Displays 35 (2014) 79–83

Contents lists available at ScienceDirect

Displays

journal homepage: www.elsevier.com/locate/displa

Short Communication

Improved efficiency and lifetime for green phosphorescent organic light-emitting diodes using charge control layer

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ARTICLE INFO

Article history:
Received 30 October 2013
Received in revised form 8 February 2014
Accepted 13 February 2014
Available online 6 March 2014

Keywords:
Green phosphorescent organic light-emitting diode
CBP
$Ir(ppy)_3$
Charge control layer
Exciton distribution

ABSTRACT

We investigated green phosphorescent organic light-emitting diodes (PHOLEDs) with charge control layer (CCL) to produce high efficiency and improve operational lifetime. Three types of devices were fabricated following the number of CCL within emitting layer (EML), maintaining the thickness of whole EML. The CCL and host material, which was 4,4′-bis (carbazol-9-yl)biphenyl (CBP) with bipolar property, can control carrier movement in EML. Therefore, the electroluminescent (EL) performance improvement as efficiency and lifetime was realized with a good charge balance, an effective triplet exciton confinement, and the reduced triplet exciton quenching effect in EML. Device 2 with a CCL as exciton distribution structure exhibits the remarkable EL performances for the maximum luminous and external quantum efficiency of 65.34 cd/A and 20.42%, respectively. Moreover, operational lifetime is nearly improved 2.5 times than the conventional device.

1. Introduction

Organic light-emitting diodes (OLEDs) are one of the most promising technologies which will likely replace the existing liquid crystal display at present [1]. The rapid pace of technological development on OLEDs directed toward display applications including all of the known products in market [2–5]. In addition, many efforts are done in order to improve the performance of OLEDs. Above all, phosphorescent OLEDs (PHOLEDs) have received a considerable attention due to their highly efficient electroluminescence (EL) performance compared with fluorescent OLEDs [6–8]. Phosphorescent light-emitting materials can generally generate both singlet and triplet exciton by converting the singlet exciton to triplet exciton via intersystem crossing [9,10]. For this reason, an application of PHOLEDs become an essential requirement to achieve highly efficient OLEDs, which can both utilize the singlet and triplet exciton for generating light emission. In order to improve the EL performance of PHOLEDs, most important task require careful selection of high performance material and more advisable device structure [11]. From the direction of device structure engineering, significant process has been made in developing device structures based on both recombination process and triplet exciton confinement [12,13]. It has been studied on various OLEDs configuration using double emitting layer (EML), mixed host in EML, stepwise doping, and hybrid EML [14–17].

In this paper, we report on fabrication and characterization of green PHOLEDs with an exciton distribution structure consisting of charge control layer (CCL), which has a bipolar property. The CCL with a high triplet state was introduced to confine triplet excitons inside the EML and to manage triplet excitons by controlling charge injection/transport. Thus, we achieved high efficiency and operational stability of green PHOLEDs by improving the carrier recombination efficiency in a wider emissive region and by prohibiting triplet excitons diffusion out of each EMLs.

2. Experiment details

To fabricate the green PHOLEDs, 180 nm thick indium-tin-oxide (ITO, sheet resistivity of 10 Ω/square) was cleaned in an ultrasonic bath using the following sequence: acetone, methyl alcohol, distilled water. After stored in ethyl alcohol for 48 h, the ITO-coated substrates were dried by nitrogen (N_2) gas and baked at 110 °C for 10 min in convection oven. The substrates were treated by oxygen (O_2) plasma with a condition of 125 W for 2 min under 2×10^{-2} torr. All stacked layers were thermally evaporated under a high vacuum (5×10^{-7} torr) at a rate of 1.0 Å/s for organic

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http://dx.doi.org/10.1016/j.displa.2014.02.002
0141-9382/

materials and 0.1 Å/s for lithium quinolate (Liq), respectively. Finally, aluminum (Al) was evaporated on Liq film at a rate of 10 Å/s as cathode. A thickness of whole film and a doping concentration of an emitter were controlled and optimized by quartz thickness monitor. The OLED devices were encapsulated in a glove box with O_2 and H_2O concentrations below 1 ppm after depositing the organic and metal layers. A barium-oxide powder as a desiccant material was used to absorb the residual moisture in encapsulated OLEDs. A current density–voltage (*J*–*V*) characteristics of the OLEDs were measured with a source measure unit (Keithley 238) with the DC voltage bias. An optical and EL properties of the OLEDs such as luminance, luminous efficiency (LE), Commission International de L'Eclairage (CIE) coordinates and EL spectra were analyzed by spectroradiometer (CHROMA METER CS-1000A). An operational lifetime was measured using lifetime tester (Polaronix M6000).

