Full-Color Phosphorescent OLEDs: Maximizing Performance Today for Small-Area Portable Products and Tomorrow for TVs

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Abstract

Phosphorescent OLED technology is a core technology driver for OLED display and lighting products due to the inherent and demonstrated efficiency advantages. Here we present recent results in our continued advancements of PHOLED power efficiency and operational stability with focus on narrowing emission line-width, reducing voltage, and overall design for maximizing device lifetime.

1. Introduction

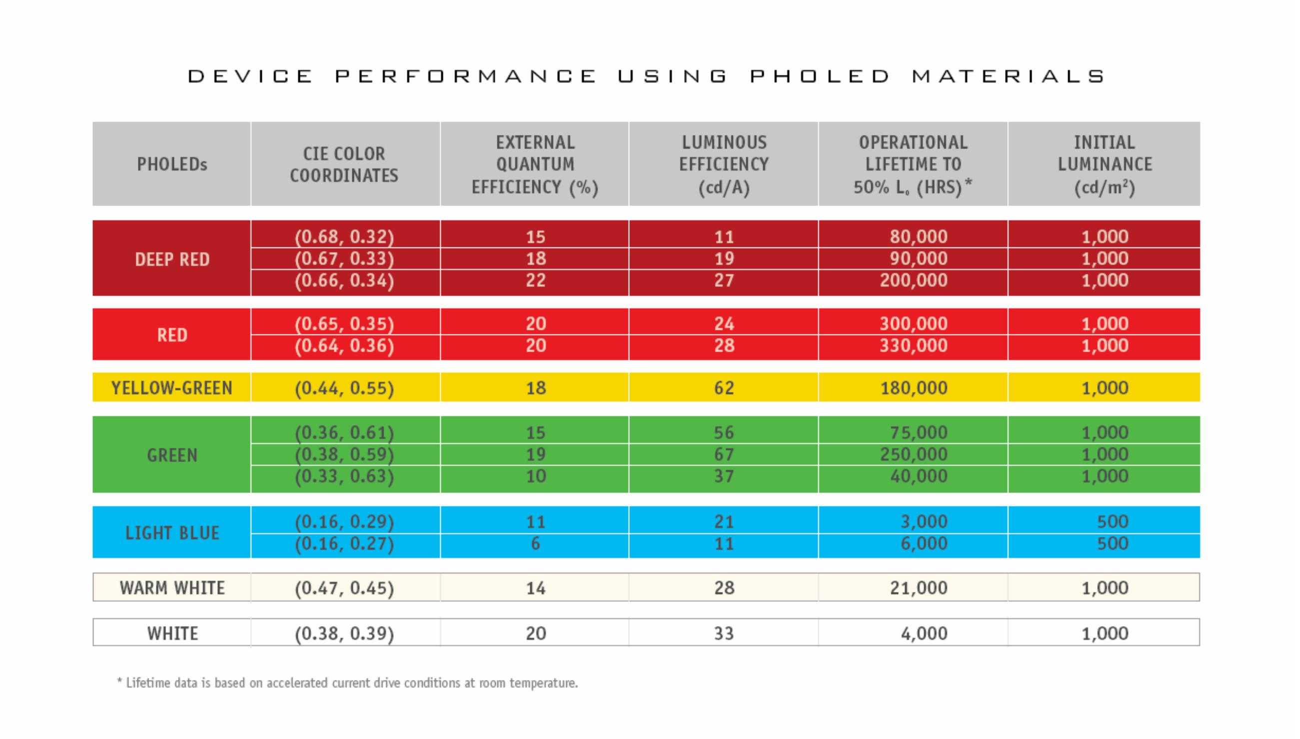
As organic light emitting device (OLED) technology is rapidly building up momentum in the commercial marketplace, phosphorescent OLED (PHOLED^{TM}) technology is proving to be a key component for a wide range of product applications: from today's small area mobile display products to tomorrow's large area TVs. Furthermore, with recent advances in high efficiency white PHOLEDs, the application into niche and potential general lighting applications is gaining increased attention.

