

Lateral-Leakage Current Reduction in Tandem RGB OLED for Enhanced Low-Gray-Level Color Accuracy

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Abstract

Our experimental results demonstrated that optimized tandem OLED exhibits an 80% increase in efficiency and a twofold extension in lifetime relative to single OLEDs. In tandem OLEDs, the charge generation layer (CGL) facilitates the lateral leakage current (LLC) into adjacent subpixels of different colors, which degrades color purity, particularly at low luminance. To mitigate LLC, we developed an advanced CGL structure that yields a threefold reduction in color coordinate variation, thereby significantly enhancing color accuracy.

Author Keywords

Organic light-emitting diodes; Tandem RGB OLED; Efficiency, Lifetime, Lateral Leakage Current; Charge Generation Layer; Color mixing; Color Accuracy; Color Coordinate.

1. Objective and Background

RGB organic light-emitting diodes (OLEDs) are widely utilized in conventional smartphone displays due to their key advantages, including low power consumption and high contrast ratios. However, with the OLED display market expands, there is a growing demand for higher efficiency and longer lifetime OLEDs. Tandem RGB OLEDs, which incorporate two emissive layers (EMLs), have emerged as a promising solution to meet these requirements. Fundamental investigations reveal that the tandem architecture offers considerable potential for substantially enhancing both efficiency and operational lifetime compared to conventional single-emissive layer OLED (single OLED). To fully realize this potential, the development of tailored materials and an optimized structure for electro-optical properties remains a critical challenge [1-2].

A crucial component in tandem OLEDs is the charge generation layer (CGL), positioned between the two EMLs. The CGL forms a heterojunction bilayer consisting of an electron donor layer and an electron acceptor layer, which is essential for the generation of electron and hole carriers. When an electric field is applied, electrons are transferred from the donor's highest occupied molecular orbital (HOMO) to the acceptor's lowest unoccupied molecular orbital (LUMO), while the holes remaining in the donor's HOMO are injected into the adjacent emissive layer, effectively separating the negative and positive carriers [3].

For optimal efficiency and lifetime, it is vital that the charges generated in the CGL and the charges injected from the cathode and anode maintain a charge balance within the two EMLs to facilitate exciton formation. To control the charge generation rate, p-dopant material with strong electron-withdrawing properties are employed to lower the LUMO level of the acceptor's, thereby modulating the energy barrier between the donor's HOMO and the acceptor's LUMO through doping ratio design [4].

However, the high electron affinity characteristic of p-dopants in the CGL also increases horizontal conductivity, establishing a

conductive pathway for lateral leakage current (LLC). LLC can result in unintended activation of adjacent sub-pixels of different colors, consequently, deteriorating color accuracy (Fig. 1). Moreover, the color shift induced by LLC is more severe at low luminance regions, causing color variations across different gray levels [5].

This development demonstrated electro-optical enhancement in tandem RGB OLEDs, with a focus on minimizing LLC and improving color purity at low luminance.

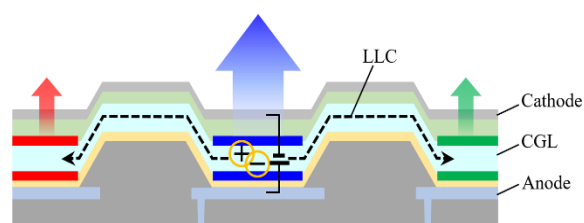


Figure 1. Schematic cross-sectional view of a tandem OLED subpixel structure. Lateral leakage current (LLC) through charge generation layer (CGL) in tandem OLED, activating adjacent subpixels and causing a color shift.

2. Experimental

Glass substrates with red, green, and blue Ag anode sub-pixel pattern were rinsed with deionized (DI) water and cured in an oven. After surface cleaning, the substrates were treated with high-density nitrogen plasma. The substrates were subsequently loaded into the organic evaporation chamber under high vacuum conditions (below 10^{-6} Torr).

