Low Temperature Encapsulation for OLEDs and PLEDs

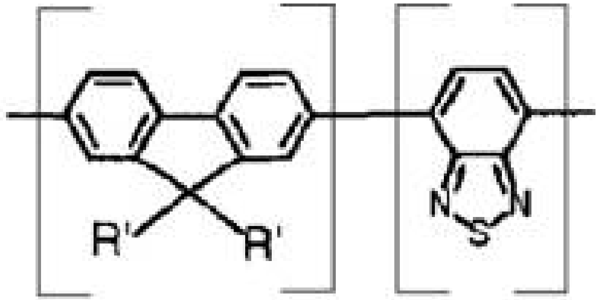
Aaron R. Johnson
Prof. Jerzy Kanicki
University of Michigan

Overview

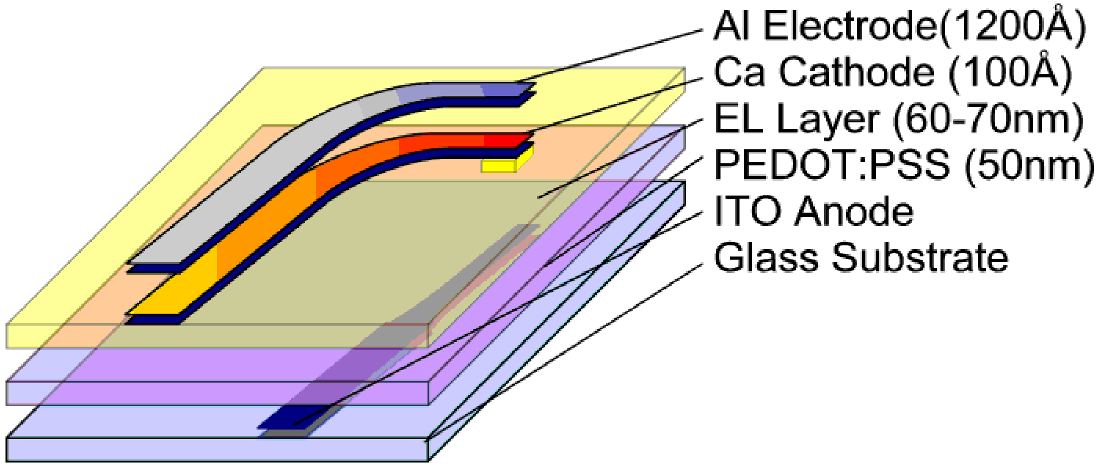
1. PLED Devices
2. Lifetime Issues
3. Thin-Film Encapsulation of PLED Devices
4. Polymer thin film encapsulation
5. Inorganic thin film encapsulation by low-temperature PECVD of nitride and oxide films

PLED with Green Polyfluorene

- **Dow Green**
  - **poly(9,9’-dioctylfluorene-alt-benzothiadiazole)**



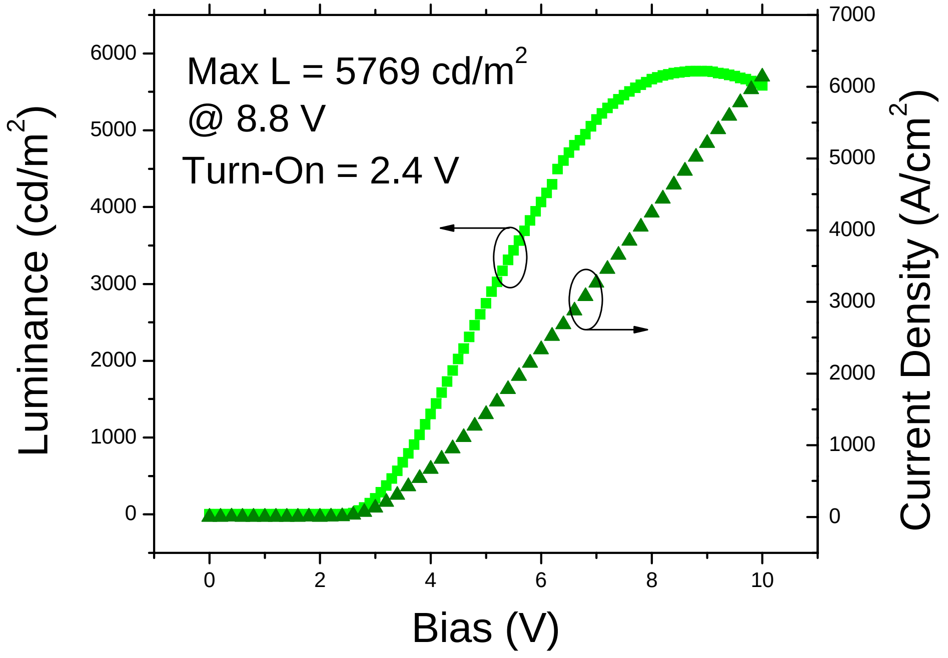
- **ITO pre-patterned on glass or plastic**
- **Bilayer (PEDOT:PSS/EL) solution processable**
- **Thermally evaporated cathode (Ca/Al, Ca/Ag, Ca/Au, etc.)**



