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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. Blunt** and M. Elrawemi

*EPSRC 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.

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.

**Experimental Work**

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 the MOCON® test.

**Mathematical Model**

The permeability coefficient is given by: $P_v = \frac{D \times S}{L} = \frac{\bar{D} \times L}{L} = \frac{\bar{D}}{L}$

The WVTR is given by: $WVTR = \frac{Q}{A} \left( \frac{m^2}{day} \right)$

**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.

**Surface Characterisation and Analysis**

Quantitative surface measurement was carried out using optical interferometry (CCI-3000 Taylor Hobson Ltd.) and the topography was characterised using areal parameters (ISO25178-2, 2012). Segmentation analysis was carried out on the data (700 data files) in order to extract and count the number of significant defects present on the substrates.

**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**
