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Implementation of wavelength scanning interferometry for R2R flexible PV barrier films

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Abstract
Roll to Roll manufacture of nano-scale thin film layers faces the challenge of micro/nano-scale defects appearing in the films. Atomic Layer Deposition (ALD) coatings of aluminium oxide, Al_2O_3 are used as barrier layers for photovoltaic (PV) solar modules where the primary function of the barrier layer is to prevent the water vapour ingress to the PV cells. Barrier layer defects have been shown to have negative impact on the performance of the barrier layers. Poor barriers cause module degradation resulting in reduced PV efficiency and lifespan. In order to ensure the quality of manufacture of the barriers, defects should be detected during the barrier production process and the information used to optimise the production process. This paper introduces, as part of EU funded NanoMend project, a full solution for inspection of entire surface regions of Al_2O_3 barrier films across large area substrates. The solution principle is based on implementing an opto-mechanical in-process inspection system to measure the significant defects using a wavelength scanning interferometer (WSI) embedded within the film-rewinder stage and integrated with the substrate translation and kinematic stages. The opto-mechanical system allows full surface measurement over full substrate widths of approximately 0.5m. The system provides an auto-focus for the WSI with an accuracy and repeatability better than 6 µm at optimum optical alignment conditions. The system is combined with a porous air-bearing conveyor used to hold the film web at fixed height within the focal depth of WSI objective lens and with height variation of < 5 µm under optimum vacuum pressure. The paper also outlines a computerised data handling process that can be used to assess hundreds/thousands of measurement files automatically by extracting and monitoring the areal root mean square roughness parameter (*Sq*) and defect statistics. Measurement results for functionally significant defects with lateral size > 3 µm is also presented as a case study to highlight the system capability.

Keywords: Roll to roll process, defect measurement, Al_2O_3 barrier, wavelength scanning interferometer, WSI, opto-mechanical inspection system, data handling

1. Introduction

Flexible PV cell degradation due to water ingress can be minimised and controlled by implementing a thin (40-100 nm thick) barrier coating of Al_2O_3 using atomic layer deposition techniques (ALD). However, it has been found in previous studies that there is a correlation between surface defects in the film barrier and the water vapour transmission rate (WVTR) [1]. In order to guarantee the barrier condition, surface inspection needs to be carried out during the roll to roll (R2R) manufacturing process. However, measuring the entire surface topography of barrier coatings over a large area substrate, under laboratory conditions, is impractical and very time consuming. Current instrumentation suffers from the inability to perform embedded (on-line) measurement and is only able to sample of very small selected zones, effectively batch sampling. In this paper the authors introduce the implementation of an on-line opto-mechanical inspection system capable of detecting and identifying surface defects such as pinholes and particles down to a lateral size of 3 µm and vertical resolution of 10 nm over 500 mm barrier width.

2. The Opto-mechanical inspection system

The difficulties in performing high fidelity surface measurements during roll to roll manufacturing process are directly related to the 'noisy' working environment, speed of production throughput and the large area that needs to be covered. Interferometric techniques have the potential to be used for on-line surface measurement but they are susceptible to environmental disturbances and subject to limited field of view (FOV) especially if high objective lenses are considered in the optical setup. The opto-mechanical system presented in this paper is based on wavelength scanning interferometry (WSI) combined with a built-in stabilisation element to compensate for environmental disturbances. The WSI is also integrated with a traverse stage (to allow full surface measurement over the substrate widths of 0.5 m) and vertical auto-focus stage (to position the WSI focus plane on the top layer of the film). The opto-mechanical system is embedded within the context of the film re-winder stand using a metrology frame and kinematic stages, resulting in the ability to align the WSI relative to film substrate. One of the measurement challenges is to guarantee the flatness of the film at a fixed height across the substrate width. A porous air-bearing conveyor is used to fulfil this condition and hold the film within the focal depth of the objective lens.

The roll to roll re-winder system has been implemented at the Centre for Process Innovation (CPI) Ltd as proof of concept demonstrator to investigate the Al_2O_3 ALD coating process by measuring and classifying all relevant defects on polymer film, see Figure 1.