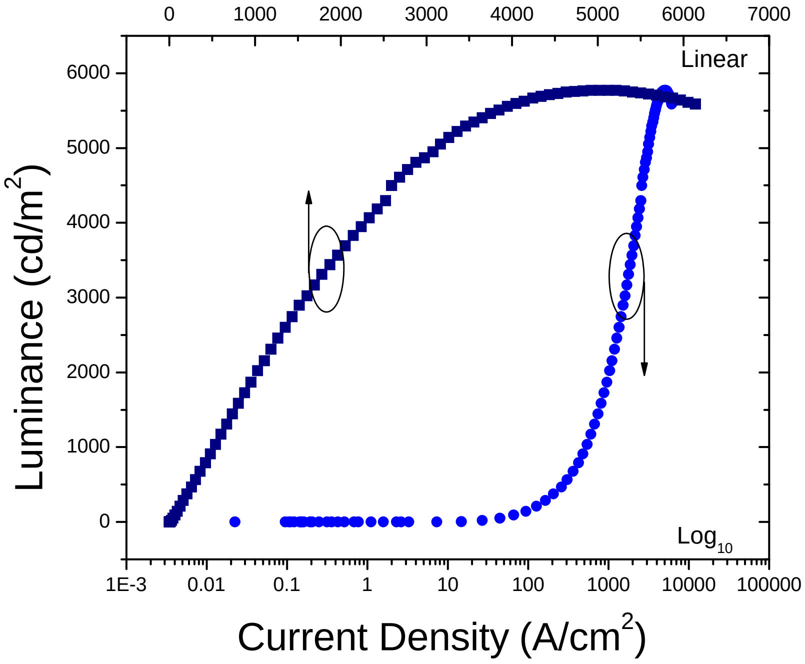
Typical Characteristics of Dow Green OLED

Solution:

- 12 mg/mL xylenes


DOW Green Luminance vs. Bias

Max L = 5769 cd/m^2
@ 8.8 V
Turn-On = 2.4 V


DOW Green Luminance vs. Current Density

See Also:

J. Kanicki, S.-J. Lee, Y. Hong, C.-C. Su, Journal of the SID 13/12, pp. 993, 2005

M. T. Bernius, M. Inbasekaran, J. O'Brien, W. Wu, Adv. Mat. Vol. 12, No. 23, pp. 1737, 2000
Y. He, J. Kanicki, Proceedings of the SPIE, Vol. 4105, oo. 143, 2001

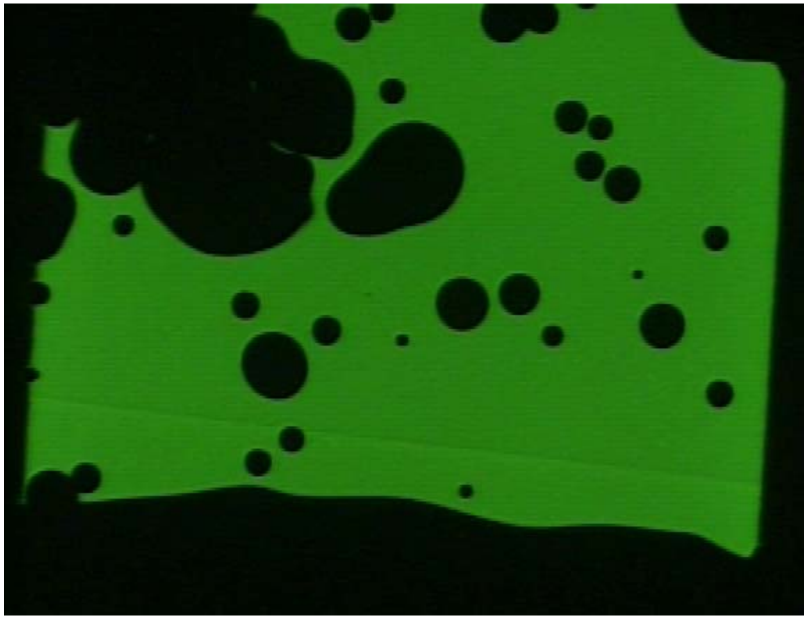
OLED Lifetime

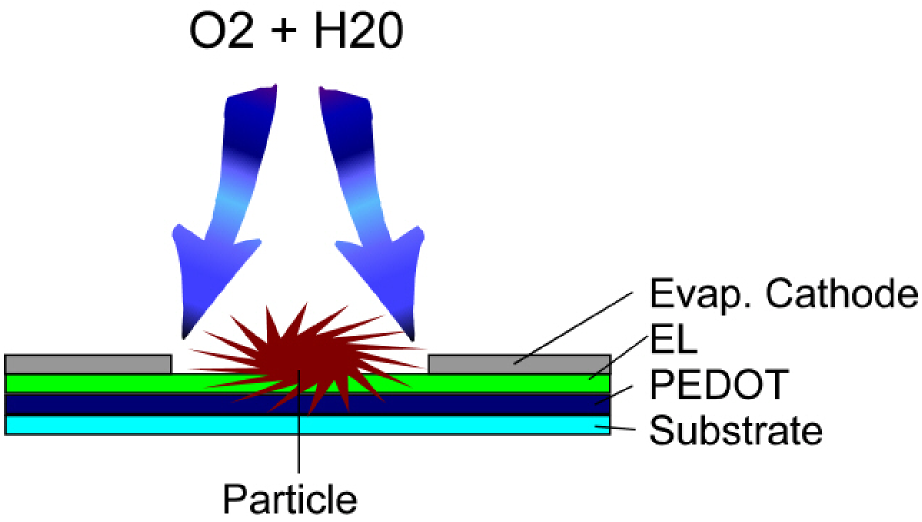
- **Extrinsic Factors**
  - **Oxygen and moisture diffusion**
  - **Growth of non-emissive regions (“dark spots”)**
  - **Presence of dust/particulate**
    - Reduce luminance of the device
    - Reduce the usable time for use in solid state lighting or display applications
  - **Joule heating**
- **Intrinsic Factors**
  - **Chemical instability**
  - **Redistribution of mobile ionic impurities**

