Development of OLED Device Technologies with High-Luminance, Long-Lifetime, and Wide-Color Gamut

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ABSTRACT

We developed technology that improves the lifetime of blue OLEDs at high temperature. We also improved the lifetime of green OLEDs for a wide color gamut by optimizing the carrier balance. The developed blue and green OLEDs were implemented in a 4.2-inch OLED display with a wide color gamut.

1 INTRODUCTION

The organic light-emitting-diode display (OLED) has several advantages over the liquid crystal display, such as the "true black" feature and fast response time. Therefore, OLED displays are widely used in the latest smartphones and TVs and recently have shown promised for use in automotive displays [1]. The requirements for OLED displays in smartphones and automotive displays are shown in Fig. 1. An automotive display requires higher luminance and a longer lifetime than a smartphone [2], which is problematic because OLED has issues with both luminance and lifetime at high temperature. Specifically, OLED devices tend to degrade when exposed to high currents and high temperatures [3]. On the other hand, OLED automotive displays have a higher aperture ratio and more options for OLED materials than smartphones.

	Smartphone 	Automotive 
Luminance	Medium	High
Temperature	Low (room temperature)	High
Lifetime	Medium	Long
Resolution	High	Medium
Color gamut	High	Medium
Power consumption	Low	Medium

Figure 1. Requirements for OLED displays.

An automotive display also requires image quality technology for the color red. The chromaticity of red is especially important because red is used to exhibit warnings to the driver. OLED devices typically utilize top emission and micro cavity structures to efficiently obtain high luminance, which presents an additional difficulty because these structures tend to worsen the angular color shift.

In a recent work, we successfully demonstrated an OLED display with the luminance of 1,000 nit and a low angular color shift of red OLEDs [4]. Table 1 shows the specifications of this display, where the color gamut covered 85% of National Television System Committee (NTSC) standard. Fig. 2 shows the lifetime of three 4.2-inch displays for full-white 1,000 nit, where their lifetime was based on 80% relative luminance and denoted as LT80. The LT80s of the displays at 85°C were over 1,000 hours.

Table 1. 4.2-inch prototype specifications.

	Specifications
Screen diagonal	4.2-inch
Resolution	RGB × 272(H) × 480(V)
Pixel density	131 ppi
OLED device	Top emission
Aperture ratio	R,G:13.6%, B:28.8%
Luminance	1,000 nit
NTSC	85%
Color shift	$\Delta u'v' \leq 0.05$ (0°~60°)

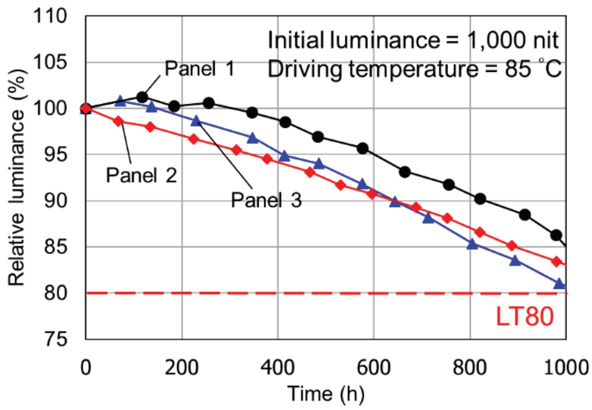


Figure 2. Decay profiles of OLED prototypes.

To take further advantage of these features and keep up with increased demand, we have recently focused on a wider color gamut, such as more than 100% of NTSC standard. We want to improve the green color in particular, as it is necessary to achieve both chromaticity and a long lifetime in green OLEDs.

In this paper, we report OLED technologies to improve both the color gamut and the lifetime at a high luminance. The lifetime of blue OLED devices has been the main obstacle when it comes to increasing lifetime, so we focused on the blue OLED device structure first. Then, to expand the color gamut, we tried to improve the green OLED structure. Finally, we demonstrated a 4.2-inch OLED display that utilizes the blue and green OLEDs we developed.

2 EXPERIMENTS and RESULTS

2.1 OLED device structure of blue OLEDs

Fig. 3 shows the energy diagram of our blue OLEDs, where ΔE_1 means the difference between the highest occupied molecular orbital (HOMO) level in HTL and HTL', and ΔE_2 means the difference between the HOMO level in HTL' and the host material of EML.

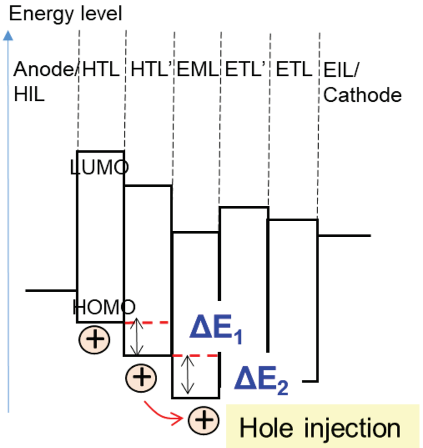


Figure 3. Energy diagram of blue OLEDs.

