Barrier Film Manufacturing for OLED Solid State Lighting

Feb 1st, 2017

DOE SSL Workshop – Long Beach, CA

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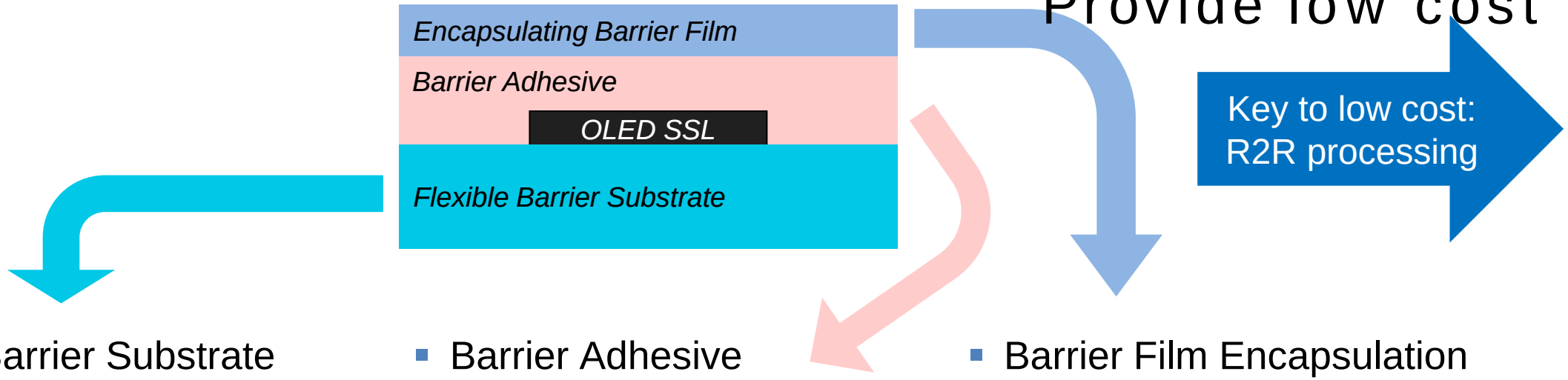
Serena Schleusner, Jacob Johnson, Mark Roehrig – Display Materials and System Division (DMSD)

3M and Minnesota

We could use “warm” OLED lighting!

OLED SSL Components

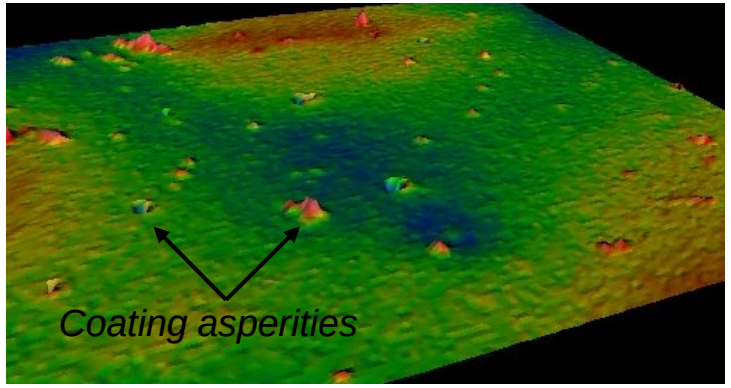
Manufacture barrier films
Validate performance
Provide low cost



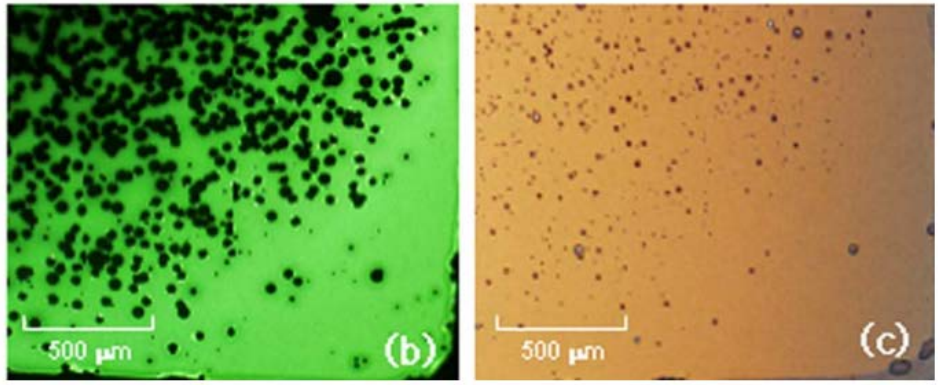
- Flexible Barrier Substrate
  - WVTR
  - Optical
  - Temperature stability
  - Mechanical
  - TCO? (Patterned?)
  - Light extraction? (int vs ext?)
- Barrier Adhesive
  - WVTR
  - Edge protection
  - Optical
    - T_{vis}, haze, index
  - PSA, UV, or thermal?
  - Environmental durability
- Barrier Film Encapsulation
  - WVTR
  - Optical
    - Bottom emitter – reflective
    - Top emitter - T_{vis}, haze
    - Transparent device
  - Light extraction?

