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Holst Centre

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Thin-film barrier on foil for organic LED lamps

Ferdie van Assche, Harmen Rooms,
Jasper Michels, Edward Young, Ton van Mol
Holst Centre

Gerard Rietjens, Peter van de Weijer, Piet Bouten
Philips Research Laboratories

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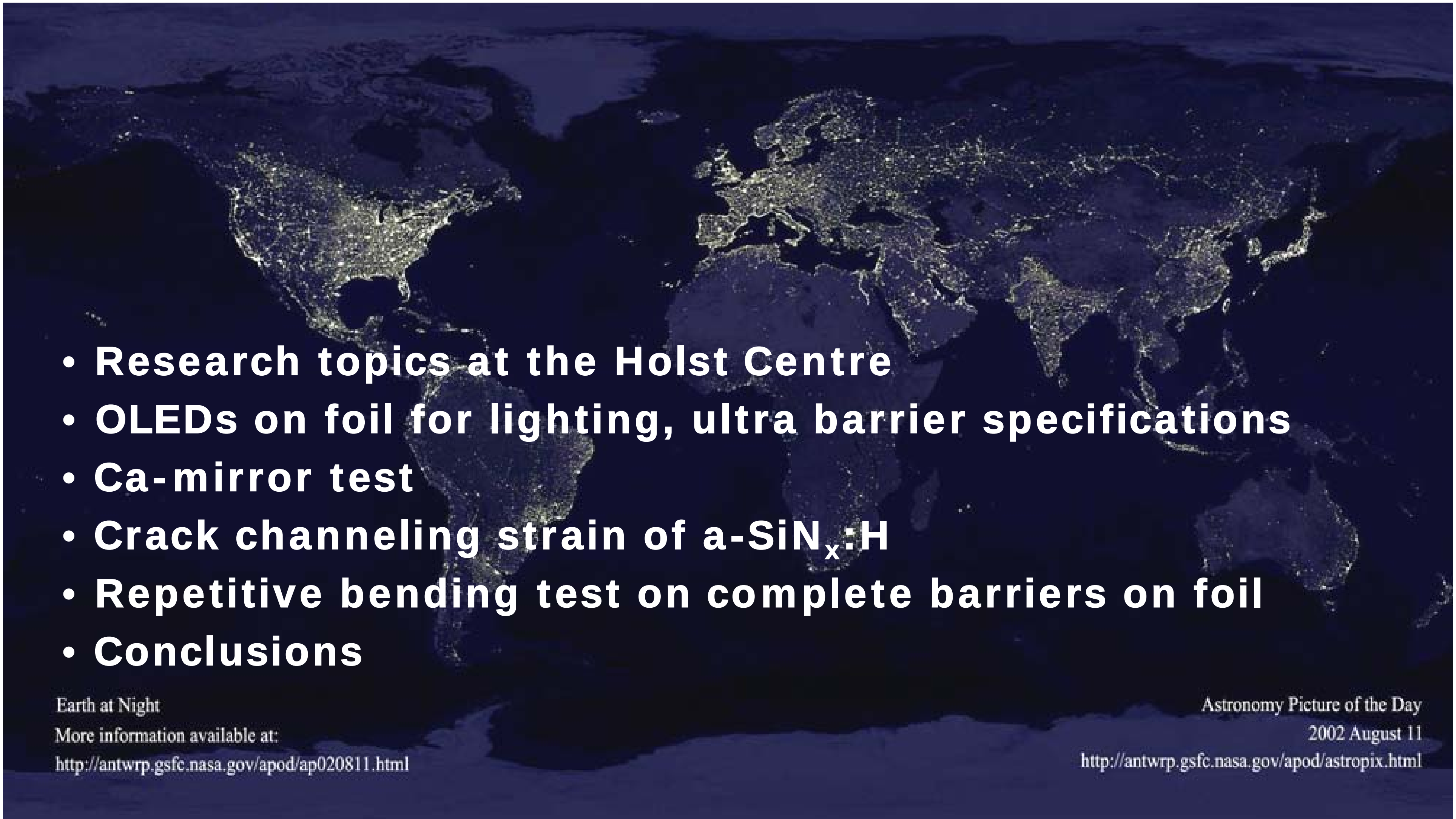


- Research topics at the Holst Centre
- OLEDs on foil for lighting, ultra barrier specifications
- Ca-mirror test
- Crack channeling strain of a-SiN_x:H
- Repetitive bending test on complete barriers on foil
- Conclusions

