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R2R in-situ defect detection system for thin film barrier coatings used for flexible PV’s

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A brief introduction

A flexible PV is assembled from several functional layers.

1) High volume large area foil production often involve the deposition and patterning of multi-layer thin films on large area substrates and foils. To achieve high yield in the coating and patterning processes the films must be uniform and largely perfect over most of the area of the foil.
2) There is an increased risk of defects forming as the number of interfaces increases in the multi-layer films.
3) Inspection of the foil surface at production speed with sufficient resolution to detect the presence of problem defects on the starting foil surface and the defects as they appear during the coating and patterning processes.
4) Effective inspection is the key for further process such as applying local repair techniques to remove the defects from the film surface.
5) Currently there is no effective inspection method that can be applied for the above applications where defects are above a few micrometres height or foil deviation is over several um.

Challenges

1) Non-contact surface measurement with nanometre vertical resolution and over a few tens micrometres vertical measurement range
2) Robust against environmental and mechanical disturbance of roll-to-roll film production line
3) Robust against film surface vibration and deformation on the production line.

Flexible PV modules

Flexible PV modules are manufactured using roll to roll (R2R) technology. These modules require a flexible barrier material to prevent water vapor ingress.

PV Encapsulation requirements

• The WVTR of present barriers is in the range of $10^{-1}$ g/m²/day, while it should not be higher than $10^{-4}$ g/m²/day to assure life-times of 20 years and more.
• A robust, transparent flexible encapsulation method for flexible PV modules is needed.
Environmental Degradation

Accelerated Life tests
- 1000 hours at 85 °C and 85% relative humidity, with simulated solar illumination.
- Efficiency drop due to water ingress due to defects

No barrier

NanoMend

NanoMend - Nanoscale Defect Detection, Cleaning and Repair for Large Area Substrates

Aim: To develop technologies that are able to detect and correct micro and nano-scale defects in roll-to-roll produced films in order to improve product performance, yield and lifetime.

Flexible Photovoltaic Modules

Flexible photovoltaic (PV) cells
- Active technology - CIGS (Copper indium gallium (di)selenide)
- Roll-to-roll process – potential for low cost PV modules
- Control of efficiency degradation over product lifetime vital.

Flexible Photovoltaic
Modules

Al₂O₃ Vapour Barrier Layer

Backsheet Encapsulation

Al₂O₃ Vapour Barrier Layer produced by atomic layer deposition (ALD) (312 cycles)

Defects classification system

Defect classification system as applied to barrier layer

DETECT CLASSIFICATION, as applied to barrier layer:
- Pin holes
- Holes
- Cracks/scratches
- Particulate debris
- Delamination
- High roughness

According to NanoMend research, the inwardly and outwardly directed defects are in the range of a few micrometres to a few tens micrometres laterally, a few nanometres to tens micrometres vertically, the delamination defects are at a range of a few millimetres to a few tens millimetres laterally.

Technologies developed in the CIMAM

---Wavelength scanning interferometry

Areal Measurement
- Rapid Thin Film and Structured Surface Measurement
- No mechanical movement required
- Vibration isolating capability
- GPU enabled parallel data processing
- Static substrate needed
Technologies under development in the CIMAM ---- Spectrally Resolved White Light Interferometry

- Spectrally resolved white light interferometry (SRW LI)
  - An alternative to WSI, large scale measurement range with a single spectral interferogram
  - Surface profile measurement

- Mirau Configuration
- Michelson Configuration

- CCD
- Halogen Light Source
- Cylindrical lens
- Sample
- Reference mirror
- Grating

Experimental setup of the SRW LI system

Defects detection comparison studies

- SEM image
- CCI image
- WSI image

Required Analysis: Running defect map using multi sensors configuration

Current Build Status

- Traverse stage
  - It will be used to translate the WSI cross the foil

- Autofocus stage
  - It will be used to auto-position the WSI head so its focal point is at the top layer of Al₂O₃ barrier

- WSI
  - It will be used for surface measurement

- Air bearing stage
  - It can hold the foil without any mechanical contact to a specific height by an array of air based actuators.

