Silver grid finger corrosion on snail track affected PV modules - Investigation on degradation products and mechanisms

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Introduction

- Snail tracks
  - Silver grid finger corrosion
  - Diffusion of reactants → Cell crack or cell edges
  - Surface related, visible effect
- Not directly correlated to power loss
- Snail track degradation products = silver salts


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**Cross section scheme of PV module**

- Glass
- EVA
- Cell
- Back sheet
- Water vapor ($H_2O$), oxygen ($O_2$), carbon dioxide ($CO_2$)
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Motivation

- Results from years of snail track study showed the existence of
  - different visual appearance of snail tracks
  - different behavior to artificial stress of snail track

More than one snail track product?!
Experimental Set-up

- Analytics for product determination
  - Raman spectroscopy
  - Verification with EDX spectroscopy
  - Further stress tests for mechanism determination

- Snail track affected c-Si PV modules from field
- Preparation of cell part and corresp. EVA material out of the affected modules
Snail Track Products detected by Raman spectroscopy

- Silver acetate: $\text{Ag}_2\text{Ac}_2$
- Silver sulfide: $\text{Ag}_2\text{S}$
- Silver carbonate: $\text{Ag}_2\text{CO}_3$
- Silver phosphate: $\text{Ag}_3\text{PO}_4$

*Note: Silver sulfide is only found under artificial stress.*
1st Snail Track Product

\[ \text{Ag}_3\text{PO}_4 \]
Silver Phosphate $\text{Ag}_3\text{PO}_4$

- Possible other reactants:
  - oxidative reagents
  - potential
  - temperature

$$\text{Ag} + \text{R-PO}_4^{3-} \rightarrow \text{O}_2, \text{H}_2\text{O}, \square \text{Ag}_3\text{PO}_4$$

Phosphor content in encapsulants (phosphite additives)

<table>
<thead>
<tr>
<th>Company A</th>
<th>Company B</th>
<th>Company C</th>
</tr>
</thead>
<tbody>
<tr>
<td>rel. signal intensity</td>
<td></td>
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Raman spectroscopy on affected grid

Bands of $\text{Ag}_3\text{PO}_4$
2nd Snail Track Product

[Diagram showing a pie chart with Ag$_2$CO$_3$ highlighted in blue]
Silver Carbonate $\text{Ag}_2\text{CO}_3$

Norrish reaction I \textbf{and/or} CO$_2$ diffusion from back sheet?

\[
\begin{align*}
R_1-\text{CH}_2-\text{CH}_2&-\text{CO}_2\text{H} \rightarrow R_1-\text{CH}_2-\text{CH}_2-\text{CO}_2\text{H} + \text{CO}_2 + \text{H}_2\text{O} \\
\text{R}_1-\text{CH}_2-\text{CH}_2-\text{CO}_2\text{H} + \text{CO}_2 + \text{H}_2\text{O} &\rightarrow (\text{AgOH})\text{Ag}_2\text{CO}_3
\end{align*}
\]

SEM/EDX measurement on affected grid

Raman spectroscopy on affected grid

3rd Snail Track Product

Ag$_2$Ac$_2$
Silver Acetate $\text{Ag}_2(\text{CH}_3\text{COO})_2$

*Photochemical degradation of EVA*

\[
\text{Ag} + \text{CH}_3\text{COOH} \xrightarrow{\text{Norrish reaction II}} \text{UV, O}_2 \quad \text{Ag}_2(\text{CH}_3\text{COO})_2
\]

*Further accelerated UV test*

*Raman spectroscopy on affected grid*
Silver Acetate $\text{Ag}_2(\text{CH}_3\text{COO})_2$

*Photochemical degradation of EVA*

$$\text{R}_1\text{C}_n\text{H}_{2n+1}\text{C}_n\text{H}_{2n+1}\text{R}_2 \xrightarrow{\text{Norrish reaction II}} \text{R}_1\text{C}_n\text{H}_{2n+1}\text{=C}\text{R}_2 + \text{CH}_3\text{COOH}$$

$$\text{Ag} + \text{CH}_3\text{COOH} \xrightarrow{\text{UV, } \text{O}_2} \text{Ag}_2(\text{CH}_3\text{COO})_2$$

*Detailed image after accelerated UV test*

*Raman spectroscopy on affected grid*
4\textsuperscript{th} Snail Track Product

\[ \text{Ag}_2\text{S} \]
Silver Sulfide $\text{Ag}_2\text{S}$

Module with high (left) and low (left) oxygen transmission after damp heat test (85 °C, 85 % RH)

$\text{Ag} + \text{R-S}^2\text{-} \xrightarrow{\Delta T, \text{H}_2\text{O}, \text{O}_2} \text{Ag}_2\text{S}$

Sulfur content in back sheets (organic sulferous additives)

Raman spectroscopy on affected grid

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Summary

silver acetate
- Quality of EVA
- Gas permeability
- UV irradiation

silver carbonate
- Composition of cell metallization
- Gas permeability
- UV irradiation

silver sulfide
- Additives of back sheet
- Gas permeability
- Humid, high temperatures (85 °C, 85 % RH)

silver phosphate
- Additives of encapsulant
- Gas permeability
- Other reactants
Thank you for your attention!

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