Recent Advances in Performance of Solution Processed Small Molecule OLEDs at DuPont Displays

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Abstract

We describe the DuPont Displays full color OLED printing and materials technologies. The process is more cost-effective and scalable than thermal evaporation through shadow masks. The materials lifetime is sufficient for most portable applications and is nearing that required for stationary displays. Recently, 4.3" WQVGA displays were demonstrated.

1. Introduction

Full color active matrix OLED displays offer many promising attributes compared to LCDs in terms of image quality, form factor, and power consumption for all types of display applications. However, to realize this potential, manufacturing methods need to be developed which allow for efficient scaling to large glass sizes while maintaining a cost advantage compared LCDs. In this regard, solution patterning methods provide tremendous benefits compared to vapor deposition of OLED materials through shadow masks. Historically though the performance of light emitting polymers, the prototypical solution processible OLED materials, has lagged behind that obtained using thermal evaporation of small molecules.

DuPont Displays has developed a high resolution solution processing technology based on small molecule emitters which preserves the lifetimes obtained by vapor deposition while delivering cost and scaling advantages intrinsic to solution processing.

2. Results and Discussion

Financial Modeling. A financial modeling analysis of manufacturing costs using moderate glass sizes predicts a significant cost advantage for solution processed OLEDs as compared to LCDs [1, 2]. As illustrated in Figure 1, this advantage grows as the mother glass and display sizes increase, mainly owing to the increasing cost of LCD-specific components (e.g., backlight unit) and the decreasing fractional cost of OLED driver electronics at larger display sizes. By contrast, OLED processes which include vapor deposition patterning are cost disadvantaged to both LCDs and solution processed OLEDs irrespective of glass and display size, even if scaling was achievable.

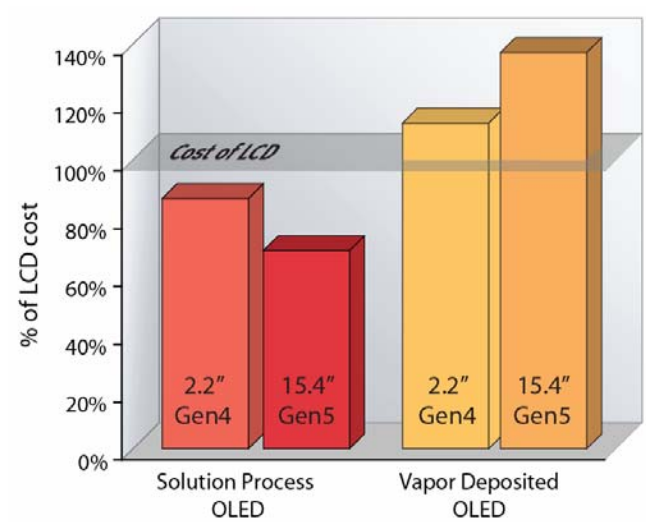

Figure 1. Financial modeling of OLED panel costs relative to LCD panels at Gen IV/V mother glass and 2.2"/15.4" display sizes.

Description of DuPont Displays OLED Process. The DuPont process relies on solution processing as many OLED layers as feasible and patterning the color layer by printing with a continuous stream coating technology, which in our experience has proven far more robust than drop-on-demand ink jet printing. The OLED stack and deposition method for each layer are illustrated in Figure 2.

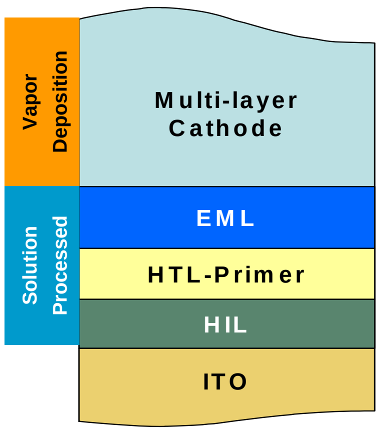

Figure 2. DuPont OLED stack and deposition method for each layer.

