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Metrology and Characterisation of Micro and Nano-scale Defects for Aluminium Oxide Barrier Films Employed in Flexible Photovoltaic Modules

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Background

Today's roll-to-roll (R2R) technologies are well known in the field of packaging manufacture. They offer high productivity, reasonable coating cost and good reliability. R2R technology can be much more environmentally benign and energy-efficient process as compared to wafer-based or vacuum-based manufacturing.

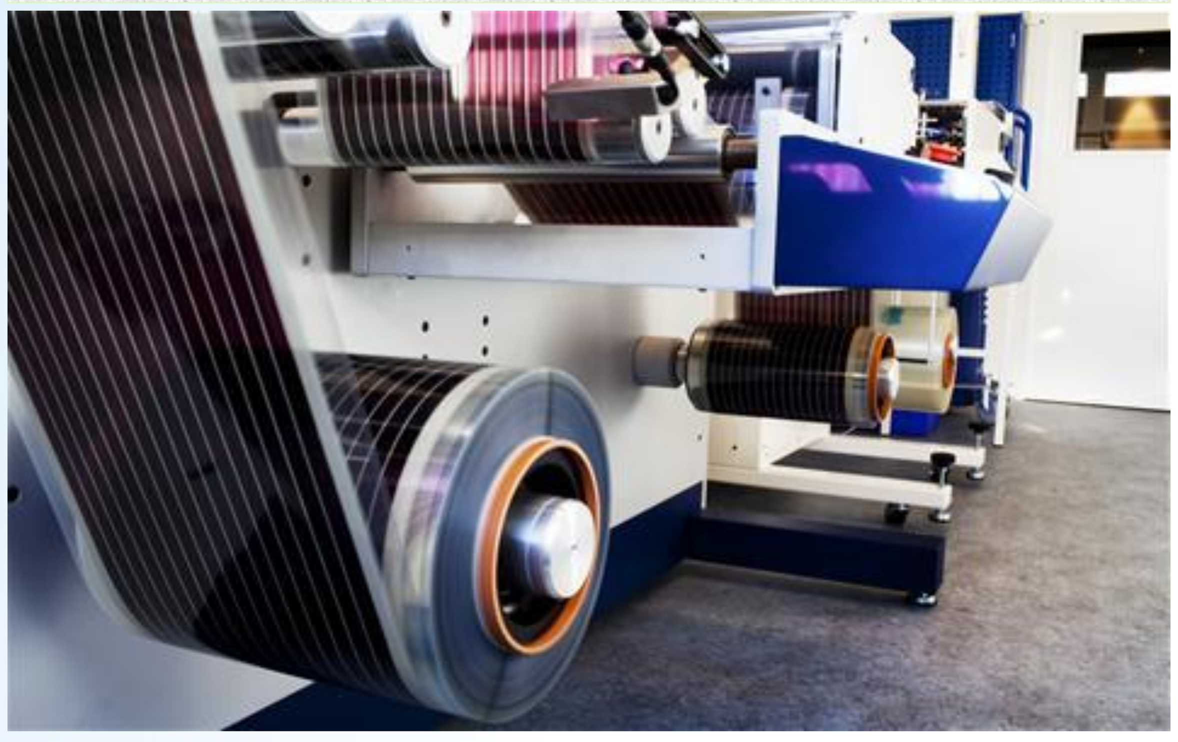

Fig.1 Roll-to-roll manufacturing process

Flexible PV Module

The state-of-the-art flexible PV film technologies have efficiencies at or beyond the level of Si-based rigid PV modules currently in use, are those based on the material $CuIn_{1-x}Ga_xSe_2$. However, they are highly susceptible to long term environmental degradation.