The basic technological requirements for both display and lighting applications include maximizing OLED device efficiency, operational stability, emission wavelength (including spectral shape) and manufacturing scale. The design to achieving maximum efficiency is built upon phosphorescence. In PHOLEDs [1,2], the singlet excited state (S_1) excitons may be converted into the triplet excited state (T_1) through inter-system crossing via the presence of a heavy metal atom. In these devices, the triplet states can emit radiatively (T_1 to S_0), enabling record high conversion efficiencies. In the first generation, platinum 2,3,7,8,12,13,17,18-octaethyl-12H,23H-porphyrin (PtOEP) was used as the emitting phosphor. An impressive external quantum efficiency, at the time, of 6% was reported for this deep red PHOLED with peak emission wavelength of 648 nm [3].

Later generations of PHOLEDs improved considerably upon the early promise of the PtOEP emitter. PHOLEDs, incorporating other families of phosphorescent compounds, have achieved external quantum efficiency (EQE) values greater than 20%. Including green PHOLEDs with EQE of 23% [4], saturated red emitters as high as 19% EQE and most recently light blue PHOLEDs with performance of 20% [2]. Adjusting for optical effects, the internal quantum efficiency of such devices is approaching 100%. Another key device parameter is operational lifetime. As shown in Table 1, both red and green have operational lifetimes to meet commercial requirements today. Currently intense focus is being given to further increasing blue lifetime. Towards this goal of an all phosphorescent display product, continued new materials and advanced device design and process research and development are key foci.

2. Experimental

In this paper, we report on most recent advances in red, green and blue PHOLEDs (see Table 1) with particular emphasis, on the design and demonstration of narrowing the emission line shape to maximize the conversion from quantum efficiency into luminous efficiency. For example if we compare the line shape of an early generation commercial red PHOLED emitter with our latest advances in red emitters (Figure 1). Here the full-width-half-maximum has been reduced by 16 nm. The reduced line-width results in a significant increase of luminous efficiency. For example at 1000 nits an increase from 15 cd/A to 24 cd/A at luminance is achieved (Figure 2).



DEVICE PERFORMANCE USING PHOLED MATERIALS

PHOLEDs	CIE COLOR COORDINATES	EXTERNAL QUANTUM EFFICIENCY (%)	LUMINOUS EFFICIENCY (cd/A)	OPERATIONAL LIFETIME TO 50% L_0 (HRS)*	INITIAL LUMINANCE (cd/m²)
DEEP RED	(0.68, 0.32)	15	11	80,000	1,000
	(0.67, 0.33)	18	19	90,000	1,000
	(0.66, 0.34)	22	27	200,000	1,000
RED	(0.65, 0.35)	20	24	300,000	1,000
	(0.64, 0.36)	20	28	330,000	1,000
YELLOW-GREEN	(0.44, 0.55)	18	62	180,000	1,000
GREEN	(0.36, 0.61)	15	56	75,000	1,000
	(0.38, 0.59)	19	67	250,000	1,000
	(0.33, 0.63)	10	37	40,000	1,000
LIGHT BLUE	(0.16, 0.29)	11	21	3,000	500
	(0.16, 0.27)	6	11	6,000	500
WARM WHITE	(0.47, 0.45)	14	28	21,000	1,000
WHITE	(0.38, 0.39)	20	33	4,000	1,000

* Lifetime data is based on accelerated current drive conditions at room temperature.

TABLE 1. Current summary of a subset of recent phosphorescent OLED performance. The devices were fabricated in a bottom emission structure with no enhanced output coupling. The lifetime results were obtained under accelerated drive current conditions at room temperature. Conventional transport layers including Alq_3 and NPD were used in these devices.

