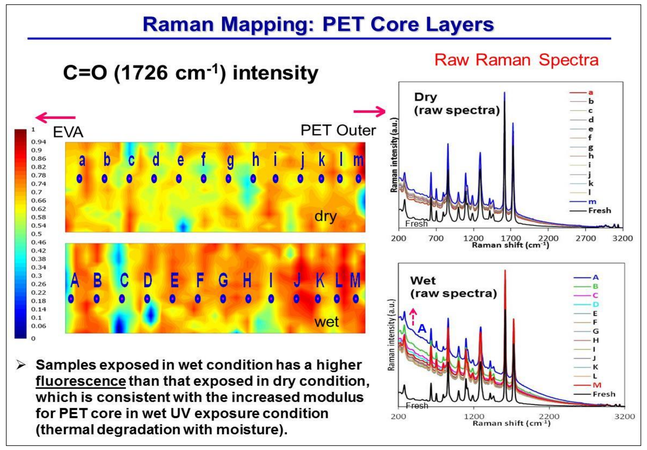
- Raman spectra in each layer reflected the effect of UV and T/RH on degradation of backsheet across the thickness. The intensity change in the background fluorescence or around the band of interest (e.g. C=O or C-H) was used to represent chemical changes of backsheet after exposure.

#### Raman Mapping: PET Outer Layer



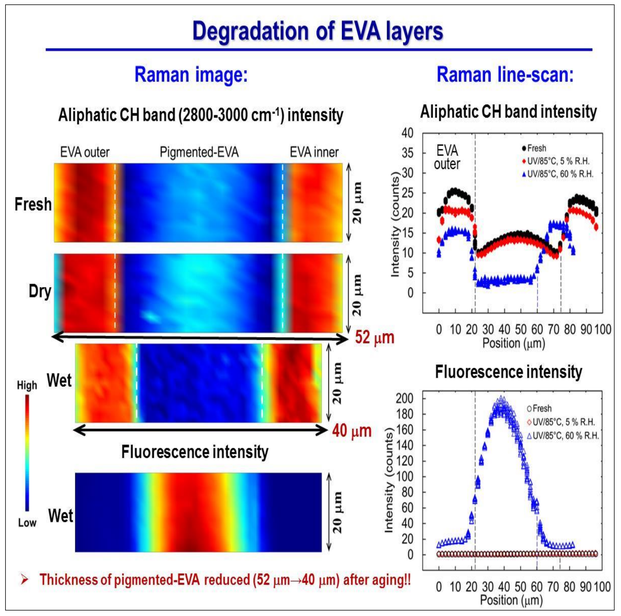

Thickness reduced (55 mm→44 mm) after aging!!

#### Raman Mapping: PET Core Layers




- Samples exposed in wet condition has a higher fluorescence than that exposed in dry condition, which is consistent with the increased modulus for PET core in wet UV exposure condition (thermal degradation with moisture).

#### Degradation of EVA layers

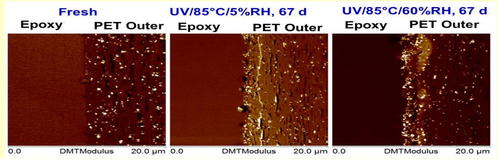



- Thickness of pigmented-EVA reduced (52 µm→40 µm) after aging!!

- The outer-most region of PET outer layer (~20 µm from surface) showed the highest fluorescence. The result is consistent with the increased modulus detected by nanoindentation.
- Thickness reduction was observed for both PET outer layer and pigmented EVA central layer after UV exposure in wet condition.
- The pigmented EVA layer displayed strong emission (yellowing) after exposure to UV wet condition, which was consistent with the mechanical depth profiling data.
- RH accelerated thermal degradation in all EVA layers.
- Non-uniform degradation was observed across backsheet multilayers after exposure to UV/T/RH. The PET outer layer and pigmented EVA layer changed most based on Raman imaging.

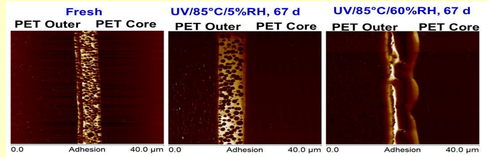
## Interfacial Mapping by AFM QNM

### Epoxy/PET Outer Interface (modulus)



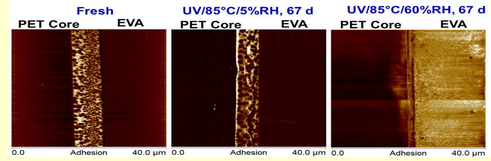

After UV exposure, PET surface showed
- aggregated pigments
- enhanced modulus

### PET Outer/Core Interface (adhesion)




High humidity is detrimental to the structure of adhesive layer between PET outer and PET core layers.

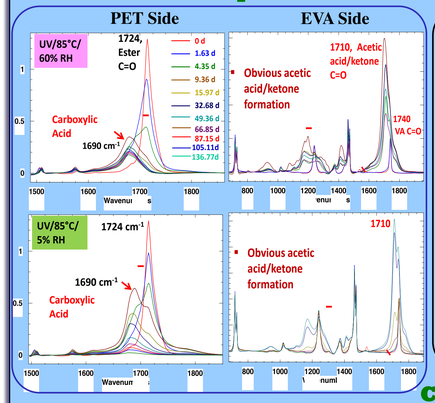
### PET Core/EVA Inner Interface (adhesion)



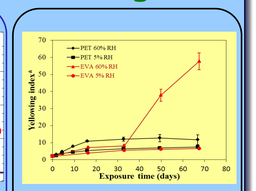

High humidity changed the interfacial structure between PET core and EVA layers.

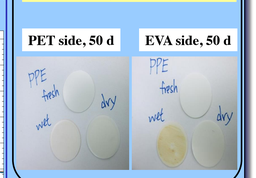
## Surface Characterization

### ATR-FTIR Spectra

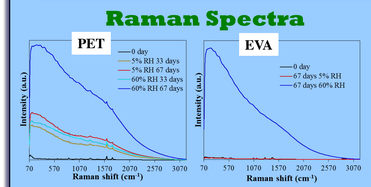



### Yellowing Index

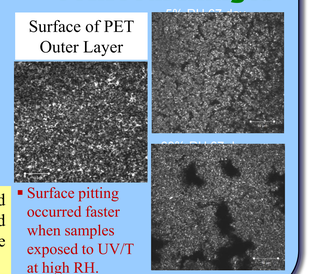



### Raman Spectra




### Confocal Images




- Surface characterizations of PET top layer and EVA bottom layer showed that UV/RH played a key role in PET degradation, and moisture accelerated yellowing of EVA.
- Surface pitting occurred faster when samples exposed to UV/T at high RH.

## Summary &

- Cross-sectional chemical and mechanical profiling is an effective tool to understand property changes of individual layers in multilayered PV backsheet during aging.
- Both nanoindentation and Raman spectroscopy suggest that high humidity accelerates the photo-degradation of backsheet materials in the presence of UV radiation.
- This study indicates that the long-term interlayer adhesion in backsheet system could be challenging, especially in humid service environments.