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Raman-Spectroscopic Degradation Analysis of Polymers for Photovoltaic Application

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Introduction

Many new materials for photovoltaic application have been introduced to the market lately. But attention has to be paid to the interaction of the components, especially in terms of stability towards oxygen and water vapor. As a non-destructive and quick method, Raman Spectroscopy can be used for materials degradation analysis on laminates as well as full PV modules.

Samples and aging tests - laminates

Laminates were made from four different types of encapsulation material (EVA, TPSE, Ionomer PVB) and three back-sheet materials (TPT, PA and PET composite film).Samples of each laminate type had been aged under following conditions:

- **damp heat conditions** (85°C/85% r.h.)
- **UV/damp heat conditions** (85°C/90% r.h., total dose of 190 kWh/m²) for up to 1000 h, respectively
- **UV** (up to 60 kWh/m²)

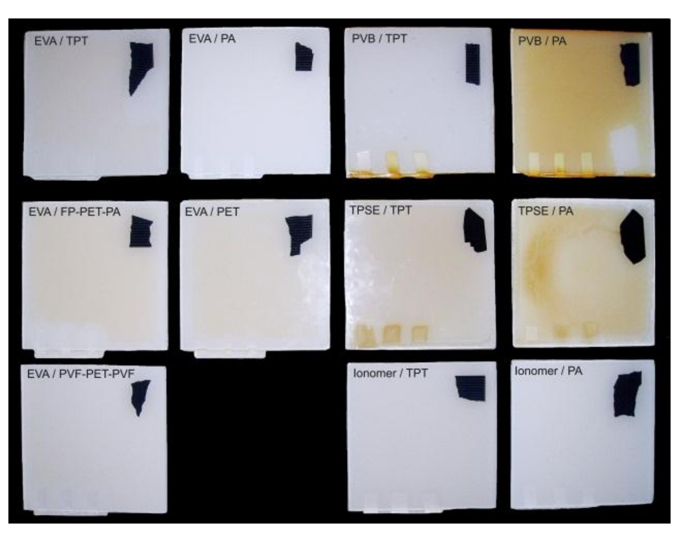


Fig.1. Laminates after 1000 h UV/DH aging showing different extends of yellowing.

Raman Spectroscopy on laminates

Comparing the Raman Spectra collected beside the cell, all UV/damp heat aged and some of the UV aged laminates, except for the PVB/TPT combination, show a broad fluorescence background. It is most likely due to additives degradation within the encapsulation material. Therefore, the intensity of the fluorescence can be regarded as an indicator for the materials aging as described by our group earlier [1]. Since the damp heat aging causes only little fluorescence, the major degradation pathway should involve photochemical reactions.