Issues Affecting Roll-to-Roll Manufacturing

- Process stability, control
- Cleanliness
- Web handling / roll formation
- Temperature stability / dimensional stability
- Static charge management
- Moisture management
- Product / material characterization



Surface map of coating defects



OLED dark spots

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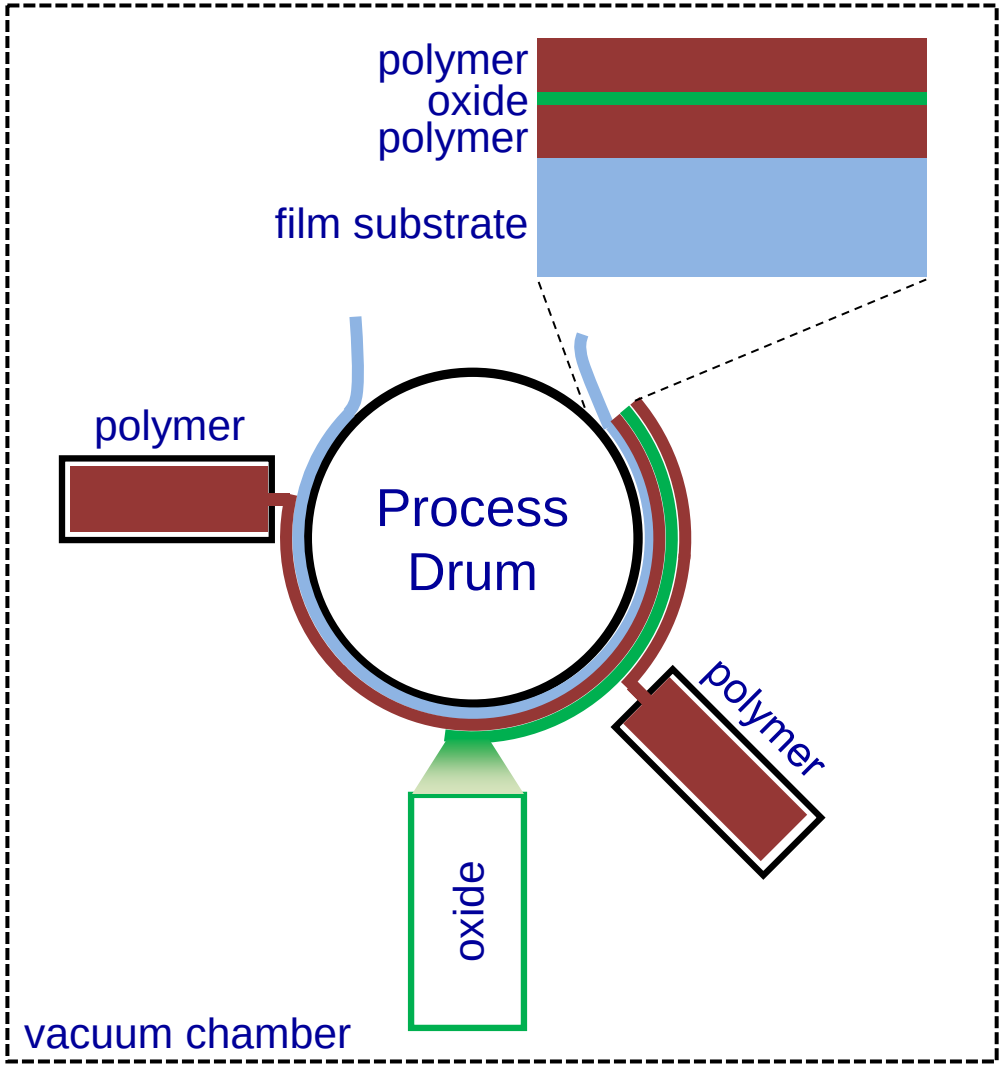
3M Vacuum Processed Barrier Film

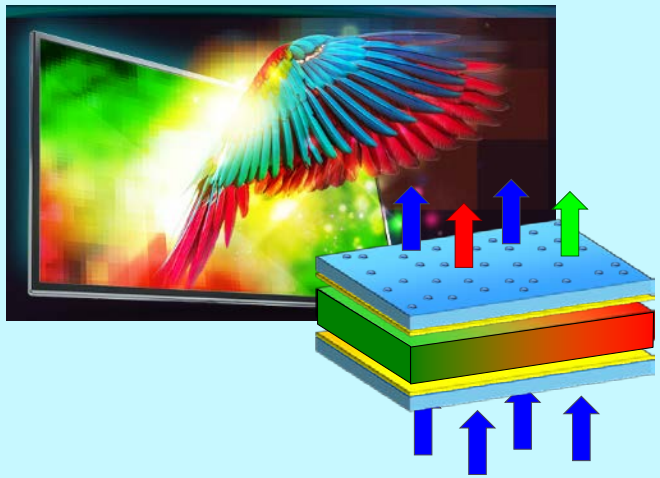
- Multi-layer construction
  - *Substrate*
  - *Oxide layers*
  - *Polymer layers*
- Flexible substrate
  - *Roll-to-roll component manufacturing*
  - *Enables roll-to-sheet or roll-to-roll OLED fab*
- Oxide provides barrier
  - *High transparency & clarity*
  - *Low haze*
  - *Good flexibility*
- Polymers planarize and protect
- Tortuous path from multi-dyads
  - *Can increase barrier performance*



