A study on full color organic light emitting diodes with blue common layer under the patterned emission layer

CrossMark

Hee Young Shin, Min Chul Suh *

Department of Information Display and Advanced Display Research Center, Kyung Hee University, Dongdaemoon-Gu, Seoul 130-701, Republic of Korea

ARTICLE INFO

ABSTRACT

Color patterning steps for red, green, and blue emission layers (EMLs) are crucial for the production of full color organic light-emitting diodes (OLEDs). The most common method to form individually patterned EMLs is to use a shadow mask as the key component for patterning. However, most pixel defects are caused by such kinds of patterning steps. Therefore, skipping certain color patterning steps could significantly improve the production yield during the fine metal masking process in the OLED fabrication. A representative example of such approach is the top blue common layer (TBCL) structure with a non-patterned BCL on top of both green and red EMLs. However, this structure could cause blue color mixing in green or red devices. To prevent this effect, we propose a newly devised bottom BCL (BBCL) structure with the BCL that is totally separated from both green and red EMLs. In particular, we utilized 1,4,5,8,9,11-hexaazatriphenylene-hexacarbonitrile interlayer (7 nm) between the underlying BCL and the hole injection layer to completely extinguish blue emission. As a result, both green and red devices with the BBCL structure showed relatively better efficiencies compared to those with the TBCL structure without any color mixing.

1. Introduction

Since Tang and Vanslyke reported organic light-emitting diodes (OLEDs) as the first thin film devices based on small molecular organic materials [1], OLEDs have attracted much attention owing to their practical applications in full color displays [2–5]. To fabricate full color OLEDs, primary colors (RGB) are mostly patterned by the fine metal masking (FMM) method [6,7]. However, the FMM method has many problems, such as misalignments, different sagging behavior between the glass substrate and the shadow mask, particle contamination, mask lifetime, cleaning, thermal expansion of masks, wrong profile of taper area of the shadow mask, among others. In particular,

different sagging behavior between the glass substrate and the shadow mask and numerous impurities imported during the evaporation process are the major causes of the delay in successful launching of high-resolution and/or large-area displays [6]. To circumvent such problems of the FMM method, several alternative patterning technologies — such as ink-jet printing [7], laser-induced pattern-wise sublimation [8], laser-induced thermal imaging [9,10], radiation-induced sublimation transfer [11] and white OLED combined with color filter (CF) [12], — have been demonstrated. Among these, only the white OLED technology is being successfully applied in commercialization (e.g. large-area TV). However, the unfavorably low efficiency of white OLEDs itself has been regarded as an obstacle preventing it to effectively compete with other types of displays, such as active matrix OLEDs (AMOLEDs) prepared by the side-by-side RGB method or active matrix liquid crystal displays fabricated with LED. In addition, due

to an additional expense for CF, manufacturing costs could increase considerably.

Hence, the motivation of the present study derives from the assumption that simplification of the FMM process for side-by-side RGB OLEDs is the best option to realize a highly efficient and low-cost AMOLED fabrication. Therefore, the blue common layer (BCL) approach was selected to reduce the blue patterning step. The basic principle of the BCL approach is to use blue materials as alternative components of the hole-blocking layer (HBL), as they normally have considerably wider band gaps and much deeper highest occupied molecular orbital (HOMO) levels compared to those of both red and green layers that prevent holes from injection into the blue emission layer (EML). Especially, such kind of the BCL system — the so-called top BCL (TBCL) system with the non-patterned BCL on top of both green and red EMLs — works very well when a fluorescent blue EML is adjacent to fluorescent green or red EMLs. However, if this fluorescent blue EML is stacked directly on phosphorescent green or red EMLs, side-emission from the former could easily be observed, presumably due to a triplet exciton migration from green or red EMLs to the BCL [13]. Matsumoto et al. took the TBCL structure to a higher level by introducing the hybrid connecting layer (HCL) by evaporation as a common layer in-between green (or red) EMLs and the BCL [14]. The main role of the HCL is to suppress the exciton migration mentioned above so that the fluorescent blue material does not produce an unnecessary side-emission from the interaction with the adjacent phosphorescent excitons formed in green and red EMLs. However, due to the complicated requirements for the HCL (e.g. high triplet energy, high electron and hole mobility), such hybrid structure is somehow difficult to realize.