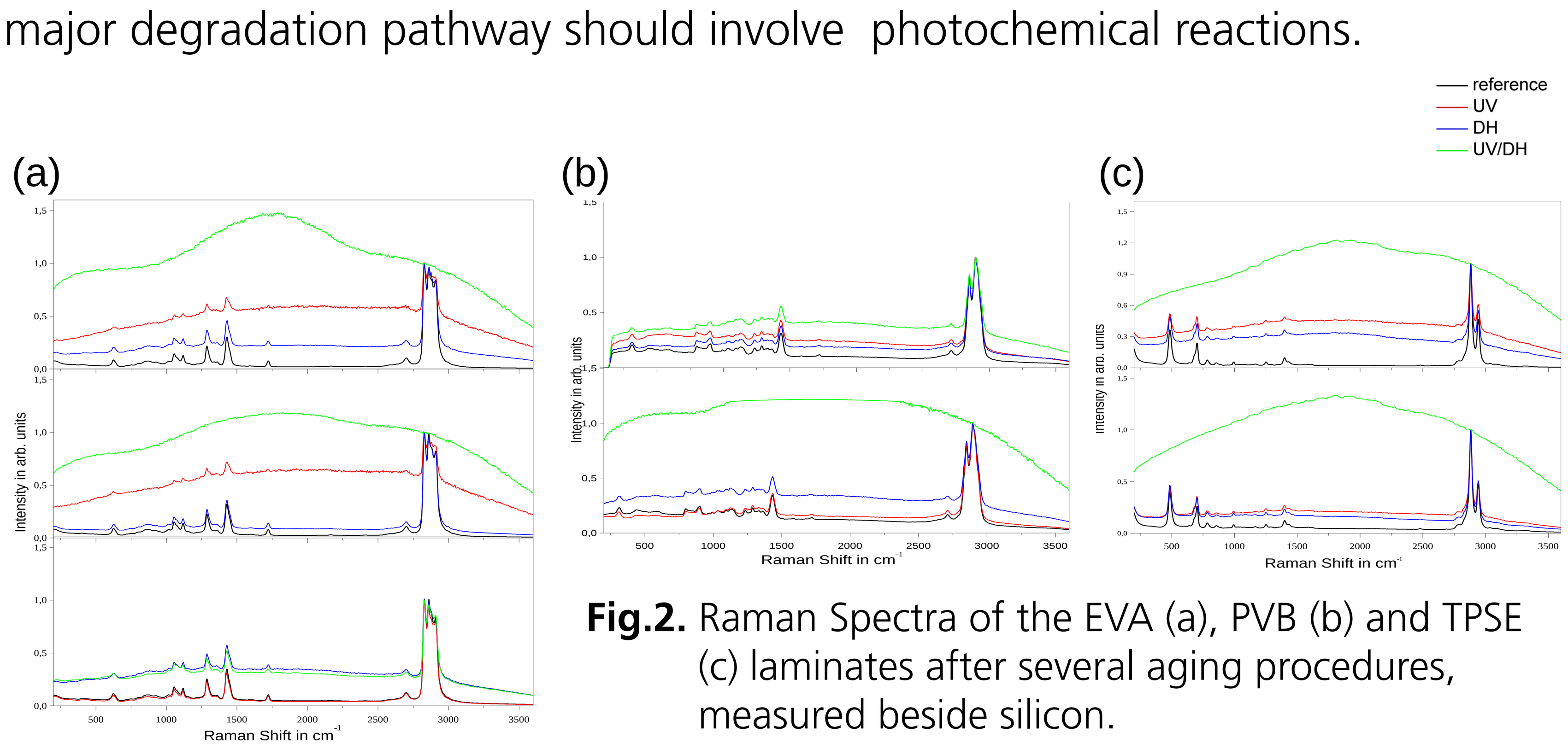
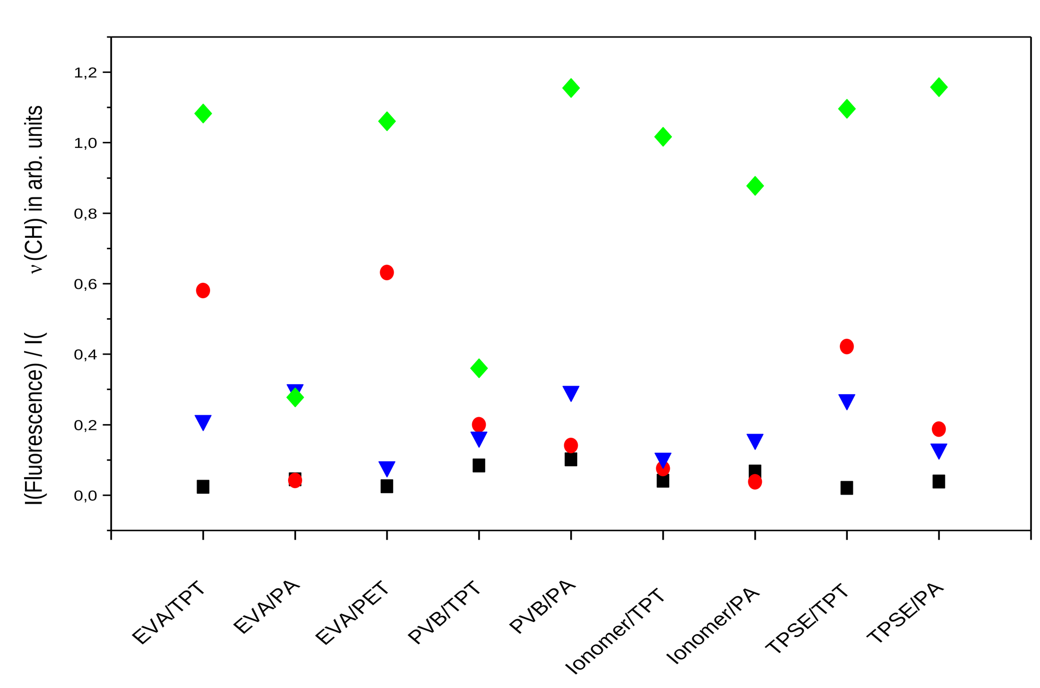


Fig.2. Raman Spectra of the EVA (a), PVB (b) and TPSE (c) laminates after several aging procedures, measured beside silicon.



The intensity ratios shown in fig. 3 display the strong influence of the back-sheet material on the amount of degradation of the encapsualtion. Especially the EVA/PA and the PVB/TPT laminates appear to be hardly degraded.

Fig.3. Fluorescence/CH-streching vibration intensity ratios calculated from the Raman Spectra of the different laminates after several aging procedures.

Samples and aging tests – PV modules

Within a BmBF project, full PV modules were exposed in different climates for several years and investigated in terms of crack formation, performance losses and polymeric degradation. Modules had a standard build-up with a TPT back-sheet, EVA encapsulation and cristalline silicon cells.

