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Control of device performances of phosphorescent white organic light-emitting diodes by managing charge transport properties of host materials

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ABSTRACT

Interlayer-free phosphorescent white organic light-emitting diodes (PHWOLEDs) with a mixed-host emitting structure in red emitting layer were developed and device performances were investigated according to the host composition in the red emitting layer. Device performances could be effectively managed by a simple change of host materials in the red emitting layer. A high quantum efficiency was obtained in PHWOLEDs with electron transport-type host in the red emitting layer and red emission was strong in PHWOLEDs with mixed-host in the red emitting layer. In addition, stable color performances were obtained in electron transport-type host rich devices.

1. Introduction

In recent years, many device architectures of white organic light-emitting diodes (WOLEDs) have been developed to improve their efficiency, luminance, color coordinates, and color stability [1–19]. Among them, WOLEDs based on stacked emitting structures are gaining interest due to their merits of high luminance and quantum efficiency.

Many studies have been conducted regarding developing the stacked emitting structures in WOLEDs, which includes double-layer and three-layer emitting structures [1–19]. Sun and Forrest [15] demonstrated that the three-layer emitting structure with the cascading highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) energy level was useful in expanding the recombination zone, and efficiency was improved. Lee et al. [16] reported that WOLEDs with mixed interfaces between the emitting layers showed high luminance and efficiency. Other than these, tandem WOLEDs with two emitting units in series showed a current efficiency of 17.14 cd/A with CIE coordinates of (0.28, 0.41) [19]. In these devices, device performances were controlled by changing the stacking sequence of emitting layers or charge transport of an interlayer. In many studies, an interlayer structure was applied as a method to control device performances of phosphorescent white organic light-emitting diodes (PHWOLEDs). However, the use of an interlayer makes the device structure and process complicated, and the interlayer-free device structure is required to simplify the device stacking sequence.

Therefore, as an approach to managing the device performances of PHWOLEDs, an interlayer-free PHWOLED with a mixed-host emitting structure in the red emission layer was developed and the device performances of the PHWOLED were correlated with charge transport properties of the host materials. A red emitting layer with a mixed-host of 4,4′,4″-tris(N-carbazolyl) triphenylamine (TCTA) and 1,3,5-tris(N-phenylbenzimidazole-2-yl)benzene (TPBI) was stacked on blue phosphorescent emitting layer with N,N′-dicarbazolyl-3,5-benzene (mCP) host material and device performances were investigated according to the host composition of the TCTA:TPBI mixed-host. This work reports the management of device performances of interlayer-free PHWOLEDs by triplet host materials.

2. Experimental

Device configuration used in this experiment was indium tin oxide (150 nm)/N,N′-diphenyl-N,N′bis-[4-(phenyl-m-tolyl-amino)-phenyl]-biphenyl-4,4′-diamine (DNTPD) (60 nm)/N,N′-di(1-naphthyl)-N,N′-diphenylbenzidine (NPB) (20 nm)/mCP (10 nm)/mCP:bis[(4,6-difluorophenyl)-pyridinato-N, C2](picolinato)Ir(III) (Flrpic) (25 nm, 15%)/4,4′,4″-tris(N-carbazolyl)triphenylamine (TCTA):1,3,5-tris(N-phenylbenzimidazole-2-yl)benzene (TPBI):bis(1-phenylquinoline) acetylacetonate ($Ir(pq)_2acac$) (5 nm, 10%)/2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (BCP) (5 nm)/tris(8-hydroxyquinoline) aluminium (Alq_3) (20 nm)/LiF(1 nm)/Al(200 nm).

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Five different mixed-host devices were fabricated to investigate the effect of mixed-host composition on white color coordinates, color stability, and efficiency. The relative contents of TPBI in TCTA:TPBI mixed-host structures were 100%, 75%, 50%, 25%, and 0%. They were named as devices A, B, C, D, and E. In the case of the mixed-host emitting layer, three materials were evaporated at the same time by controlling the evaporation rate. The deposition rate of dopant materials was fixed at 0.1 Å/s and that of TCTA and TPBI was controlled depending on the host composition. For example, in the case of the TCTA:TPBI (50:50) device, the deposition rates of TCTA, TPBI, and red dopant were 0.5, 0.5, and 0.1 Å/s, respectively. Current density–voltage–luminance characteristics of the devices were measured with a Keithley 2400 source measurement unit and a CS-1000 spectrophotometer.

3. Results and discussion

It has been reported that device performances of phosphorescent devices can be controlled using a mixed-host emitting structure [17]. A simple change of host composition affected the charge injection and quantum efficiency of phosphorescent devices, and it is expected that device performances such as color coordinate and quantum efficiency of PHWOLEDs can be managed by introducing a mixed-host emitting structure in PHWOLEDs.

