



Highly efficient solution-processed small-molecule white organic light-emitting diodes



Xiaoyang Du, Xiaoxia Yang, Juewen Zhao, Hui Lin, Caijun Zheng*, Silu Tao**

School of Optoelectronic Information, University of Electronic Science and Technology of China (UESTC), Chengdu 610054, PR China

ARTICLE INFO

Article history:

Received 14 June 2016

Received in revised form

24 August 2016

Accepted 12 September 2016

Keywords:

Solution process

Phosphorescent

WOLEDs

Co-host

ABSTRACT

Solution-processed small-molecule white organic light-emitting diodes (WOLEDs) were fabricated with a co-host of hole-transporter 4,4',4''-Tris(carbazol-9-yl)triphenylamine (TCTA) and electron-transporter 2,7-Bis(diphenylphosphoryl)-9,9'-spirobifluorene (SPP013). By doping 15 wt% FIrpic or F₃Irpic and 0.5 wt% Ir(MDQ)₂(acac) in to the TCTA/SPP013 host, highly efficient white OLEDs have been achieved which exhibit nearly identical emission spectra at different luminance. The F₃Irpic and Ir(MDQ)₂(acac)-based WOLED shows maximum efficiencies of 40.9 cd/A, 36.7 lm/W and 16.9%, and even high efficiencies of 30.1 cd/A and 12.3% at the practical luminance of 1000 cd/m², which are among the highest efficiencies of the solution-processed small-molecule WOLEDs. These results demonstrate a convenient way to realize solution-processed WOLEDs with high efficiency and high spectral stability through full small-molecule materials system.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

In the past decades, organic light-emitting diodes (OLEDs) have gained tremendous scientific and industrial attentions since the first report by Tang et al. [1] Although OLEDs have been used in commercial TVs after dramatic progress in this field, most TVs with OLEDs are fabricated via vacuum thermal evaporation process, which has several disadvantages such as complicated co-evaporation technique, poor scalability and inefficient usage of materials [2–4]. Correspondingly, the solution process can fully address these problems due to its superiorities of easily controllable doping concentrations, simple fabrication procedures, potential low cost in large-area manufacturability, compatibility with flexible substrates, and so on, making it competitive in next-generation techniques [5,6].

Initial solution-processed OLEDs were mainly based on polymers for their super film-forming property [7,8]. However, the performance of polymer-based OLEDs is limited due to relatively poor purity and uncontrollable molecular weight of polymeric materials. Compared with polymers, small-molecule materials

have well defined molecular structures, and are much easier to be synthesized and purified. Thus, considerable efforts have been made to develop solution-processed OLEDs based on all small-molecule materials in recent years [9–16]. And highly efficient monochromatic devices with different colors have been reported recently [17–23]. Giridhar et al. reported a red solution-processed device with max external quantum efficiency (EQE) of 21% by doping new guest Ir-(Th-PQ)₃ into TCTA/TPBi mixed host [20]. C. W. Lee and J. Y. Lee reported a blue solution-processed small-molecule OLED with a maximum EQE of 23.9% [22]. High EQE of 22% was also achieved in green small-molecule OLEDs by solution process [23]. These results suggest that the performance of solution-processed small-molecule OLEDs can catch up with that of the devices fabricated via vacuum thermal evaporation process. However, compared with the monochromatic devices, the solution-processed small-molecule white OLEDs (WOLEDs) still exhibit unsatisfactory performance. D. G. Ma et al. reported a solution-processed small-molecule WOLED with a maximum current efficiency of 37.1 cd/A and a maximum power efficiency of 32.1 lm/W [24]. Y. L. Deng et al. reported a solution-processed WOLED with a maximum current efficiency of 28.9 cd/A and a maximum EQE of 12.1% by small molecule system [25].

In this work, we used a mixture of conventional hole transporting material 4,4',4''-Tris(carbazol-9-yl)triphenylamine (TCTA) and electron transporting material 2,7-Bis(diphenylphosphoryl)-9,9'-spirobifluorene (SPP013) as the host materials to develop

* Corresponding author.