3. Results and discussion

Fig. 1(a) shows chemical structures of key materials used in this study including 4,4,N,N′-dicarbazolebiphenyl (CBP) and tris(2-phenylpyridine)iridium ($Ir(ppy)_3$). CBP is a typical bipolar host material and $Ir(ppy)_3$ is the most well-known material as a phosphorescent green emitter [18,19]. The lowest unoccupied molecular orbital (LUMO) and the highest occupied molecular orbital (HOMO) of CBP and $Ir(ppy)_3$ were 2.6/5.9 eV and 2.8/5.2 eV, respectively [20]. The LUMO and HOMO of $Ir(ppy)_3$ are located inside the band gap of CBP. As shown in Fig. 1(b), three types of OLEDs with structures of ITO (180 nm) as an anode/4,4′-bis[N-(napthyl)-N-phenyl-amino]biphenyl (NPB, 50 nm) as a hole transporting layer (HTL)/4,4′,4″-tris(N-carbazolyl)triphenylamine (TCTA, 10 nm) as a triplet exciton blocking layer (TEBL)/$Ir(ppy)_3$ doped in CBP as an EML (8 wt.%, 30 nm) and CBP (5 nm) as a CCL (devices 2 and 3)/2,2′,2″-(1,3,5-benzenetryl)tris(1-phenyl)-1H-benzimidazol (TPBi, 10 nm) as a TEBL/4,7-diphenyl-1,10-phenanthroline (Bphen, 30 nm) as an electron transporting layer (ETL)/Liq (2 nm) as an electron injection layer (EIL)/Al (100 nm) as a cathode were fabricated. In these structures, each of devices has one CCL (device 2) with a fixed thickness (5 nm) and two CCLs (device 3) within EML, respectively, and device 1 without any CCL is reference device. All devices also maintain an overall thickness of the EML as 30 nm.

Fig. 2 shows a luminance versus voltage characteristics and inset of Fig. 2 also shows current density versus voltage characteristics of green PHOLEDs. Devices 1, 2, and 3 exhibited current density values of 21.76, 8.59, and 9.49 mA/cm^2 at 7 V, and luminances of

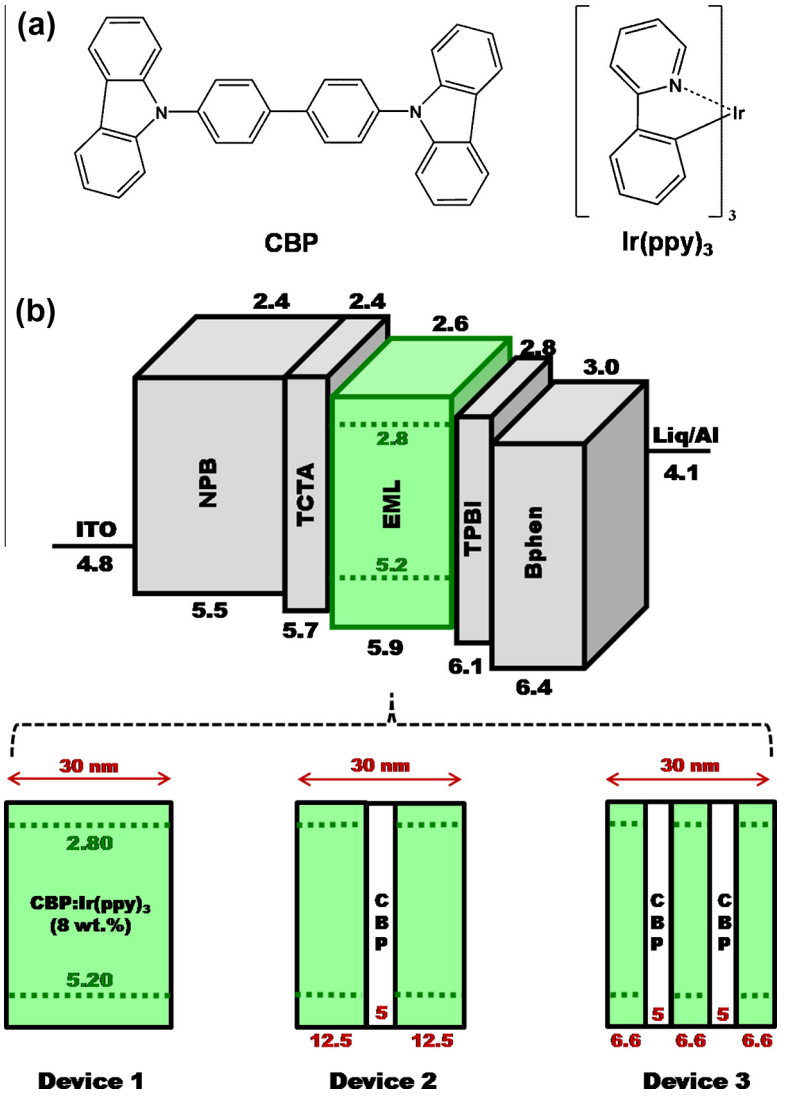

Fig. 1. (a) Chemical structure of CBP and $Ir(ppy)_3$ materials. (b) Device structure and energy level diagrams of green PHOLEDs (devices 1, 2, and 3).