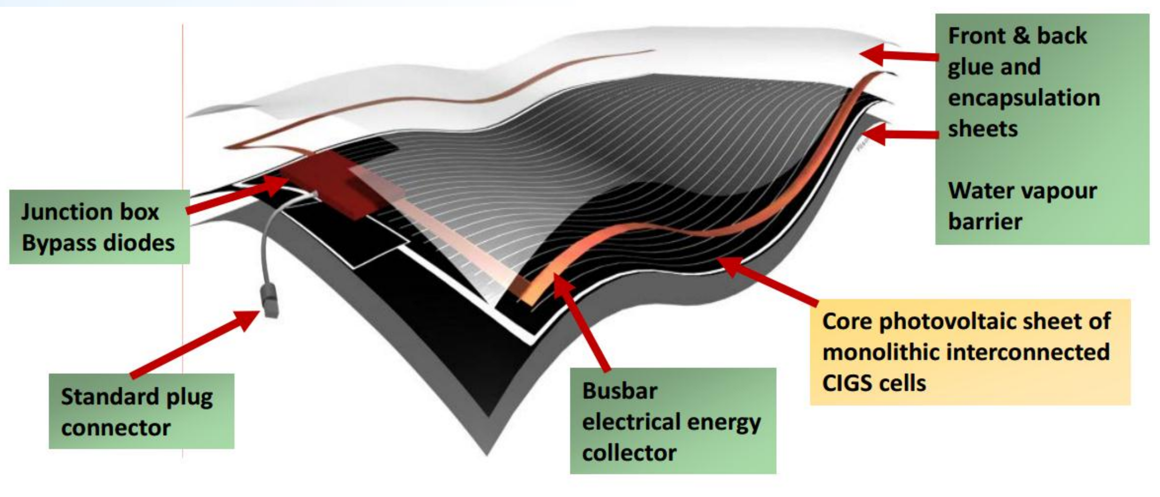

Fig. 2 Structure of CIGS PV module (Courtesy of Flisom, Switzerland)

Manufacturing Challenge

The most critical problem of CIGS PV modules is the transmission of water vapor into the active layer (CIGS). According to international standard (IEC 61646), A WVTR of ~10^{-1} g/m²/day is sufficient for most packaging applications, but ≤10^{-6} g/m²/day is required for encapsulation of long-life flexible PV modules as shown in figure (3).

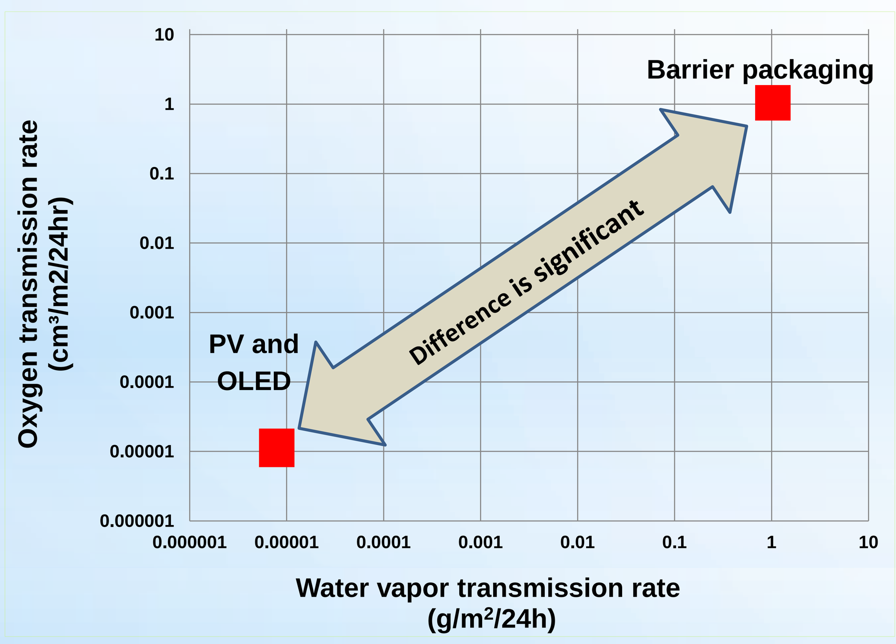

Fig. 3 OTR versus WVTR requirements for different applications [1]

PV Environmental Protection

Environmental protection of the GIGS cells can be provided by a thin (40nm) barrier coating of Al_2O_3. The highly conformal aluminium oxide barrier layer is produced by atomic layer deposition (ALD) where, the ultra-thin Al_2O_3 layer is deposited onto polymer thin films before these films encapsulate the PV cell. However, even these barriers are not 100% effective. Water vapour permeation still caused by micro and nano-scale defects in the barrier coating.