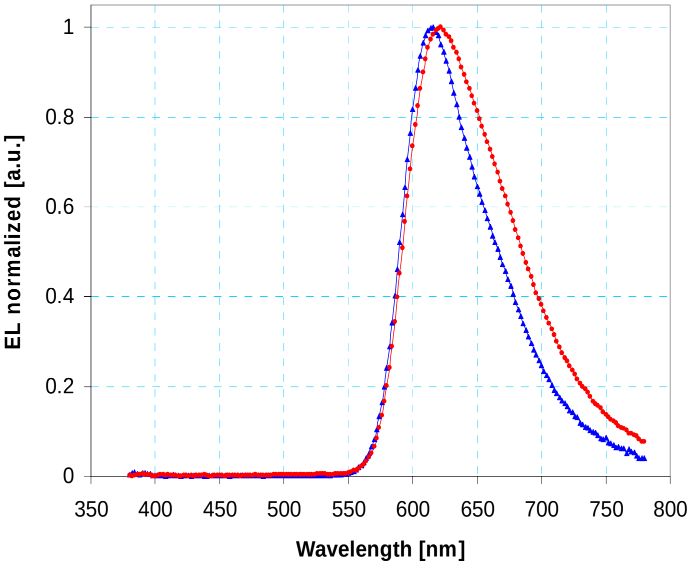


Fig. 1. Comparison of electroluminescent spectrum for a first generation commercial red PHOLED (red circles) and second generaton red PHOLED (blue diamonds).

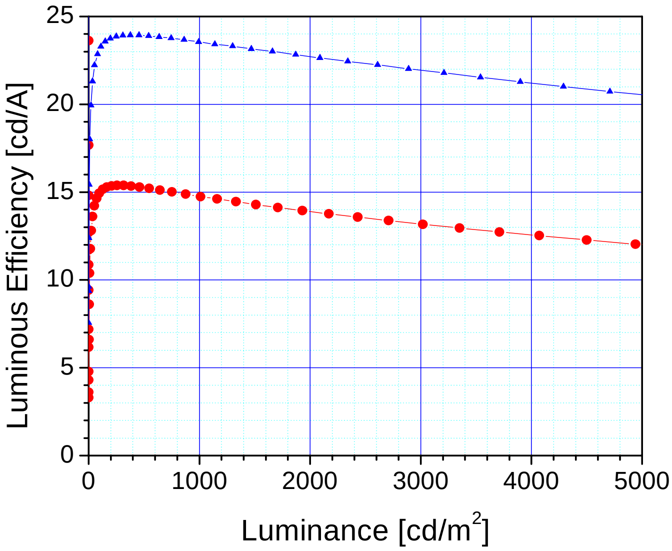


Fig. 2. Comparison of luminous efficiency as a function of luminance for a first generation commercial red PHOLED (red circles) and second generation red PHOLED (blue diamonds).

Next, we focus on recent advances in reducing the device operating voltage. For example, in an active matrix display, the power consumption is determined in part by the TFT and the OLED. The TFT voltage is typically assumed to be 4 V (for LTPS backplane technology), so a target operating voltage for OLEDs is in the range of 4-5 V. To fabricate PHOLEDs that operate in this range at 1,000 cd/m^2, one effective strategy is to use high conductivity transport materials such as LG101 as the hole transport material instead of 4,4-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (NPD), and to replace the electron transport material, tris(8-hydroxyquinolinato) aluminum (Alq$_3$) with LG201 [5]. Figure 3 shows the luminance versus voltage characteristics of a green (CIE: [0.36, 0.60)]) and a red (CIE: [0.64, 0.35]) PHOLEDs with the LG Chemical transport materials, respectively. The 53 cd/A green PHOLED has an operating voltage of 4.8 V at 1,000 cd/m^2, and the 17 cd/A, red PHOLED operates at 4.4 V at 500 cd/m^2. Figure 4 shows the comparison for the green PHOLED when using the high conductivity electron transport material (LG201) as compared to Alq$_3$. These low-voltage devices have operational lifespans that are comparable to devices containing Alq$_3$ and NPD.

