A new environmental barrier layer for organic light-emitting displays

Sigurd Wagner*, Prashant Mandlik, and Lin Han

Department of Electrical Engineering and Princeton Institute for the Science and Technology of Materials, Princeton University, Princeton, New Jersey, USA
Phone: +1-609-258-4641, E-mail: wagner@princeton.edu

Jeff A. Silvernail, Rui-Qing Ma, Michael Hack, and Julie J. Brown

Universal Display Corporation, 375 Phillips Blvd., Ewing, New Jersey, USA

Abstract

We have discovered a new single-layer environmental barrier for OLEDs. In storage at 65℃ and 85% relative humidity, OLED pixels encapsulated with this barrier have half-lives of approximately one year. We describe the fabrication and properties of the barrier, and results of accelerated storage tests.

1. Objectives and Background

Organic light-emitting displays (OLEDs) and organic solar cells degrade upon exposure to humidity or oxygen [1]. Today OLEDs are protected against atmospheric reactants by encapsulation between glass plates that are edge-sealed with a polymer. While glass is an excellent permeation barrier, it is heavy, brittle, and rigid. Lightweight and flexible OLEDs and solar cells need transparent thin-film encapsulation that must meet stringent impermeability requirements, which are met by the inorganic materials SiO_2, SiN_x, and $A\ell_2O_3$. When made thin these become flexible but remain brittle. Therefore we have been seeking a barrier material that combines impermeability and resistance to crack propagation with the simplicity of preparation of single layers. We have discovered such a material, and report its deposition as thin-film barrier, tests of its permeability on OLEDs, and its physical and chemical properties.

2. Results

2.1 Layer deposition

The layer is deposited by plasma-enhanced chemical vapor deposition from a mixture of hexamethyl disiloxane (HMDSO) and oxygen. Protective coatings of SiO_xC_y have been deposited from glow discharges in many laboratories [2,3,4], but not under conditions that produce a barrier layer with the ultra-low permeability needed for OLEDs [5,6,7]. HMDSO vapor and O_2 gas are fed into a single-chamber PE-CVD system. Substrates of OLEDs, silicon wafers or polyimide foil are held at nominal room temperature, facing downward into the radio frequency (13.56 MHz) excited discharge.

2.2 Permeation tests on OLEDs

We tested these layers as permeation barriers by encapsulating OLEDs. Layers were deposited on green phosphorescent OLEDs made in bottom-emitting (BOLED) and transparent (TOLED) configurations on glass substrates. Fig. 1 shows schematic cross sections of the encapsulated OLEDs, which have an active area of 2 mm^2. For accelerated testing the encapsulated OLEDs are stored at 65ºC and 85% relative humidity, and are periodically evaluated for electroluminescence. Industry targets a lifetime under these conditions of 1,000 hours. Figure 1 shows photographs of the luminescent areas of four BOLEDs and TOLEDs before storage (t = 0), after 1,128 hours, and after 6,749 and 6,748 hours, respectively. The average of the active areas of the four BOLEDs and TOLEDs normalized to its initial value at t = 0, is plotted in Figure 2. The lifetime for barrier coated OLEDs, defined as the time when the active area has shrunk to 50% of its initial value, is as high as 7,500 hours.

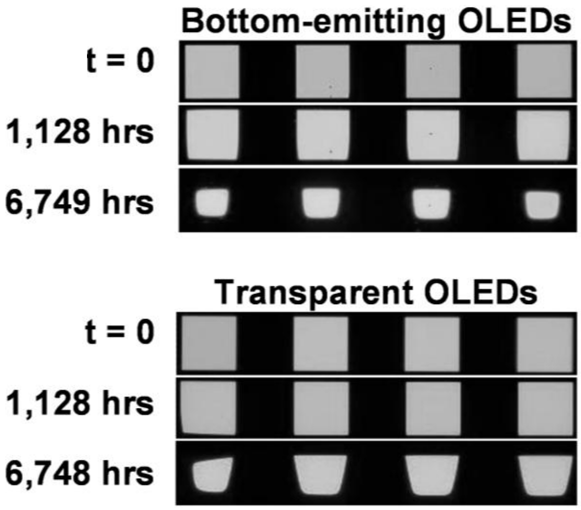

Figure 1 Average active pixel area of the four TOLEDs and BOLEDs plotted against duration of accelerated storage. The horizontal line denotes the lifetime criterion of 50% active area.

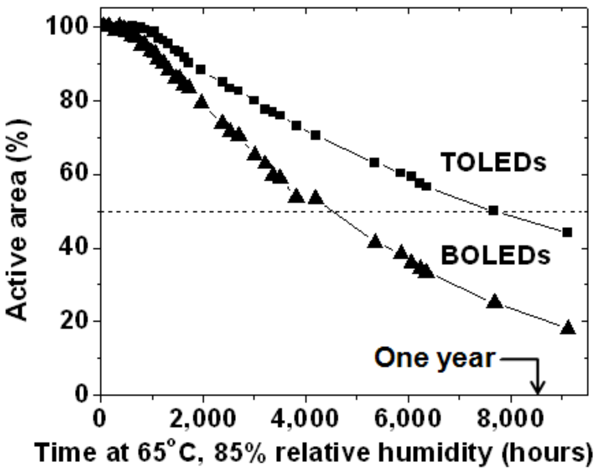

Figure 2 Average active pixel area of the four TOLEDs and BOLEDs plotted against duration of accelerated storage. The horizontal line denotes the half-life criterion of 50% active area.

2.3 Layer properties

We measured the intensity of the Si-O-Si infrared absorption band at the wavenumber of 1,075 cm^{-1}, which is a measure of the oxygen content, the contact angle of a 7.6-μℓ droplet of water on the layer surface, the hardness derived from nano-indentation with a diamond tip, and the surface roughness determined by atomic force microscopy. The data reflect a continuum of properties that ranges from those of nearly pure SiO_2 to those of plasma-polymerized HMDSO (pp-HMDSO). The layers, though largely SiO_2-like, do not fracture in the nano-indenter in contrast to thermally grown SiO_2, and also not during bending to ~ 1% tensile strain.

3. Impact

A highly impermeable permeation barrier layer is deposited from environmentally-friendly and inexpensive precursors in a single-chamber reactor. It is sufficiently flexible for roll-to-roll fabrication and bending in use. The barrier layer is a promising candidate for the encapsulation of OLEDs.

4. Acknowledgements

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5. References

[1] J. S. Lewis, and M. S. Weaver, IEEE J. Selected Topics in Quantum Electronics 10, 45-57 (2004).
[2] L. Zajickova et al., Plasma Sources, Sci. Technol. 16, S123–S132 (2007).
[3] F. Fracassi et al., Plasmas and Polymers 8 (4), 259-269 (2003)
[4] D.S. Wavhal et al., Plasma Processes and Polymers 3 (3), 276-287 (2006)
[5] A. G. Erlat et al., J. Mat. Res. 15 (3), 704-717 (2000)
[6] A. Gruniger et al., Surface and Coatings Technology 200 (14-15), 4564-4571 (2006)
[7] Ph. R. Von Rohr et al., Surface and Coatings Technology 200 (1-4), 928-931 (2005)