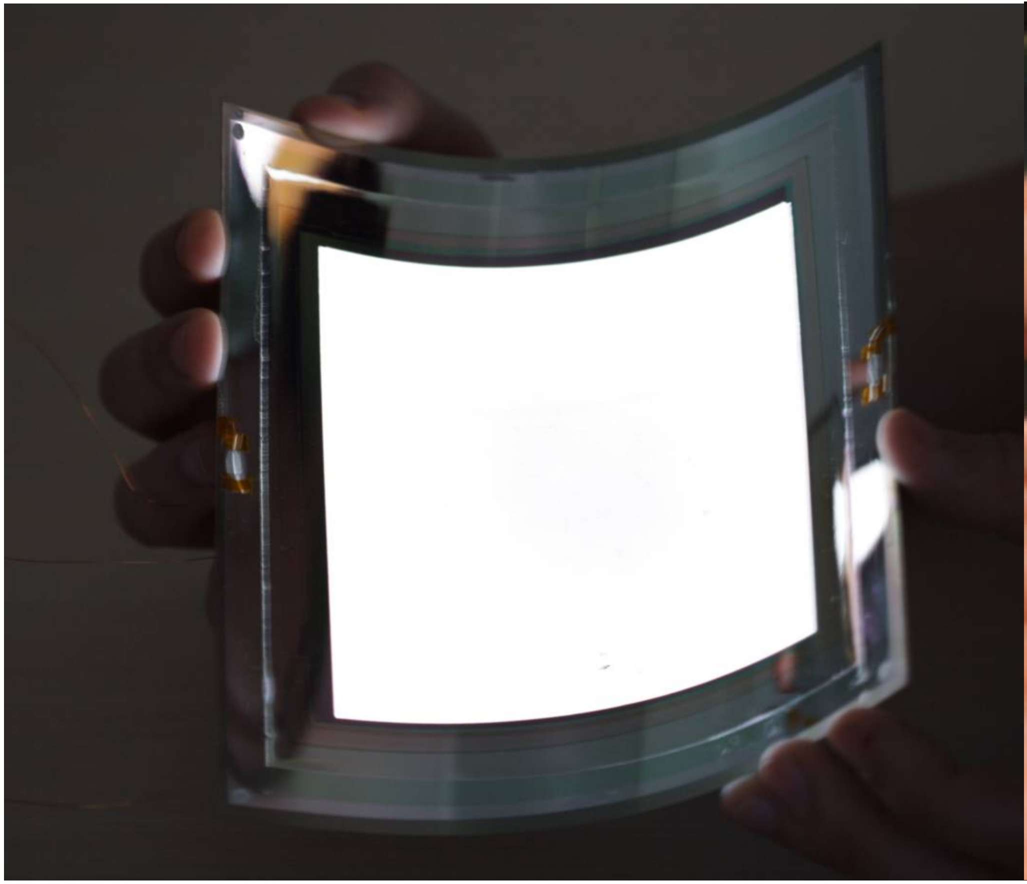
Research topics at the Holst Centre

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

Technology programs:
Development of key technologies

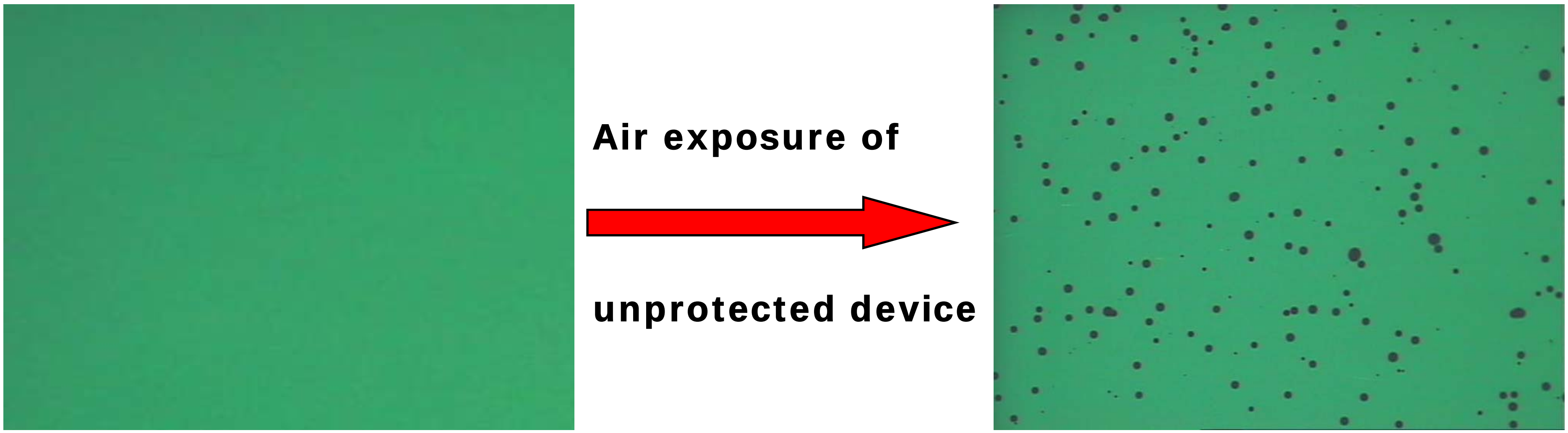
Technology programs	Printed Organic Lighting & Signage	Smart Bandage	Smart Blister
Large Area Printing	■■	■□	■□
Electrodes and Barriers	■■	■□	■□
Foils Integration	■□	■□	■□
Printed Structures on Foil	■□	■□	■□
Organic Circuitry	□□	■■	■■
Lithography on Foil	□□	■■	■■