We propose an entirely different BCL structure, the so-called bottom BCL (BBCL) with an entirely separated BCL under the optical path-length compensation layer [OPCL: G′ (or R′) layer] and both phosphorescent green and red EMLs. To improve the device performance, a 1,4,5,8,9,11-hexaazatriphenylene-hexacarbonitrile (HATCN) layer between the BCL and OPCL with same composition as the hole transport layer (HTL) was introduced; furthermore, it was found that this layer was able to intrinsically suppress the blue side-emission and the driving voltage increase.

2. Experimental

2.1. Materials

We used indium tin oxide (ITO) or ITO/silver (Ag)/ITO as an anode, N,N′-bis(naphthalen-1-yl)-N,N′-bis(phenyl)benzidine (NPB) as a HTL, HATCN as an electron accepting layer and/or charge generation layer, bis(10-hydroxybenzo[h]quinolinato)beryllium (Bebq$_2$) as a red host (RH) material, bis(2-phenylquinoline)(acetylacetonate)iridium(III) [Ir(phq)$_2$(acac)] as a red dopant (RD) material, bis[2-(2-hydroxyphenyl)pyridinato]beryllium (Bepp$_2$) as a green host (GH) material, bis(2-phenylpyridine)(acetylacetonato)iridium(III) [Ir(ppy)$_2$(acac)] as a green dopant

(GD) material, 2-methyl-9,10-bis(naphthalen-2-yl)anthracene (MADN) as a blue host (BH) material, p-bis(p-N,N-diphenyl-aminostyryl)benzene (DSA-Ph) as a blue dopant (BD) material, 4,7-diphenyl-1,10-phenanthroline (Bphen) as a HBL and/or electron transporting layer (ETL), lithium fluoride (LiF) as an electron injection layer, and aluminum (Al) as a cathode. Tris(4-carbazoyl-9-ylphenyl)amine (TCTA) was used as an exciton blocking layer (EBL) to prevent triplet exciton quenching in the fabricated green devices. All the materials were purchased from commercial suppliers and used without purification.

2.2. Device fabrication

To fabricate OLED devices, clean glass substrates with an ITO layer or ITO/Ag/ITO layers formed by photolithography process were used. The bank layers were also formed on the anode and glass substrate by photolithography process to define the pixel aperture area by using photoresist. The glass substrates with anode as well as bank layer were cleaned by sonication in isopropyl alcohol and acetone, rinsed in deionized water, and finally treated in a UV–ozone chamber. All organic materials were deposited by the vacuum evaporation technique under a pressure of $\sim 1 \times 10^{-7}$ Torr. The deposition rate of organic layers was about 0.5 Å/s. Then, LiF and Al were deposited without breaking vacuum. Deposition rates of LiF and Al were about 0.5 Å/s and 3 Å/s, respectively.

2.3. Measurements

Optical simulation results were obtained using an optical simulator, Sim-OLED [15] (Sim4Tec.). The current density–voltage (J–V) and luminance–voltage (L–V) data of OLEDs were measured by Keithley 2635A and Minolta CS-100A, respectively. Electroluminescence (EL) spectra and the Commission Internationale De'Eclairage (CIE) coordinate were obtained using a Minolta CS-2000A spectroradiometer. The OLED area was 4 mm^2 for all the samples studied in this work.

3. Results and discussion

3.1. Design of full color OLEDs with BCL

We designed and tested two types of full color OLEDs with the BCL. A full color OLED with the TBCL was selected as a control device, as it is a well-known structure to reduce the blue patterning step in the FMM process [12,13]. The device structures and schematic energy band diagrams are shown in Fig. 1(a) and (b), respectively. Meanwhile, to eliminate the possibility of color mixing, we proposed a full color OLED with the BBCL structure by a perfect separation of the BCL from both green and red EMLs and the insertion of the HATCN interlayer between the underlying BCL and HTL included in the OPCL. The device structures and schematic energy band diagrams are shown in Fig. 1(c) and (d), respectively. The chemical structures of organic materials used in this study are shown in Fig. 2.