** Corresponding author.

E-mail addresses: zhengcaijun@uestc.edu.cn (C. Zheng), silutao@uestc.edu.cn (S. Tao).

devices. This system has been reported as the host for blue, green and red monochromatic devices, and proved to form high-quality film via a solution fabrication method by D. G. Ma et al. [10] We aimed to further develop efficient and color-stable WOLEDs which is significant to future lighting and display development. To realize high performance solution-processed small-molecule WOLEDs, complemented blue and red phosphorescent devices are studied firstly. The blue solution-processed devices based on bis(3,5-difluoro-2-(2-pyridyl)phenyl)-(2-carboxypyridyl)iridium(III) (Flrpic) or iridium(III) bis[(3,4,5-trifluorophenyl)-pyridinato-N,C^{2'}] picolinate (F₃lrpic) and the red solution-processed device based on bis(2-methylidibenzo[f,h]quinoxaline)(acetylacetonate)iridium(III) (Ir(MDQ)₂(acac)) successfully exhibit good performance with the co-host system of TCTA/SPPO13. Finally, the WOLEDs were constructed by simultaneously doping blue and red phosphors (Flrpic and Ir(MDQ)₂(acac) or F₃lrpic and Ir(MDQ)₂(acac)) into the TCTA/SPPO13 host. Both two white devices exhibit nearly identical emission spectra at different luminance. The optimized two-element WOLED with F₃lrpic and Ir(MDQ)₂(acac) shows maximum current efficiency, power efficiency and EQE of 40.9 cd/A, 36.7 lm/W and 16.9%, respectively. These results are even higher than the results of the solution-processed small-molecule WOLEDs reported before [24–29].

2. Device fabrication and measurement

The hole-injection material poly-(3,4-ethylenedioxythiophene):poly-(styrenesulfonate) (PEDOT:PSS), hole-transporting materials TCTA and electron-transporting material SPPO13, red phosphor Ir(MDQ)₂(acac) and blue phosphor Flrpic were purchased from Luminescence Technology Corp.

Indium tin oxide (ITO)-coated glass substrates with a sheet resistance of 15 Ω per square were used as the starting substrates. The ITO glass substrates were carefully cleaned in an ultrasonic bath with detergent, ethyl alcohol and deionized water in sequence, then dried in an oven at 120 °C over 2 h. Before device fabrication, the substrates were treated with ultraviolet-ozone for 30 min. A water-dispersed PEDOT:PSS mixture was first spin coating on top of the ITO surface to form films with thickness of 40 nm. The films of PEDOT:PSS were baked at a hot plate at 140 °C for 15 min to remove residual water. On the top of that, the emission layer was spin-coated from chlorobenzene solution to form approximately 70 nm thick films. Then the films were annealed at a hot plate at 120 °C for 30 min. Both the spin-coating and anneal processes were carried out in N₂ glove box. Then the substrates were transferred to the thermal deposition system. Electron transporting layer, LiF and Al were deposited on to the substrates sequentially under a base pressure 5 × 10⁻⁴ Pa. SPPO13 was deposited with a rate of 1–2 Å s⁻¹, the electron-injecting layer LiF and cathode Al were deposited with a rate of 0.1 Å s⁻¹ and 5 Å s⁻¹, respectively.

PL spectra were measured using a Hitachi fluorescence spectrometer F-4600, the related room temperature time-resolved transient PL decay characterizations were conducted by the Analysis and Test Center of Beijing University of Chemical Technology with lifetime and steady state spectrometer FLS980. Film morphologies were investigated by Atomic Force Microscope (AFM, Bruker-Dimension Icon). EL spectra, CIE coordinates, and current density-voltage-luminance (J-V-L) characteristics were evaluated with a Spectrascan PR655 photometer and a computer-controlled Keithley model 2400 source meter under ambient atmosphere.