OLEDs for lighting and signage applications



OLEDs need encapsulation

- **OLEDs' low work function cathodes oxidize rapidly**

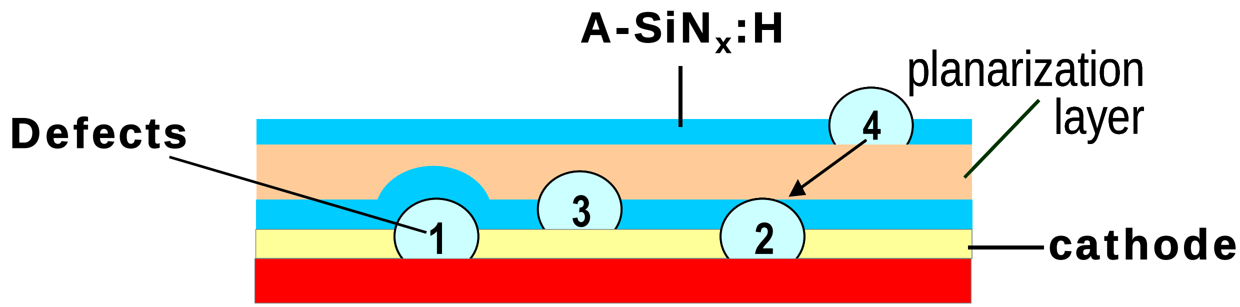


- **Black spots form due to water diffusion through pinholes in Al cathode**
- **Black spots grow linearly in time, shelf effect**

Requirements for a barrier

- **Almost hermetic**
  - maximum water vapor transmission rate estimated at ~10^{-6}g/m^{2}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

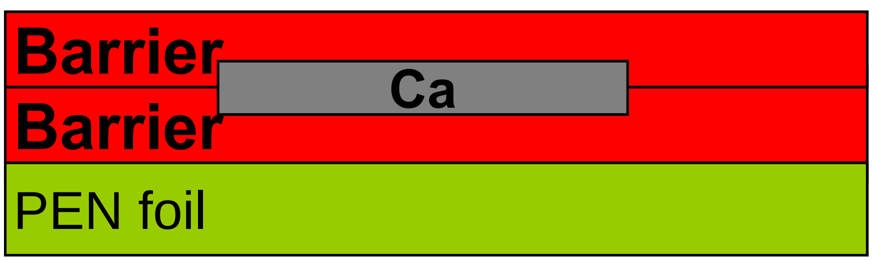


- **Plasma deposited amorphous hydrogenated silicon nitride (a-SiN_x:H)**
  - RF 13.56 MHz driven parallel plate source
  - Static substrate
  - SiH_4/NH_3/N_2 gas mixture, tens-hundreds of sccm
  - Pressure 0.1-1 mbar, roots pump
  - Substrate temperature 100-130°C
  - Typical deposition rate: 0.5 nm/s
  - *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 → CaO (transparent)**
  - **Measurement of WVTR down to 10^{-6} g/m^{2}day**
  - **Visualisation of defects**

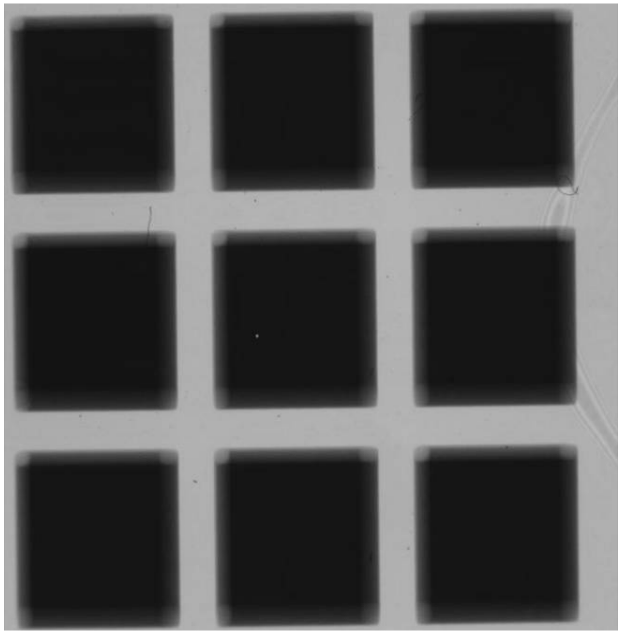
- **Initial tests on unbended barriers**