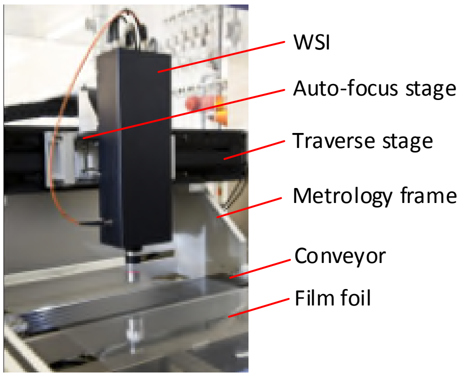

Figure 1. Opto-mechanical system on film re-winder stand

2.1. Wavelength Scanning Interferometry (WSI)

WSI, as shown in Figure 2, is employed to measure the surface topography of the barrier coating without the well-known 2π phase ambiguity limitation. The interferograms are produced with no mechanical movement by scanning the wavelength of a halogen light in the visible region (683.4 nm-590.9 nm) using an acousto-optic tuneable filter (AOTF). During the scanning process, 256 frames are typically captured and transferred to a graphic processing unit (GPU) in order to accelerate the fringe analysis process down to less than a second. Fringe analysis based on Fourier theorem can effectively retrieve the 3D surface map of the barrier layer. In addition, the WSI can be stabilised against environmental disturbances by using an active control of the reference arm [1]. This active control consists of a reference interferometer, which provides positional feedback, and a piezo-electric transducer (PZT), which moves the reference mirror.

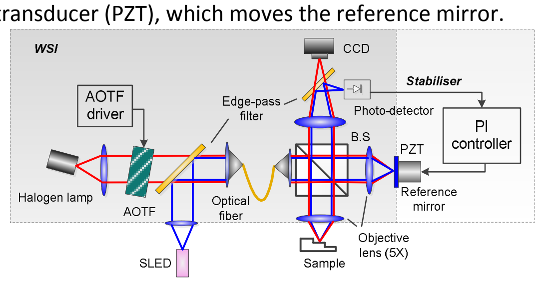

Figure 2. WSI configuration [2]

2.2. Auto-focus function

The auto-focus method is based on tracking the peak of the coherence envelope of the reference interferometer sourced by the SLED, see Figure 3, when the WSI head is moved normal to the web to scan the focal plane of the WSI objective lens using a stepper motor [2]. Simultaneously the intensity response is monitored by the reference interferometer, with the maximum intensity (coherence envelope peak) being found to be the point of focus.

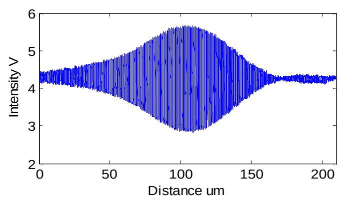

Figure 3. Coherence envelope of SLED

2.3. Air bearing system

The film handling for roll to roll process demands non-contact solution that supports the film at a fixed height and maximises the flatness of the web relative to the measurement plane. An air bearing conveyor type H-Series from New Way Ltd was used to supply uniform clean dry air (CDA) pressure, through a porous medium with a thin air gap, resulting in a more consistent flying height and better flatness across the full width of the flexible foil web < 5um.

3. Computerised Method for data handling

Many measurement files (typically 1000 measurement files per substrate width with overall data size larger than 300 M byte) will be produced over large area substrates with a limited field-of-view (FOV = 0.5mm x0.7 mm for 5x objective lens). To access these files automatically, a computerised solution was developed based on monitoring surface topography parameters as illustrated in Figure 4. Significant defects have a direct impact on the global surface roughness of the measured data set. Consequently the *Sq* parameter is chosen as a monitoring function to distinguish between data sets with significant and non-significant/free defects.

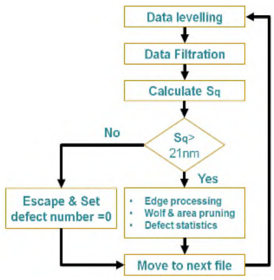

Figure 4. Computing model of data handling method

3. Measurement results

Gold coated PET film has been measured to obtain preliminary results in situ, where defects are detected as shown in Figure 5. The system was then run to capture a series of static areal measurements over the Al_2O_3 ALD foil, comprising 216 measurements in 1hr, thus allowing significant areas but not the entire substrate surface to be measured.

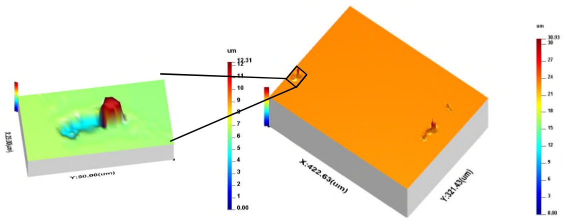

Figure 5. In situ coated film measurement, inset image 50 x 25 µm

4. Conclusion

The opto-mechanical system can be considered as a solution for R2R process as combined to traverse and autofocus stages and air bearing conveyor. The data handling model can effectively distinguish significant defects from non-significant defects without interaction from the inspector.

5. Acknowledgement

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