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

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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.

Fig.1 Roll-to-Roll flexible PV modules [Source: Grafisk Maskinfabrik A/S]

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 Al_2O_3 barrier coating (≤ 40 nm thick).

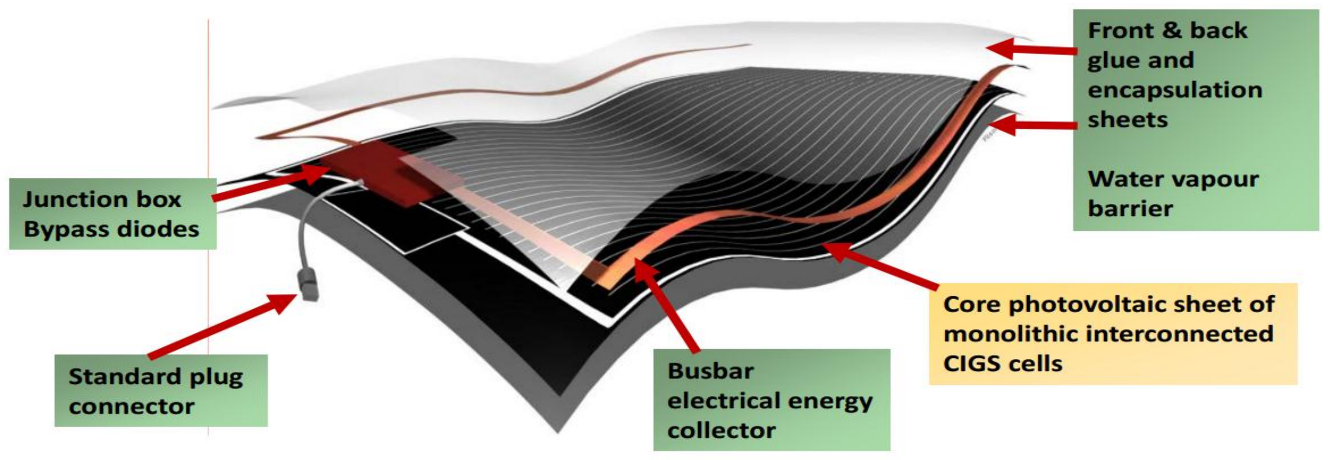


Fig. 2 Flexible PV modules [Courtesy of Flisom, Switzerland]

R2R Al_2O_3 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.

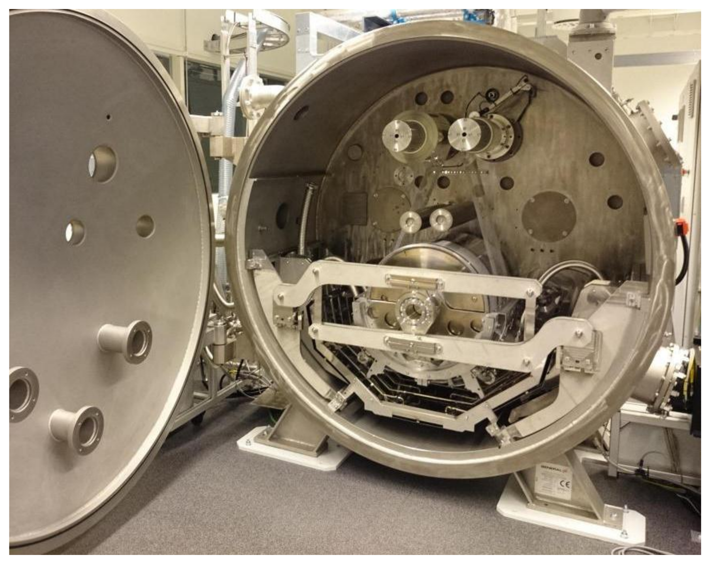


Fig. 3 R2R coater [Courtesy of Centre for Process Innovation]