Initial tests

- A series tests on the R2R film shown the system was able to perform the defect inspection for the first dozens of individual tests.
- Test results became corrupt after a few dozens of tests.
- To find out the source of this problem, a series tests on the system operating conditions, auto-focus system and its repeatability and the system alignments have been conducted.
- The test results are critical and will provide guidance for future system adjustment and operation.
Repeatability test of the autofocus system on the standard sample

- The tests conducted on the surface of a NPL Bento Box calibration standard
- The z positions of the tests are recorded in the above table.
- The autofocus system only works on the condition that the surface is aligned with less than 5 fringes in the imaging field.
- The repeatability of the autofocus system is 5.48 µm on the calibration standard surface when the surface is properly aligned.

<table>
<thead>
<tr>
<th>Z position (mm)</th>
<th>0.008</th>
<th>0.008</th>
<th>0.008</th>
<th>0.008</th>
<th>0.008</th>
<th>0.008</th>
<th>0.008</th>
<th>0.008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.008</td>
<td>0.008</td>
<td>0.008</td>
<td>0.008</td>
<td>0.008</td>
<td>0.008</td>
<td>0.008</td>
<td>0.008</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
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<tr>
<td>Mean deviation</td>
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</tbody>
</table>

Repeatability test of the autofocus system on uncoated PET film

- The tests conducted on uncoated PET film with 35µm thickness and 400 mm width.
- Five traverse stage positions are selected for the tests.
- Autofocus repeatability is around 10 µm at three positions, which is adequate for the test.
- The autofocus at the other two positions were not functioning.
- The causes are due to the local surface tension and slope.

<table>
<thead>
<tr>
<th>Z position (mm)</th>
<th>1.543</th>
<th>0.555</th>
<th>1.614</th>
<th>1.618</th>
<th>1.653</th>
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<tbody>
<tr>
<td>Mean</td>
<td>1.600</td>
<td>1.600</td>
<td>1.600</td>
<td>1.600</td>
<td>1.600</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1.600</td>
<td>1.600</td>
<td>1.600</td>
<td>1.600</td>
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</tr>
<tr>
<td>Mean deviation</td>
<td>1.600</td>
<td>1.600</td>
<td>1.600</td>
<td>1.600</td>
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</tr>
</tbody>
</table>

Parallelism test on gold coated PET film using autofocus positions

- The traverse stage is tilted against the conveyor.
- The bending of the traverse stage can be ignored.
- The traverse stage is about 140 µm apart in Z direction in about 300 mm slope in Y direction.

<table>
<thead>
<tr>
<th>Y position (mm)</th>
<th>1.800</th>
<th>1.800</th>
<th>1.800</th>
<th>1.800</th>
<th>1.800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.800</td>
<td>1.800</td>
<td>1.800</td>
<td>1.800</td>
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<tr>
<td>Standard deviation</td>
<td>1.800</td>
<td>1.800</td>
<td>1.800</td>
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<tr>
<td>Mean deviation</td>
<td>1.800</td>
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</table>

Conclusions

1. R2R film inspection systems have been explored in the CIMAM of University of Huddersfield.
2. The autofocus system is adequate if the tested film surface is aligned to within 5 fringes in the whole image field for most of the tested films.
3. The tension system of the R2R film production line should be finely adjusted to reduce the local stress and local waviness for a better autofocus and better measurement results. For thin films, such as the 35 µm thickness uncoated PET film tested, this issue is more critical than for thick film (the 125 µm thick gold coated PET film).
4. To achieve an inspection which is valid for all the inspected surface strip is possible on the condition that the inspected surface is within the coherence range of the WSI.
5. The system can be used for inspection without any problems if the system has been adjusted and operated at its optimised condition, which is: parallelism between the traverse stage and the conveyor surface such that it is within a few micrometres, local stresses and waviness caused by the tension system are mainly eliminated.

Acknowledgement

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Thank you!