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Blunt, Liam and Elrawemi, Mohamed

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Functional Modelling of Water Vapour Transmission Through Surface Defects Using Surface Segmentation Analysis

L. Blunt¹ and M. Elrawemi¹
¹EPSRC Centre for Innovative Manufacturing in Advanced Metrology, University of Huddersfield, UK;

Background
Flexible Photovoltaic (PV) modules are manufactured using roll to roll (R2R) technology. These modules require a flexible barrier material to prevent water vapour ingress into the core material.

Thin-Film Flexible PV Modules
Flexible solar modules comprise four functional layer groupings. The main focus of the investigation in this work is the barrier layer, which is incorporated in the encapsulation layers. This layer is typically formed from a planarised Polyethylene Naphthalate (PEN) sheet with an amorphous Al₂O₃ barrier coating (≤ 40 nm thick).

R2R Al₂O₃ ALD Barrier Film
Thin layers of aluminum-oxide, of the order of a few tens of nanometers deposited via R2R atomic layer deposition (ALD) method, have been introduced to allow PV modules transparency and flexibility and to provide an effective barrier layer.

Research Challenges
Micro and nano scale defects existing in the PV barrier films degrades their performance over time due to water vapour ingress.

Experimental Work
Two representative Al₂O₃ ALD samples were processed by the Centre for Process Innovation Ltd (CPI). The samples have an 80 mm diameter area coated with a 40nm Al₂O₃ layer. The WVTRs of samples were carried out using an Isostatic Standard test method (MOCON®) at specified conditions of (38 °C and 90% RH) respectively.

Mathematical Model
The basic assumption of the model is that, the combined film of thickness L has a transparent flexible barrier coating of (Al₂O₃) with a single circular hole (defect), and that it is exposed to permeant water vapour from the lower side. This orientation is consistent with that used in a MOCON® test.

Permeability coefficient \( K = \frac{(\text{quantity of permeant}) \times \text{(film thickness)}}{(\text{area}) \times \text{(time}) \times \text{(pressure drop across the film)}} \) (1)

\[ P_s = \frac{D \times S}{L} = \frac{q_L}{T} \left( \frac{\text{cm}^2 \text{ cm}}{\text{cm}^2 \cdot \text{s} \cdot \text{Pa}} \right) \] (2)

\[ Q = \frac{\text{area}}{L} \times \pi \frac{D}{D_L} \frac{D}{D_F} \] (3)

\[ \text{WVTR} = \frac{Q}{A} \left( \frac{\text{m}^2}{\text{day}} \right) \] (4)

Table 1. WVTR at 38°C and 90% RH

<table>
<thead>
<tr>
<th>Sample No</th>
<th>Water vapor transmission rate (g/m²/24 hrs.)</th>
<th>Stabilisation time (day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.1×10⁻³</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>2.0×10⁻³</td>
<td>5</td>
</tr>
</tbody>
</table>

Results
The results seem to show that for the barrier coating a small number of large defects dominates the WVTR, and thus these defects should be the focus of any detection system.

Conclusion
The segmentation analysis method and the theoretical model results, both indicate that the major contributing factor for determining the WVTR is the total number of larger defects, where the sample with higher density of defects > 3 µm (lateral diameter) exhibit inferior barrier properties. Therefore, the critical spatial resolution required for defect detection need not be less than 3 µm, as any defect that has less than this lateral size seems to have a much lower effect on the barrier properties.

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References