Characterization of EVA degradation processes in Si-based PV modules by means of spatially-resolved luminescence spectroscopy

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Degradation of PV modules

Typical construction of a c-Si PV module

Main problems of service life prediction of PV modules:
- Low sensitivity of measurement methods
- Non-destructive characterization necessary
- Occurrence of many different failure modes

2 Köhl (2014): 29th EUPVSETDP.1.3.
A very brief history of Polymer Luminescence

Ashby 1961 - Oxyluminescence from polypropylene

Charlesby 1965 - The Identification of Luminescence Centres in Polyethylene and other Polymers

(I) $R-C=O$

(II) $R-C=O$

(III) $R-C-R$

*Figure 7. Phosphorescence (longer wavelengths) and fluorescence (shorter wavelengths) spectra of polypropylene. Spectra not drawn to common intensity scale.*

**But:** Complex changes of luminescence could not be correlated to the degradation of physical properties!
Since 2008 - Polymer Luminescence at AG Röder: Theory

Steffen 2016 - Density of States Model of Polymer Luminescence

- **CB**
- **VB**

Energy

- fluorescence of non-interacting states
- depolarization
- DOS luminescence

State of degradation

- initial
- intermediate
- final

Insulating band gap
Polymer Luminescence at AG Röder: Application to PV modules

• Identification spatial luminescence patterns in mini modules and full-scale PV modules after
  – accelerated aging
  – outdoor weathering
• Comparison PV modules of different manufactures to access performance/material differences
• Parallel aging under different conditions (Multiageing Chamber)
• Categorization crack damage of PV modules
• Correlation EVA-Luminescence with mechanical parameters
• Correlation EVA-Luminescence with crosslinking
Luminescence upon accelerated aging

Sketch of the optical setup:

- Spectrometer
- Fiber
- UV-filter
- Lens
- Dichroic mirror
- UV-laser
- Sample

Luminescence shows a correlation to the aging duration from the beginning of accelerated aging.
2D Luminescence scanning of commercial PV modules

Setup for 2D-photoluminescence detection (scanning) of embedding polymers in PV-Modules

Detail:
Scan head with excitation laser and collecting optics
Luminescence field inspection device
First step of analysis: integration of luminescence spectra and graphical presentation of the location dependent total intensity.

Presentation with space-resolution via integration of the spectra.

Line-Scan – with spectral information

Line-Scan – Total intensity
3. Luminescence patterns upon accelerated aging

Dry heat (H), damp-heat (DH)

Accelerated aging without UV

Accelerated aging with UV

and DH aging followed by UV (DH+UV)
3. Influence of different materials (accelerated DH aging)

DH aging results in similar patterns in most modules

Only manufacturer C1 used SC-EVA

Other manufacturers used fast/ultrafast cure EVA
3. Influence of different materials (accelerated UV aging)

UV aging results in similar patterns in most modules

The patterns are fundamentally different from DH aging

Luminescence of manufacturer C2 does not reduced to zero.

Only manufacturer to use Ce-containing frontglass!
Luminescence patterns after outdoor weathering

c-Si- PV-Modules from 7 companies (data anonymized)

4 different weathering sites:

- Moderate, Germany: Cologne
- Alpin, Germany: Zugspitze, 2650 m
- Desert, Negev, Israel
- Tropic, Indonesia
Similar patterns are observed in all modules (e.g. Isreal, 3 years).

Patterns are most similar to those of accelerated aging with UV.

Modules of manufacturer C2 deviate from others (as observed for UV aging).

Patterns (and spectra) are distinct for:
1) Exclusive thermal aging
2) UV aging or outdoor weathering
### 5. Influence of outdoor weathering time

<table>
<thead>
<tr>
<th>Location</th>
<th>PV Modules</th>
<th>Manufacturer</th>
<th>Weathering Time</th>
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<td>Indonesia 2y</td>
<td>C5</td>
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**PV modules of manufacturer C5**
Luminescence intensity upon outdoor weathering

Evaluation of the luminescence intensity on the center of the cell (No change of spatial patterns, no visible yellowing):

Influence of temperature

Influence of (UV) radiation

The luminescence intensity correlates with the duration of exposure, the average temperature and the UV dose.
A good correlation exists for modules by manufacturers C5 and C6.

Modules by manufacturer C2 show no correlation to all others.

Different materials show differences in luminescence.

1) The luminescence intensity is specific for the material and the weathering location.
2) A good correlation between modules of similar composition is observed.
3) Differences are observed for different materials.
Application of Luminescence to damage characterization

„normal“ outdoor exposure
transport damage, dendritic fracture
exposure damage (Zugspitze)

c-Si modules from different weathering sites, measurement after 2 years
Luminescence along cracks shows similar reduction like at the cell edges.

Conclusions

• **Luminescence intensity is an indicator for ageing time indoor and outdoor**
• In PV modules the luminescence is distributed inhomogeneously
• Diffusion processes (mostly O\textsubscript{2}) enable destruction of chromophores in the polymer resulting in decreased luminescence intensity
• The shape of the spectrum is different for DH and UV ageing
• Complex behaviour of the spectra after combined ageing procedures esp. outdoors
• **UV aging and outdoor weathering cause similar luminescence patterns**
• Spectral effects of UV and DH ageing can be separated also in case of outdoor weathered modules
• The EVA luminescence of different manufacturers correlates for different ageing methods, indicating that luminescence can be used to monitor the condition of the encapsulating EVA in PV modules

• Using minimized multi ageing chamber developed at HU Berlin different ageing parameters can be applied to one mini-module and differences in degradation behaviour can be analysed
• **Luminescence can be used for crack inspection (e.g. age of cracks)**
• It can be used for PV module inspection: in- and out-door
THANK YOU FOR YOUR ATTENTION

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