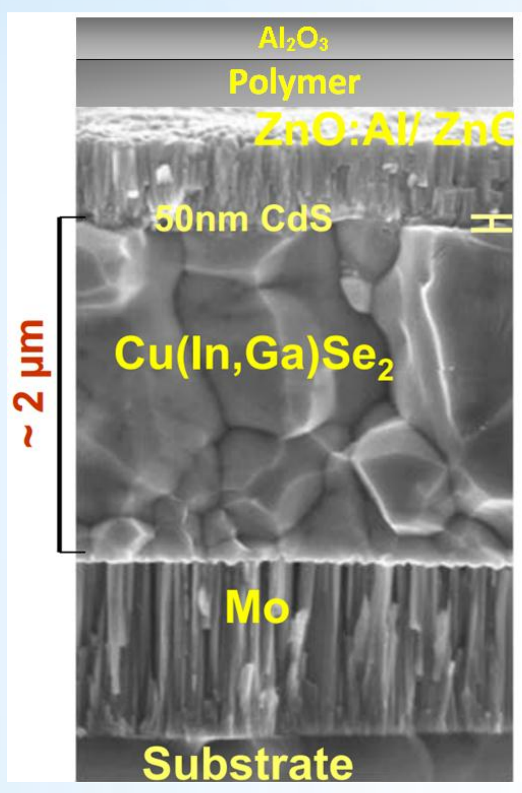

Fig. 4 Barrier film layers(Courtesy of Flisom, Switzerland)

Cataloguing of the Defects

A set of Al_2O_3 ALD representative samples were assessed for environmental degradation test "MOCON". Following that surface metrology techniques were employed to detect defects are postulated to be responsible for causing efficiency drop. Different types of features were noted on each sample; these features are different in terms of their type and size. Typical examples of these features are shown in the following figures.

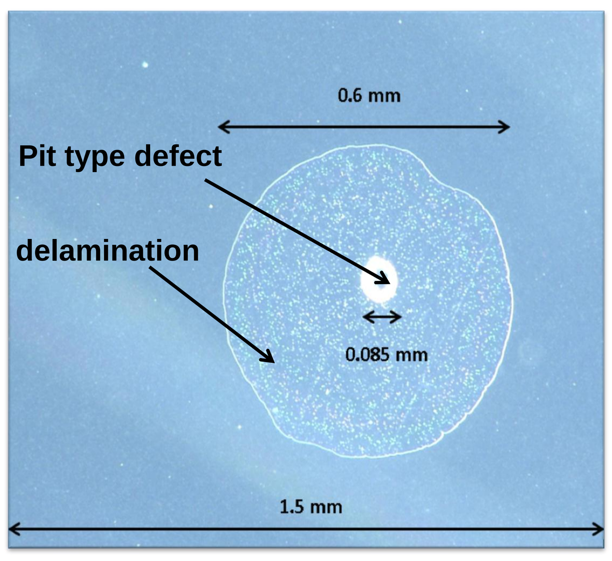

Fig. 5 x 200 Optical Microscope image Scale of large defect (possible delamination)

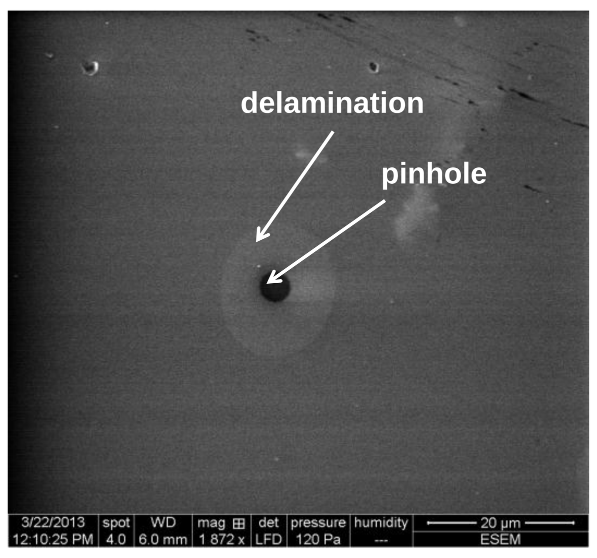

Fig. 6 ESEM image "Scale of small defect" (Hole type defect)

Methodology

A method of 'Wolf pruning' (ISO 25178-2:2012) has been utilised to carry out topography segmentation analysis. This method provide a reliable approach for extracting features of functional interest by accurately excluding insignificant geometrical features that are induced such as measurement noise [3]. In order to extract information relating to the defects, segmentation analysis was applied.