Y.- F. Liew, H. Aziz, N.-X. Hu, H. S.-O. Chan, G. Xu, Z. Popovic, Appl. Phys. Lett. Vol. 77, pp. 2650, 2000

Dark Spots

- Dark Spot Formation
  - Particulate Matter
  - Pinhole Defects
- Dark Spot Growth
  - Primarily due to cathode delamination
  - Nucleation occurs at organic/metal interface



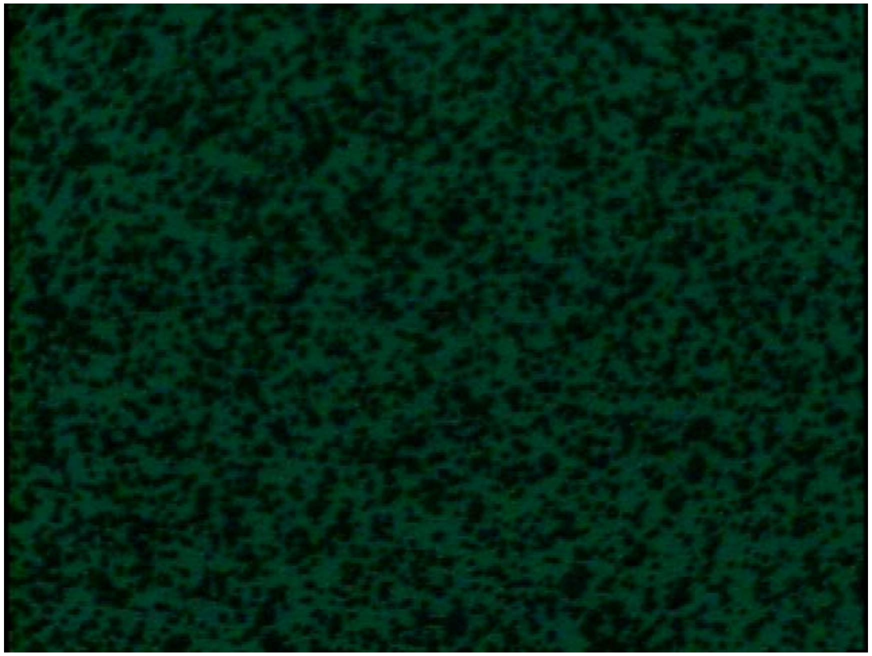


H. Aziz, Z. Popovic, C. P. tripp, N.-X. Hu, A.-M. Hor, G. Xu, App. Phys. Lett. Vol. 72, No. 21, 1998
K. K. Lin, S. J. Chua, S. F. Lim, J. App. Phys. Vol. 90, No. 2, pp. 976, 2001