The DuPont hole injection layer (DuPont™ HIL) and DuPont hole transport-primer (HTL-P) layer are deposited sequentially via blanket solution coating onto an active matrix backplane, with slot die being the preferred method for large scale manufacturing. Careful optimization of the coating formulations affords uniform films of both materials (RMS roughness <5% of each film thickness). The DuPont HTL-P is also formulated to incorporate periodic wetting and non-wetting lanes on the surface, which serve to contain the incoming RGB emissive layer inks in their respective channels during liquid application and drying. Figure 3 shows examples of ink spreading on substrates prepared with and without the repellent lanes; clearly the non-wetting channels are a key to preventing RGB mixing and maximizing the printing resolution. This methodology does not require any physical containment features (banks) to be fabricated onto the substrate, thus making it widely applicable to different backplane designs and surface topography.

A critical element of OLED performance is emissive layer thickness uniformity (<10% over the entire pixel region, ideally <5%). Undoubtedly this is a tremendous challenge for any solution patterning technique due to the inherent physics of thin film drying, which favor diffusion and uneven accumulation of solute material rather than uniform distribution throughout the target region. We have developed practical solutions to this problem through formulation and our aforementioned ink containment methodology (Figure 4).

DuPont OLED Materials. Achieving commercially useful materials performance, while a challenge using any deposition technology, is particularly complex for solution processing. OLEDs require multiple layers with precisely defined interfaces. To achieve this in solution processing, materials need to be engineered with differential solubility properties so that the incoming solution does not dissolve underlying layers. Moreover, this needs to be accomplished while still maintaining materials properties essential for performance- for example, optimal energy levels and

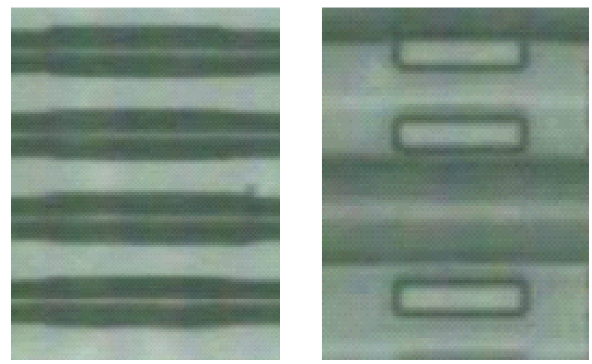

Figure 3. EML ink spreading with (left) and without (right) containment pattern on HTL-P. Final widths of the dried films are 70 and 150 µm, respectively.

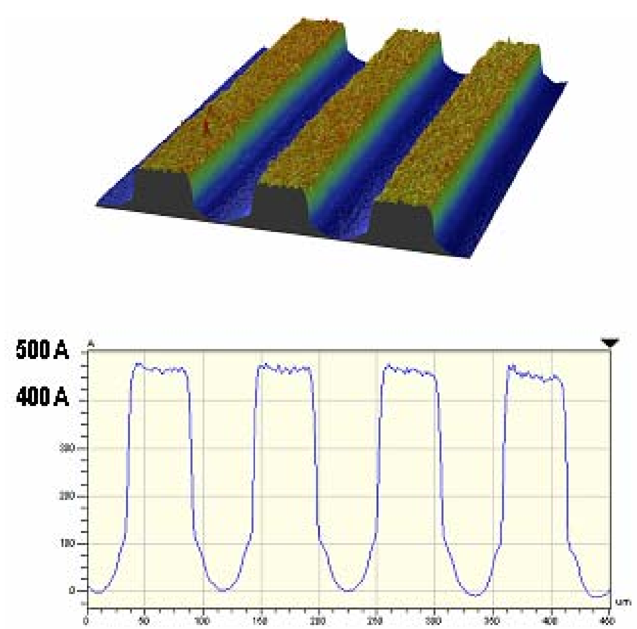

Figure 4. Optical profilometer trace of dried EML film printed using DuPont ink containment method on a flat substrate. X and Y axis limits: 0-450 µm and 0-500 Å, respectively.

charge mobilities. Solvent processing can also bring along impurities which are difficult to remove from the dried films and can be detrimental to performance.

