Journal of Luminescence 153 (2014) 104–108

Contents lists available at ScienceDirect

Journal of Luminescence

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

Study of energy transfer in single and multi-emissive layer using Gaussian peak fitting

Ju-An Yoon [a], You-Hyun Kim [a], Nam Ho Kim [a], Chang-Bum Moon [a], Gufeng He [c], Woo Young Kim [a,b,*]

[a] Department of Green Energy & Semiconductor Engineering, Hoseo University, Asan 336-795, Republic of Korea
[b] Department of Engineering Physics, McMaster University, Hamilton, ON, Canada L8S 4L7
[c] Department of Electronic Engineering, Jiao Tong University, Shanghai 200240, China

ARTICLE INFO

Article history:
Received 7 January 2014
Accepted 27 February 2014
Available online 15 March 2014

Keywords:
WOLEDs
Multi-emissive layer
Fluorescence
Charge blocking structure
Luminous efficiency

ABSTRACT

White organic light-emitting diodes(WOLEDs) were fabricated with the device structure of ITO(1800 Å)/NPB(700 Å)/emissive layer(300 Å)/Bphen(300 Å)/Liq(20 Å)/Al(1200 Å) using the two complementary colors method. Then, we investigated their electrical and optical characteristics to determine luminous efficiency, luminance and color coordinates of single, double, triple and quadruple emissive layered-WOLED. Thickness of emissive layer was fixed at 30 Å, and DPASN and BAlq were used for blue emissive host material and DCJTB was added as red dopant in the emissive layer. Then, we investigated the performance of OLEDs via its charge blocking structure and its different emissive region with emissive layers. Luminous efficiency of 5.30 cd/A at 50 mA/cm^2 of current density is obtained in WOLED device with double emissive layer of DPASN:DCJTB-0.1% (150 Å)/BAlq:DCJTB-0.1% (150 Å) and these are 80% higher than WOLED device with single emissive layer of DPASN:DCJTB-0.1% (300 Å).

1. Introduction

White organic light-emitting diodes (WOLEDs) have attracted worldwide interest due to their attractive advantages for displays such as reduced power consumption, compatibility with flexible substrates, high color rendering index, high contrast and wide viewing angle [1–4]. WOLEDs have emerged as a strong candidate for next generation flat panel displays and solid-state lighting [5–7]. Much progress has been made in the development of high performance WOLEDs through materials innovation and device optimization. It has been reported that power efficiency of WOLEDs could achieve more than 40 lm/W at 100 cd/m^2 [3]. Recently, a semitransparent WOLED with a visible-light transparency of $>50\%$, an almost identical power efficiency of 11 lm/W measured at 100 cd/m^2 and the similar CIE coordinates of (0.36, 0.43) and (0.38, 0.46) from both sides has been demonstrated [8]. Various methods have been applied to achieve efficient and color-balanced WOLED devices. First method was to replace emitters from fluorescent to phosphorescent materials [9] and the second was to balance the charge carrier ratio in the emissive layers(EML) [10]. The third method was to design a better surface texture for improving external quantum efficiency [11]. Lastly, a multi-emissive layer (MEML) structure was used for high performance OLEDs [12,13] and this structure, reported in earlier papers, also has been able to achieve the high performance white organic light-emitting diodes [14–17]. For MEML OLEDs, the broadened carrier recombination region, carrier trapping, exciton diffusion and the emission of each EML can be tuned appropriately to obtain desired color purity and high efficiency, and enhanced efficiency roll-off characteristic compared to conventional single-EML OLEDs [16–19].

In this paper, we fabricated WOLEDs with multi-emissive structures by n-type (BAlq) and p-type (DPASN) fluorescent blue host materials only using a small quantity of fluorescent red dopant materials. Each OLED structure was designed under different orders and numbers of EMLs, and then optimized to obtain WOLED's best electrical and optical performances under total thickness of EMLs at 300 Å. Luminous efficiency and current density–voltage–luminance (*I–V–L*) characteristics and spectroscopic analysis using multi-peak fits with a Gaussian function of the emission spectra were observed considering the effects of MEML structures and the variations in recombination region of EML.