Dark Spots from Poor Cathode Adhesion

Delaminated regions result in non-luminescent area

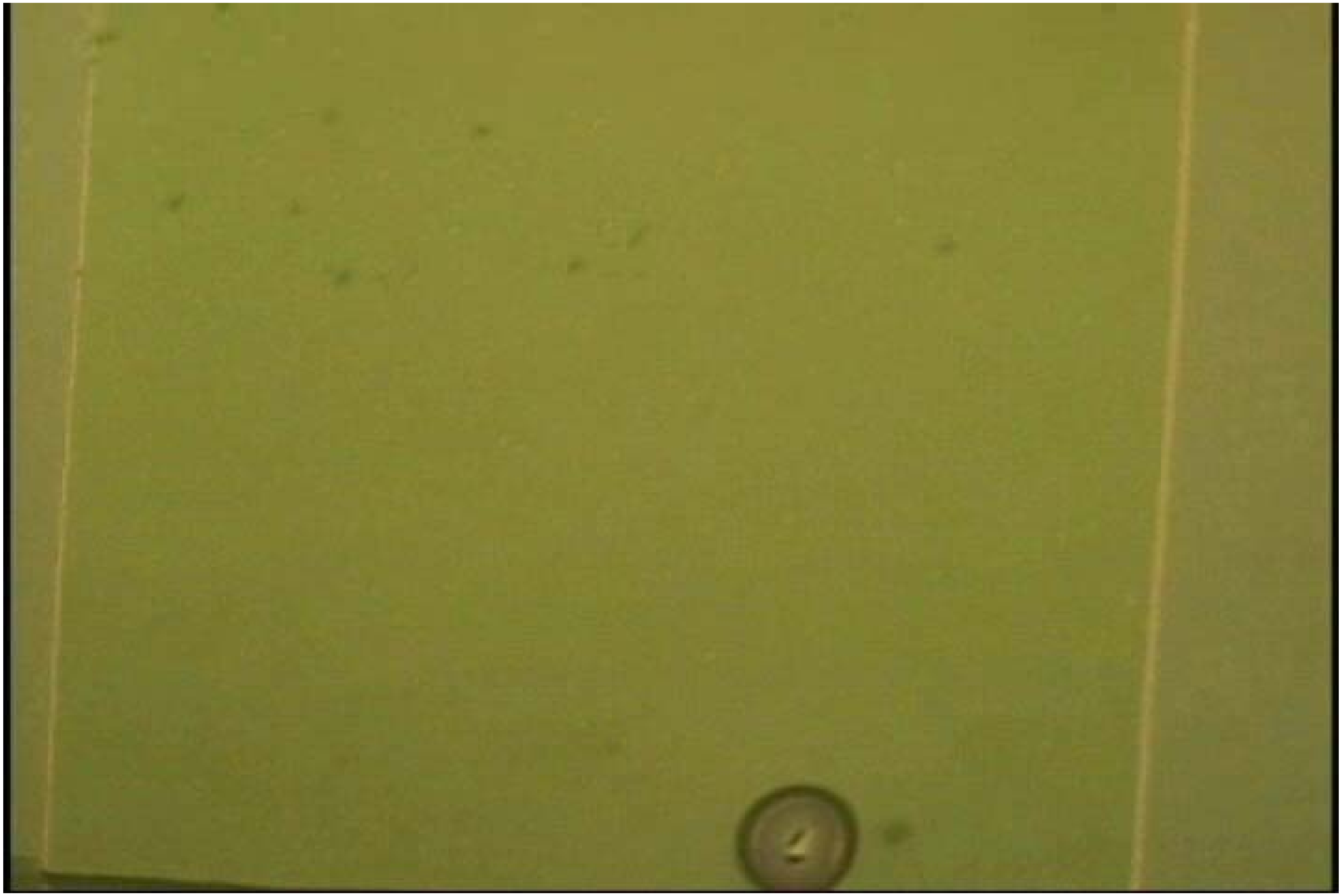
Device: OFF



Device: ON

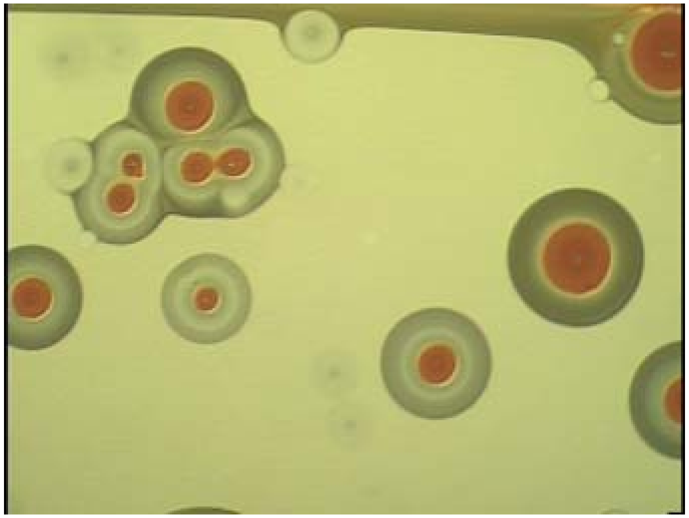
OLED Lifetime I (1 hr. 8 min.)