The DuPont small molecule solution materials technology has addressed all of these issues, to the extent that the best efficiencies and lifetimes achieved are quickly approaching the best obtained by thermal evaporative processing of the EML. Representative DuPont RGB performance data are summarized in Table 1 for devices fabricated using either EML deposition method. The devices are prepared on ITO/glass test coupons. Representative luminance (power) efficiency (with CIE color coordinates) and lifetime curves for the solution processed devices are illustrated in Figures 5 and 6, respectively. We do not observe a significant change in the color coordinate values (<0.005 in x and y) for any of these devices when measured after 50% decay of the initial luminance. The two different red and blue devices illustrate typical tradeoffs in color, lifetime, and power efficiency, depending on the specific device architecture.

EML	EML Deposition Method	CIE 1931 (x,y)	Voltage (V)	C.E. (cd/A)	E.Q.E. (%)	P.E. (lm/W)	Lifetime T-50 (hr)
Red	Vapor	0.655, 0.345	4.7	26.8	22.3	17.7	>50,000
Green	Vapor	0.293, 0.651	5.9	32.1	8.48	19.3	>330,000
Blue	Vapor	0.136, 0.139	6	6.58	5.9	3.45	>17,000
Red A	Solution	0.662,0.335	6.2	20.8	19.7	10.6	46,000
Red B	Solution	0.662,0.334	4.9	23.9	22.2	15.2	25,000
Green	Solution	0.292,0.650	4.3	23.8	6.3	17.3	230,000
Blue A	Solution	0.137,0.141	5.7	4.1	3.7	2.3	10,000
Blue B	Solution	0.137,0.151	5.5	4.7	3.6	2.2	14,000
All JVL data acquired at 1000 nits. Lifetime data taken at accelerated luminance values and extrapolated to 1000 nits using measured acceleration factors.							

Table 1. Performance data for DuPont RGB devices, fabricated by either solution or vapor deposition processing of the EML.

Figure 7 shows progress achieved by DuPont for R, G, and B lifetime over the past three years using DuPont solution processing technology. The data are taken from test coupons and mapped onto a simulated 200 nit white active matrix display with a 40% aperture ratio, a 55% loss due to a circular polarizer, and a common architecture for all three colors. Lifetimes are defined as 50% of the initial R, G, and B luminance required to achieve 200 nit white luminance from the display. The DuPont materials are now sufficiently robust to address most portable display applications, and we anticipate further lifetime gains over the next year which will open up stationary applications.

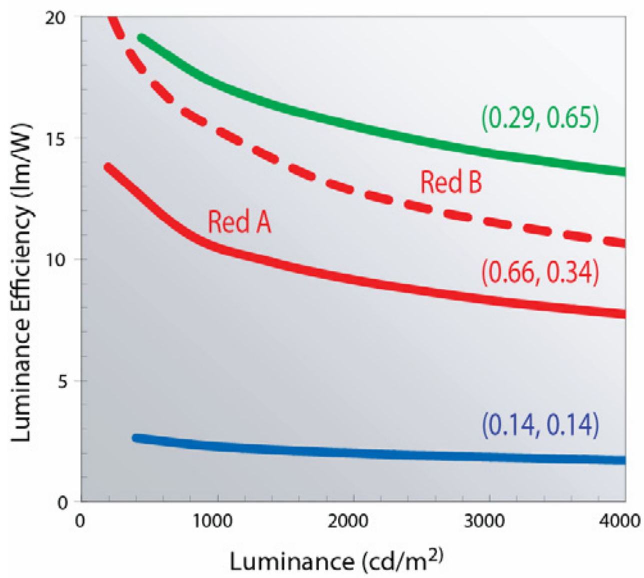

Figure 5. Luminance (power) efficiency vs. luminance curves (with CIE color coordinates) for DuPont Red A, Red B, Green, and Blue A solution processed OLEDs.