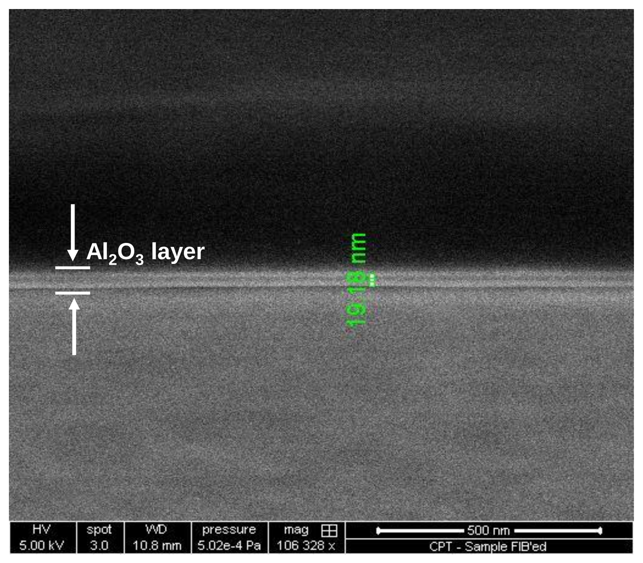


Fig. 4 The FIB image of Al_2O_3 encapsulated PEN film

Research Challenges

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

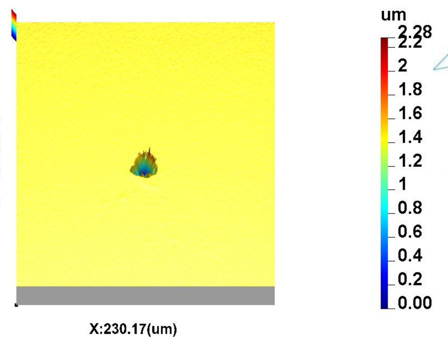


Fig. 4 Hole type defect (CCI-3000 image)

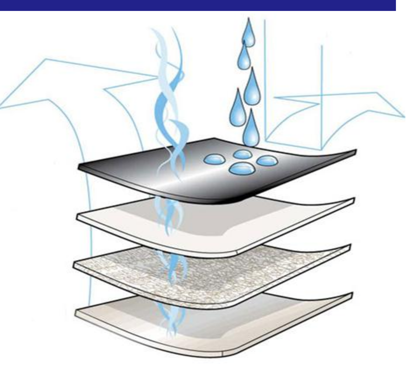


Fig. 5 Water vapor ingress

Experimental Work

Two representative Al_2O_3 ALD samples were processed by the Centre for Process Innovation Ltd (CPI). The samples have an 80 mm diameter area coated with a 40nm Al_2O_3 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.