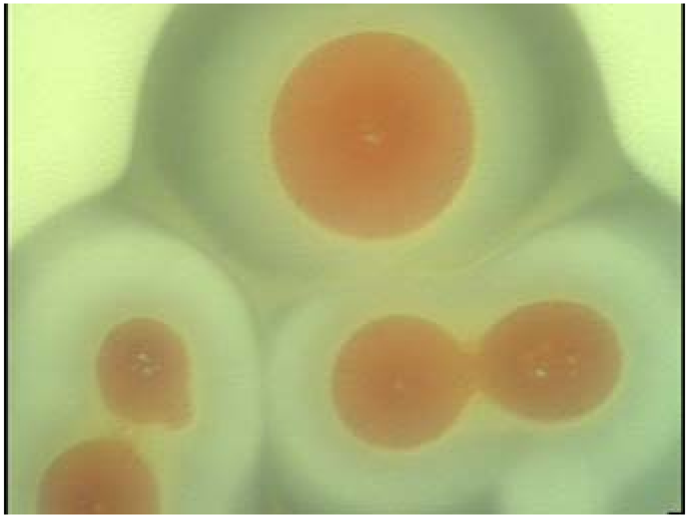
EL: DOW Green



OLED Failure Details

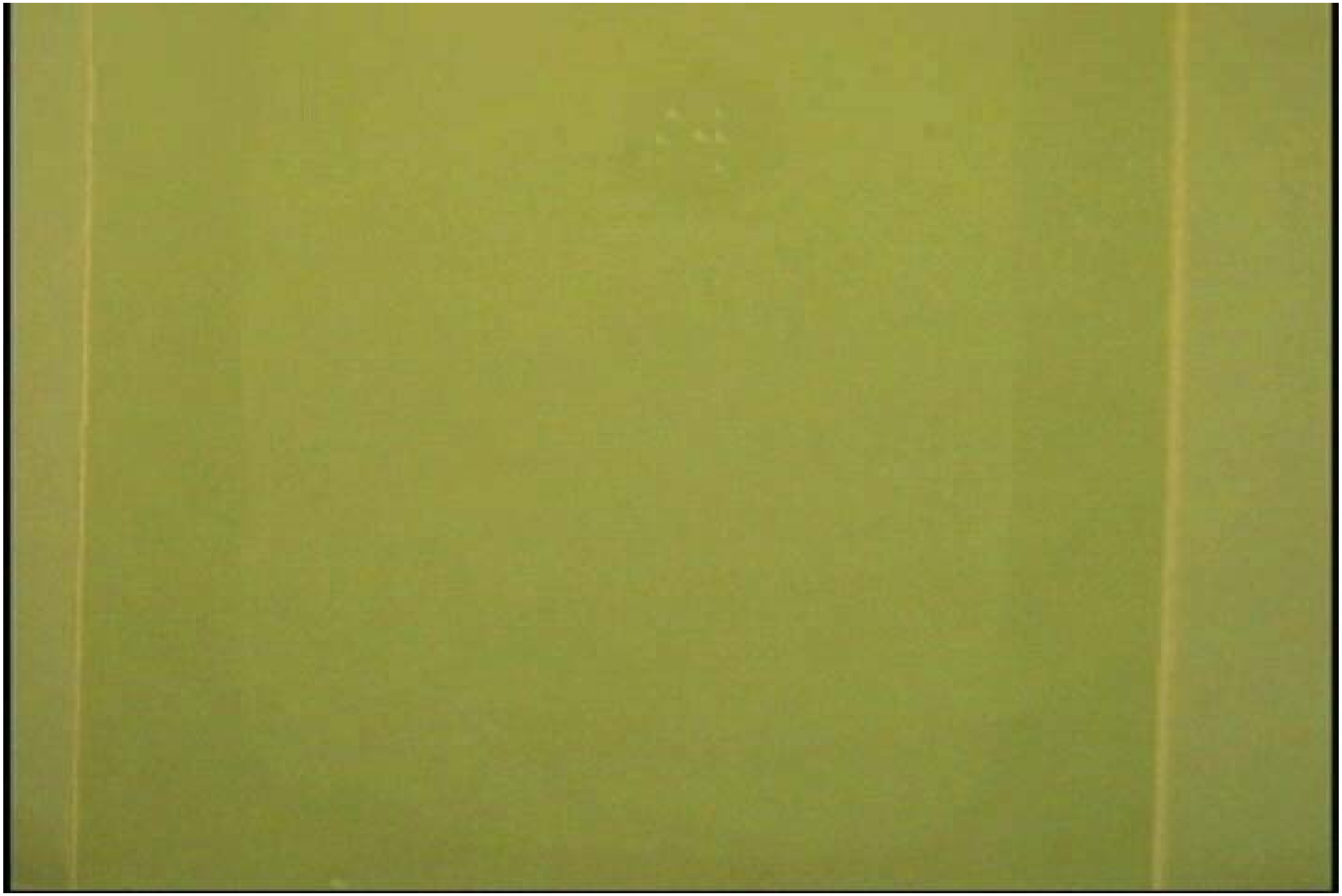
Images taken after "Lifetime I" video ended





OLED Lifetime II (1 hr. 48 min.)

EL: DOW Green



PLED Encapsulation

Requirements

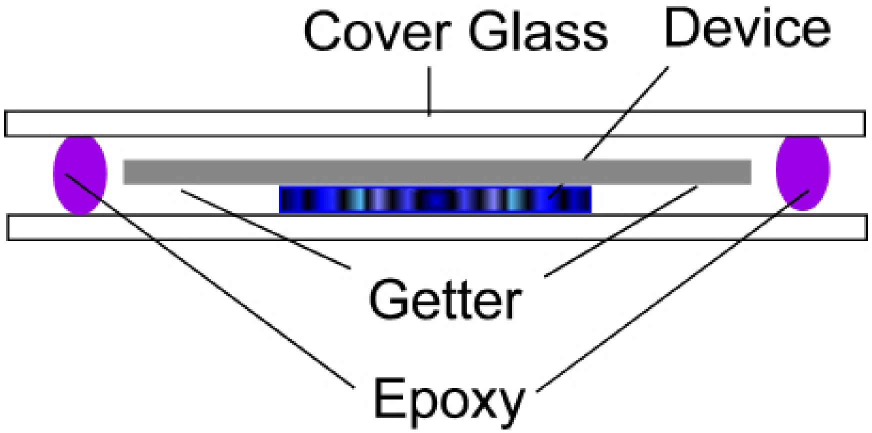
- Good barrier to diffusion of O_2 and H_2O
  - WVTR: ~10^{-6} g/m^2-day
  - OTR: 1×10^{-5} cm^3 (STP)/m^2-day
- Pinhole free
- Mechanically robust
- Commensurate with limitations of PLED devices

