



Multiple emissive layers white organic light emitting device with nanoplatforms patterning structure for improved current efficiency and color balance



Yanqin Miao^{a,c}, Zhixiang Gao^b, Yuanhao Li^{a,c}, Aiqin Zhang^{a,c}, Hua Wang^{a,c},
Yuying Hao^a, Husheng Jia^{a,d,*}, Xuguang Liu^e, Bingshe Xu^{a,c}

^a Key Laboratory of Interface Science and Engineering in Advanced Materials, Taiyuan University of Technology, Ministry of Education, Taiyuan 030024, China

^b School of Physical Science and Electronics, Shanxi Datong University, Datong 037009, China

^c Research Center of Advanced Materials Science and Technology, Taiyuan University of Technology, Taiyuan 030024, China

^d College of Materials Science and Engineering, Taiyuan University of Technology, Taiyuan 030024, China

^e College of Chemistry and Chemical Engineering, Taiyuan University of Technology, Taiyuan 030024, China

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ABSTRACT

In this paper, white organic light-emitting device (WOLED) with the structure of ITO/NPB/EML (blue)/CBP/EML (red)/CBP/EML (blue)/TPBi/LiF/Al was selected as reference. Then, the reference device was modified by nanoplatforms patterning structure at the TPBi/LiF or NPB/EML interface. The electroluminescence performance of above two kinds of devices was carefully investigated. The results indicate that WOLED with nanoplatforms at TPBi/LiF interface exhibits an enhanced current efficiency relative to reference device, and the enhancement factor is 1.52, which is due to improved light extraction efficiency. When nanoplatforms are located at the NPB/EML interface, WOLED shows more significantly improved current efficiency relative to reference device, and the enhancement factor is 1.80. Here, the improvement in current efficiency is attributed to increased light extraction efficiency and broadened carrier recombination zone. In addition, it is also found that WOLED with nanoplatforms located at the NPB/EML interface exhibits remarkably strengthened red light intensity in electroluminescence spectrum and good color balance, in which the intensity ratio of red-light to blue-light (I_{red}/I_{blue}) is 0.68, higher than that of reference WOLED ($I_{red}/I_{blue} = 0.5$). The implanting process of nanoplatforms patterning structure introduced in this paper is very simple and low-cost, which can be scaled up to large area WOLED manufacturing.

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1. Introduction

Since Kido's group demonstrated the first white organic light-emitting device (WOLED) by mixing different color emitters in 1995 [1], WOLEDs have attracted considerable attentions in the past two decades owing to their potential applications in next-generation full-color flat-panel displays and solid-state lighting sources [2–6]. Till now, a variety of WOLED structures have been invented, for example, single emissive layer WOLEDs [7–9], hybrid WOLEDs [10–12], tandem WOLEDs [13–15], and multiple emissive layers WOLEDs [16–18]. Among them, the multiple emissive layers

WOLEDs is considered to be the most cost-effective methods to achieve white light emission aiming for mass production [19]. However, in the multiple emissive layers WOLEDs, the carrier recombination zone rarely covers all different light-emitting layers simultaneously and normally shifts with increases of driving voltage, which leads to WOLEDs with poor color balance and color stability. So, improving the color balance of multiple emissive layers WOLEDs is vital to obtain high quality white emission for wide utilization.

In addition, WOLEDs still suffer low efficiency for further utilization. To obtain higher efficiency, phosphorescence materials have been widely used in WOLEDs because of higher internal quantum efficiency of 100% than that (25%) of fluorescent materials [20–22]. However, generally, only a small fraction of total photons generated inside thin films of WOLED is utilized owing to wave guiding effects and high total internal reflection coefficient in nanofilms [23]. Classical ray optics shows that the

* Corresponding authors at: No. 79 Yingze Street, Taiyuan, Shanxi, China. Tel.: +86 351 6014852; fax: +86 351 6010311.