Segmentation Process

Surface segmentation through Wolf pruning method with threshold conditions at area prune 2.5% of the total area, and area combine of 1% of Sz was found to be optimal prune criteria which could help to predict PV module efficiency degradation and lifespan reduction.

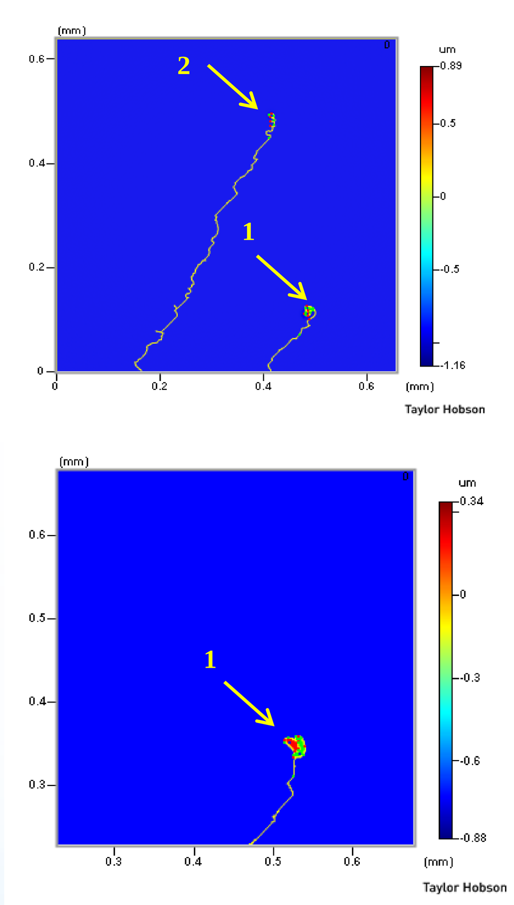

Fig.7 Defects after segmentation

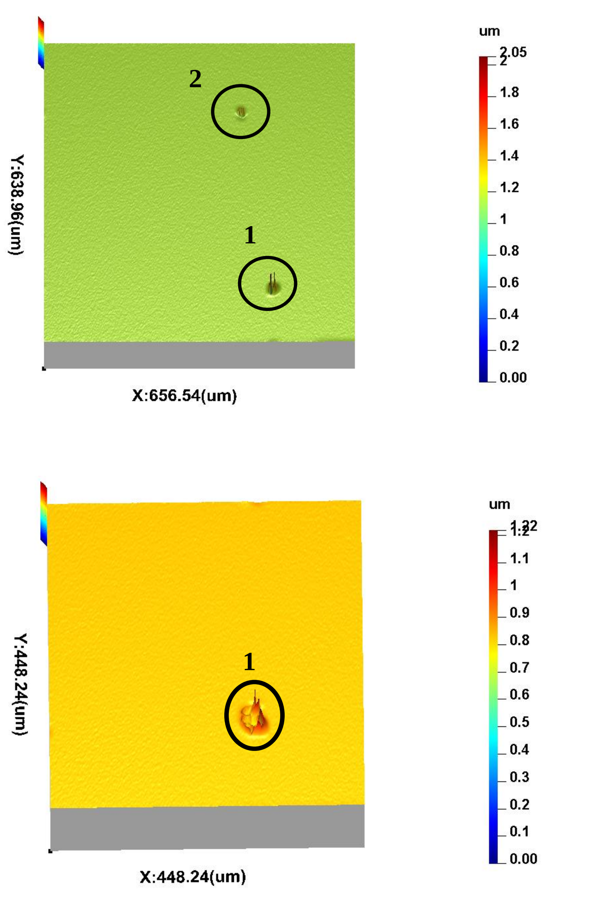

Fig. 8 Defects count before segmentation

Results and Discussion

Feature parameters have been shown to correlate with solar cells barrier performance and lifespan. Thus, monitoring the barrier film surface texture to maintain process parameters would increases the quality of the solar cell produced.

