Polymeric Materials Group
Engineering Laboratory

Effects of Simultaneous UV Radiation, Temperature and Moisture on Degradation of PV Polymers

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INTRODUCTION

A fundamental understanding of degradation mechanism of photovoltaics (PV) materials under simultaneous multiple stresses (temperature, moisture, UV radiation) is important to the development of reliable accelerated laboratory test methods that correlate to field performance.

In this study, the laboratory accelerated tests of several PV polymers, such as ethylene vinyl acetate (EVA), poly (methyl methacrylate) (PMMA), and ionomers were conducted on the well-controlled NIST SPHERE environmental chamber. A factorial experiment was designed to evaluate the effects of temperature, relative humidity, and spectral ultraviolet (UV) irradiance, either applied individually or in combination on the main degradation mechanisms of these materials. The outdoor exposure was carried out in Gaithersburg, MD. Multiscale chemical, optical, mechanical and morphological measurements were performed to follow changes during accelerated and outdoor exposures. The degradation mechanism and failure mode of PV materials and components were studied.

Linking Laboratory and Outdoor Exposures

Reliability-based Methodology

Accelerated Laboratory Exposure
(to study effects of critical environmental factors on degradation mechanism of PV materials/modules)

Outdoor Exposure
(with monitored weather parameters)

Cumulative Damage Prediction Model

Failure Mode Analysis

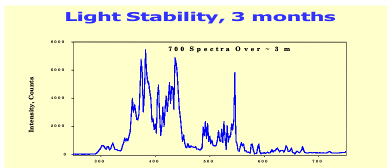
➢ To develop reliable accelerated laboratory test methods that correlate to field performance.

ACCELERATED LABORATORY EXPOSURE DEVICE

NIST Integrating Sphere-based UV Chamber

NIST-Patented 2-meter SPHERE

(*S*imulated *P*hotodegradation via *H*igh *E*nergy *R*adiant *E*xposure)



- High UV Radiant Exposure (8400 W UV)
- 95% exposure uniformity
- Visible and infrared radiation mostly removed
- Temperature and relative humidity around specimens precisely controlled (25-75 °C; 0-95 % RH)
- Capability for mechanical and electrical loadings
- Exposure conditions of 32 chambers can be individually controlled (UV, RH,T)

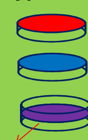
• Chin et al, Review of Scientific Instruments (2004), 75, 4951; Martin and Chin, U.S. Patent 6626053

EXPERIMENTAL

Materials

(A) EVA

3 Types of Sample Designs



CaF_2 Substrate *(for FTIR UV-visible and AFM)*

(B) PMMA

(C) Ionomer

SPHERE Exposure

UV/T/RH, individually or in combination, under

- Different Spectral UV Intensities *(25-200 W/m², 295-480 nm)*
- Different Temperatures *(25-85 ℃)*
- Different RHs *(0-75%)*