Test configuration

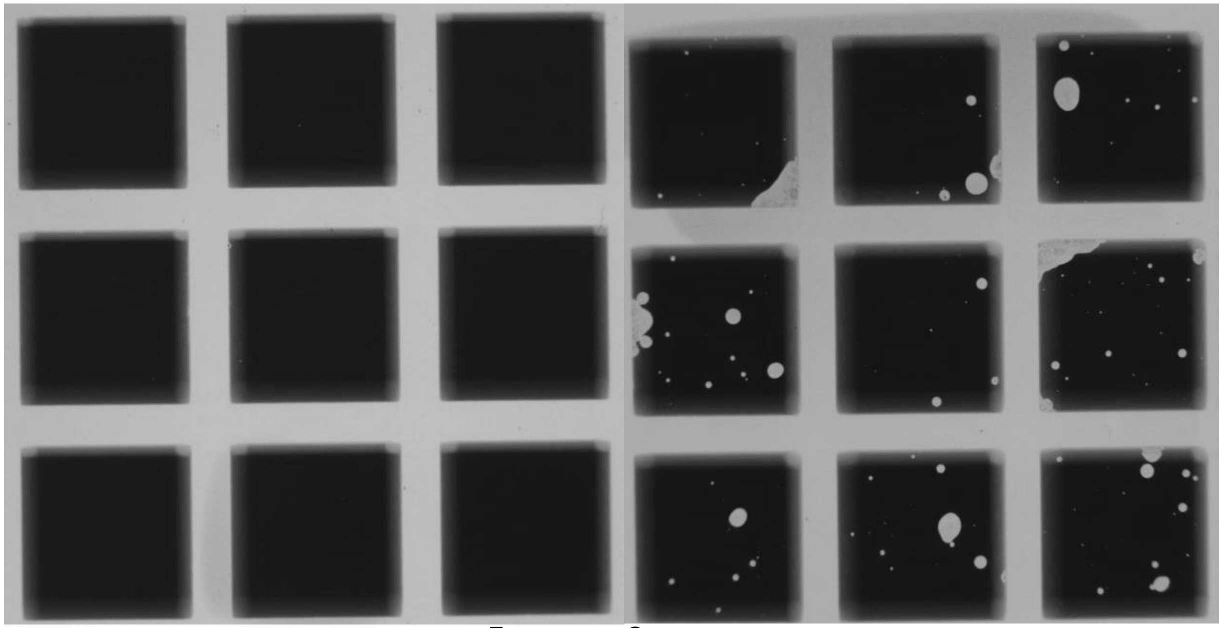
Ca-mirror test of barriers

67 days, 20°C/50%rH



No decay, test ongoing

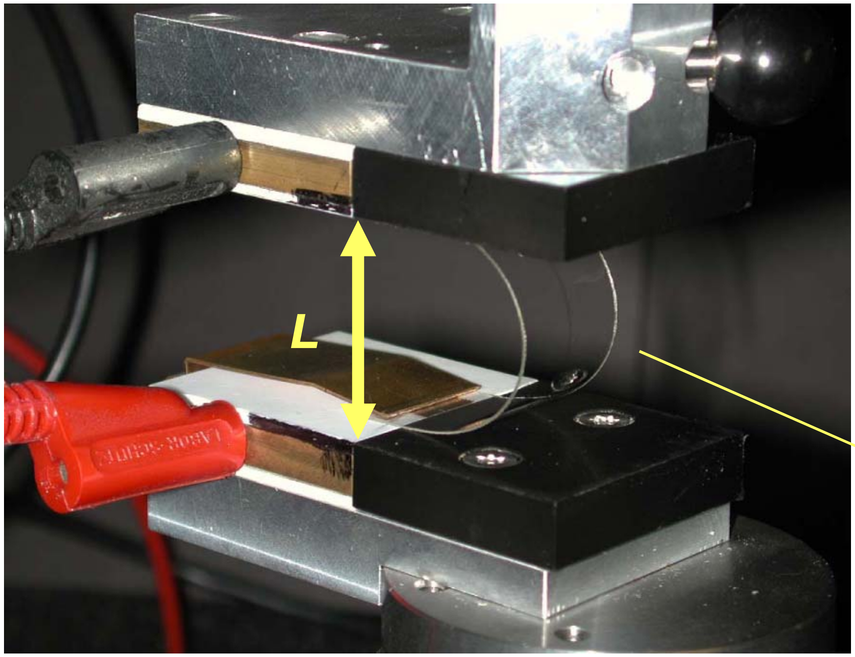
25 days, 60°C/90%rH

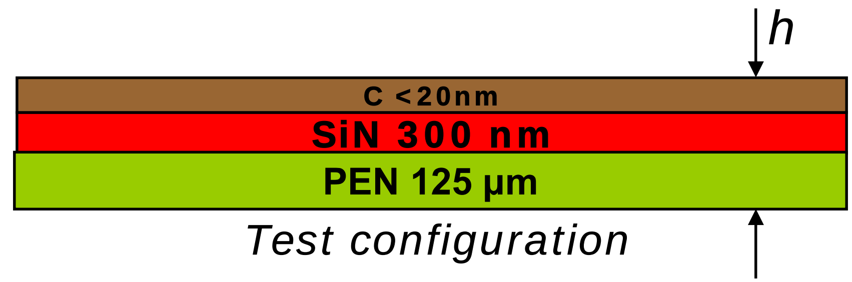