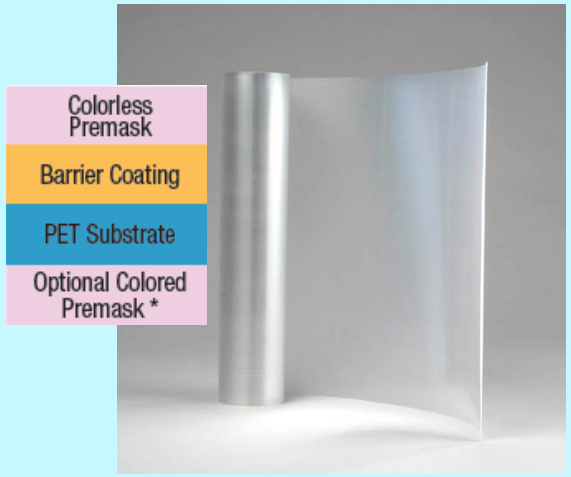
3M Barrier Film Commercialization

3M Corporate Research Laboratory

Display Materials and Systems Division



3M™ Quantum Dot Enhancement Film



3M™ Flexible Transparent Barrier Film (FTB)

WVTR < $1x10^{-3}$ g/m²/day @ 20°C

Barrier Adhesive, OLED Encapsulation

Renewable Energy Division

3M™ Ultra Barrier Solar Film

WVTR < $5×10^{-4}$ g/m²/day @ 23°C 85%RH

Ultra Barrier Solar Film for OPV & Perovskite PV

⬆ Commercial ⬆

⬇ Development ⬇

Barrier Films – Display Product Offerings and Development

Commercialized

FTB3-50
FTB3-125

~ 50 um
~ 125 um

WVTR < $1x10^{-3}$ g/m^2/day @ 20C
Mocon Permatran 700

BPS-270

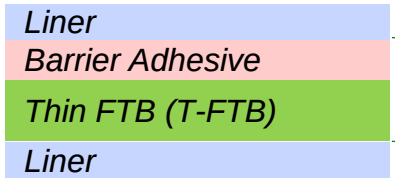
~ 270 um

WVTR < $1x10^{-3}$ g/m^2/day @ 20C
Mocon Permatran 700

Developmental

FTB3-50a
FTB3-125a

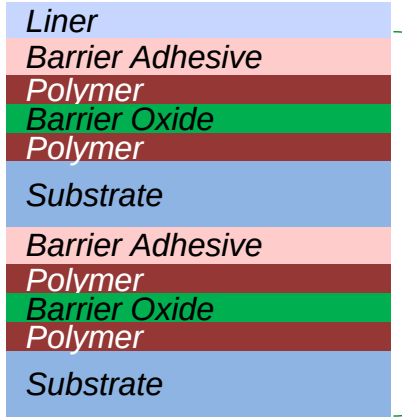
~ 62 um
~ 138 um



~ 20 um

WVTR < $1x10^{-3}$ g/m^2/day @ 20C
Mocon Permatran 700

FTB6-125L



