Development of P-OLED Materials For Displays and Lighting

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Keywords : Polymer, P-OLED, Degradation, Modeling, Printing

Abstract

Rapid progress has been made in the development of commercially viable Light Emitting Polymer (LEP) materials for display and lighting applications. This presentation will focus on:

- *Degradation studies that have led to the design of new and improved materials*
- *Recent lifetime and efficiency results for red, green, blue, and white polymers*
- *Challenges of formulating inks that can be used in a production environment*

1. Introduction

Polymer-based organic light emitting diodes (P-OLEDs) are attracting significant interest as a next generation display technology due to their excellent performance characteristics, which include good viewing angle, high contrast ratio, fast switching speeds, and low power consumption. Light emitting polymers (LEPs) are solution processable and may be deposited using low cost manufacturing approaches such as spin-coating or printing. P-OLED technology may be used in a range of applications beyond displays, including lighting, signage, and organic print heads.

To reach its full potential, P-OLED technology must meet customer expectations in terms of device lifetime, power efficiency and cost. Performance is already sufficient for a number of applications but continuous improvement is required to enable more demanding applications such as large screen TV or general purpose lighting[1].

Device degradation, reverse engineering and investigations into material structure-performance relationships have led to a better understanding of device operation and molecular design. As a result, significant improvements in colour, efficiency and lifetime have been achieved.

This paper summarises results from device degradation studies and the impact these have had on Red (R), Green (G), Blue (B) and White (W) material development. For white materials, color stability is a particularly important factor, requiring the development of new materials with enhanced properties.

In most cases, white devices can be simply fabricated using traditional spin-coating processes. Full color, pixelated devices typically require deposition of RGB materials using an ink jet or other printing process, for which LEPs must be formulated into inks that have good shelf life, exhibit consistent jetting or transfer properties, and dry uniformly to give defect-free panels.

2. Results and Discussion

Studies have shown that devices suffer a reduction in photoluminescence (PL) and an increase in driving voltage (V) during operation (e.g. Figures 1 and 2).

Electron-only devices exhibit similar increases in operating voltage during lifetime to those observed in bipolar devices, whereas voltages measured[2] in hole-only devices show no change over time (Figure 2). Current density at a given voltage is higher for pristine devices compared to devices driven to half initial luminance (Figure 3). While the external efficiency at a given voltage is also lower in driven devices when compared to undriven devices, the reduction in efficiency is greater at lower voltages (Figure 4).

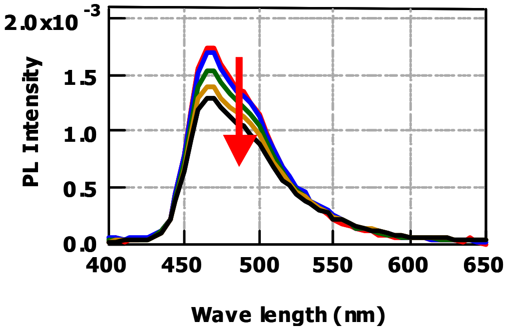

Fig. 1. **Reduction of PL intensity during lifetime measurement.**

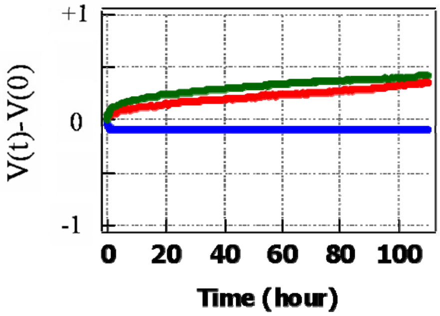

Fig. 2. **Changes in operating voltage during driving bipolar (red), electron only (green), or hole only devices (blue).**

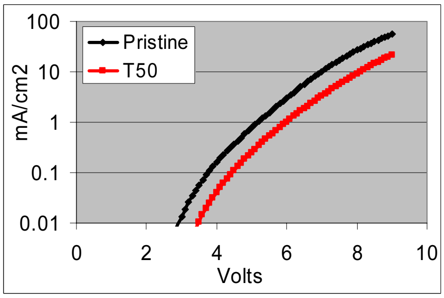

Fig. 3. **Current density (mA/cm^2) versus voltage (V) curves for driven (red) and undriven (black) devices.**

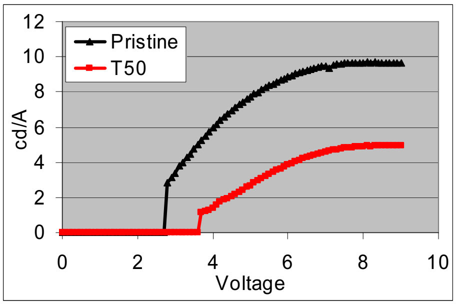

Fig. 4. **Efficiency (cd/A) versus voltage (V) curves for driven (red) and undriven (black) devices.**

Some reduction in external efficiency is expected as a result of PL decay. However, to investigate the impact of changes in electrical properties within devices, exciton formation efficiency was modeled as a function of voltage (Figure 5).