WVTR = 5·10^-5 g/m²day, local failure after three weeks for most samples

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

Critical strain measurement method





Test configuration

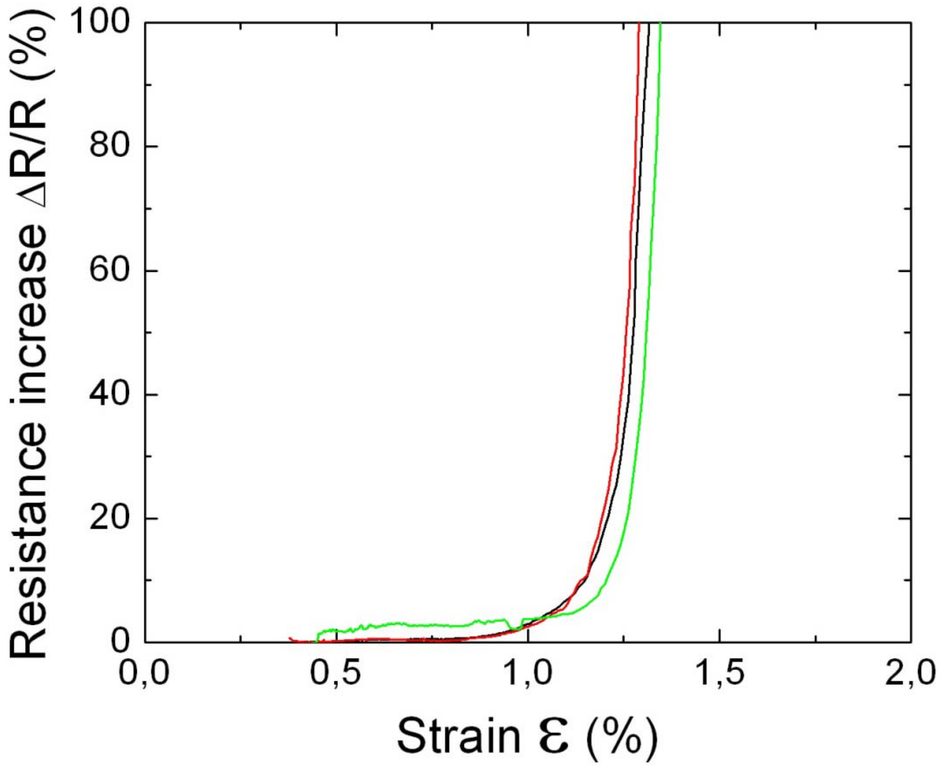
$$\varepsilon_{\max} = \frac{1.198h}{L}$$