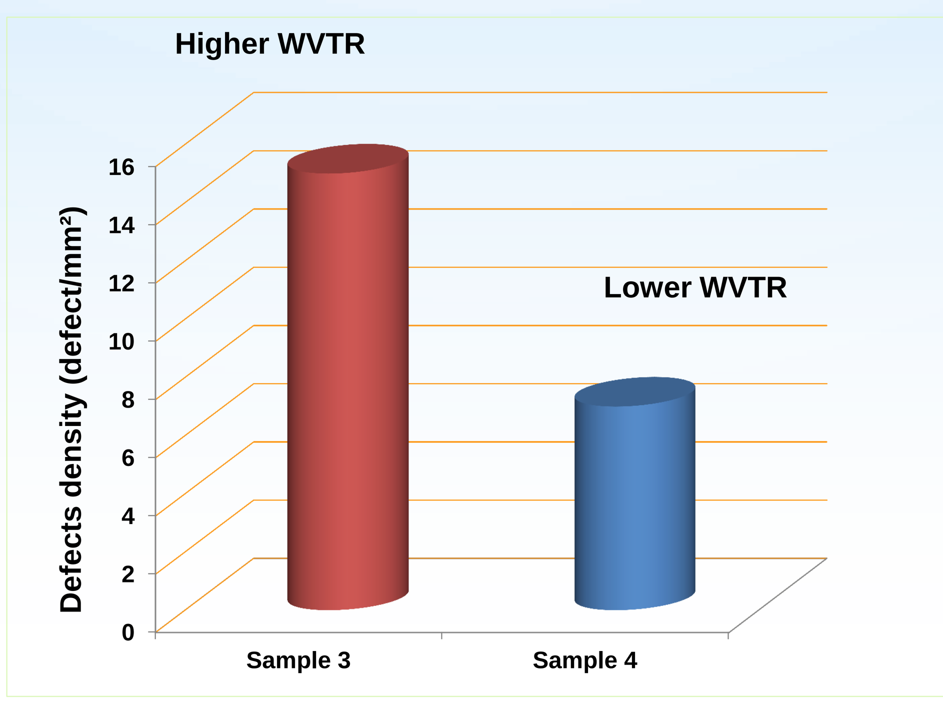

Fig. 9 Defect density values for coated barrier substrates

Analysis of the results showed that there was good correlation between the number of large defects and the WVTR value. The "poor" specimen had a larger density of significant defects as compared to one of the better performing substrates.

Conclusion

The results suggest that small numbers of large defects have the dominant effect on the WVTR .This study provides the basis for in process metrology for roll 2 roll production of barrier coatings for flexible PV modules.

Process Optimization Solutions

The Wavelength Scanning Interferometry (WSI) will be mounted as a metrology tool on the linear stage, where the goal is to achieve the z-positioning with an auto focus option within the WSI. A capture of the WSI takes approximately 2 seconds, where a 3D measurement of the surface will be achieved.