Encapsulation Methods

1. Glass/Rigid cap
   - Sealed with UV-curable epoxy
2. Polymeric Film
   - Spin-cast
3. Inorganic Film
   - SiNx, SiOx, AlOx
4. Hybrid Approach
   - Combination of 2 or more of the above

J. S. Lewis, M. S. Weaver, IEEE J. Sel. Top. Quan. Elec. Vol. 10, No. 1, pp. 45, 2004
A. P. Ghosh, L. J. Gerenser, C. M. Jarman, J. E. Fornalik, Appl. Phys. Lett., Vol 86, pp. 223503, 2005

Rigid Glass Cap Encapsulation



Pro

- Very good water and moisture barrier properties
- Transparent

Con

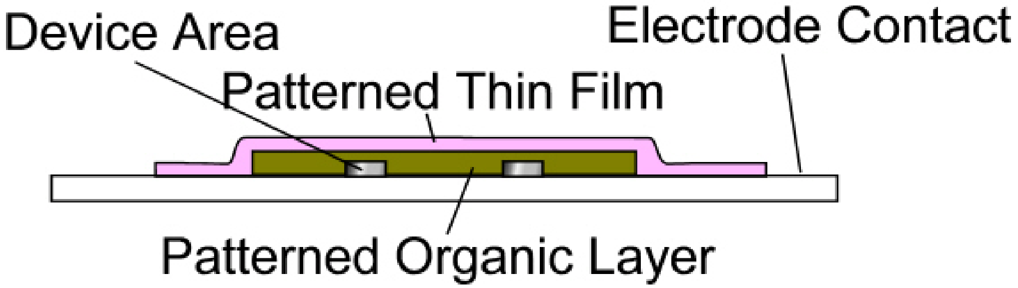
- Thick
- Rigid
- Requires the use of a getter
  - Unsuitable for top emission because opaque getter is placed on top of PLED device

Thin-Film Encapsulation - Polymers

Polymeric Films

- **Good Conformal coverage**
- **Encases particulate matter to prevent formation of hole**
- **Planarizes device**
- **Ability to embed oxygen scavenging oxide particles in polymer matrix**
- **Prone to oxygen and moisture diffusion**

Polymer	**WVTR**	**OTR**
Polyethylene	1.2-5.9	70-500
Polypropylene	1.5-5.9	93-300
Polystyrene	7.9-40	200-540
PET	3.9-17	1.8-7.7
Poly(ethersulfone)	14	0.04
PEN	7.3	3.0
Polyimide	0.4-21	0.04-17
15nm Al/PET	0.18	0.2-2.9



Permeability and Other Film Properties of Plastics and Elastomers, 1st ed. Norwich, NY: Plastic Design Library (1995)
E. H. H. Jamieson, A. H. Windle, J. Mater. Sci. Bol. 18, pp. 64, 1983
E. Lueder, Electrochem. Soc. Proc. Vol. 98-22, pp. 1982, 1991
Y. Leterrier, Prog. In Mater. SCi, Vol. 48, pp. 1, 2003
J. S. Lewis, M. S. Weaver, IEEE J. Sel. Top. Quan. Elec. Vol. 10, No. 1, pp. 45, 2004

Thin Film Encapsulation – Inorganic Films

Inorganic Films

- **Low temperature PECVD processes for SiNx, SiO2**
    - **IC systems “Low Temperature” considered 300-400C**
    - **Organic films require < 130C**
- **Other low temperature processes available**
- **Dense films**