The single OLED structure consisted of the following layers: hole injection layer (HIL), hole transport layer (HTL), emissive layer (EML), hole blocking layer (HBL), electron transport layer (ETL), electron injection layer (EIL), cathode, capping layer (CPL), and thin-film encapsulation. The tandem OLED structure included the following layers: hole injection layer (HIL), 1st hole transport layer (HTL2, 1st emissive layer (EML1), 1st hole blocking layer (HBL1), 1st electron transport layer (ETL1), n-doped charge generation layer (nCGL), p-doped charge generation layer (pCGL), 2nd hole transport layer (HTL2), 2nd emissive layer (EML2), 2nd hole blocking layer (HBL2), 2nd electron transport layer (ETL2), electron injection layer (EIL), cathode, capping layer (CPL), and thin-film encapsulation. For both EML1 and EML2, red, green, and blue subpixels were patterned using a fine metal mask by deposition.

To investigate the electro-optical performance as a function of the CGL properties, two distinct CGL materials were used, and the optimal structure for each material was determined experimentally. The fabricated tandem OLED devices were designated as Device A and Device B, respectively. In addition, a conventional single-layer OLED was fabricated to enable a direct performance comparison.

Before optoelectronic evaluation, OLED devices were annealed in the oven at 100°C for 30 minutes. The electroluminescence spectrum, current density-voltage and current density-luminance characteristics were measured with a current source meter (Keithley 2635B) in conjunction with a spectrometer (Photo Research PR 705). All measurements were performed under room temperature and pressure

Lifetime measurements were conducted in a temperature-controlled chamber maintained at 35°C. Devices were operated at a fixed initial current and mounted on a photodiode-equipped jig that was inserted into the chamber, where the photodiode output was measured at 60-minute intervals to monitor luminance decay. The lifetime was defined as the time required for the luminance to decrease to 95% of the initial luminance (LT95).

Results

Initially, both tandem OLED devices, Device A and Device B with different CGLs, underwent independent optimization of their architectures in terms of efficiency and lifetime. As shown in Figure 2, the resulting current density-voltage (J-V curve) characteristics, normalized efficiency versus current density (efficiency curve), and normalized luminance (lifetime) are nearly identical between the two devices. The match of the J-V curve indicates that the optimal structures for each device have similar energy barriers characteristic between the donor's HOMO and the acceptor's LUMO in CGLs. This, in turn, results in coincidentally balanced charge generation and injection into the two emissive layers of both devices, as evidenced by the overlapping efficiency curves and lifetime.

In comparison to the single OLED, the tandem OLEDs, as summarized in Table 1, exhibit a remarkable 80% increase in luminous efficiency and a doubling of lifetime (LT95) for the blue color. The tandem OLED devices require a 50% higher driving voltage to achieve the same luminance, an expected outcome due to the additional functional layers present in the tandem configuration. Despite this higher voltage requirement, this performance advancement is attributed to the optimized CGL, which enhances exciton formation and improves overall performance.

Table 1. Driving voltage, efficiency and lifetime(LT95) of single and tandem OLED in blue color.

Stack	Structure	Voltage	Efficiency	Lifetime
Single	-	100%	100%	100%
Tandem	Device A	150%	180%	200%
	Device B	150%	180%	200%

To further investigate display quality at the low gray level, the electroluminescence spectra of blue emissions were analyzed for both devices under different input voltage condition. Under 7V bias, the electroluminescence spectrum exhibited a distinct, sharp blue peak spectrum (430-490nm) for both devices (Fig. 3a). In contrast, when a 5V bias was applied, the two devices displayed markedly difference electro-optical performance. Device A has unintended parasitic spectral peaks in green (510-560nm) and red (610-650nm) wavelength. Device B exhibited a significant

suppression of unintended green and red emissions, with intensities approximately fivefold lower than those of Device A, resulting in a cleaner blue spectrum (Fig. 3b).

This observation indicates that the CGL materials and architecture are critical for minimizing LLC and preventing unwanted color mixing under low-voltage conditions. Moreover, although the vertical charge transfer and injection characteristics determined by the OLED stacks are similar, differences in the horizontal electrical properties of the common layer—which facilitates LLC—can lead to conductivity variations that ultimately impact display performance and quality.

