Surface defects in water vapour barrier layers for structured plastic electronics

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Surface defects in water vapour barrier layers for structured plastic electronics

Liam Barr*, David Hobbs**, Richard Leach*, Leigh Framing** and Michael Evers
*University of Huddersfield, NHS, **Centre for Process Innovation, Sedgefield, UK

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
€7.2 million, 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

NanoMend

NPL

National Physical Laboratory

Fraunhofer

EMFT

KITE Innovation Facility

IBS

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TCI

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University of Technology

SUNY

IsraTel Tech

University of Technology

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.

Re: This material appears to be an academic paper discussing research on surface defects in water vapor barrier layers for structured plastic electronics. The paper presents results from the first stages of a project called NanoMend, funded by the European Framework 7 Programme. The project focuses on nanosciences, nanotechnologies, materials, and new production technologies. The project is a €7.2 million, 4-year project involving 14 European partners.

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**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 and other applications).

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

- Light management layers
- Encapsulation/buffer 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 40 nm 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.

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**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.

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**Visualisation of defects**

Scale of large defects

Scale of small defects

Optical microscope images × 200 k magnification

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**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: \( S_{\text{pp}} \text{/mm}^2 \)
- Density of dales (pits): \( S_{\text{dd}} \text{/mm}^2 \)
- Density of significant defects: \( S_{\text{sp}} \text{/mm}^2 \)

Possible defect counters

When counting all of defects there was no correlation between WVTR and possible defect density or types.

Density of dales, \( S_{\text{dd}} \)

A dales is defined as a region around a pit such that all maximal downward paths end at the pit (ISO 25178-2:2012(E)).

Exercise 2

Structured Feature ‘Filtering’ - Wolf Pruning

Noise and measurement errors can also create artificial “small” critical points.

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 \( S_{\text{pp}}=0.8 \text{mm} \)) and total height \& width > 15µm) (as area and height pruning/square elimination).
- 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

- 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

Interferometer analysis of defect

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

Step Height Segmentation across defect area

Light Management Film Dimensions

- Insert picture microsharp
- Pitch Diameter

Insert picture microsharp
Original surface structure

- A roll to roll, UV curing process that produces microstructure to extreme accuracy is implemented.

<table>
<thead>
<tr>
<th>Lenticular structure - design parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lens diameter</td>
</tr>
<tr>
<td>Pitch</td>
</tr>
</tbody>
</table>

Prime shape - spherical & aspherical

Prime width | 4560-5800mm

Prime estimation - Period in mm length

Defective in optical film (AFM)

Defect size scale
- Width: 0.57nm
- Depth: 50nm

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!

Acknowledgements

The NanoMend the funding under EC FP7 NMP initiative