We investigated the relation between ΔE_1, ΔE_2, and the lifetime of the blue OLEDs. Fig. 4 shows the relation between ΔE_1 and the lifetime at 85°C and 10mA/cm^2. An apparent dependence was not confirmed. Fig. 5 shows the relation between ΔE_2 and the lifetime at 85°C and 10mA/cm^2. There was a correlation between ΔE_2 and the lifetime, contrary to the relation between ΔE_1 and the lifetime. Therefore, we attempted to decrease ΔE_2 to improve the lifetime. As a result, we confirmed that the LT80 of the blue OLEDs (Device-A) was improved, as shown in Fig. 5.

Moreover, we confirmed that the region that contributed to emission was near the interface between HTL' and EML. HTL connected to EML in known to degrade due to hot electrons when the emission concentrates at the interface between HTL and EML, such as the fluorescent material utilized triplet-triplet annihilation [5]. Therefore, we assume that small ΔE2 increased the hole injection from HTL' and EML and the recombination region between the hole and the electron widened. Then, the degradation in HTL' may be suppressed, and the lifetime at high temperature will improve.

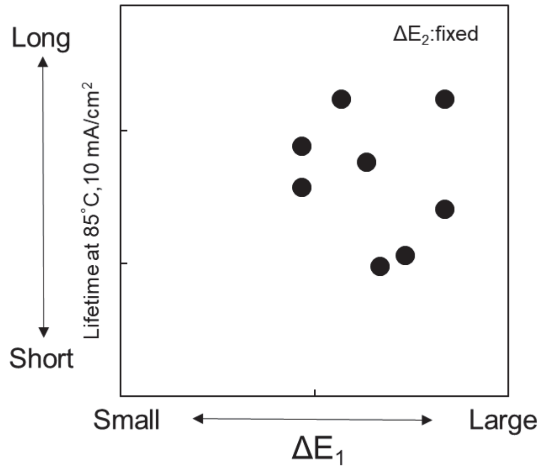


Figure 4. Relation between ΔE1 and lifetime of blue OLEDs.

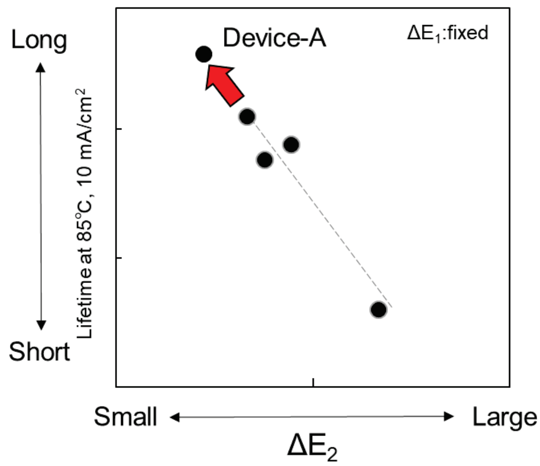


Figure 5. Relation between ΔE2 and lifetime of blue OLEDs.

2.2 Improvement of green OLEDs characteristics for wider color gamut

We confirmed that the lifetime of the deeper green device deteriorated drastically, emphasizing the problem with the lifetime of deeper green OLEDs.

There are several candidate OLED structures for achieving both wide color gamut and long lifetime, as shown in Fig. 6 [6]. We compared the structures of a conventional TEOLED to that of an OLED with a tandem structure composed of two stacked EMLs and a charge generation layer (CGL). This OLED structure was designed to have a strong interference condition (S1, S2 in Fig. 7) under the condition that the thickness between the anode and cathode was the same as the conventional TEOLED by optical simulation, as shown in Fig. 7. We found that the external quantum efficiency of the tandem structure was 1.8 times higher than that of the conventional TEOLED, and we found its lifetime at the same luminance was 1.8 times longer. However, the driving voltage was 1.9 times higher than the conventional TEOLED. Moreover, the conventional TEOLED is not as complicated as the tandem structured OLED and is better at suppressing the driving voltage. Therefore, we utilized the conventional TEOLED to improve the lifetime of green OLEDs by optimizing the carrier balance in the same way as blue OLEDs.

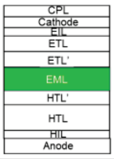
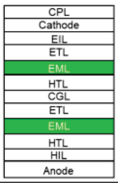
	Conventional TEOLED	Tandem structured OLED
		
Relative external quantum efficiency	1	1.8
Relative lifetime at the same luminance	1	1.8
Relative driving voltage	1	1.9

Figure 6. OLED device structures and performance for achieving both wide color gamut and long lifetime.

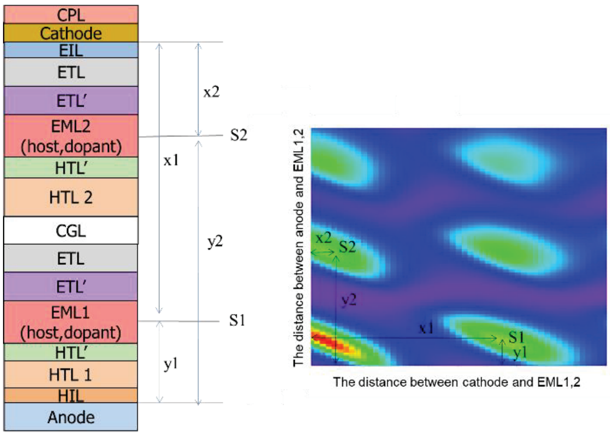


Figure 7. Calculated radiance plots as function of the distance between anode and EML and between cathode and EML.

