Green Phosphorescent OLEDs for Low Power Displays

Michael S. Weaver, Vadim I. Adamovich, Raymond C. Kwong and Julie J. Brown
Universal Display Corp., Ewing, NJ 08540, USA
TEL: +609 671 0980, e-mail: mikeweaver@universaldisplay.com

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Abstract

High efficiency phosphorescent organic light emitting devices (PHOLED™s) are now widely used in commercial displays. In this paper we describe some of the work behind the development of high efficiency stable green PHOLEDs capable of fulfilling display specifications.

1. Introduction

After the discovery of PHOLED™s [1], operational stability presented a challenge to the wide-spread acceptance of the technology for use in flat panel displays and solid-state lighting [2]. However, the recent steady progress in device performance is a testament to the strength of phosphorescent emitters to provide long operational lifetime with record high efficiency. Table 1 shows the state-of-the-art red and green commercial PHOLED performance. Green [3] and red [4] PHOLEDs have high efficiencies and long lifetimes to meet the specifications for display applications, and these characteristics have been engineered through the development of synthetic and fabrication processes, materials design and device architectures.

Table 1. Red and green commercial PHOLED performance data [5] based on various device structures and support materials fabricated by vacuum thermal evaporation.

PHOLEDs	1931CIE Color Coordinates	External Quantum Efficiency [%]	Luminous Efficiency [cd/A]	Operational Lifetime to 50% L_0 [hrs]	Initial Luminance [cd/m^2]	Voltage [V]
Deep red	(0.67, 0.33)	21	21	80,000	1,000	4.3
	(0.66, 0.34)	19	22	200,000	1,000	2.8
Red	(0.64, 0.36)	21	28	500,000	1,000	2.8
Green	(0.36, 0.61)	15	56	75,000	1,000	4.5
	(0.36, 0.60)	16	58	100,000	1,000	2.8

A key challenge to improving OLED device lifetime performance is to understand the intrinsic luminance loss and voltage rise accompanying long term device operation [6]. Various hypotheses have been offered to explain the basis for intrinsic degradation in device efficiency, with the most widely accepted advocating chemical degradation of a fraction of the emissive molecules [7]. Presumably, bond cleavage produces radical fragments, which then participate in further radical addition reactions forming degradation products. These products act as non-radiative recombination centers, deep charge traps, and luminescence quenchers. For example, evidence has recently been presented that the excited states themselves may form reaction centers in the case of the green host material 4,4'-bis(9-carbazolyl)-2,2'-biphenyl (CBP) [8]. In this paper we describe some of the work behind the development of high efficiency stable green PHOLEDs.

2. Experimental

Each layer in a standard green PHOLED architecture was investigated in terms of its functionality and stability. Device stability can be compromised by defect generation due to polarons, excitons, exciton-exciton annihilation and exciton-polaron annihilation. Defects can act as luminescent quenchers, non-radiative recombination centers, and deep charge traps. Luminance loss results from the first two, while voltage rise, which has been linked to the presence of fixed space charge in the emissive region, can result from filling of the deep traps.

In this paper we investigate the relative stability of materials within and in contact with a green phosphorescent emitter containing emissive layer (EML). Bottom emission PHOLEDs were fabricated on 120nm indium tin oxide (ITO) anodes by sequentially depositing layers of a 10nm hole

injection layer (HIL), a 30nm hole transporting layer (HTL) which was either 4,4'-bis[N-(1-napthyl)-N-phenyl-amino] biphenyl (α-NPD) or a proprietary HTL material (HTLX), a 30 nm EML consisting of a host doped with a green emitter, a blocking layer (BL) which was either material BLA or the host material HX, and a 40-45nm electron transport layer (ETL) tris-(8-hydroxyquinoline) aluminum (Alq_3). The structure was completed with a 1 nm layer of LiF and a 100 nm layer of aluminum as the cathode contact. The organic and metal layers were thermally deposited at 0.2–4 Å/s in a high vacuum of $<10^{-7}$ Torr to yield devices with an active area of 4 mm^2. The PHOLEDs were encapsulated in a dry nitrogen atmosphere (<1 ppm H_2O and O_2) using a glass lid and a UV cured epoxy edge seal. A CaO getter was inserted inside the package to absorb byproducts of the cured epoxy and any residual water or oxygen present within the encapsulated volume.

3. Results and Discussion

Table 2. Performance evolution of the green PHOLED with different HTLs, hosts and BLs with a 120nm ITO anode and LiF/Al (100nm) cathode.

Structure	1	2	3	4
HIL 100Å	HIL	HIL	HIL	HIL
HTL 300Å	NPD	NPD	NPD	HTLX
Host 300Å GD48 %	CBP 10%	HX 10%	HX 15%	HX 15%
BL	BLA 50Å	BLA 50Å	HX 100Å	HX 100Å
ETL	Alq_3 450Å	Alq_3 450Å	Alq_3 400Å	Alq_3 400Å
1931 CIE (x, y)	0.35, 0.61	0.36, 0.60	0.38, 0.59	0.37, 0.60
Luminous efficacy [cd/A] at 1000cd/m^2	61	59	54.7	51.8
EQE [%] at 1000cd/m^2	17.7	16.3	15.3	14.4
Lifetime at 1000cd/m^2 [h]	25,000	55,000	75,000	>500,000

Table 2 shows the progression in lifetime as each layer in the green PHOLED is made more robust to the function it performs. Lifetime throughout was quoted as the time taken to reach half of the initial luminance of 1000cd/m^2 at a fixed dc current. The 1931 Commission Internationale d'Éclairage (CIE) color co-ordinates, luminous efficacy and external quantum efficiency (EQE) of each device structure are also given.