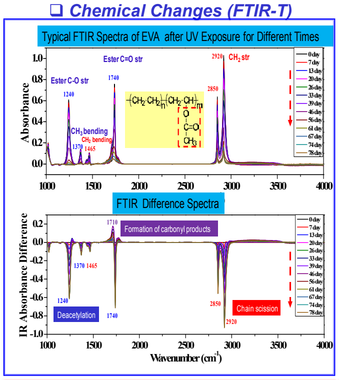
Outdoor Exposure

Gaithersburg, MD

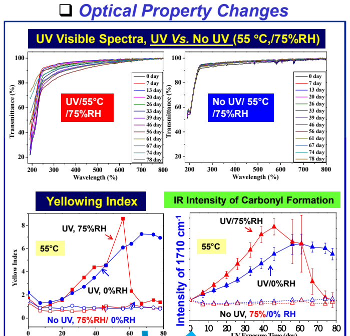
RESULTS FROM LABORATORY EXPOSURE

Effect of Simultaneous UV/RH/T on Degradation of EVA

❑ *Chemical Changes (FTIR-T)*

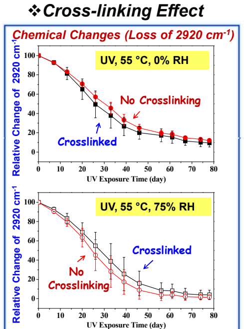


❑ *Optical Property Changes*

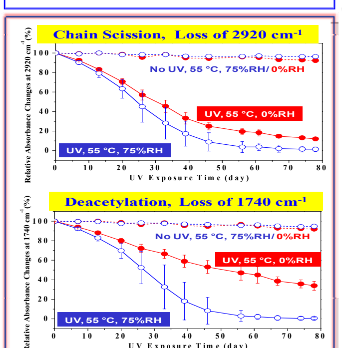


• Carbonyl formation may contribute to yellowing.

❖ *Cross-linking Effect*

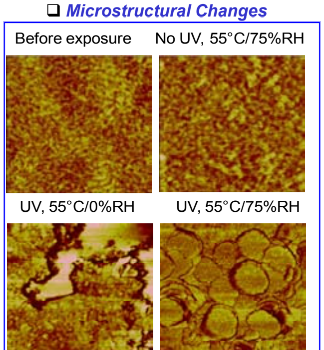


• Essentially no effect on chemical changes observed from crosslinking.



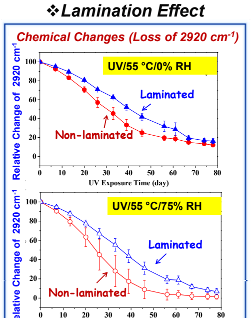
• Both UV and RH are important factors.
• Synergistic effect between UV and RH.

❑ *Microstructural Changes*



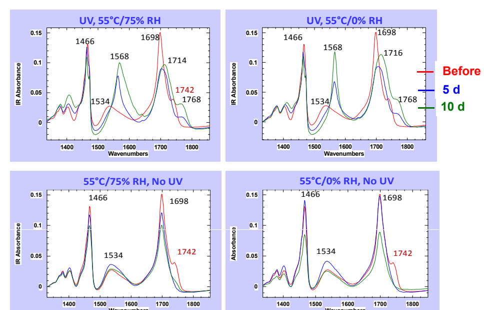
1 µm × 1 µm *78 days exposure

❖ *Lamination Effect*



• Lamination reduced EVA degradation rate.

UV Effect on PV Ionomers

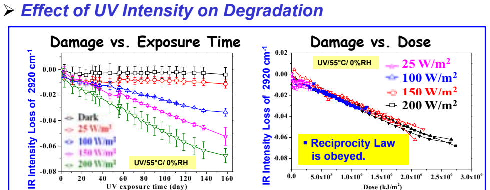


$1466\ cm^{-1}$: $-CH_2$
1534 -$1568\ cm^{-1}$: C=O, carboxylate ions
$1698\ cm^{-1}$: C=O, carboxylic acids (H-bond)
$1768\ cm^{-1}$: C=O, anhydrides or lactones

❖ UV radiation has a strong effect on chemical changes of PV ionomers, but humidity does not.

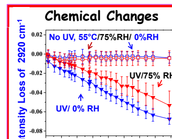
Photodegradation of PMMA (4UVs/55°C/2RHs)

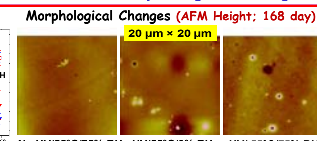
➢ *Effect of UV Intensity on Degradation*



• Degradation rates increase with higher UV intensities, but the degradation mechanism of PMMA remains same at 4 UV intensities.

➢ *Effect of UV/RH/T on Chemical / Morphological Changes*





• UV has strong effect on PMMA degradation, but humidity does not.

SUMMARY

➢ UV radiation was the most important factor for degradation of all studied materials. A RH/UV synergistic effect was observed for EVA, but not for PMMA and PV ionomer.
➢ A higher UV intensity led to a higher degradation rate, but there was no change in degradation mechanism for PMMA exposed to T/RH/UV with different UV intensities.