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Metrology and Characterisation of Micro and Nano-scale Defects for Aluminium Oxide Barrier Film 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.

**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 CuInGaSe₂. However, they are highly susceptible to long-term environmental degradation.

**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 \( \leq 10^{-11} \) g/m² day is sufficient for most packaging applications, but \( \leq 10^{-6} \) g/m² day is required for encapsulation of long-life flexible PV modules as shown in figure (3).

**PV Environmental Protection**

Environmental protection of the CIGS cells can be provided by a thin (40nm) barrier coating of Al₂O₃. The highly conformal aluminium oxide barrier layer is produced by atomic layer deposition (ALD) where, the ultra-thin Al₂O₃ 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.

**Cataloguing of the Defects**

A set of Al₂O₃ 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.

**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 Sx was found to be optimal pruning criteria which could help to predict PV module efficiency degradation and lifespans reduction.

**Results and Discussion**

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

**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.

**Research Impact**

- High efficiency solar cells.
- Low cost.
- Low 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**