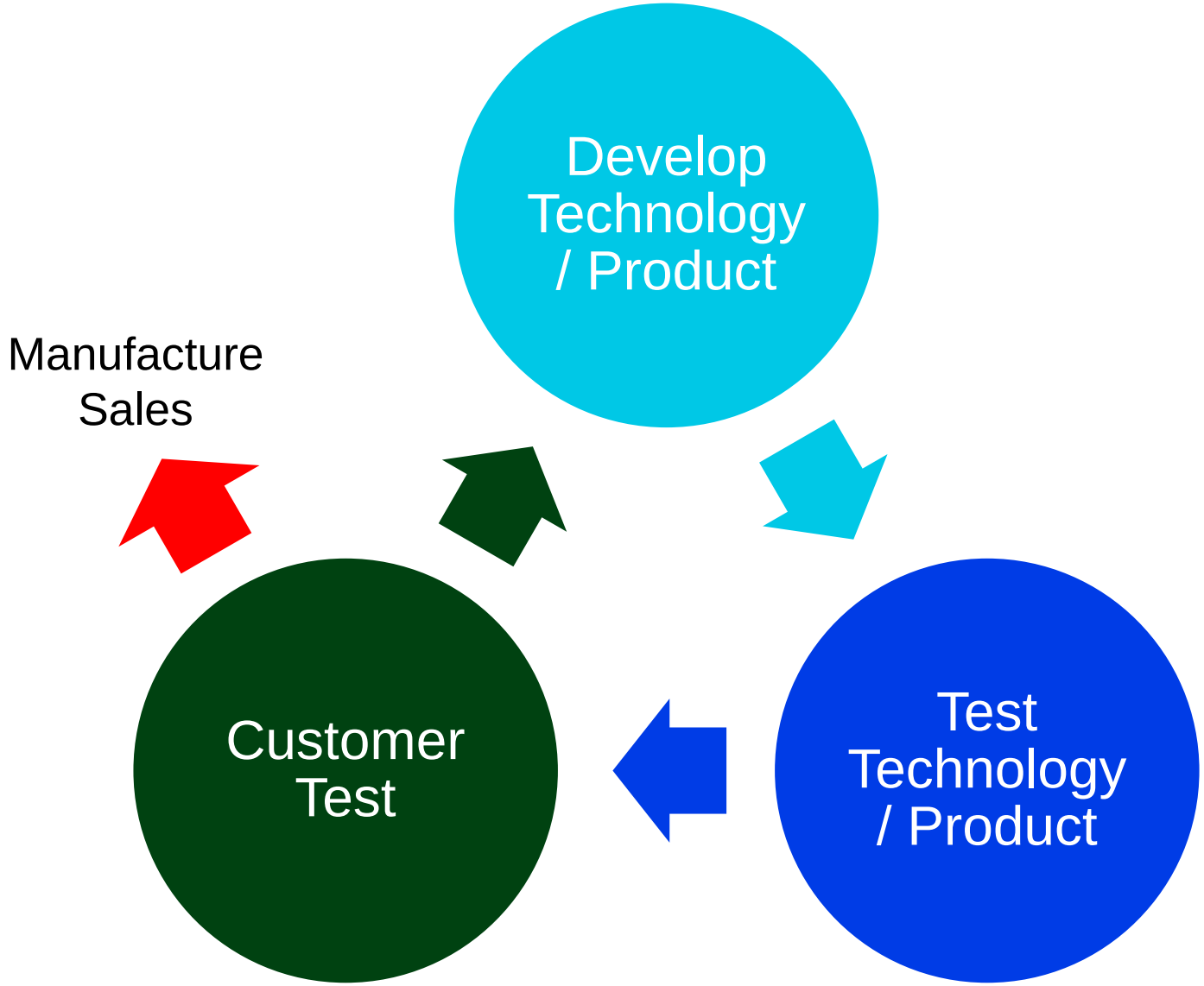
~ 125 um

FTBA-12

WVTR < 2 g/m^2/day @ 20C

OLED Barrier Characterization

- Develop technology/product
- Test technology/product
  - WVTR
  - Optical
  - Mechanical
  - Chemical
  - Electrical



Characterizing Barrier Performance - WVTR

Water Vapor Transmission Rate
(g/m²/day)

$$WVTR = \frac{m_p}{A * t} \rightarrow \frac{10^{-6} g}{m^2} / day$$

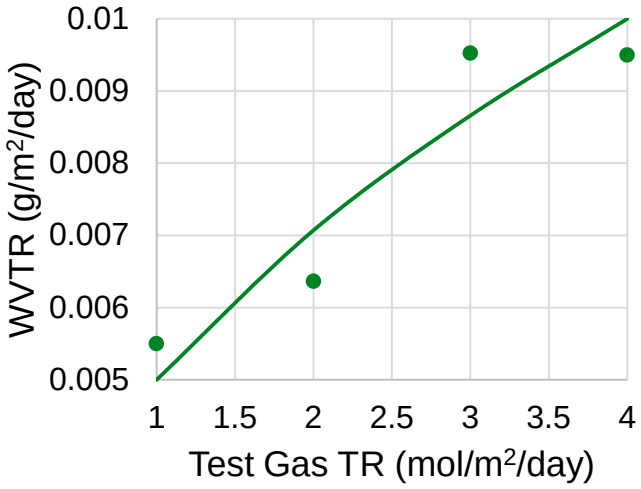
Direct WVTR Measurement

Mocon Aquatran 2, SEMPA HiBarSens2

Measure H_2O (or O_2) TR

Indirect WVTR Correlation

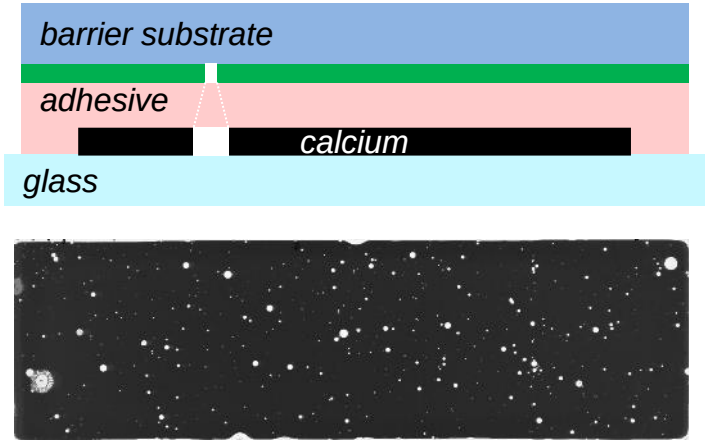
Mass Spectroscopy, i.e. Vinci QHV-4



Measure test gas (He, etc.), correlate to H_2O

Indirect WVTR Prediction

Optical or electrical Ca test



Measure OD vs time, model WVTR – oCa
Measure σ vs time, model WVTR – eCa (NREL)

3M Optical Calcium Test

1) Deposit Ca (1000Å thick) on glass slides

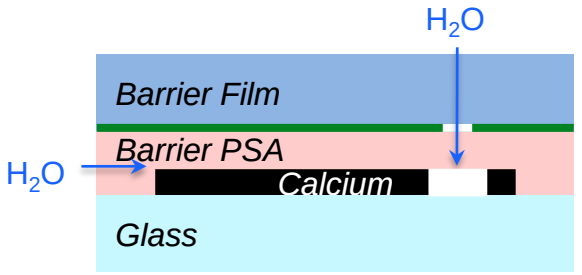
2) Encapsulate with barrier film and barrier adhesive