Modeling predicts that at higher voltages, exciton formation efficiencies are close to 100% but that at voltages below 5V exciton formation efficiency decreases, most likely as a result of holes reaching the cathode. Furthermore, a small change in the barrier to electron injection produces a further dramatic drop in exciton formation efficiency at low voltage (Figure 5). This is consistent with the drop in conductivity and external efficiency observed in driven devices (Figures 3 and 4). An order of magnitude reduction in electron mobility would be expected to produce similar results.

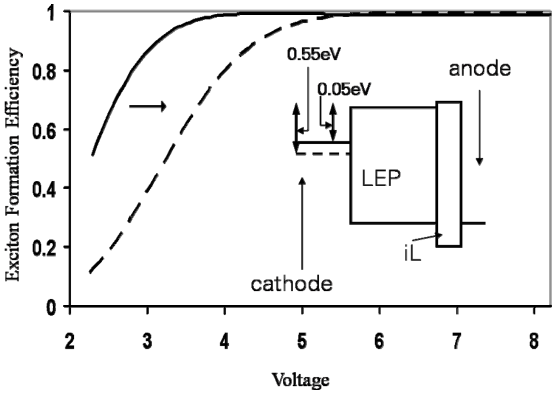

Fig. 5. **Modeling predictions of exciton formation efficiency as a function of voltage. Solid line represents baseline case whereas dotted line shows the impact on exciton formation efficiency of a 0.05eV increase in the barrier to electron injection.**

In contrast, modeling predicts that a change in the hole injection from an ohmic condition to a non-ohmic one, or a change in the mobility has a negative impact on exciton formation efficiency at all voltages (Figure 6).Such changes, however, are expected to have a small impact on conductivity (Figure 7) at operating voltage.

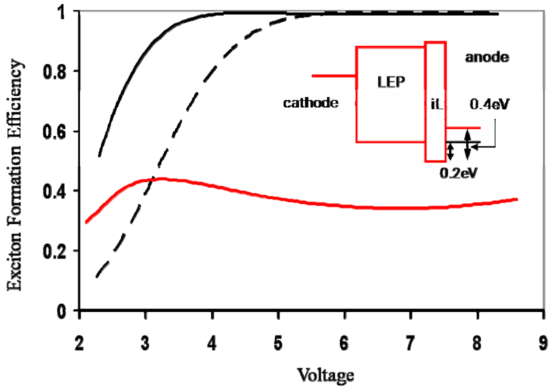

Fig. 6. Modeling predictions of exciton formation efficiency as a function of voltage. Solid black line represents the baseline case whereas the red line shows the impact on exciton formation efficiency of a 0.2eV increase in the barrier to hole injection.

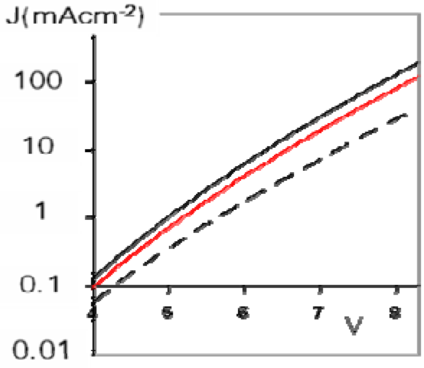

Fig. 7. Modeling predictions of current density (mA/cm^2) as a function of voltage (V). The black line is a simulation of a pristine device, whereas the black dotted and red lines show the impact on conductivity of an increase in the electron or hole injection barrier, respectively.

These results demonstrate the importance of maintaining good hole injection during driving if good exciton formation efficiency at operating voltage is to be achieved. Changes in anode work function can cause a voltage rise; however this is significantly smaller than the changes expected from a change in cathode work function or electron mobility. Results from this modeling study can be summarized as shown in Table 1.

TABLE 1. Effect of charge injection and mobility on voltage and efficiency.