- **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

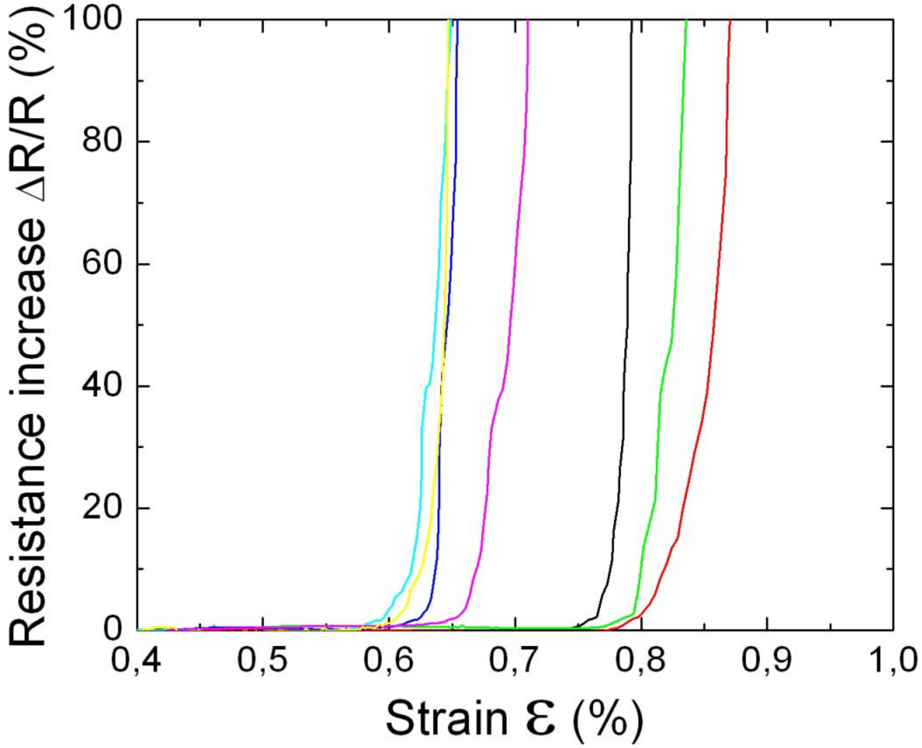
C <20nm
PEN 125 µm

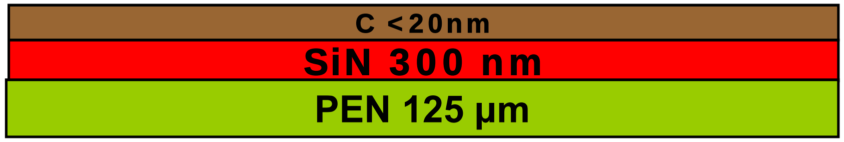


- **Resistance increase at**

  ε = 1.2 %

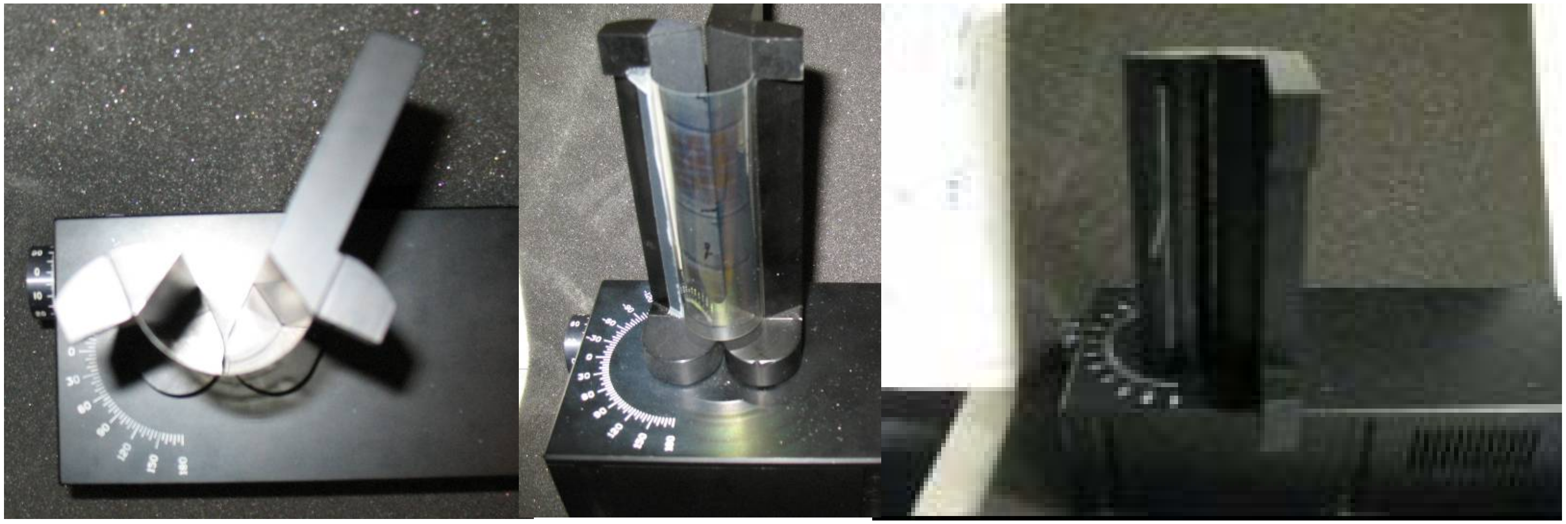
Critical strain of a-SiN_x:H films

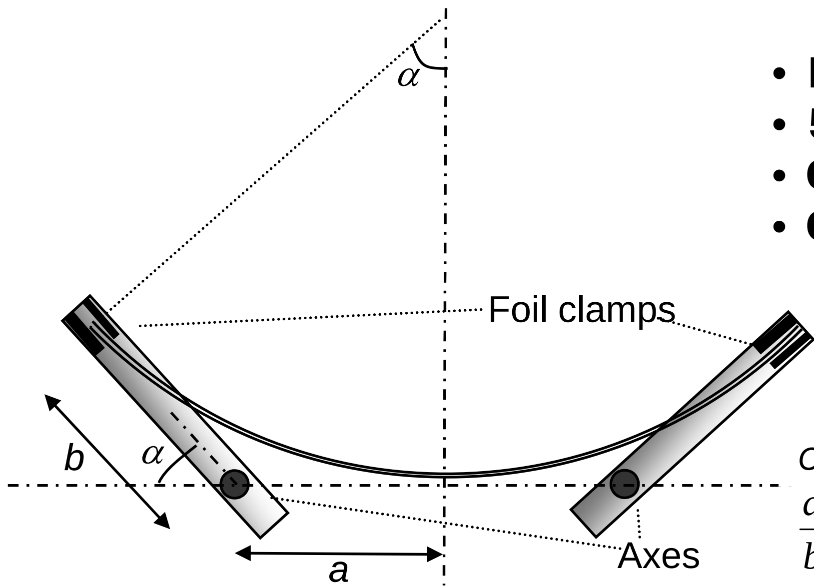




- **Critical strain of a-SiNx:H on PEN foil: ε_c = 0.6-0.8%**
  - For a 125 µm thick foil, this corresponds to radius of 11 mm
- **Identical films: spread in ε_c may be caused by defect distribution**