Raman Spectroscopy on PV modules

Spectra measured across a cracked cell in outdoor aged PV module show

- cracked part : good EVA spectra most likely due to fluorescence quenching being possible because of O_2 ingress
- part without cracks : good EVA spectra at edges and strong fluorescence in the center of the cell

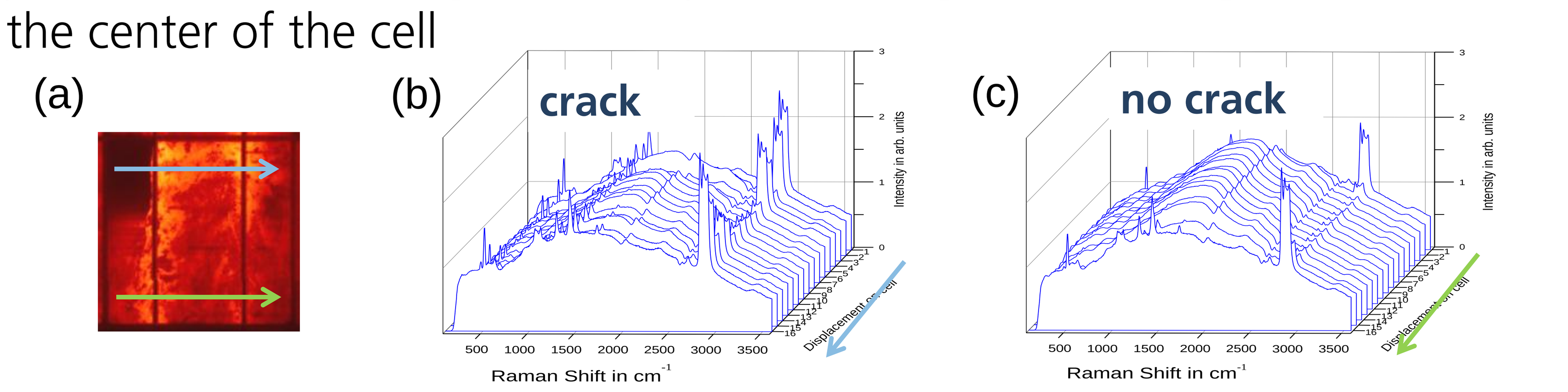


Fig.4. Raman spectra and electroluminescence picture (a) of a cell in a PV module after 3 years of outdoor exposure in Indonesia. Spectra are measured across one half-cracked cell directly above crack (b) and in non-influenced region (c).

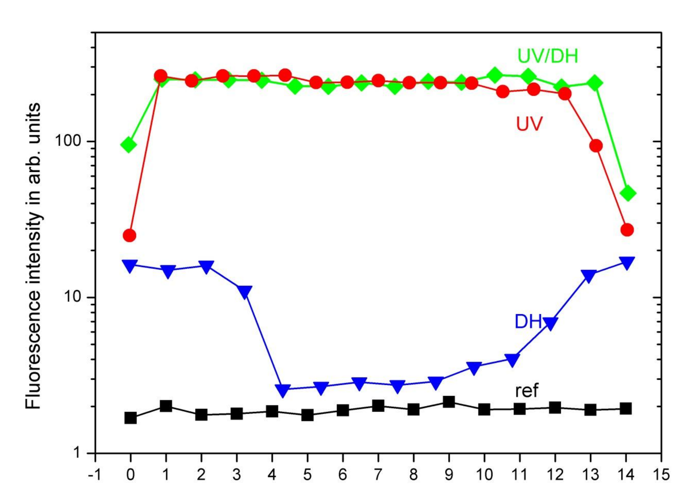


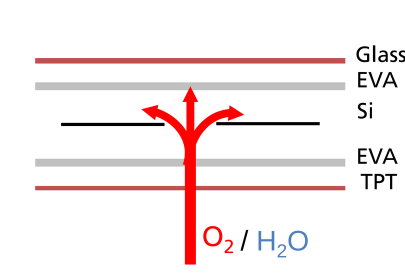
Fig.5. Distribution of fluorescence intensities over one cell in differently aged modules.

Exemplarily, the distribution of fluorescence intensities across a cell in differently aged modules of one type is shown. A striking difference between the degradation distribution in modules aged with or without UV light becomes clear:

- DH aging causes strong fluorescence at the edges of the cells
- UV and UV/DH aged modules show strong fluorescence in the center of the cell and less at the edges

Conclusion

The degradation, especially of the encapsulant, results in yellowing and an increasing fluorescence background in the Raman spectra. The chemical properties of the back-sheet material, mainly the permeation properties, showed a significant impact on the fluorescence intensity.



A dependence of the degradation distribution on the aging procedure could be found. UV and UV/damp heat aging causes a degradation behavior similar to that observed whilst outdoor aging.

References

[1] Peike, C., Kaltenbach, T., Weiß, K.-A., Koehl, M.,"Non-destructive degradation analysis of encapsulants in PV modules by Raman Spectroscopy" Sol. Energy Mater. Sol. Cells 95, 1686–1693 (2011).

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