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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 \(\sim 10^{-3} \text{g/m²/day} \) is sufficient for most packaging applications, but \(\leq 10^{-4} \text{g/m²/day} \) 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 LVs was found to be optimal pruning criteria which could help to predict PV module efficiency degradation and lifespan reduction.

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.

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.
- Light weight solar modules.
- Maximise production yield.
- Maximise production speed.
- Less energy.
- Low cost.
- Implementation of in-line metrology and process control.

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


Fig. 1 Roll-to-roll manufacturing process

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

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

Fig. 4 Defect density values for coated barrier substrates

Fig. 6 ESEM image “Scale of small defect”

Fig. 7 Defects after segmentation

Fig. 8 Defects count before segmentation

Fig. 9 Defect density values for coated barrier substrates

Fig. 10 Photos of WSI in test setup

Fig. 11 Initial ALD coated film inspection results

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