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Surface defects in water vapour barrier layers for structured plastic electronics

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Topical Meeting: Structured and Freeform Surfaces
NPL Teddington, UK
December 2012

The paper presents results from the first stages of Nanomend

NanoMend
European Framework 7 Programme
€7.2m, 4 year long project
14 European Partners

Contents
- The Project
- Project Ambition
- Applications
- Flexible PV
- Barrier Layer Metrology
- Defect vs Barrier Function
- Back Contact Metrology
- Light Management Films
- In process Metrology
- Conclusions

Consortia

Applications
Nanomend will tailor its technology to the specific needs of the following applications:

- Flexible solar modules
- The food packaging

Project Ambition
To develop technologies that are able to detect and correct micro and nano-scale defects in Roll to Roll produced films, without slowing production speed.

In order to improve product performance, yield and lifetime.
**Why is this project necessary**

- Thin films can take the form of:
  - Functional layers within a product (flexible photovoltaics).
  - Protective coatings (used to weatherproof flexible photovoltaics, food packaging, digital displays, other applications).

- Defects within these films reduce the yield, performance and life time of the products:
  - By reducing their resilience to environmental conditions.
  - By increasing the scrap rate.
  - Reducing the proportion of defects will make a range of products more competitive.

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**NanoMend Flexible Solar Modules: basic layer groupings**

- Light management layers
- Encapsulation/buffer layers
- CIGS PV layers
- Back sheet encapsulation

**Functional elements of flexible photovoltaic cells**

- Encapsulation of the PV layer by polymer film layers is designed to protect the PV modules from water ingress through the polymer layers to the cells which reduces efficiency over time.
- The most expensive element of PV cells per m² is the barrier layer.
- ALD layer of Al₂O₃ 40nm thick on a planarised polymer substrate.
Encapsulation 2
- Defects: “pin holes” and particles in the ALD layer are thought to significantly affect the barrier properties.
- Test substrates were produced at CPI and measured using a MOCON Water Vapour Transmission Rate (WVTR) test.

Defects density and its correlation with WVTR
- Water vapor transmission rate (WVTR) for 40nm film at specified conditions 38°C @90% RH

<table>
<thead>
<tr>
<th>Sample</th>
<th>WVTR (g/m²/24 hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 2701</td>
<td>$1.1 \times 10^{-3}$</td>
</tr>
<tr>
<td>Sample 2702</td>
<td>$1.3 \times 10^{-3}$</td>
</tr>
<tr>
<td>Sample 2705</td>
<td>$4.1 \times 10^{-3}$</td>
</tr>
<tr>
<td>Sample 2706</td>
<td>$2.0 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

From the above table it can be observed that sample 2705 has the highest value of WVTR.

Visualisation of defects
- Scale of large defects
- Scale of small defects

Optical microscope images × 200x magnification

Types of defects 1
- Pinholes
  - Ranging from 1 to 3µm in size
  - Roughness excluding defects ~0.6µm

Types of defects 2
- Peaks/particles of ≤ 30 nm height
  - Roughness excluding defects ~0.6µm

Types of defects
- Holes
  - Of about 60 µm lateral dimension
  - Roughness excluding defects ~0.6µm
Defining significant peaks and dales

- Density of peaks: $S_{dp}/mm^2$
- Density of dales (pits): $S_{dp}/mm^2$
- Density of significant defects: $S_{dp}/mm^2$

Possible defect counters

When counting all defects there was no correlation between WVTR and possible defect density or type

Density of dales, $S_{dd}$

A dales is defined as a region around a pit such that all maximal downward paths end at the pit (ISO 25178:22012(E)).

Exercise 1

Exercise 2

Exercise 3

Structured Feature ‘Filtering’ - WolfPruning

Noise and Measurement errors can also create artificial “small” critical points
- Function splits features into functionally significant and insignificant sets

Exercise 4

“Number of data files with large defects”

- Exercise 4: A comparison of defects on sample 2706 and sample 2706.
- More than 500 locations were inspected at a magnification of X 20 on the CCI for both samples.
- Only large defects for height & width > 15um (as area and height proporional to square root)
- Small numbers of larger defect seem to have the dominant effect on WVTR (no clear distinction between peaks and dales)

Super-resolution

- Clearly many defects are smaller than the diffraction limit any may affect WVTR.
- A priori data can be used with super-resolution techniques to measure (or simply detect) sub-resolution features
- NPL developing instrumentation along with phase-retrieval techniques
- Investigating the use of optical singularities
Structured Surface Analysis in Flexible PV metrology

Laser Cell scribing in Mo back contact

- Optical & CCI analysis
- The PV cell back contact is made from a layer of Molybdenum. After the coated polymer web leaves the vacuum chamber, it passes over a laser that scribes lines into the metallic layer to delineate the individual solar cell back-contact.

Laser Cell scribing in Mo back contact

Possible defects

Defects “bridging” the cell gaps can give rise to shorts across cell reducing overall efficiency.

Interferometer analysis of defect

- Particle inside the scribe line.
- Height 1 um.
- Width about 18 um.
- EDAX analysis confirms Mo.

Step Height Segmentation across defect area

Set trough bottom to be zero and use
- Relative heights
- Through width
- Defect width as % of trough width
- As a defect detector

Light Management Film Dimensions

- Insert picture microsharp
- Pitch
- Diameter
Original surface structure
A roll to roll, UV coating process that produces micro structure to extreme accuracy is implemented.

Defective in optical film (AFM)

In Process Systems Wavelength scanning Interferometry (WSI)

Conclusions
- Flexible PV cells critical functionality depends on barrier properties
- Defect density seems to correlate with WVTR
- Structured surface approach useful in monitoring defect presence in all layers
- In process sensors needed!

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