Consequences of Low T

- Higher H Content →Lower Density
- More Pinholes

Assche et. al.: 3 SiNx layers, <100nm organic spacers

60C → WVTR = ~10^{-1} g/m^2-day

100C →WVTR = ~10^{-4} g/m^2-day

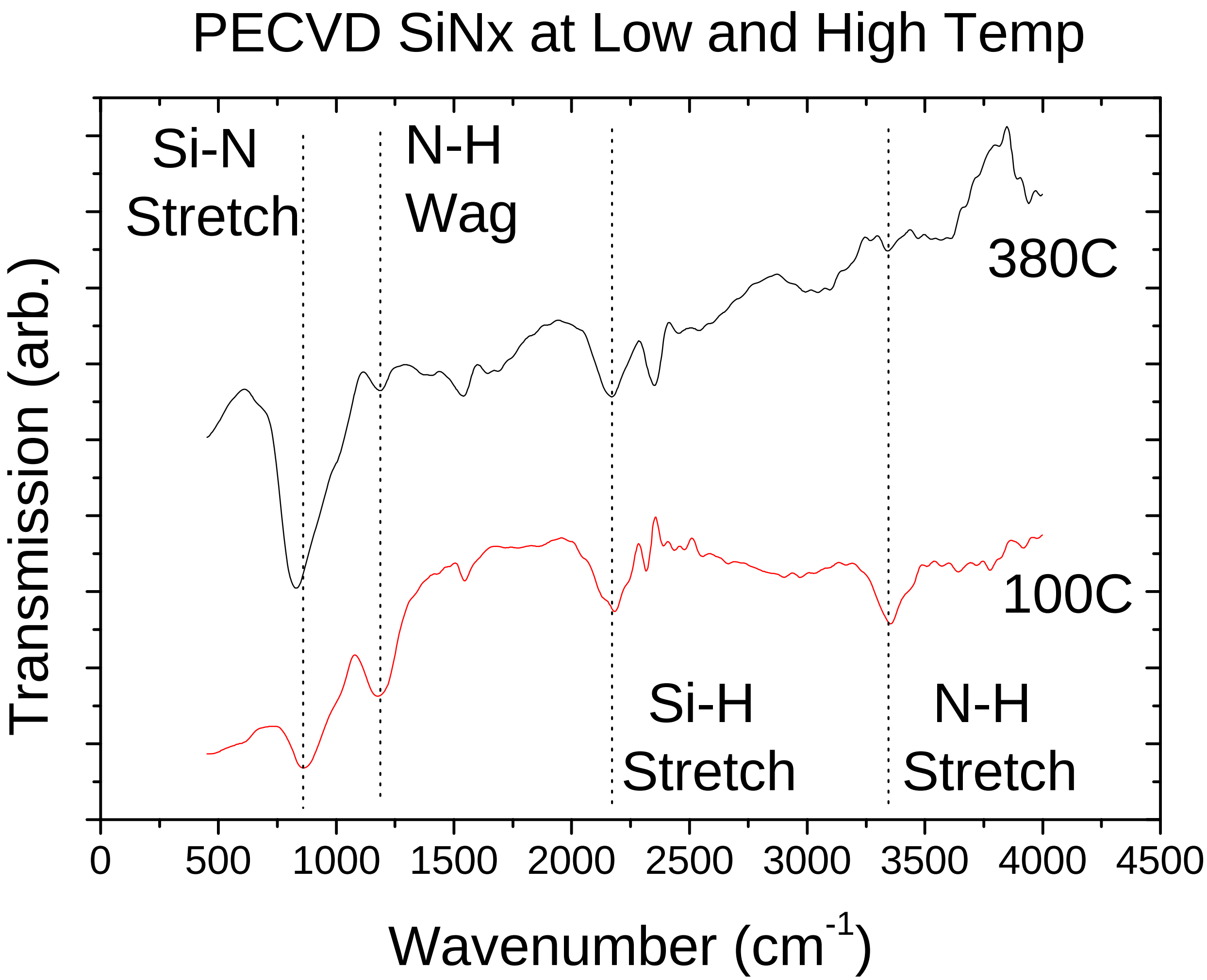
140C → WVTR = ~10^{-6} g/m^2-day

SiN_x n = 1.95-2.2 (Sparse – Dense) → 100C SiN_x n= ~1.8 (experimental)

SiO_x n = 1.46 – 1.96 (di – mono) → 100C SiO_x n= ~1.8 (experimental)

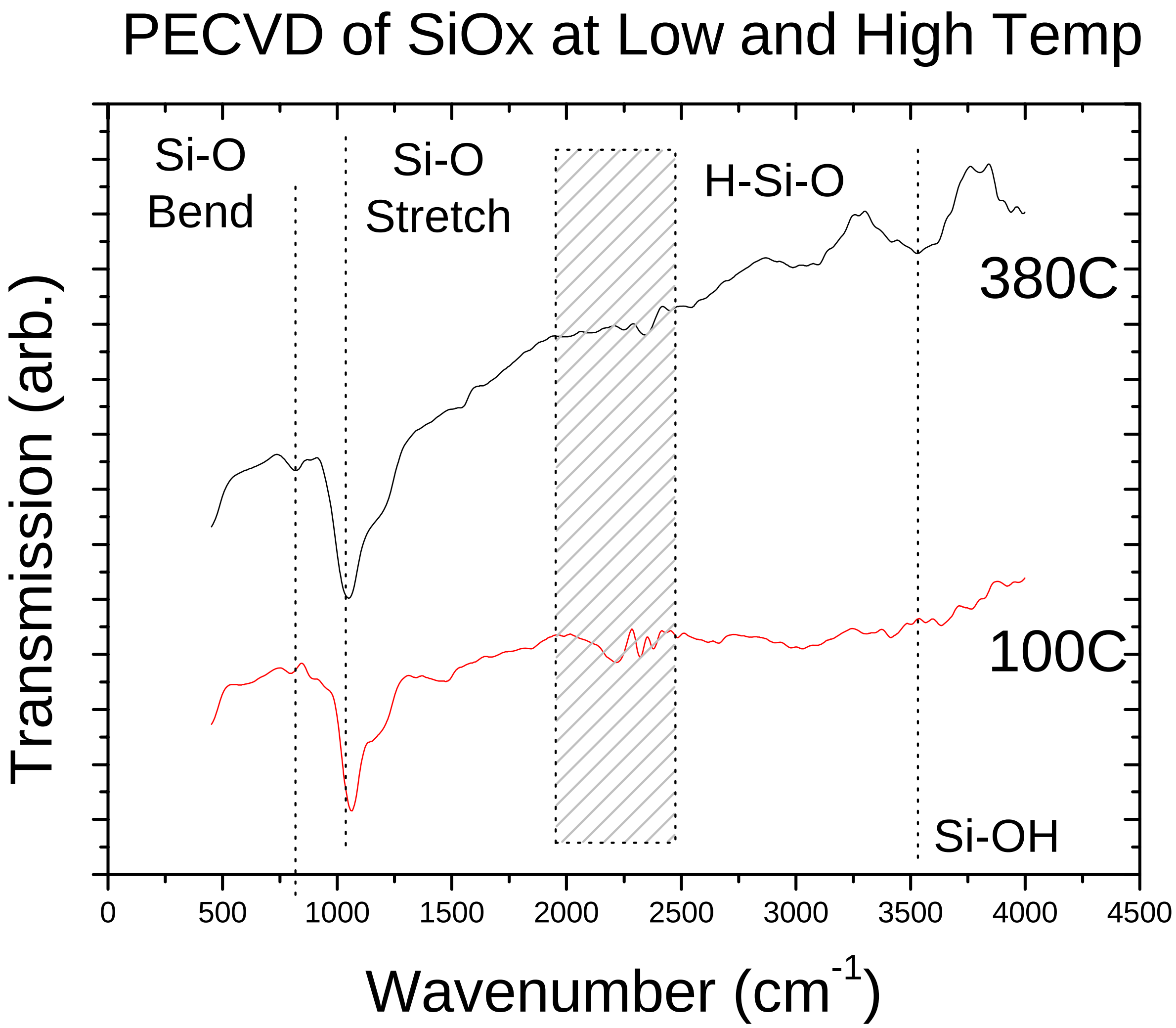
F. J. H. van Assche, R. T. Vangheluwe, J. W. C. Maes, W. S. Mischke, M. D. Bijker, F. C. Dings, M. F. J. Evers, W. M. M. Kessels, M. C. M. van de Sanden, SID 04 Digest, 695, 2004