Fig. 1 shows more detail of the luminous efficacy of the four device structures as a function of luminance. The two BLA blocked PHOLEDs have higher efficiency at luminance levels up to ~7000cd/m^2 with peak efficiencies for structures 1 and 2 of 67cd/A at 10cd/m^2. The observed higher efficiency at lower luminance is believed to be due to the superior hole blocking characteristics of BLA as compared to using the host material as the blocking layer. Structure 3 exhibited low luminous efficacy at low luminance before increasing to a peak of 55.5cd/A at 610cd/m^2. Structure 4 had a similar luminous efficacy profile to structures 1 and 2 but was not as efficient with a peak luminous efficacy of 58cd/A at 14cd/m^2.

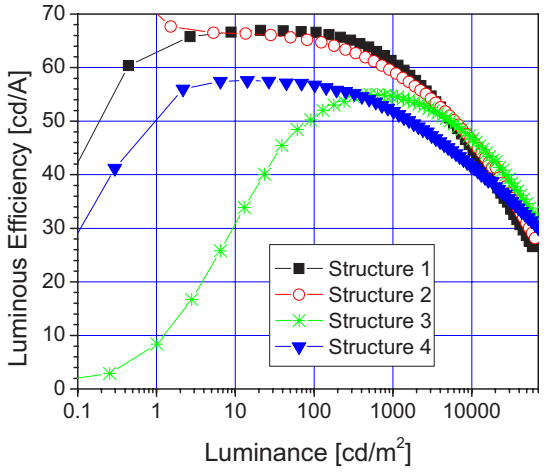

Fig. 1. Luminous efficacy vs. luminance of the green PHOLED structures 1 through 4 (structure 1 – solid squares, structure 2 – open circles, structure 3 – crosses, structure 4 – solid triangles).

The choice of host, BL and HTL all have a major influence on the device stability. Device structures 1 and 2 had a lifetime of 25,000hrs and 55,000hrs respectively from an initial luminance of 1000cd/m^2.

This difference was due to the host material. In structure 1 CBP was used as the host and is a material reported to be unstable in devices due to reactive centers formation [8]. It is believed that this phenomenon limits the lifetime of structure 1. The proprietary host HX is more stable than CBP in an otherwise identical device structure with a more than 100% lifetime improvement demonstrated without significant changes in the device efficiency.

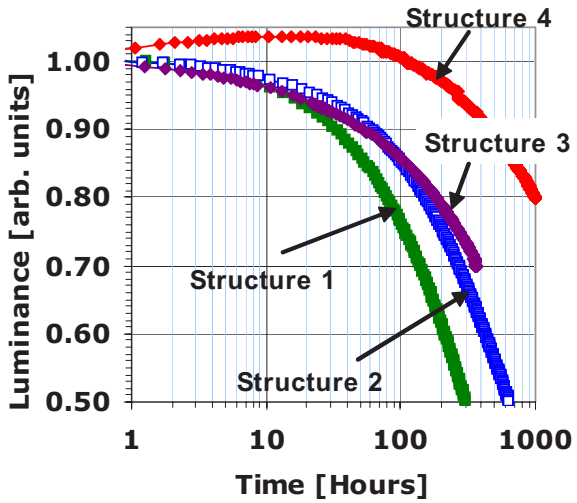

Fig. 2. Accelerated lifetime of green PHOLED structures 1 – 4 measured a fixed dc current density of 40mA/cm^2.

PHOLED structures 2 and 3 were identical save for the BL material used and they contained BLA and HX respectively. Replacement of BLA with the host material HX resulted in a lifetime improvement of 20,000hrs from 55,000hrs to 75,0000hrs from an initial luminance of 1000cd/m^2. The exact reason for this stability increase is not clear although HX is believed to be more stable to electrons.

However the HTL was found to have the largest impact on device stability. PHOLED structures 3 and 4 show the difference in lifetime with the replacement of α-NPD with a new HTL material HTLX. α-NPD is believed to be an unstable material in the presence of electrons and or excitons. The use of the HTLX material led to a more than a six fold increase in device lifetime from 75,000 to >500,000h. This is believed to be the longest lifetime demonstrated to date for a green PHOLED and meets commercial display requirements.

4. Summary

The development of this high efficiency green PHOLED with commercial stability will allow manufacturers, in combination with red PHOLEDs, to reduce the power consumption in AMOLED displays by ~40% compared to an all fluorescent OLED display. In summary this paper presented the evolution in performance of a green PHOLED examining the impact of the host, BL and HTL materials on device performance. Since the discovery of the phosphorescent emitter *fac*-tris(2-phenylpyridine) iridium(III) ($Ir(ppy)_3$) [9] great progress has been made in the performance of green PHOLEDs. Here we have demonstrated a green PHOLED with an efficiency of 58cd/A and a half lifetime of >500,000hrs from an initial luminance of 1000cd/m^2.

5. References

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