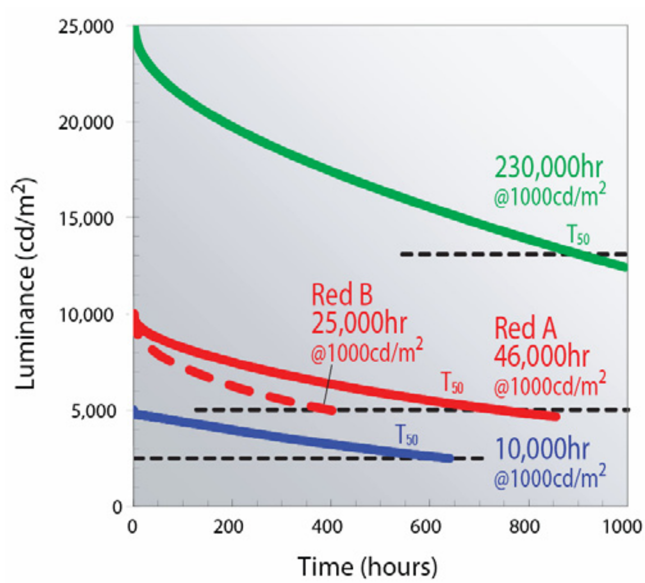

Figure 6. Lifetime curves for DuPont Red A, Red B, Green, and Blue A solution processed OLEDs, each run at a high test luminance and extrapolated to 1000 nits.

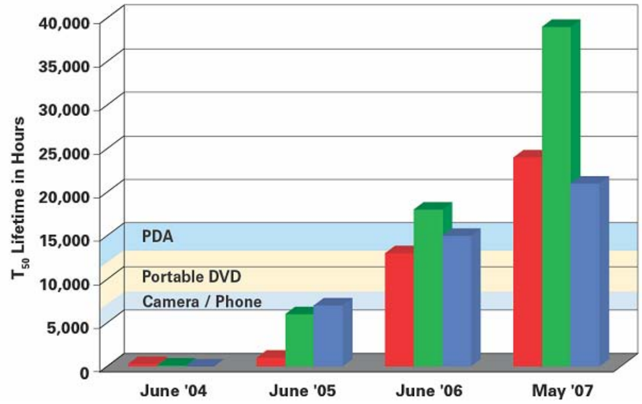

Figure 7. Lifetime improvements of DuPont solution processed materials over the past three years.

DuPont™ HIL. A key enabler of all the high efficiency and lifetimes described in Tables 1 and 2 is DuPont™ HIL [3]. It is a water based formulation which can be blanket coated or printed by a wide variety of techniques to yield smooth films (RMS roughness <1 nm). The dried films exhibit the following attractive properties for OLEDs and other organic electronics applications: (1) Conductivity adjustable from 10^{-2}-10^{-5} S/cm; (2) Very high work function (5.5-6.1 eV, adjustable depending on pH) for effective hole injection into materials that are difficult to oxidize; (3) Excellent transparency (95% transmission for a 100 nm film); (4) Low moisture uptake (<4% wt:wt) under ambient conditions; (5) Stable (insoluble) when immersed in a range of organic solvents; and (6) pH adjustable from 2-6 while retaining favorable injection properties across this range.

Active Matrix OLED Demonstration Displays. DuPont recently demonstrated 4.3" WQVGA displays, which utilized the solution patterning methods and materials described in this article, at SID 2007 (Figure 8). This technology is poised for commercialization, and will provide a cost effective and high performance display platform for the marketplace.

3. Summary

DuPont Displays has developed a set of full color OLED materials with high performance, and an economical and scaleable patterning process. Our technology should accelerate the usage of OLEDs throughout the display industry. We have made significant steady performance improvements over the past three years, to the point where stationary display applications are within reach using this technology.

Figure 8. 4.3" WQVGA display printed by DuPont using DuPont materials and containment technology. The LTPS backplane was supplied by CMO/CMEL Corporation.

4. Acknowledgments

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5. References

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