E-mail addresses: wanghua001@tyut.edu.cn (H. Wang), jia_husheng@126.com (H. Jia).

ratio of outcoupled photons is limited to only about 20% in conventional planar bottom-emitting OLEDs [24–26]. So, many light extraction structures were introduced in OLEDs for improving light extracting efficiency, such as, mesa structures [25], spherical substrates [27,28], microlens array [29], corrugated structures [30,31], and textured surface [32,33]. However, most techniques aforementioned still involve complicated and expensive fabrication processes, and are limited to small area or monochromatic emission, which is not acceptable for practical applications.

In this study, we choose our previously reported WOLED as reference for comparing discussion [34]. We modified two kinds of layer–layer interfaces in reference WOLED with nanoplatforms patterning structure, and consequently achieved improved current efficiency and color balance. Here, the implanting process of nanoplatforms is simple and low-cost, which can be scaled up to large area WOLED manufacturing. We believe that this novel WOLED system is a key step toward low-cost, high efficiency, and good color balance WOLEDs.

2. Experimental details

The chemical structures of organic materials involved in this paper are shown in Fig. 1. Bis(3,5-difluoro-2-(2-pyridyl)phenyl-(2-carboxypyridyl))iridium(III) (Flrpic) and bis(1-phenylisoquinoline) (acetylacetonate) iridium(III) ($\text{Ir}(\text{piq})_2\text{acac}$) were used for blue and red emission, respectively. N,N' -bis(naphthalen-1-yl)- N,N' -bis(phenyl)-benzidine (NPB) served as hole transport layer (HTL), 1,3-bis(carbazol-9-yl)benzene (mCP) and 1,3,5-tri[(3-pyridyl)phen-3-yl]benzene (TmPyPB) served as triplet hosts, neat 4,4'-bis(carbazol-9-yl)biphenyl (CBP) acted as interval layer, 2,2',2''-(benzene-1,3,5-triyl)-tri(1-phenyl-1H-benzimidazole) (TPBi) acted as electron-transport layer (ETL). LiF and Al were used as electron injection layer (EIL) and cathode, respectively.

As shown in Fig. 2, three kinds of WOLEDs were fabricated in our experiment, which are denoted as W0 for the reference white device, WI-z-x for the first series of white devices, and WII-z-y for the second series of white devices. The device structures are as follows:

Device W0: ITO/NPB (35 nm)/mCP: 8 wt% Flrpic (10 nm)/CBP (5 nm)/CBP: 7 wt% $\text{Ir}(\text{piq})_2\text{acac}$ (5 nm)/CBP (5 nm)/TmPyPB: 8 wt% Flrpic (10 nm)/TPBi (30 nm)/LiF (1 nm)/Al (200 nm).

Devices WI-z-x: ITO/NPB (35 nm)/mCP: 8 wt% Flrpic (10 nm)/CBP (5 nm)/CBP: 7 wt% $\text{Ir}(\text{piq})_2\text{acac}$ (5 nm)/CBP (5 nm)/TmPyPB:

8 wt% Flrpic (10 nm)/TPBi (30–x nm)/TPBi (x nm) (z nanoplatforms)/LiF (1 nm)/Al (200 nm). Here, nanoplatforms are located at the TPBi/LiF interface, x represents the height of the nanoplatforms filled with TPBi, which is 3, 5, and 8 nm, separately, and z represents the number of the patterned nanoplatforms, which is 1, 2, and 3, separately.

Devices WII-z-y: ITO/NPB (35–y nm)/NPB (y nm) (z nanoplatforms)/mCP: 8 wt% Flrpic (10 nm)/CBP (5 nm)/CBP: 7 wt% $\text{Ir}(\text{piq})_2\text{acac}$ (5 nm)/CBP (5 nm)/TmPyPB: 8 wt% Flrpic (10 nm)/TPBi (30 nm)/LiF (1 nm)/Al (200 nm). Here, nanoplatforms are located at the NPB/EML interface, y represents the height of the nanoplatforms filled with NPB, which is 3, 5, and 8 nm, separately, and z represents the number of the patterned nanoplatforms, which is 1, 2, and 3, separately.