2. Experimentals

ITO coated glass was cleaned in ultrasonic bath by regular sequences: in acetone, methanol, diluted water and isopropyl alcohol. Hereafter, pre-cleaned ITO was treated by O_2 plasma

* Corresponding author at: Department of Green Energy & Semiconductor Engineering, Hoseo University, Asan 336-795, Republic of Korea.
Tel.: +82 41 540 5944; fax: +82 41 548 0650.
E-mail addresses: kimnh1203@naver.com, wykim@hoseo.edu (W.Y. Kim).

http://dx.doi.org/10.1016/j.jlumin.2014.02.038
0022-2313/

under condition of 2.0×10^{-2} Torr, 125 W for 2 min [20]. White OLEDs were fabricated using the high vacuum of 1.0×10^{-6} Torr thermal evaporation and NPB, BAlq, DPASN, Bphen, and Liq and Al were deposited in order by evaporation rate of 1.0, 0.5, 0.5, 1.0, 0.1, 5.0 Å/s, respectively.

Fig. 1 shows the molecular structures of the blue chromophores used in the two type blue host materials and red dopant material at white OLEDs. We fabricated the devices with different emissive structures based on host-dopant systems such as two different blue fluorescent host materials with red fluorescent dopant materials. Two types of host materials bis(2-methyl-8-quinolinolate)-4-(phenylphenolato)aluminium (BAlq) and (*E*)-6-(4-(diphenylamino)styryl)-*N*,*N*-diphenyl naphthalen-2-amine (DPASN), serving as p- and n- type host emissive materials, and the red dopant material is (1,1,7,7-tetramethyljulolidin-4-yl-vinyl)-4*H*-pyran (DCJTB). The basic structure of white OLED with multi-EML is: ITO/*N*,*N*′-bis-(1-naphyl)-*N*,*N*′-diphenyl-1,1′-biphenyl-4,4′-diamine (NPB)/single, double, triple or quardruple EML using DPASN and BAlq/4,7-di-phenyl-1,10-phenanthroline (Bphen) as an electron transport layer/lithium quinolate (Liq)/aluminum (Al) cathode, where ITO serves as a front anode, a layer of NPB is the hole transporting layer, Liq is the electron injection layer. Five types of white OLEDs with different EML such as DPASN:DCJTB-0.1% (device A), BAlq:DCJTB-0.1% (device B), DPASN:DCJTB-0.1%/BAlq:DCJTB-0.1% (device C), DPASN:DCJTB-0.1%/BAlq:DCJTB-0.1%/DPASN:DCJTB-0.1% (device D) and DPASN:DCJTB-0.1%/BAlq:DCJTB-0.1%/DPASN:DCJTB-0.1%/BAlq:DCJTB-0.1% (device E) were fabricated. The thickness of the individual emissive layer in the stack of EMLs was optimized by keeping a total thickness of emissive layer as 300 Å. A summary of the OLED device structures is shown in Table 1. With various DC voltage bias, the optical and electrical properties of blue OLEDs such as the current density, luminance, luminous efficiency, Commission Internationale deL'eclairage (CIE_{xy}) coordinates and electroluminescence spectra were measured with Keithley 238, LMS PR-650 spectrophotometer and colorimeter and the IVL system.

3. Results and discussion

Fig. 2 shows the multi-Gaussian peak fits in the EL spectra of host materials such as DPASN and BAlq at an applied voltage of 6 V. EL spectra of DPASN and BAlq consisted of three major peaks and two minor peaks. The multi-curve fits based on the Gaussian distribution allows the determination of the peak positions according to the energy transitions and the relative yield for the electromagnetic wave transitions between the host and dopant molecules. Table 2 summarizes peak wavelength and the corresponding transition energies, and it indicates the emission spectra have five transitions in each of DPASN and BAlq. Obviously the green emission shows major peak and the yellow emission does minor peak. The dominant transitions occurred at 459, 487 and 518 nm from DPASN, and 468, 496 and 531 nm from BAlq corresponding to the transitions from the first electronic excited state to the vibrational states in the electronic ground state [21,22].