The EML of our green OLEDs consists of two types of host material with different carrier transport properties: p-type and n-type. First, we investigated the ratio of these materials in the EML, as depicted in Fig. 8, which shows the relation between the lifetime and the ratio of both materials. We found the most suitable ratio for the lifetime was on the p-type host material side. Then, we focused on the hole injection from HTL' to EML.

Fig. 9 shows the decay profiles of the conventional green TEOLEDs with HTL' of different thickness. The hole mobility of the HTL' is much lower than that of the HTL in our OLEDs. Therefore, the hole injection from HTL' to EML may be improved when HTL' is thin. We confirmed that the lifetime of green OLEDs was improved and the LT80 was over 1,000 hours at 85°C and 10mA/cm^2 by utilizing a thin HTL'. We conclude that the hole injection to EML may be improved by utilizing a thin HTL' and that the carrier balance between the electron and the hole would subsequently also improve.

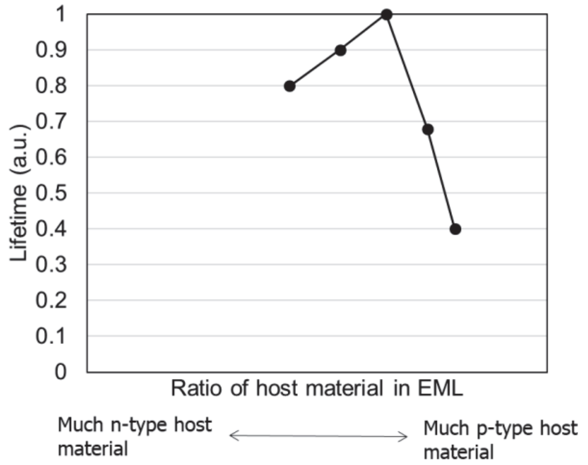


Figure 8. Relation between ratio of p-type and n-type host materials and lifetimes.

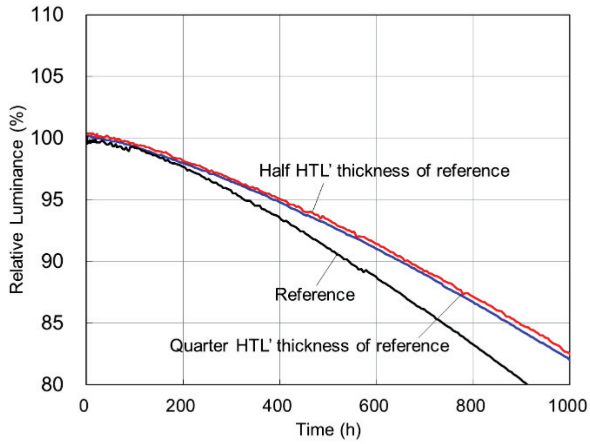


Figure 9. Decay profiles of three green OLEDs with HTL' of different thickness.

2.3 4.2-inch prototype display characteristics for wide color gamut

We fabricated the 4.2-inch OLED prototype display with wide color shown in Fig. 10 to demonstrate our long-lifetime technologies and wide color gamut. Fig. 11 shows the color diagram of the prototype display with a wide color gamut. The color gamut covered 100% of NTSC standard, thus demonstrating the potential of a long lifetime at high luminance, high temperature, and a wide color gamut.

Figure 10. Sample display with wide color gamut image.

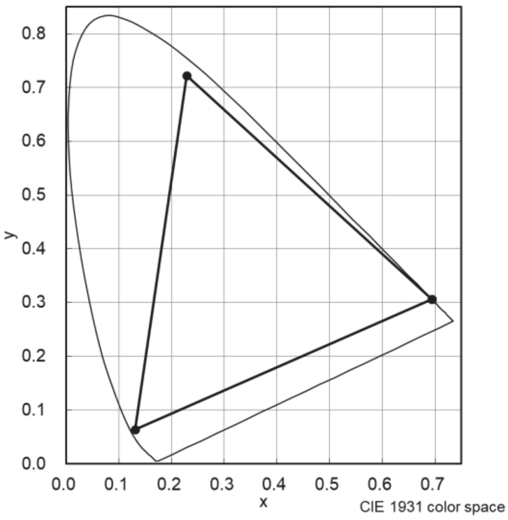


Figure 11. Color diagram of 4.2-inch prototype display with wide color gamut.

3 SUMMARY

We developed a 4.2-inch OLED prototype with a high luminance of 1,000 nit and a long lifetime of LT80 > 1,000h at 85°C. Our key finding is that the energy gap between the HOMO levels of HTL' and EML should be decreased to improve the lifetime at a high temperature in the blue OLED device.

We also presented a green OLED device that can achieve a wide color gamut with a long lifetime at high luminance. Consequently, our 4.2-inch OLED panel demonstrated a wide color gamut covering 100% of NTSC standard.

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