The preparation process of WOLEDs is shown in Fig. 3. The devices were fabricated on the pre-patterned indium tin oxide (ITO) glass substrates with sheet resistance of $15 \Omega/\text{sq}$. The overlap between ITO anode and Al cathode is $3 \text{ mm} \times 3 \text{ mm}$, as the active emissive area of the devices, in which nanoplatforms with width of 0.4 mm were implanted, as shown in Fig. 3(a). Firstly, ITO glass substrates were ultrasonically cleaned consecutively with detergent water, deionized water, and acetone, dried in drying cabinet, and irradiated by ultraviolet light for 10 min. After these processes, the cleaned ITO substrates were put into the pallet (Fig. 3(b)). Then, the pallet was transferred into a deposition chamber. When the vacuum in the deposition chamber is below $5 \times 10^{-4} \text{ Pa}$, the shadow mask with a square frame was opened for sequential deposition of all organic functional layers. In the case of depositing nanoplatforms patterning, the pallet was transferred onto the shadow mask with 1–3 line arrays. Finally, Al cathode was deposited onto organic layers using metal shadow mask. The masks for depositing organic layers, nanoplatforms, and Al cathode are shown in Fig. 3(c). The exact position of nanoplatforms array in the active area is shown in Fig. 3(d). The evaporating deposition rates of organic materials, lithium fluoride (LiF), and aluminum (Al), were about 1, 0.1 and $3 \text{ \AA}/\text{s}$, respectively. The thickness and deposition rates of films and nanoplatforms were controlled by a quartz thickness monitor.

The device performances of WOLEDs were characterized by Keithley 2400 source meter combined with Photo Research PR 655 spectrometer simultaneously. All the samples were measured directly after fabrication without encapsulation in ambient atmosphere at room temperature in the darkroom. The partial

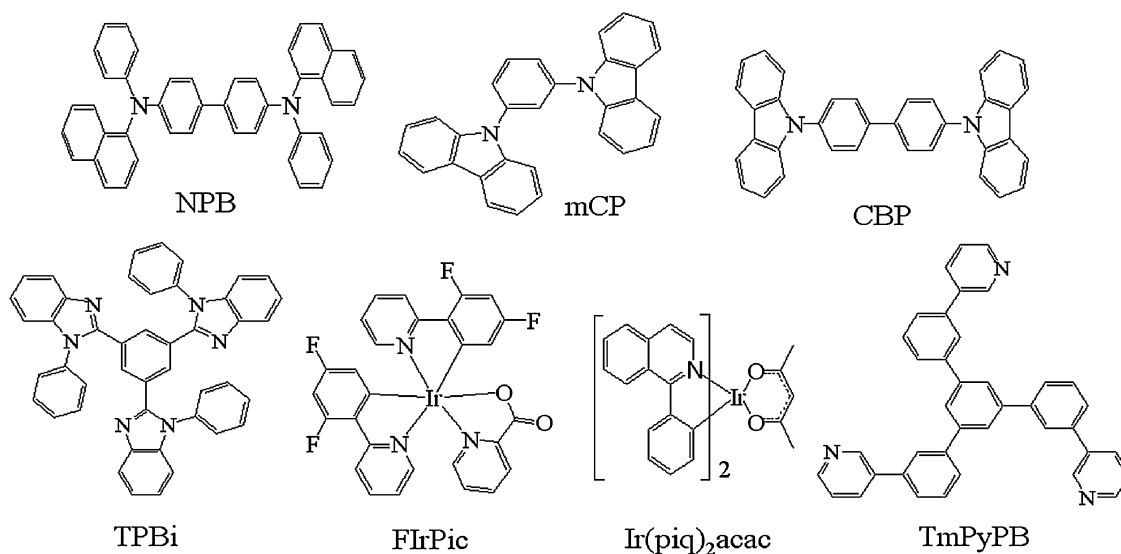


Fig. 1. The chemical structures of organic materials used in this paper.

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