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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
NMP-2011 Nanoscience, Nanotechnologies, Materials and New Production Technologies.
€7.2m, 4 year long project
14 European Partners

Contents

- The Project
- Project Ambition
- Applications
- Flexible PV
- Barrier Layer Metrology
- Defect vs Barrier Function
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Consortia

NPL National Physical Laboratory
Fraunhofer Fraunhofer
Femt Femt
KITE Innovation KITE Innovation
Vapornet Vapornet
IBS IBS
Isovoltaic Isovoltaic
TN+I TN+I
Sapienza University of Technology
Open your mind Open your mind

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).

Why is this project necessary

- Defects within these films reduce the yield, performance and lifetime 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.

NanoMend Flexible Solar Modules: basic layer groupings

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 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.

**Defects density and its correlation with WVTR**
- Water vapor transmission rate (WVTR) for 40nm film at specified conditions 36°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 × 300k 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

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

- Density of peaks: \(-\frac{S_ds}{mm^2}\)
- Density of dales (pits): \(-\frac{S_dd}{mm^2}\)
- Density of significant defects: \(-\frac{S_dd}{mm^2}\)

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

### Significant defects density, \(S_{fd}\)

\(S_{fd}\) (density of peaks + density of dales)

### Exercise 1

- Total area in both samples (mm)

### Exercise 2

- Total area in both samples (mm)

### Exercise 3

- Total area in both samples (mm)

### 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 (\(D_{\text{max}}=0.8\) mm, height \& width > 15um) (as area and height profiles/aggregation).
- Small numbers of larger defect seem to have the dominant effect on WVTR (no clear distinction between peaks and dales).

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

- A dalie is defined as a region around a pit such that all maximal downward paths end at the pit (ISO 29178-2:2012(E)).

### Exercise 2

- Total length in both samples in m

### Exercise 3

- Total length in both samples in m

### 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.

### 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.

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**Laser Cell scribing in Mo back contact**

Possible defects

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

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**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

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**Light Management Film Dimensions**

Insert picture microsharp

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

Defective in optical film (AFM)

In Process Systems Wavelength scanning Interferometry (WSI)

Conclusions
- Flexible PV cells critical functionality depends of 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
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