Low Temperature Nitride FTIR



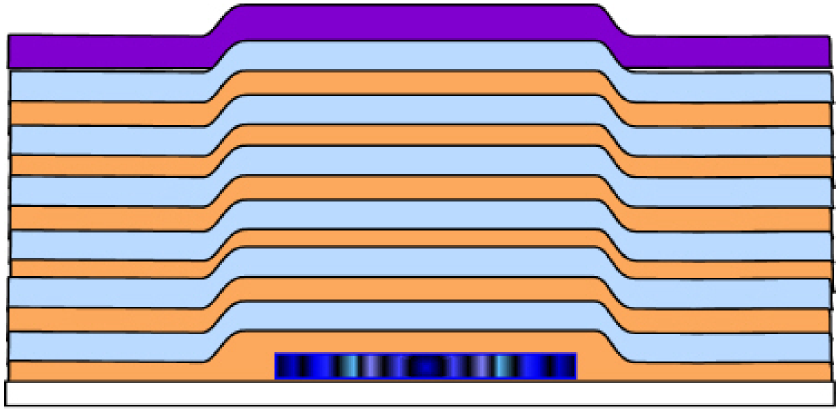
Significant enhancement of Si-H and N-H absorption indicating H-rich, less-dense films

Low Temperature Silicon Oxide FTIR



Small enhancement of H-Si-O absorption. No Si-OH absorption detectable

Thin-Film Encapsulation – Hybrid



12 layer: {N/O} x 6

- **12-layer stack of alternating SiNx and SiOx**
- **Printed topcoat embeds particles in to scheme**

{N/O} Stack	WVTR (g/m^2-day)
5 Layers	2.1 x 10^{-3}
12 Layers	3.0 x 10^{-5}
5 Layers + topcoat	1.6 x 10^{-4}
12 Layers + topcoat	3.6 x 10^{-6}

J. J. W. M. Rosink, H. Lifka, G. H. Rietjens, A. Pierik, SID 05 Digest, pp. 1272, 2005

Polymer-Based Oxygen Scavenger Layer

- **Ceramic oxide**
  - **Particulate reactant phase is dispersed throughout a polymer matrix [1]**
- **Amine-based Bairocade®**
  - **Increases oxygen barrier of encapsulation schemes by almost 25x [2]**
- **Mitsubishi offers an iron powder-filled polymer**
  - **Shown to absorb 300cc of O_2 per gram of iron [3, 4]**
- **Lucent copper particles suspended in a polymer matrix**
  - **Shown to reduce corrosion [5]**

Active barrier films widely used in the food packaging industry

[1] Higgins, L. M., Advancing Microelectronics, July/August, p. 6 (2003)
[2] PPG Industries Bairocade product information, www.ppg.com/packaging.
[3] Mitsubishi Gas and Chemical, Product Information
[4] Vermeiren, L. et al., Rutgers University publication, Oct. 27, 2000, www.foodsci.rutgers.edu/yam/packaging%20Network/Oxygen%20Scavenging%20Packaging.htm
[5] Conservation By Design, Ltd., Corrosion Intercept technical Bulletin 11, “Corrosion of Copper,” 1994.

Conclusions

- Degradation of PLED/OLED from dark spot formation and growth due to oxygen and moisture diffusion through pinhole defects in cathode
- Encapsulation of devices required for extended lifetime
- Optimized low temperature PECVD process for SiNx and SiOx produce porous, sparse films.
- Efficacy of these films enhanced with a hybrid approach

Typical Characteristics of Dow Green