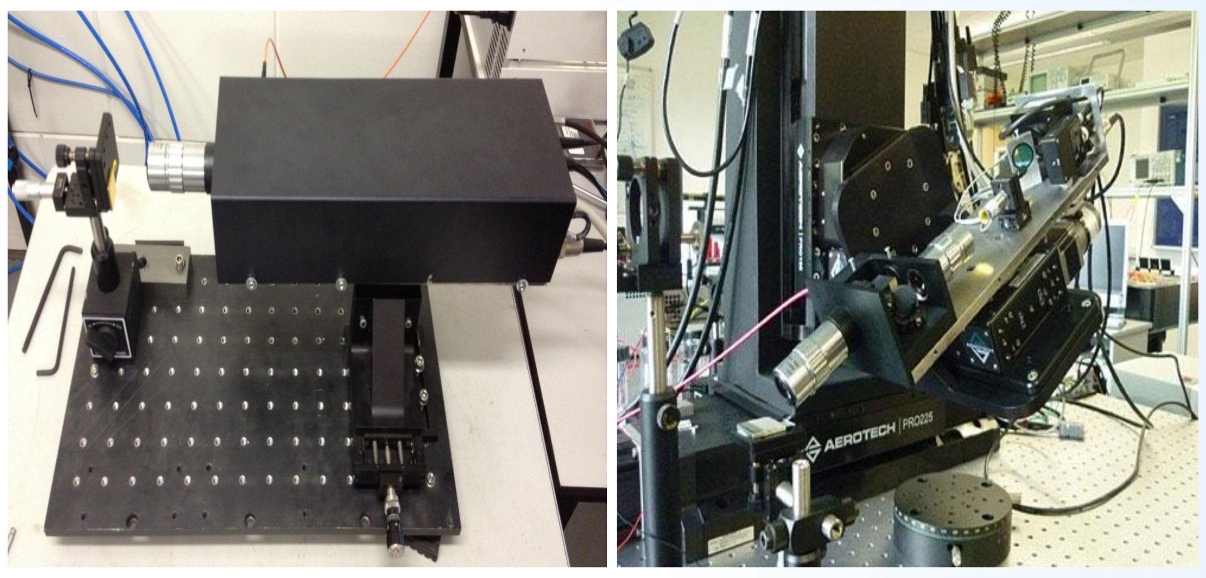

Fig. 10 Photo of WSI in test setup

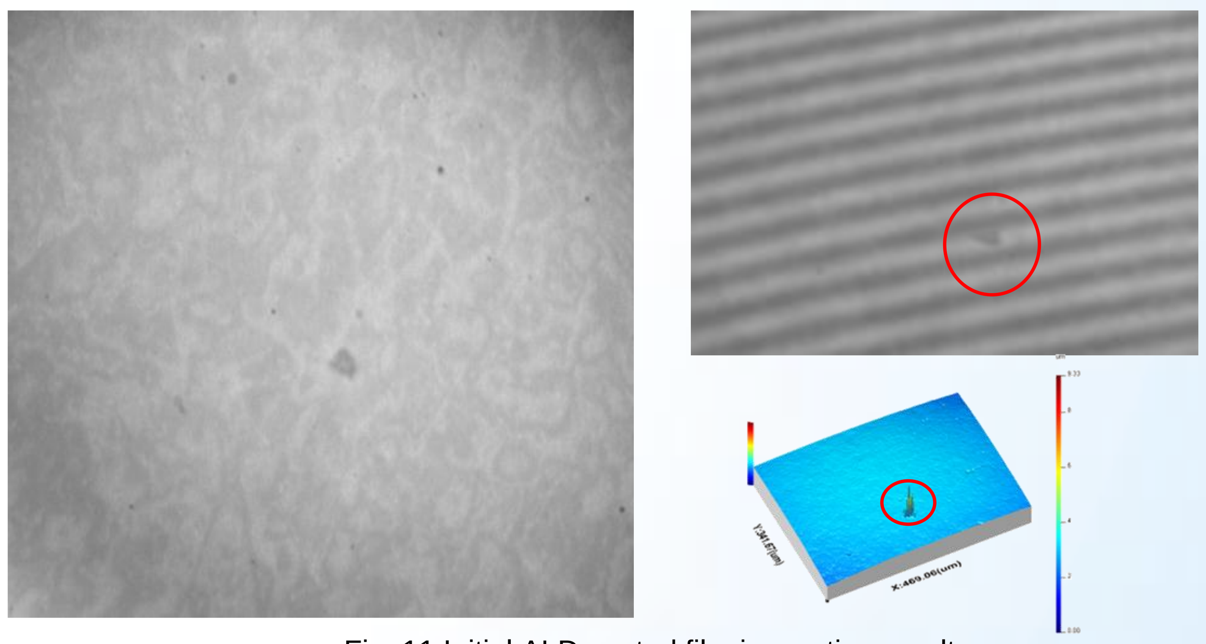

Fig. 11 Initial ALD coated film inspection results

Research Impact

- ✓ High efficiency solar cells.
- ✓ Low cost.
- ✓ Light weight solar modules.
- ✓ Flexible solar modules.
- ✓ Maximise production yield.
- ✓ Reduction in scrap.
- ✓ Maximise production speed.
- ✓ Less energy.
- ✓ Low cost.

Future work

- Implementation of on line metrology for the roll to roll ALD process at the centre for Process innovation (CPI) using the knowledge gained from the present work.
- Implementation of the areal feature analysis to carry in-line metrology and process control.

References

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