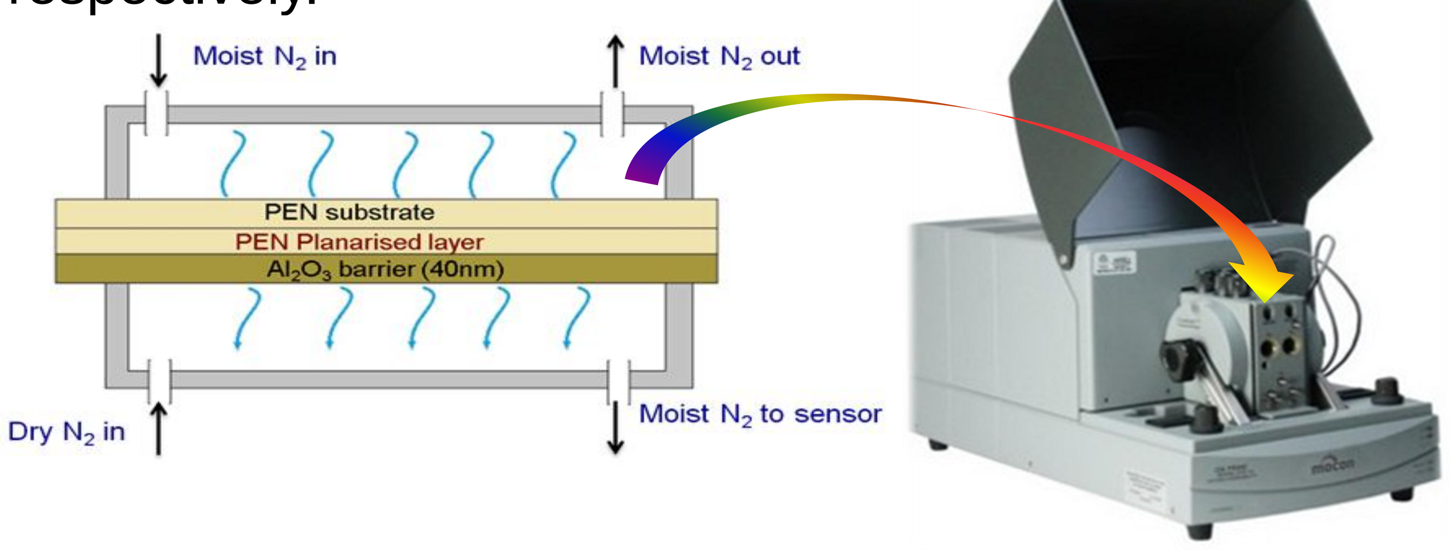
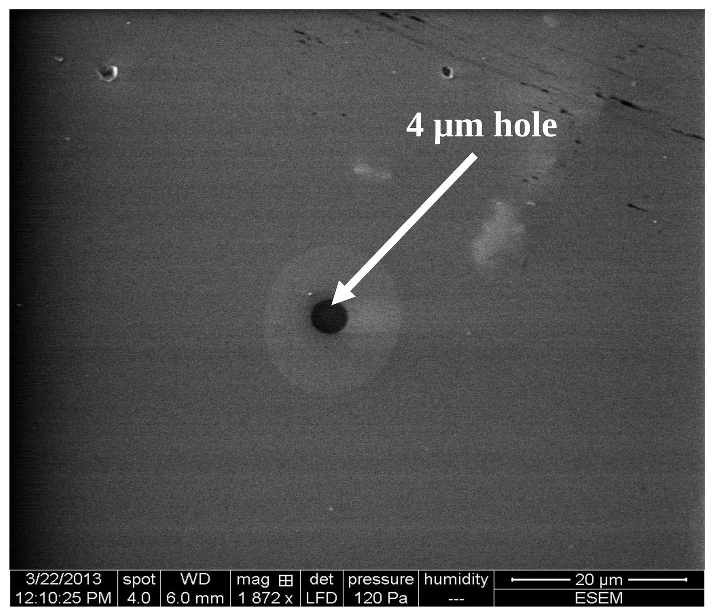


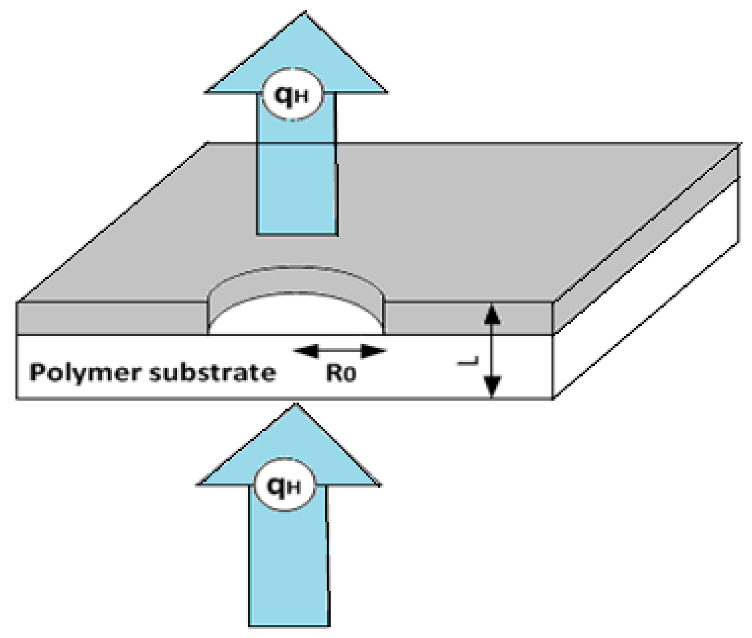
Table 1. WVTR at 38C° and 90% RH

Sample No	Water vapor transmission rate (g/m²/24 hrs.)	Stabilisation time (day)
1	4.1×10^{-3}	5
2	2.0×10^{-3}	5

Mathematical Model

The basic assumption of the model is that, the combined film of thickness L has a transparent flexible barrier coating of (Al_2O_3) 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.