3) Measure optical density at t = 0 hr

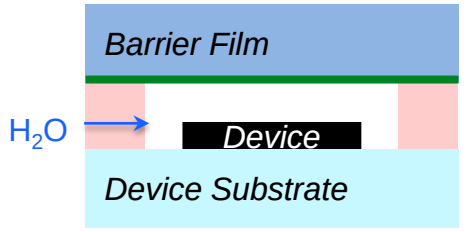
4) Place in 60ºC / 90%RH and periodically remove for scanning

5) Use image analysis software to measure
   - Optical density → WVTR
   - Moisture edge ingress
   - Defects
   - Barrier uniformity

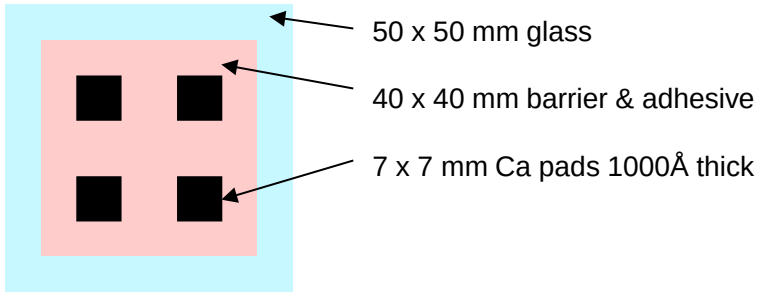
Test Coupon



Edge Ingress Model

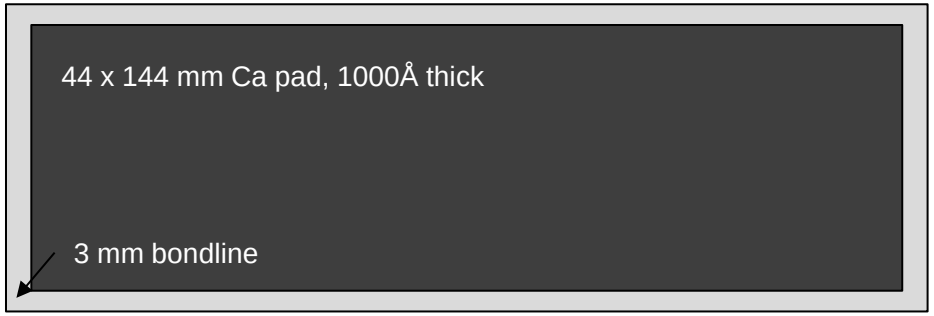