3. Results and discussions

The chemical structures of materials used in this paper and the

devices structure are described in Fig. 1. F₃lrpic is an efficient blue phosphorescent emitter reported by our group recently [30]. TCTA and SPPO13 not only possess relatively high charge-transporting property and high-lying triplet energy (TCTA: 2.76 eV, SPPO13: 2.78 eV), but also own good solubility and film morphology [10,12,26]. Thus, the mixture of TCTA and SPPO13 with excellent charge balance can be capable of using as the host materials of solution-processed devices with various colors. The AFM morphology of solution processed host TCTA:SPPO13 deposited on the surface of quartz substrate from chlorobenzene is shown in Fig. 2 (a). The film shows small surface roughness and good uniformity, indicating TCTA and SPPO13 have high solubility and are applicable for solution-processed devices. Fig. 2(b)–(f) reveal the AFM images of solution-processed EMLs containing with different dopants. Films (c) and (f) respectively exhibits much smoother morphology than that of films (b) and (e), resulting device B2 and W2 would possess lower V_{on} and higher power efficiency than that of device B1 and W1. All of the films show small root-mean-square surface roughness around 0.3 nm, suggesting small molecule based solution-processed film is comparable to the film that performed by vacuum evaporation.

Blue solution-processed OLED based on Flrpic (device B1) was firstly fabricated with a structure of ITO/PEDOT:PSS (40 nm)/TCTA:SPPO13:Flrpic (70 nm)/SPPO13 (40 nm)/LiF (1 nm)/Al (100 nm). In the device, ITO and Al respectively functioned as anode and cathode; LiF was used as electron injecting layer (EIL); TCTA and SPPO13 were blended with an appropriate proportion (6:3) and used as host to maintain a good balance between electron and hole currents for all devices; SPPO13 acts as electron transporting layer (ETL) which can reduce electron injection barrier and confine the triplet excitons in EML. The doping concentration of Flrpic was optimized and exactly controlled at 15 wt%.

Fig. 3a depicts the electroluminescence (EL) spectra of the device B1 at the luminance of 10, 100 and 1000 cd/m². The device B1 exhibits a typical emission of Flrpic with a peak at 472 nm and a sub-peak at 498 nm, indicating full energy transfer from TCTA/SPPO13 host to Flrpic. The current efficiency, power efficiency versus luminance properties are depicted in Fig. 3b. The device B1 shows a peak current efficiency of 29.8 cd/A, a peak power efficiency of 20.8 lm/W and a peak EQE of 12.5% at a brightness of 15 cd/m². The current-voltage-luminance (J-V-L) characteristics are shown in the insert of Fig. 3b. The device B1 exhibits a V_{on} (the voltage at 1 cd/m²) of 3.8 V. The key parameters of devices of this work are listed in Table 1.

F₃lrpic was then doped into co-host system to develop a new blue solution-processed device with the same structure of device B1. And the F₃lrpic-based device was named as device B2. The optimal weight ratio of F₃lrpic was also fixed at 15 wt%. As shown in Fig. 4a, the EL spectra of the device B2 indicates that the emission is completely from F₃lrpic. The emission has a main peak at 489 nm and a shoulder peak at long wavelength. The efficiency characteristics and J-V-L curves are illustrated in Fig. 4b. The device B2 owns maximum current efficiency, power efficiency and EQE of 35.8 cd/A, 32.1 lm/W and 12.4%, respectively. And the V_{on} of device B2 is 2.9 V.

Next, red solution-processed device (device R) using Ir(MDQ)₂(acac) as the dopant was also fabricated with the same device structure. The doping concentration of Ir(MDQ)₂(acac) was optimized at 1 wt%. Fig. 5a depicts the EL spectra of device R at different luminance. Without any undesired emission, the stable red emission from Ir(MDQ)₂(acac) has a peak at 605 nm and a CIE coordinate of (0.59, 0.40). The current and power efficiency curves of device R are described in Fig. 4b. The device R shows maximum current efficiency and power efficiency of 28.2 cd/A and 17.7 lm/W. The corresponding maximum EQE is 14.9%. The insert of Fig. 5b shows the J-V-L characteristics of the red device. The device has a V_{on} of

Download English Version:

<https://daneshyari.com/en/article/7700737>

Download Persian Version:

<https://daneshyari.com/article/7700737>

[Daneshyari.com](https://daneshyari.com)