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

$$P_r = D \times S = \frac{q\,L}{A\,t\,P}\left(\frac{cm^3\,cm}{cm^2.s.Pa}\right) \quad (2)$$

$$Q = \frac{q_H}{t} = \frac{\pi R_0^2\, D\, \emptyset}{L} \quad (3)$$

$$WVTR = \frac{Q}{A}\left(\frac{g}{m^2}\Big/day\right) \quad (4)$$

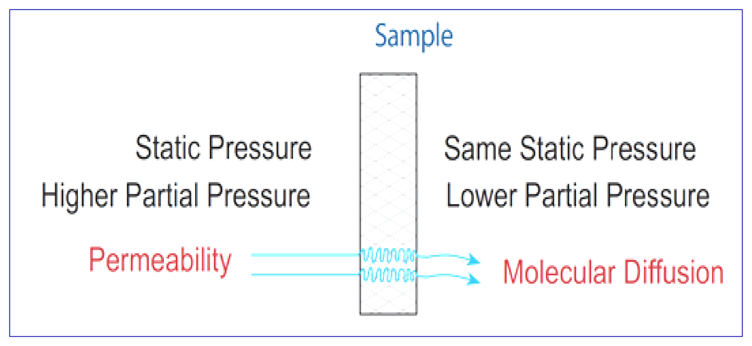
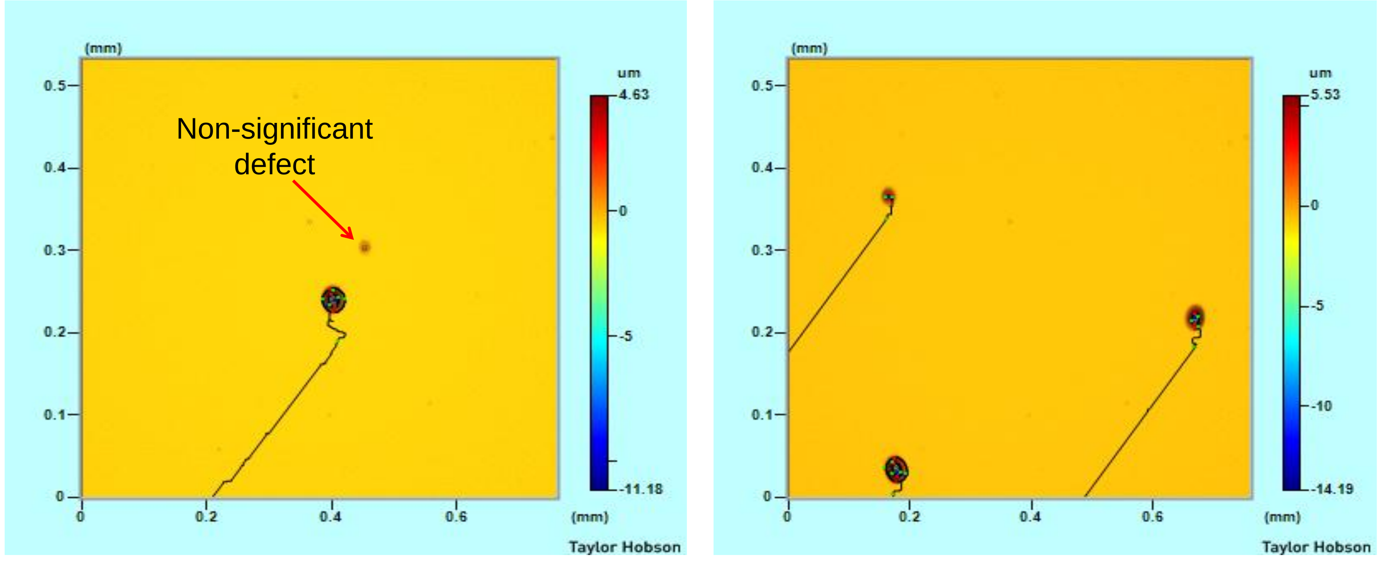