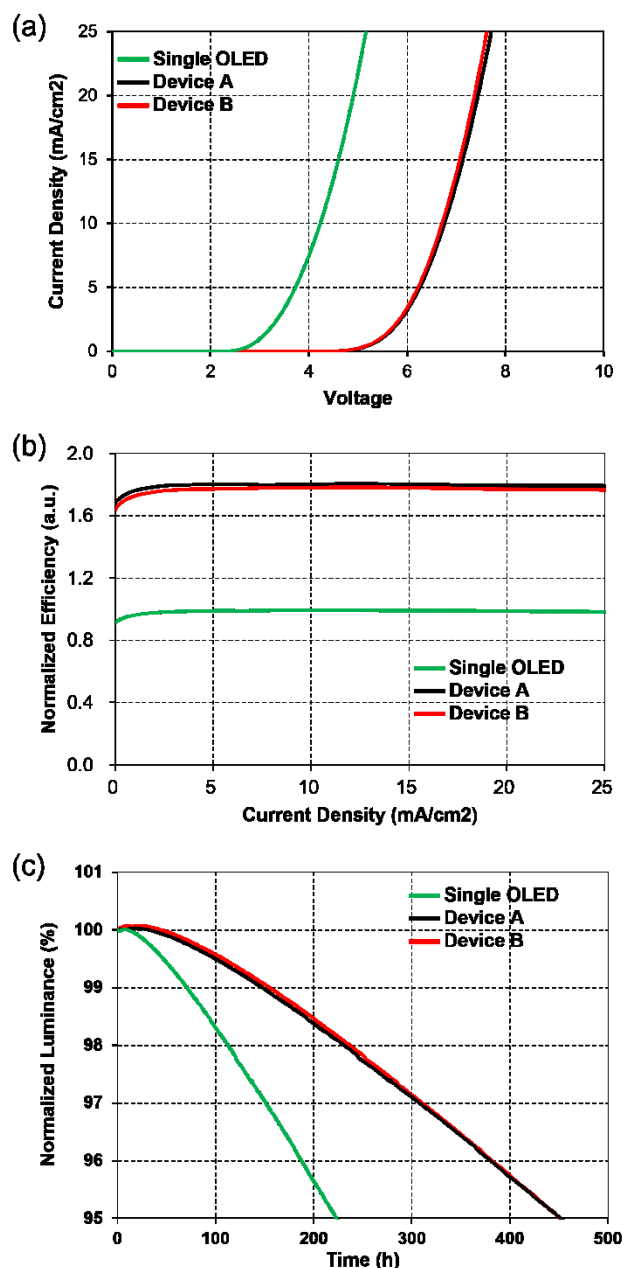


Figure 2. Current density-voltage (J-V) curve, normalized efficiency, and lifetime of Device A and Device B for blue emission: (a) J-V characteristics, (b) normalized efficiency, and (c) lifetime.

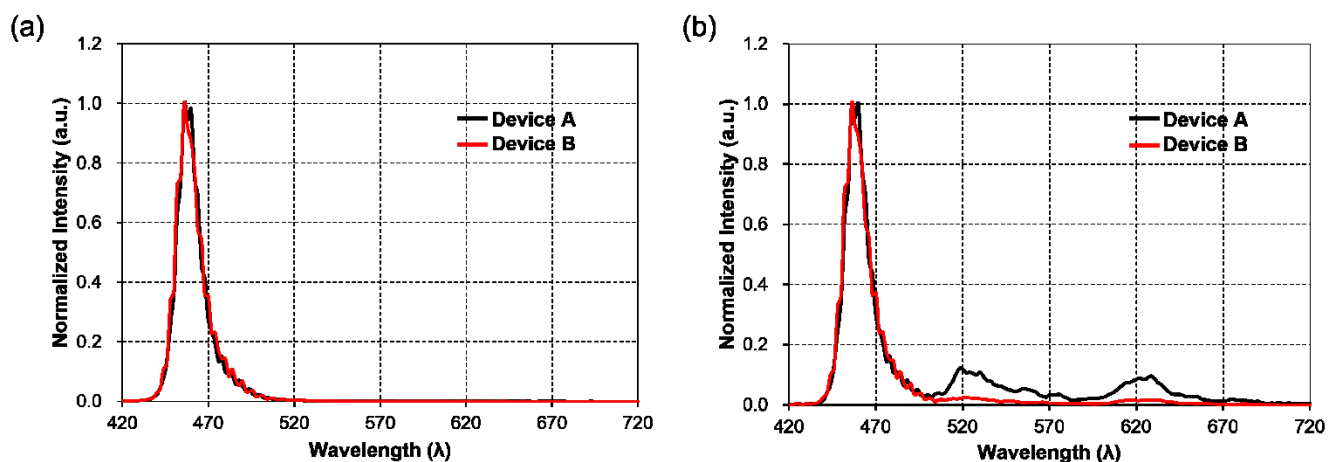


Figure 3. Normalized blue electroluminescence spectrum of Device A and Device B: (a) at 7V, (b) at 5V.