Small Area Calcium

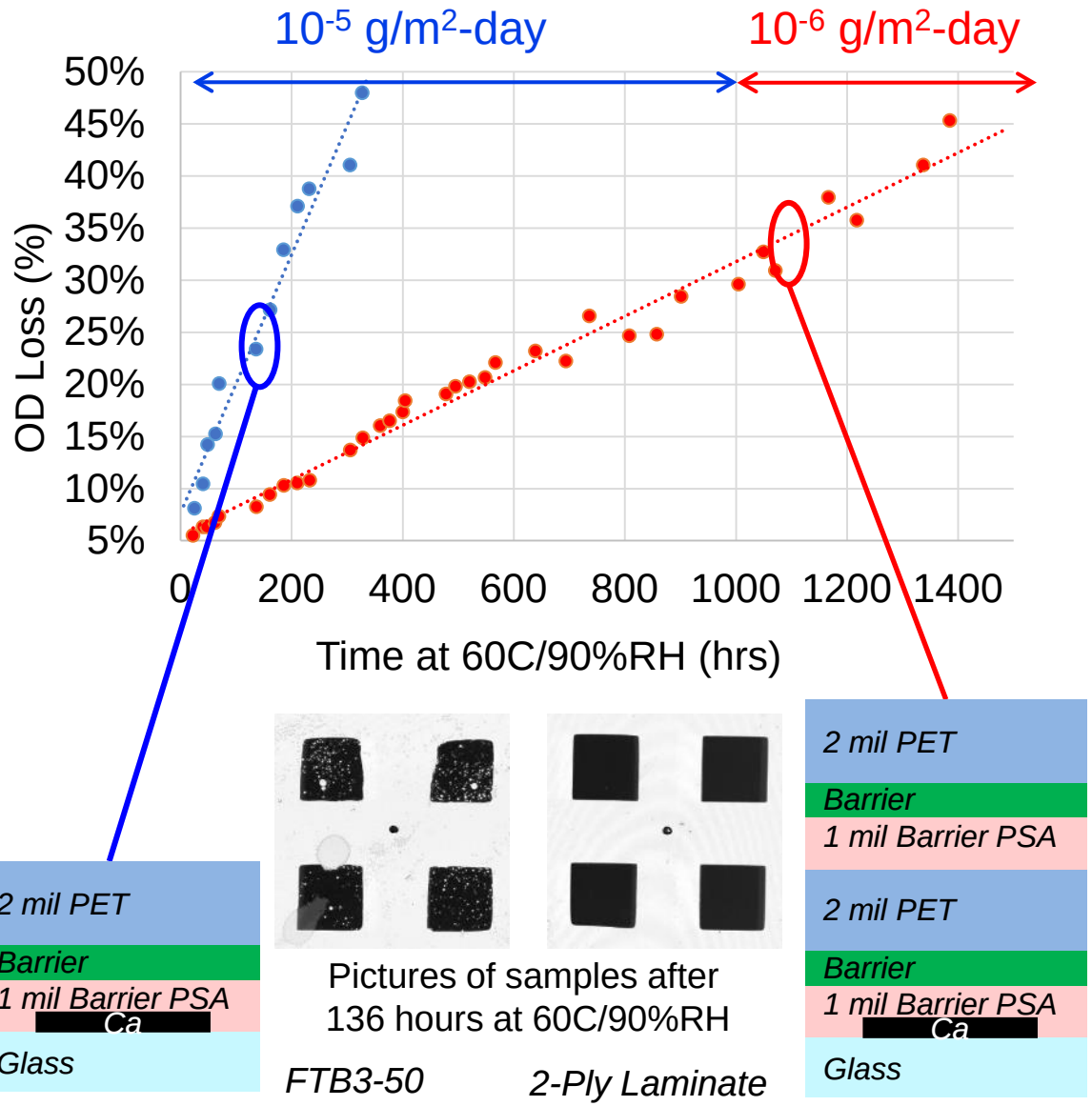


Large Area Calcium

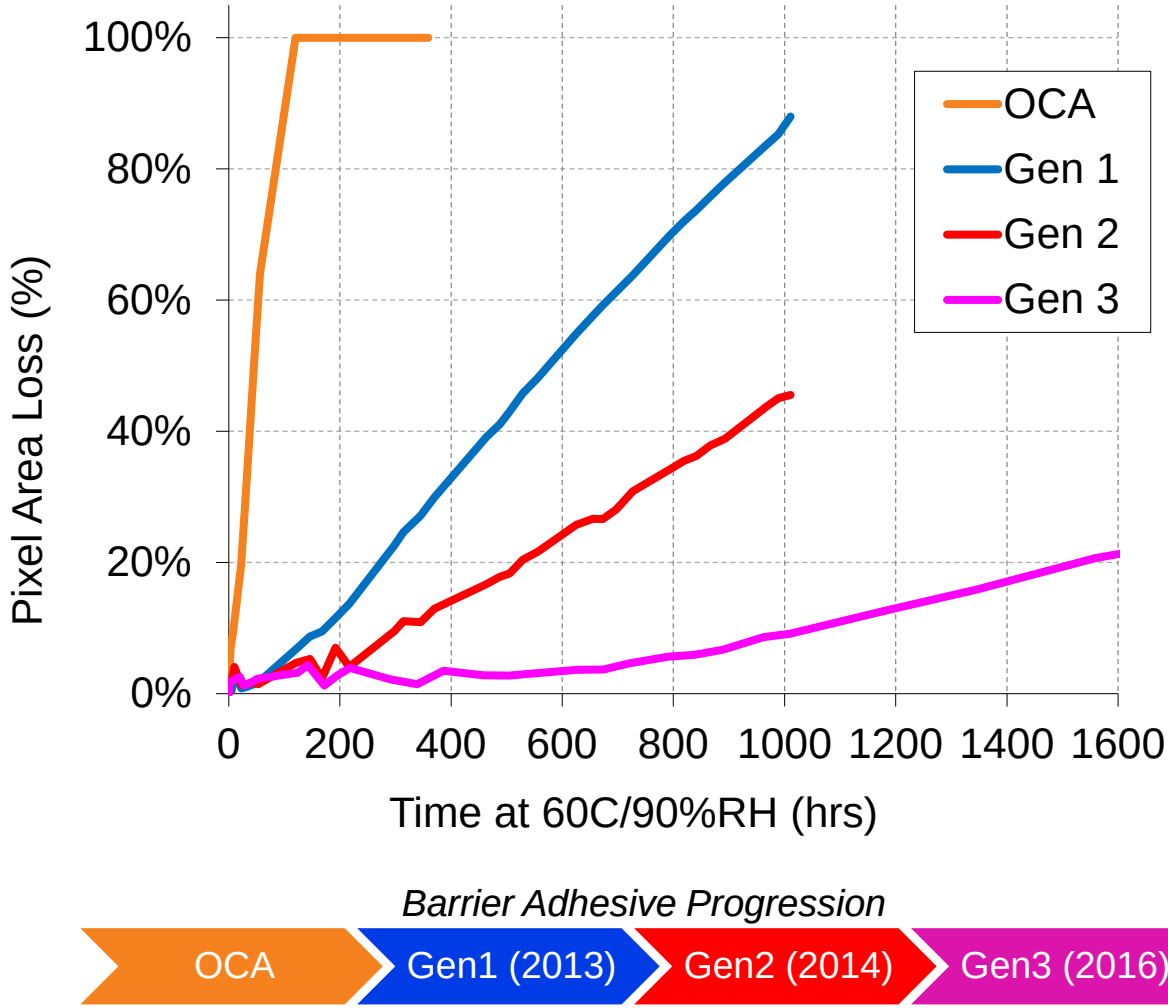
50 x 150 mm glass covered by
50 x 150 mm barrier & adhesive



Barrier Film Characterization by Optical Ca test



Pictures of samples after 136 hours at 60C/90%RH



Barrier Adhesive Progression

OCA → Gen1 (2013) → Gen2 (2014) → Gen3 (2016)

