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

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.

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

- Flexible solar modules
- The food packaging
**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 resistance 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 1**

- 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>Water vapor transmission rate (g/m²/24 hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 2701</td>
<td>1.1 x 10⁻³</td>
</tr>
<tr>
<td>Sample 2702</td>
<td>1.3 x 10⁻³</td>
</tr>
<tr>
<td>Sample 2705</td>
<td>4.1 x 10⁻³</td>
</tr>
<tr>
<td>Sample 2706</td>
<td>2.0 x 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 × 200 km magnification

Types of defects 1
- Pinholes

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

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 25178-2:2012(E)).

**Exercise 2**

*Total length of dales in mm per area*

**Exercise 3**

*Total length of dales in mm per area*

**Exercise 1**

*Total length of dales in mm per area*

**Structured Feature ‘Filtering’ - Wolf Pruning**

- 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 2705 and sample 2706.
- More than 500 locations were inspected at a magnification of X 20 on the CCD for both samples.
- Only large defects (for \( 1 \leq 0.8 \mu \text{m} \)) height & width > 15μm (as area and height: length/width)
- 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.

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
Original surface structure
- A roll to roll, UV coating process that produces microstructure to extreme accuracy is implemented.

Defective in optical film (AFM)
- Defect size scale
  - Width: 0.57 μm
  - Depth: 60 nm

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