Testing of complete barrier: bending test setup





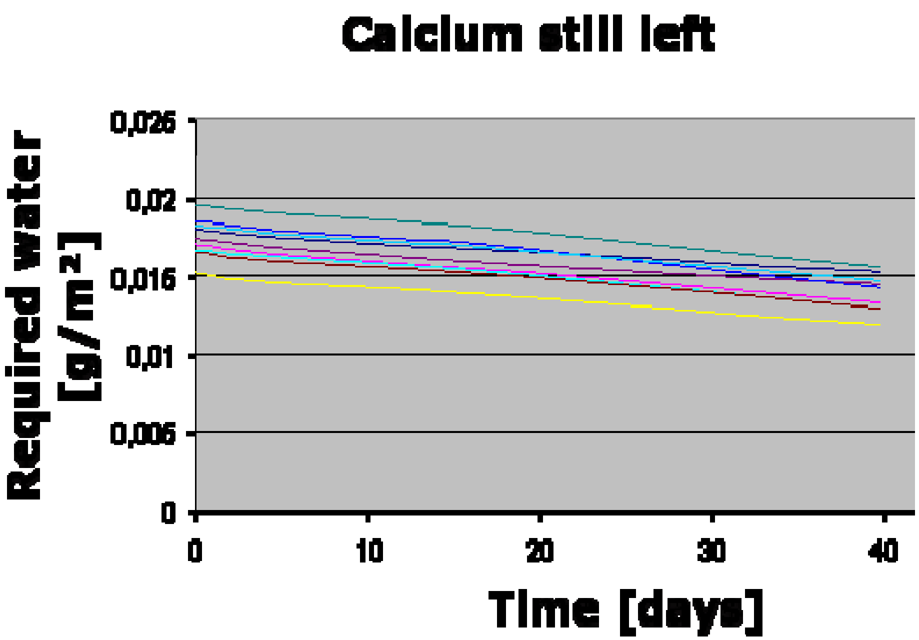
- **Minimum bending radius of 14 mm**
- **5-100 bends**
- **Compressive and tensile strain on barrier**
- **Ca test performed before and after bending**

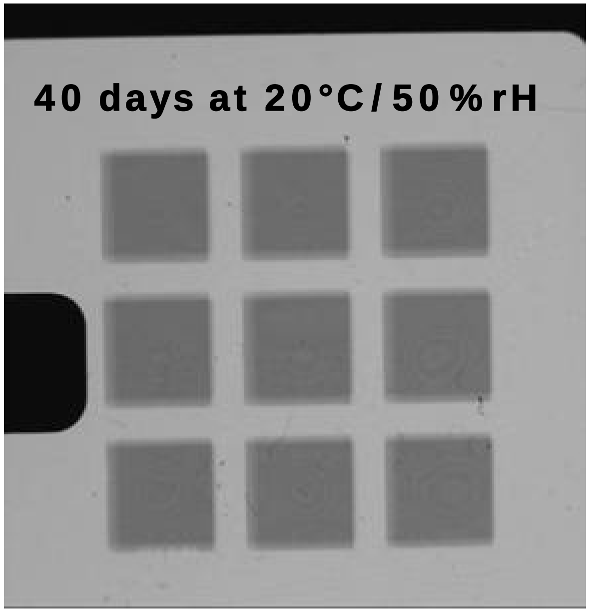
Circular shape:

