Thin-film barrier on foil for organic LED lamps

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• Ca-mirror test
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## Research topics at the Holst Centre

**Strategic programs:** windows on application areas, guiding choices in the technology programs

### Technology programs: Development of key technologies

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<th>Printed Organic Lighting &amp; Signage</th>
<th>Smart Bandage</th>
<th>Smart Blister</th>
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OLEDs for lighting and signage applications
OLEDs need encapsulation

- OLEDs’ low work function cathodes oxidize rapidly

- Black spots form due to water diffusion through pinholes in Al cathode
- Black spots grow linearly in time, shelf effect
Requirements for a barrier

- **Almost hermetic**
  - maximum water vapor transmission rate estimated at \( \sim 10^{-6} \text{g/m}^2\text{day} \)

- **No black spots**
  - Low pinhole density, pinhole coverage

- **Low cost**
  - High deposition rates

- **Feasibility for R2R**
  - *Barriers should be bendable*
Approach: SiN–organic planarization layer–SiN

- **Plasma deposited amorphous hydrogenated silicon nitride (a-SiN$_x$:H)**
  - RF 13.56 MHz driven parallel plate source
  - Static substrate
  - SiH$_4$/NH$_3$/N$_2$ gas mixture, tens-hundreds of sccm
  - Pressure 0.1-1 mbar, roots pump
  - Substrate temperature 100-130°C
  - Typical deposition rate: 0.5 nm/s
  - *Intended for proof of principle of barrier configuration, plasma source not feasible for low cost production line*

- **Organic planarization layer is used to spatially separate defects**
Ca-mirror test of barriers

- Degradation of Ca layer: Ca (reflective) + -O $\rightarrow$ CaO (transparent)
  - Measurement of WVTR down to $10^{-6}$ g/m$^2$day
  - Visualisation of defects

- Initial tests on unbended barriers

Test configuration
Ca-mirror test of barriers

67 days, 20°C/50%rh

No decay, test ongoing

25 days, 60°C/90%rh

WVTR = $5 \cdot 10^{-5}$ g/m²day, local failure after three weeks for most samples

- No measurable decay after 2 months at ambient conditions
- At 60°C/90%: WVTR = $5 \cdot 10^{-5}$ g/m²day, defects appear only after 3 weeks for most samples
- Estimated WVTR at ambient conditions < $10^{-6}$g/m²day
Critical strain measurement method

- 2-point bending test on Carbon coated a-SiNₓ:H
  - Maximum tensile strain on outer edge
  - Electrical resistance monitored to detect crack formation Ca (reflective) + -O → CaO (transparent)

*Bouten, Leterrier et al, Flexible flat panel displays. 2005, John Wiley & Sons, p.528*
Bare PEN foil

- Resistance increase at \( \varepsilon = 1.2\% \)
Critical strain of a-SiN$_x$:H films

- Critical strain of a-SiN$_x$:H on PEN foil: $\varepsilon_c = 0.6$-0.8%
  - For a 125 $\mu$m thick foil, this corresponds to radius of 11 mm
- Identical films: spread in $\varepsilon_c$ may be caused by defect distribution
Testing of complete barrier: bending test setup

- Minimum bending radius of 14 mm
- 5-100 bends
- Compressive and tensile strain on barrier
- Ca test performed before and after bending

Circular shape:
\[
\frac{a}{b} \approx \frac{\alpha - \sin \alpha}{\sin \alpha - \alpha \cos \alpha}
\]
Bending test of (not fully optimized) barrier

- Bending radii: $\sim 10$ cm—1.4 cm, 5—100 times
- WVTR before bending $7 \cdot 10^{-5} - 1 \cdot 10^{-4} \text{g/m}^2\text{day}$ (1 week at 20°C/50%rH)
- WVTR after bending still in same range, no white spots
Critical bending radius of barrier stack

- More close look reveals critical bending radius of \(~20\) mm
- Amount of bending cycles not important
- Factor of 2 increase suggests failure of top \(a\text{-SiN}_x\text{H}\)

**Comparison WVTR before and after bending**

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<tr>
<th>Ratio WVTR after/before bending</th>
<th>No bending</th>
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<th>10 times</th>
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Ratio of unbended samples not equal to 1. This may be due non-linear Ca transparency vs WVTR in initial oxidation stage.
Bending test on optimized barrier, 60°C/90%

- More aggressive bending radius/larger amount of cycles: 1.4 cm, 100–400 times
- At 60°/90% WVTR = 5·10^{-5} g/m²day
- After (too aggressive) bending immediate local decay

- To be repeated at more gentle bending angles
Conclusions

- Barriers on PEN foil have been produced with a WVTR of $5 \times 10^{-5}$ g/m$^2$day at 60°C/90%rh conditions
- At ambient conditions no decay visible after 2 months, WVTR estimated $<10^{-6}$g/m$^2$day
- Barrier bendable down to a minimum radius of 20 mm, hence suitable for R2R
- A crack channeling strain of 0.6-0.8% has been measured for 300 nm thick a-SiN$_x$:H on PEN foil

Near future

- Bending testing of encapsulated OLEDs
- Scaling up to pilot sheet-to-sheet, then R2R line for barrier and cathode
  - Implementation of microwave plasma source
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Questions or Remarks?

Thank you for your attention!

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