OLED Barrier Characterization

- Develop technology/product
- Test technology/product
  - WVTR
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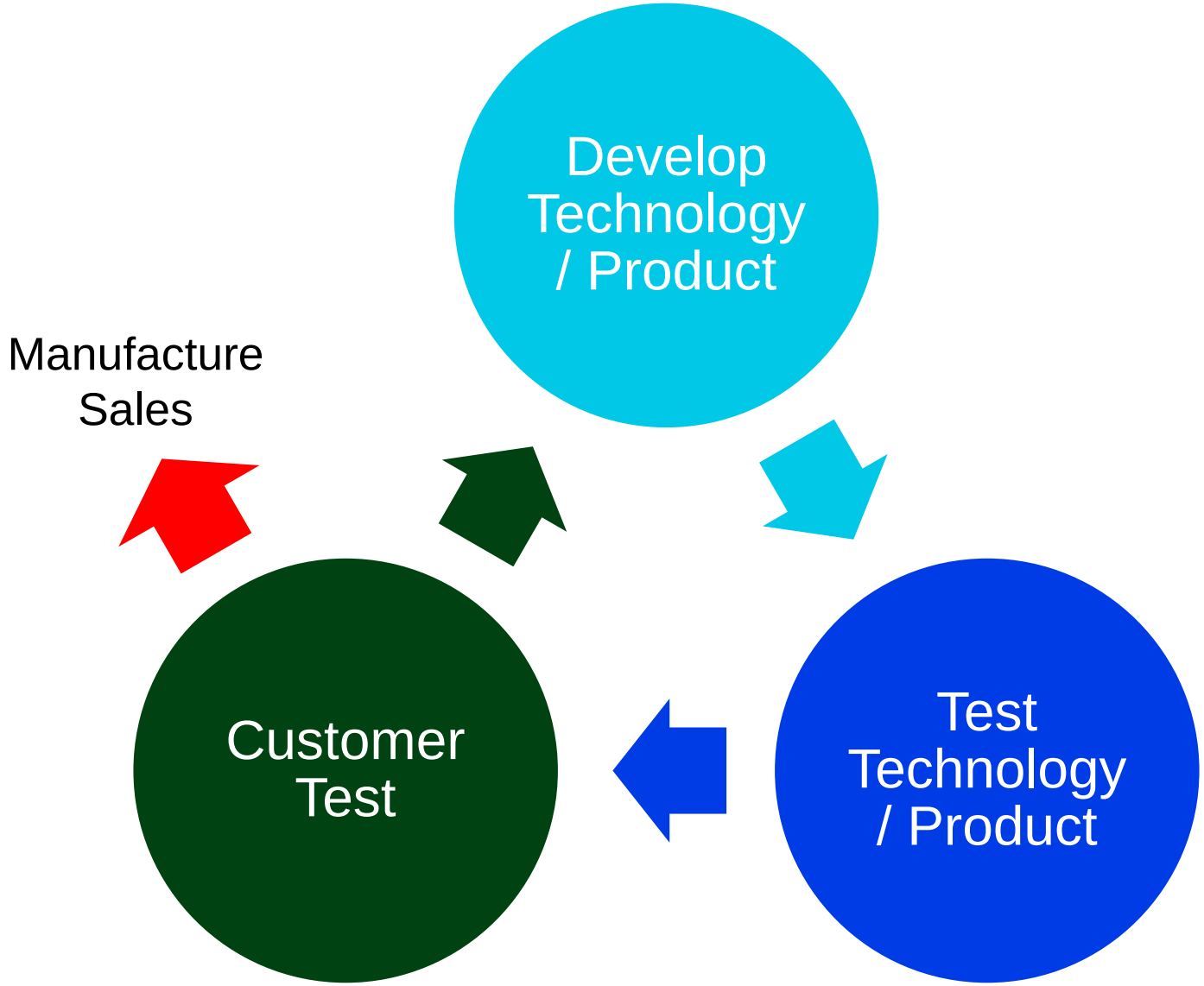
  - Mechanical
  - Chemical
  - Electrical

- Do these tests validate device performance?
  - Lifetime
  - Brightness
  - Uniformity
  - Form Factor



In-device characterization

Manufacturing success

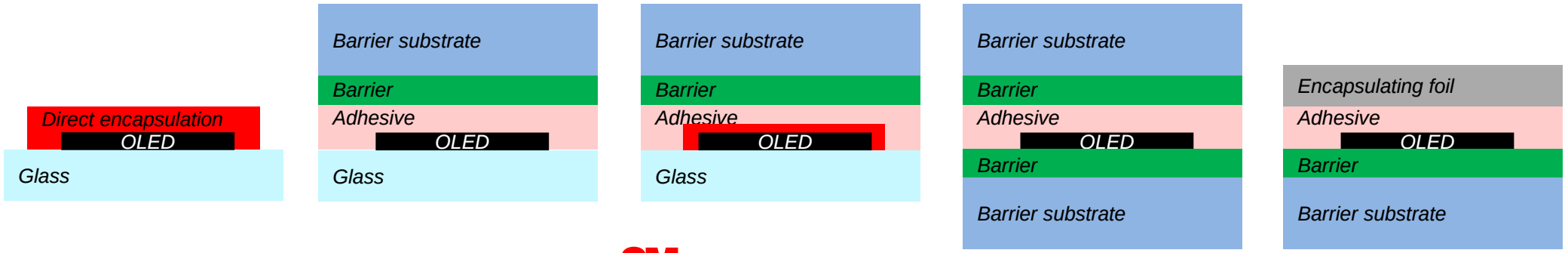
- *Product performance*
- *End-use performance*
- *Reliability*
- *Reproducibility*
- *Customer acceptance*