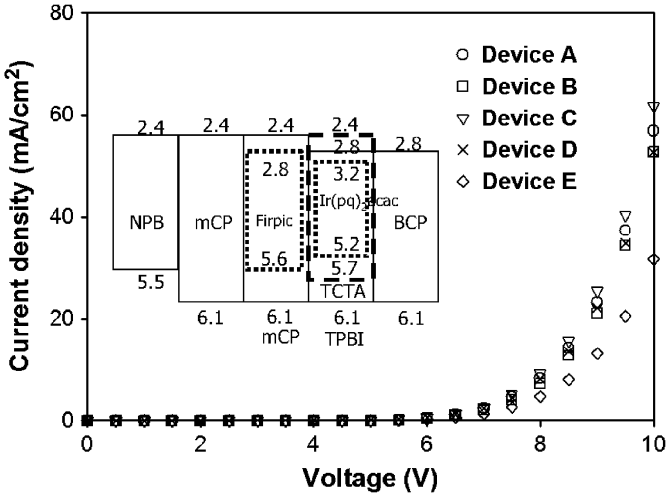

Fig. 1. Current density–voltage characteristics of WOLEDs with various compositions of mixed-host in the red emitting layer (inset: energy level diagram).

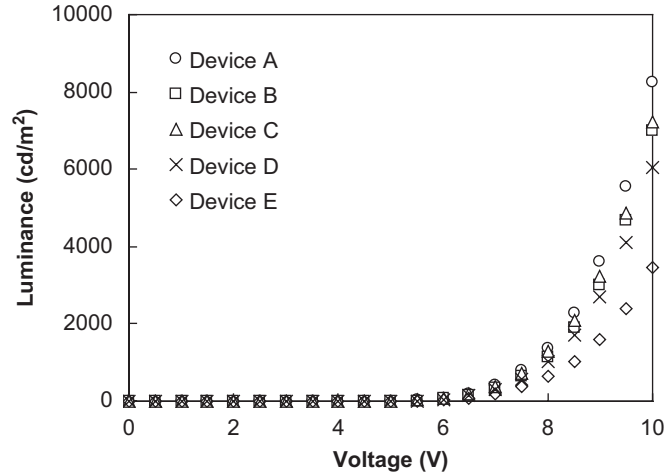

Fig. 2. Luminance–voltage characteristics of WOLEDs with various compositions of mixed-host in red emitting layer.

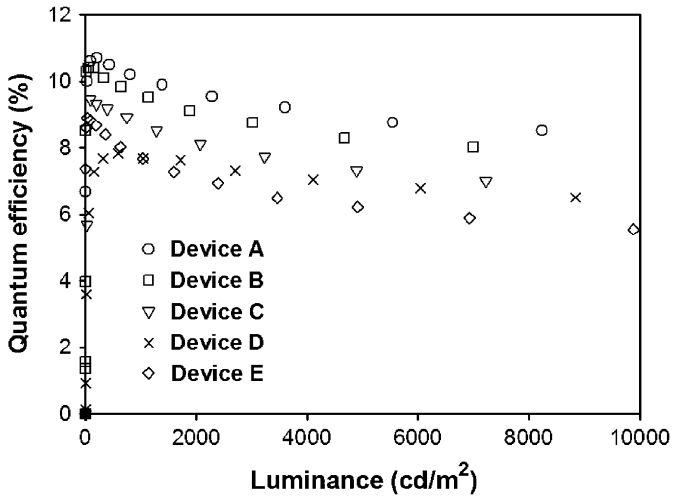

Fig. 3. Quantum efficiency–luminance characteristics of WOLEDs with various compositions of mixed-host in red emitting layer.

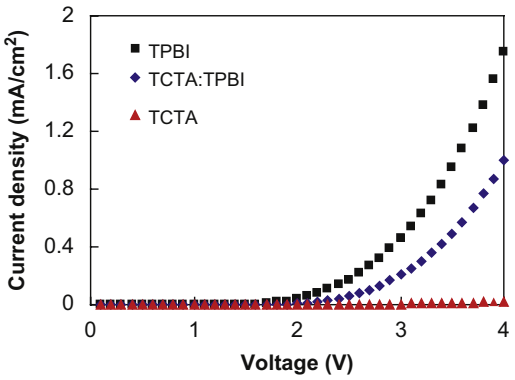

Fig. 4. Current density–voltage curves of electron-only devices of TCTA, TCTA:TPBI(50:50) and TPBI.

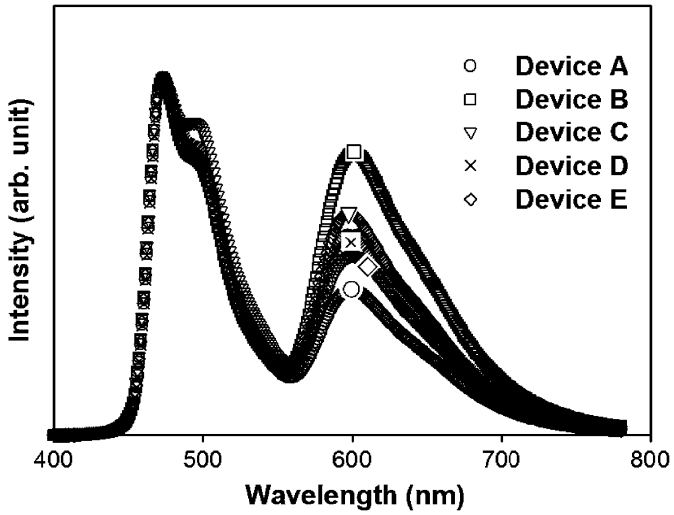

Fig. 5. Electroluminescence spectra of WOLEDs with various compositions of mixed-host.