	Effect on drive voltage	**Effect on efficiency**
Electron injection/ mobility	Strong	Strong at low voltage, weak at high voltage
Hole injection/ mobility	Weak	Strong at all voltages

Comparing these results with those obtained experimentally, it seems most likely that in P-OLED devices, it is electron injection and/or a reduction in electron mobility in combination with PL decay of the LEP that is primarily responsible for device degradation.

P-OLED devices are usually comprised of a layer of hole injection material, such as PEDT:PSS on ITO, an interlayer material, a layer of LEP and a low work-function metal cathode. By tuning the HOMO and LUMO levels of the interlayer and LEP layer, balancing the charge mobilities in these layers, and stabilizing charge injection, device efficiency can be improved and increases in driving voltages can be suppressed.

Time resolved PL spectroscopy was used to probe PL decay during device operation and the results obtained indicate that quenching sites are generated during device operation. Partial recovery of PL can be achieved by annealing the device to above the Tg of the LEP. One possible explanation for this is that the formation of quenching sites is a result of morphological changes in the layers within the device during driving. Non-recoverable PL decay is most likely the result of emitter degradation.

Once formulated into inks, materials can be printed into RGB arrays using ink jet printing. Without modification, drops of ink do not produce flat films upon drying. Moreover, if panels are printed in swathes, non-uniformities due to uneven drying across the panel are seen. Additives can be formulated into PEDT to avoid print swathes[3] but these often have a detrimental impact on efficiency or lifetime. New PEDT inks have been developed that give swath-free displays without affecting performance (Figure 8).

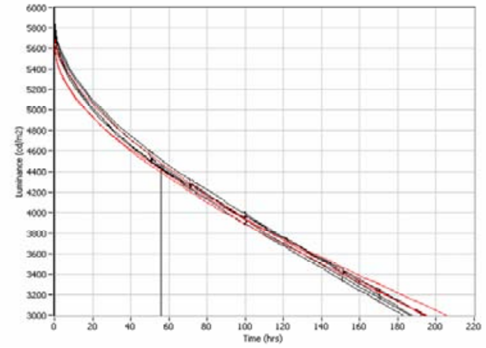

Fig. 8. Typical lifetime curves for spin coated (red) and printed (black) devices.

White materials have been made by incorporating two (R and B) or three (R, G and B) emitters into the polymer chain. By carefully controlling the ratio of emitters, good color reproducibility can be achieved. The color stability of devices made using white LEPs has been studied. Early white materials produced reasonable color (CIEy,x=0.293,0.366) but significant color shift was observed over the lifetime of the device (ΔCIEy,x=0.04,0.09). Development of longer-lived RGB emitters has allowed white materials with improved color stability to be made. The latest white materials show very little change color during driving (ΔCIEy,x=0.01,0.01) (Figure 9).

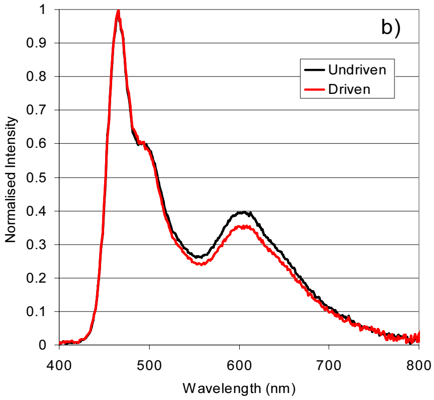

Fig. 9. Emission spectra for a white material before and after lifetime test.

These studies have led to improved material performance. Current performance data for RGB and W maerials are summarized in Table 2.

TABLE 2. Current Material Performance.

T50 (1000 cd/m^2)	Performance Data			
	Red	Green	Blue	White
Efficiency (cd/A)	10	16	9	7
Colour (at 100 cd/m^2)	x=0.67 y=0.32	x=0.29 y=0.64	x=0.14 y=0.19	x=0.33 y=0.31
Lifetime (spin) (hrs)	24k	50k	10k	5.2k
Equivalent lifetime at 400 cd/m^2 (hrs)	150k	285k	62k	27k
Acceleration Factor	2	1.9	2	1.8

3. Summary

The degradation studies described herein, and improvements in material performance that have been achieved as a result, open up many more applications for P-OLED technology. New ink formulations allow panels to be printed with better uniformity without sacrificing performance.

4. Acknowledgements

The authors wish to thank colleagues at Cambridge Display Technology (CDT) Ltd. and at Sumitomo Chemical Co. Ltd. for analytical support and useful discussions.

This paper is dedicated to our friend and colleague, Dr. Carl Towns (14.12.63 – 20.05.07).

5. References

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