$$\frac{a}{b} \cong \frac{\alpha - \sin\alpha}{\sin\alpha - \alpha\cos\alpha}$$

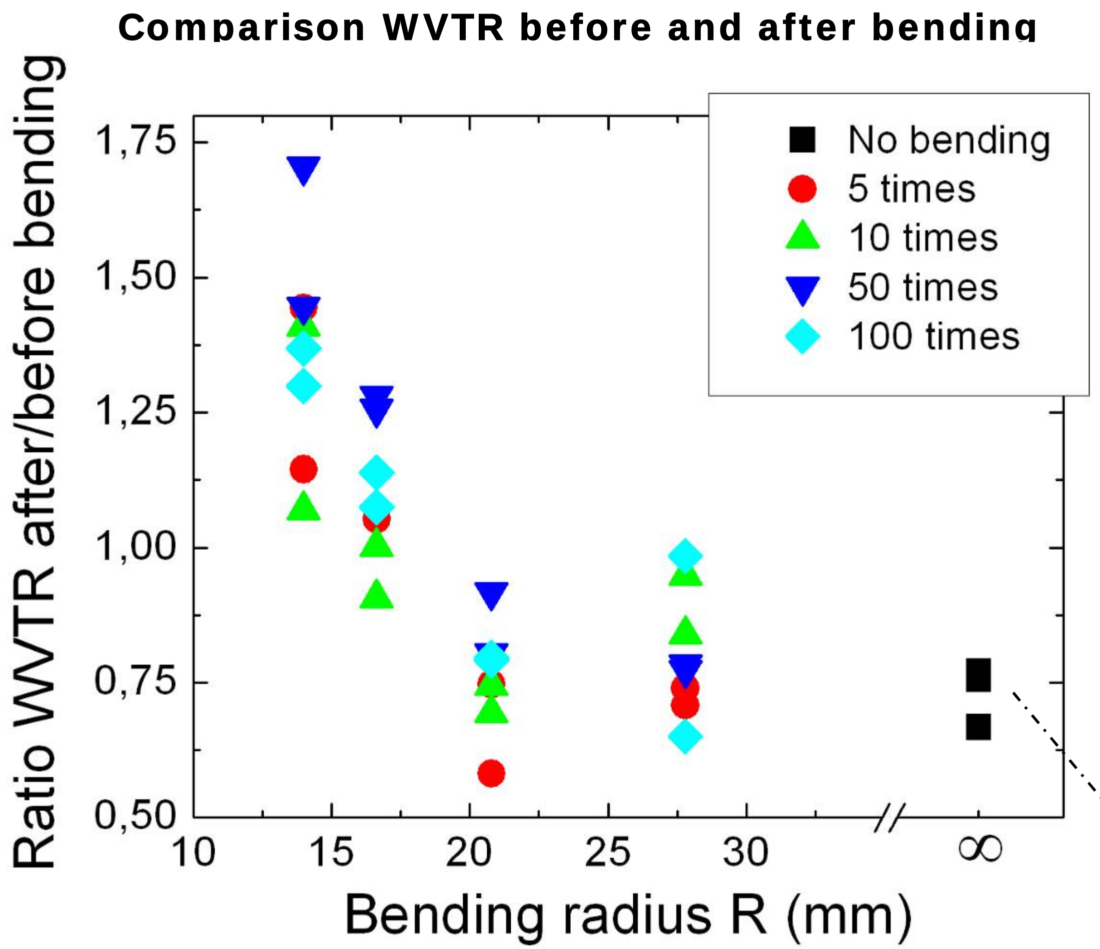
Bending test of (not fully optimized) barrier

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





Critical bending radius of barrier stack

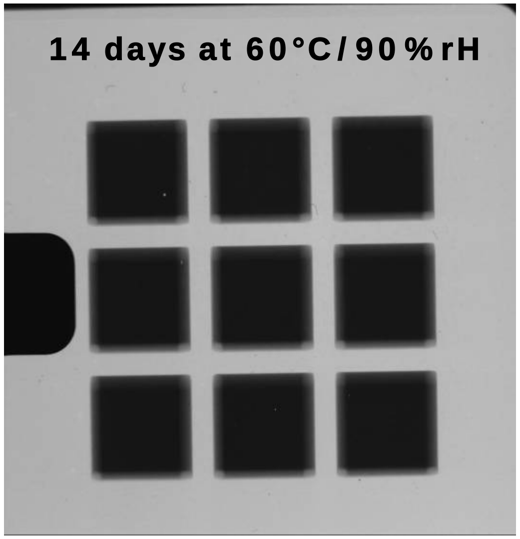


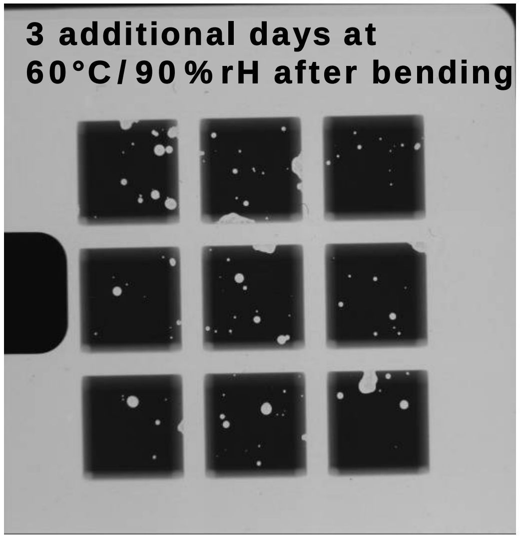
- More close look reveals critical bending radius of ~20 mm
- Amount of bending cycles not important
- Factor of 2 increase suggests failure of top a-SiN_x:H

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 = $5 \cdot 10^{-5}$ g/m^{2}day
- 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 $5 \cdot 10^{-5}$ g/m^2day at 60°C/90%rH conditions**
- **At ambient conditions no decay visible after 2 months, WVTR estimated <10^{-6}g/m^2day**
- **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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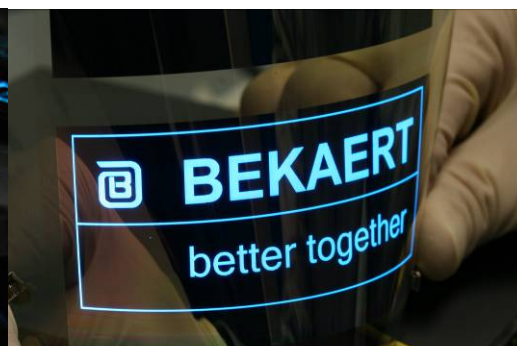

Questions or Remarks?

Thank you for your attention!

Ferdie van Assche, MSc
T: + 31 6 12 642 246
E: ferdie.vanassche@tno.nl