Regarding color accuracy, Device B employing an advanced stack design in the aspect of LLC, effectively suppressed color shift at low-gray-level. At 150 nit, the blue CIE_{xy} coordinates was identical (0.139, 0.046) for both devices—attributable to their identical materials and structure except for the charge generation layer (CGL). However, at 0.15 nit, Device A showed CIE_{xy} coordinates of (0.177, 0.117) compared to (0.151, 0.069) for Device B (Fig. 4). The variation in blue emission coordinates (Δu^*v^*) remains nearly constant from 1500 nits down to 15 nits. A significant divergence occurs below 15 nits, with Device B exhibiting a threefold reduction in Δu^*v^* relative to Device A. This marked improvement enhanced both color accuracy and purity over a broad luminance range.

This study presents a tandem RGB architecture with suppressed LLC, enabled by an optimized CGL design. The resulting device not only ensures consistent color performance at low luminance at low luminance but also maintains competitive operating voltage, efficiency, and lifetime.

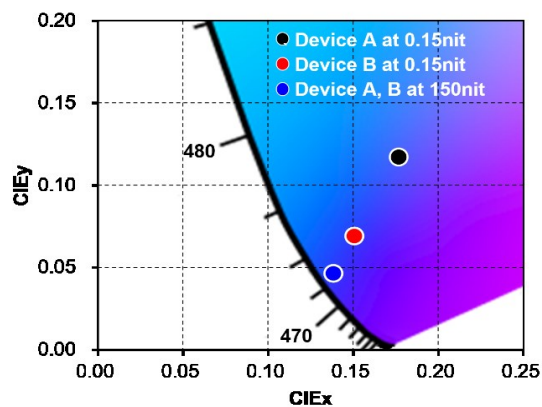


Figure 4. color coordinates in 0.15 nit and 150 nit for Device A and Device B ^[6].

3. Conclusion

In this study, we demonstrated that optimized tandem OLED architecture substantially outperforms conventional single-layer devices. Our experimental results show that the tandem configuration achieves an 80% increase in efficiency and a

twofold extension in operational lifetime compared to single OLEDs. Moreover, by optimizing the charge generation layer (CGL), we effectively minimized lateral leakage current (LLC), which in turn reduced color coordinate variation by a factor of three and significantly enhanced color accuracy, especially at low luminance levels. These findings underscore the critical role of CGL design and material selection in addressing with LLC while maintaining the J-V characteristics.

Finally, the robustness and scalability of our optimized tandem structure have been validated through successful mass production trials, paving the way for its widespread commercialization in next-generation display and lighting applications

4. References

- Chen Q, Wang Z, Li Y, Yan Z, Zhang H, Hu X, et al. Toward High-Performance Pure-Green Tandem Organic Light-Emitting Diodes by Employing Barrier-Free Strategies in the Charge Generation Layer. *ACS Appl Mater Interfaces*. 2024;17(1):1760-9. doi: 10.1021/acsami.4c19993.
- Kang SC, Choi EY, Kim HB, Song JK. Efficient Charge Generation Assistant Layer for Tandem Organic Light Emitting Diodes Using Ytterbium–Silver Alloy. *Adv Opt Mater*. 2025;13(3):2402162. doi:10.1002/adom.202402162.
- L Kido J, Kimura M, Nagai K. Highly efficient tandem organic light-emitting devices with a charge generation layer. *Adv Mater*. 2002;14(7):487-490.
- Tsang WY, Forrest SR. Mechanism of charge generation in organic tandem electroluminescent devices. *Appl Phys Lett*. 2002;81(19):3634-6.
- Kim YH, Weegels L, Eickhoff C, May F, Engelhart J, Meyer S, et al. Improving Lateral Leakage Current in OLED Pixels by New Hole Transport Materials: Resolving the Crosstalk Issue. *SID Symp Dig Tech Pap*. 2024;55(1):373-6. doi:10.1002/sdtp.17535.
- CIE 1931 color space [Internet]. Wikipedia. [cited 2022 Jul 15]. Available from: https://en.wikipedia.org/wiki/CIE1931_color_space#/media/File:CIE1931xy_CIERGB.svg