Fig. 3 shows the multi-Gaussian peak fits in the EL spectra of WOLEDs using multi-emissive layer at an applied voltage of 6 V. Two key results are obtained from these EL spectra: First, the multi-Gaussian fits of all devices consisting eight peaks appeared at different wavelengths including three green peaks at 459, 488 and 519 nm caused by host materials of DPASN and BAlq along with three blue peaks at 558, 591 and 629 nm caused by dopant materials of DCJTB. This phenomenon indicates that the emission peaks were evenly distributed and formed by host and dopant materials in EML due to low concentration of DCJTB. Considering energy transfer in the host-dopant system of EML in OLEDs, the excitation energy undergoes substantial transfer from host to dopant molecule before relaxation occurs [21,22]. Under low concentration of dopant, blue host molecule's energy represented by minor peaks in EL spectra was readily transferred to red dopant molecule generating emission zone evenly distributed for better WOLED devices; second, the peak intensity at 488 nm enhanced in WOLEDs compared to the blue OLED using DPASN only as host material. This result is caused by the energy transfer between host and dopant materials, and the constructive optical interference of EL spectra with DPASN and BAlq. Also the energy transfer from the host material to the dopant material occurred at emission at 459 nm rather than emission at 488 nm. As a result, the emission peak's intensity was almost equal at 459 nm and 488 nm in WOLEDs.

The major peak of BAlq EL spectra was located at 490 nm as shown in Fig. 2(b). Therefore, the constructive optical interference occurred between BAlq's emission at 490 nm and DPASN's emission at 488 nm in multi emissive layer WOLED, and then the emissive proportion of 488 nm region was enhanced as demonstrated by

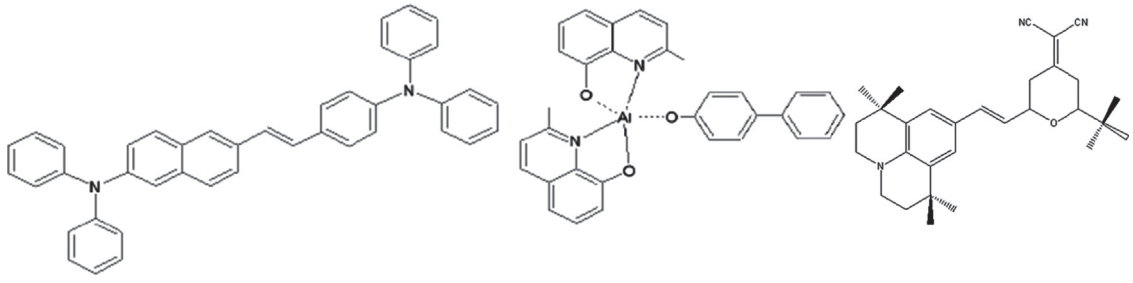

Fig. 1. Molecule structures of blue emissive host materials and red dopant material.

Table 1
Layer structures of white OLED devices A, B, C, D and E.

Device	Layer structure
Device A	ITO(1800 Å)/NPB(700 Å)/DPASN:DCJTB-0.1%(300 Å)/Bphen(300 Å)/Liq(20 Å)/Al(1200 Å)
Device B	ITO(1800 Å)/NPB(700 Å)/BAlq:DCJTB-0.1%(300 Å)/Bphen(300 Å)/Liq(20 Å)/Al(1200 Å)
Device C	ITO(1800 Å)/NPB(700 Å)/DPASN:DCJTB-0.1%(150 Å)/BAlq:DCJTB-0.1%(150 Å)/Bphen(300 Å)/Liq(20 Å)/Al(1200 Å)
Device D	ITO(1800 Å)/NPB(700 Å)/DPASN:DCJTB-0.1%(100 Å)/BAlq:DCJTB-0.1%(100 Å)/DPASN:DCJTB-0.1%(100 Å)/Bphen(300 Å)/Liq(20 Å)/Al(1200 Å)
Device E	ITO(1800 Å)/NPB(700 Å)/DPASN:DCJTB-0.1%(75 Å)/BAlq:DCJTB-0.1%(75 Å)/DPASN:DCJTB-0.1%(75 Å)/BAlq:DCJTB-0.1%(75 Å)/Bphen(300 Å)/Liq(20 Å)/Al(1200 Å)