Beyond steady state WVTR

- *Handle-ability*
- *Form factor (rolls vs sheets)*
- *Mechanical durability*
- *In-device flexibility*
- *Optical interactions*
- *Permeation dynamics*
- *Defect distribution*
- *Device lifetime*

- Sustainable Development Technology Canada
  - OTI Lumionics Inc. — OLED Lighting Pilot Production Line
  - SDTC Investment: $5,700,000
    Total Project Value: $17 million
  - Consortium Members: OTI Lumionics, 3M, Dr. Reddy's Laboratories, NSG-Pilkington, TE Connectivity, Teknion, Lumentra
- Fraunhofer FEP
- DOE SSL Proposal

How could barrier films be used?



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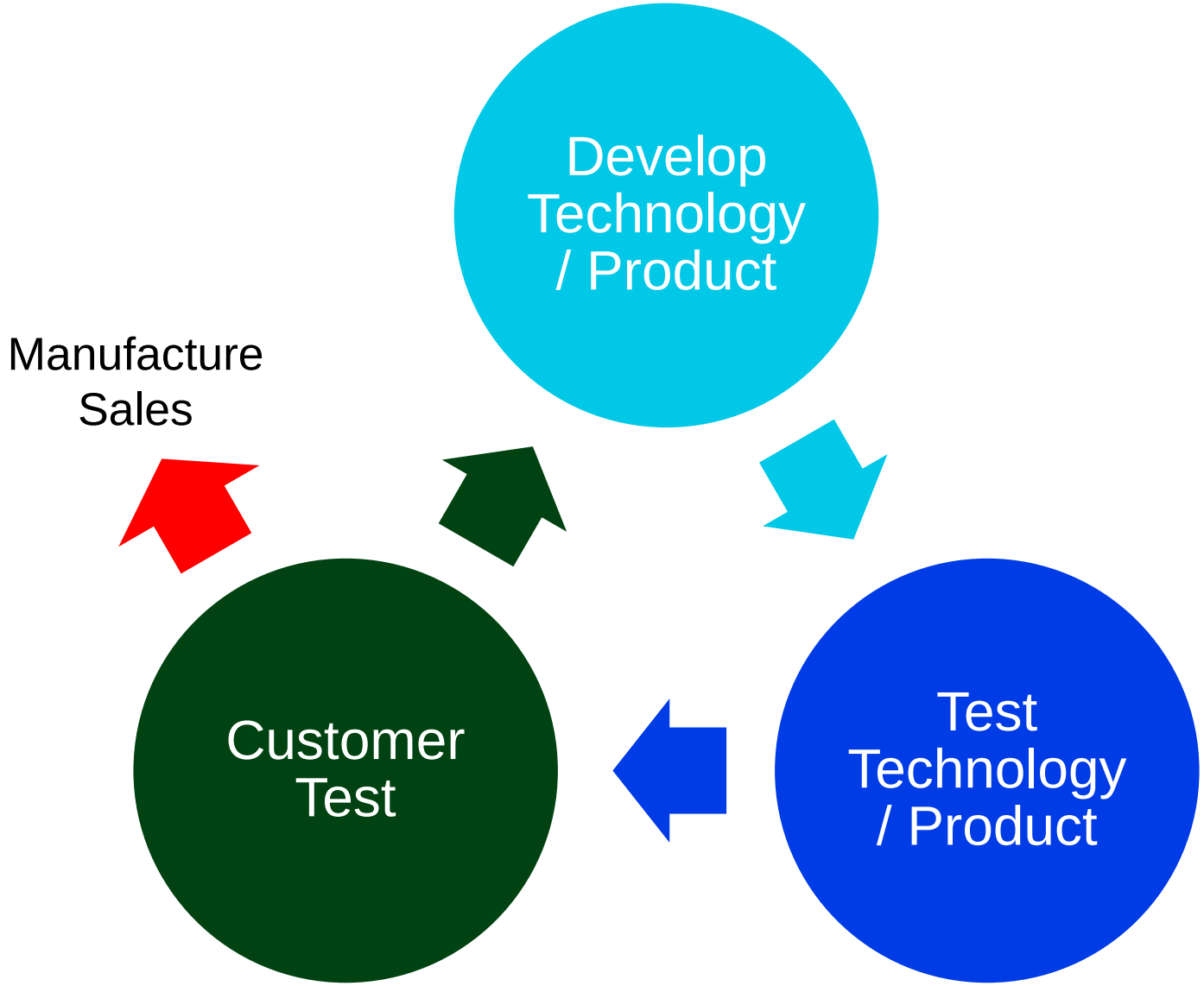

Suggested Areas for Research

- WVTR measurement techniques
  - *Faster methods with lower detection limits*
  - *Commercially available systems and standards*
- In-line characterization techniques
  - *Faster methods for validating control, performance*
- Flexibility characterization techniques
  - *Commercially available systems and standards*
- Edge ingress & edge sealing
- Defects
  - *Elimination, reduction, rapid detection*
- Substrates
  - *Low cost*
  - *Heat stable*
- Electrical interconnects for flexible devices
- Large area transparent conductors
  - *ITO alternatives*
  - *Pattern-able*

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