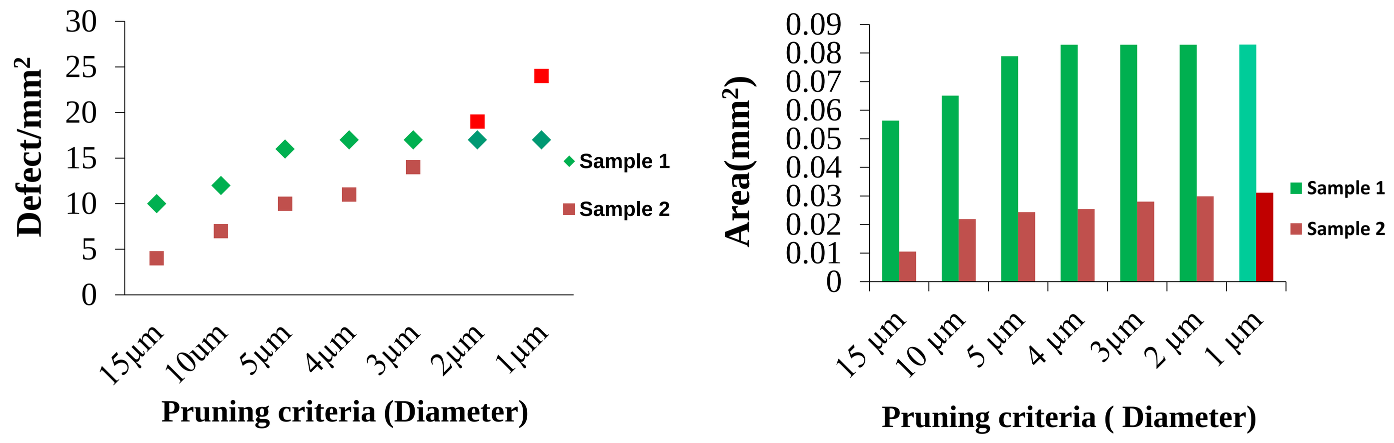
Fig. 6 Pressure gradient across a sample

Surface Characterisation and Analysis

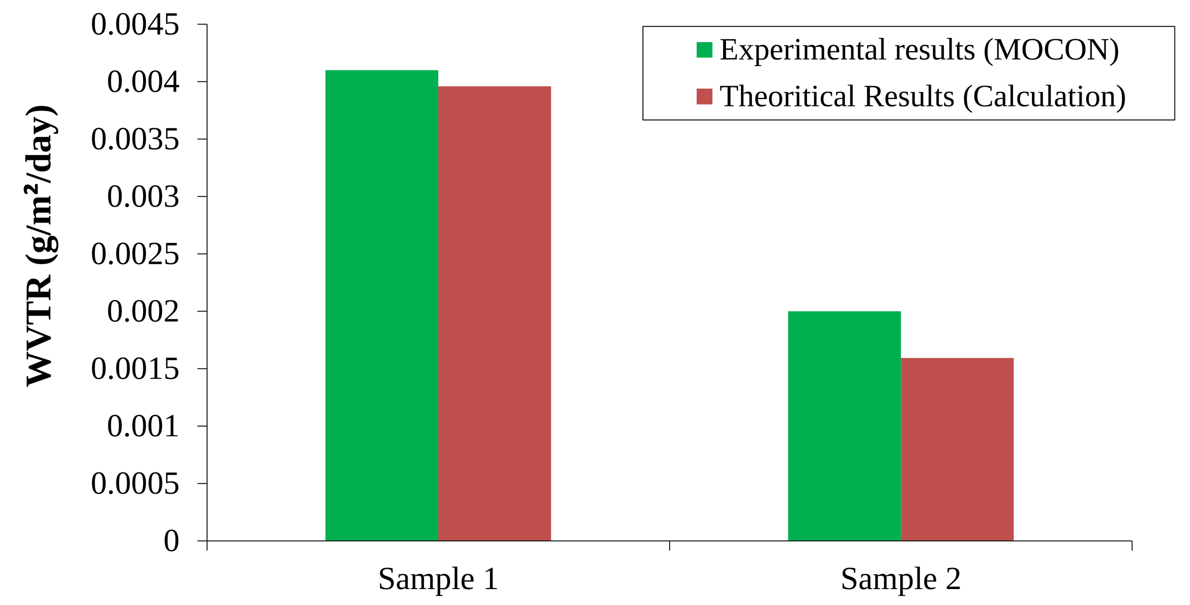
Quantitative surface measurement was carried out using optical interferometry (CCI-3000 Taylor Hobson Ltd.) and the topography was characterised using areal parameters (ISO25178-2, 2012). Segmentation analysis was carried out on the data (700 data files) in order to extract and count the number of significant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



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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