These results demonstrate that this set of conductive transport layers do not negatively impact the operational stability. Furthermore, the emissive layer thickness, the emitter host, and the emitter concentrations can all also be manipulated to reduce the operating voltage by an additional 0.5 V to 1.0 V.

3. Results and Discussion

The impact of narrowing line shape on device efficiency is demonstrated. Specifically, a red PHOLED with 78nm FWHM and luminous efficiency of 24 cd/A at 1000 cd/m^2 is reported. Furthermore, the effect of using high conductivity bulk transport materials to reduce operating voltage below 5 volts at 1000 cd/m^2 was accomplished. Potentially most important is that the significant increase in overall power efficiency was obtained without negatively impacting device operational lifetime. The understanding of how to achieve ever increasing power efficiencies with long device lifetime is key to today's growing small-area AMOLED display business and also critical to support the move to large area TV displays and white lighting sources.

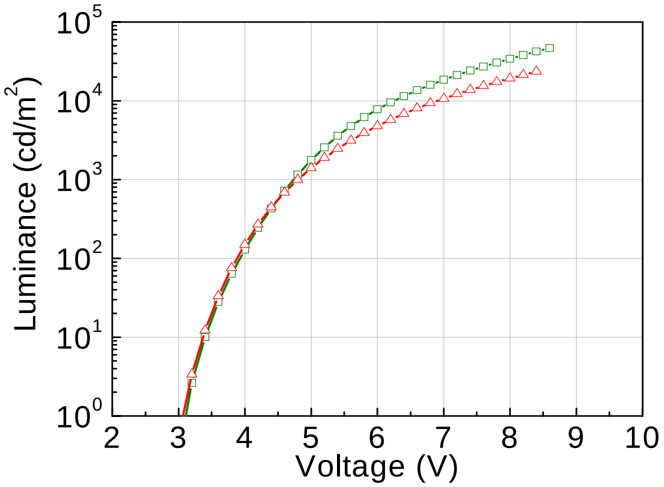


Fig. 3. Luminance versus voltage characteristics are shown for a green (green curve) and red (red curve) PHOLED with low voltage design.

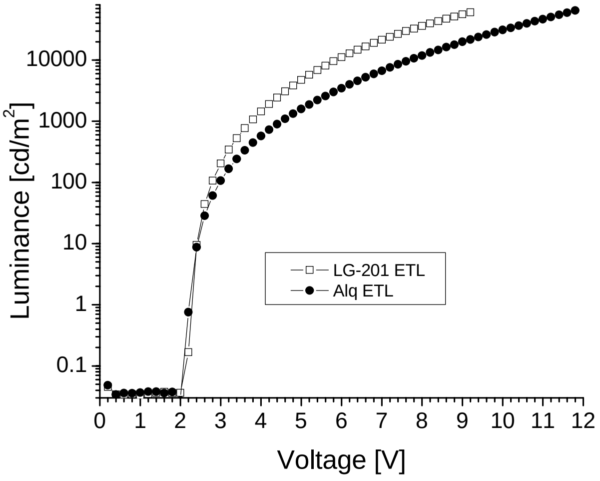


Fig 4. Luminance versus voltage for green PHOLEDs with different electron transport layers (ETLs).

PHOLEDs have already been incorporated into commercial small area passive matrix and AMOLED displays. The challenge for the OLED community now is to translate these low power consumption displays, enabled by phosphorescence, into large area applications.

In this paper we demonstrated the progress being made in PHOLEDs to help enable this goal. Narrowed EL spectra were demonstrated to increase the color gamut of a display. High efficiencies (>20%EQE) and low voltages (approaching the photon energy) were also demonstrated. Finally lifetimes for red and green PHOLEDs that are sufficient for TV applications were shown e.g. 200,000hrs from an initial luminance of 1000cd/m^2 for a 27cd/A red PHOLED.

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5. References

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[5] LG101 and LG 201 obtained from LG Chemical Korea.