Organic Electronics 45 (2017) 104–107

Contents lists available at ScienceDirect

Organic Electronics

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

Exciton management by co-doping of blue triplet emitter as a lifetime improving method of blue thermally activated delayed fluorescent devices

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ARTICLE INFO

Article history:
Received 23 January 2017
Received in revised form
25 February 2017
Accepted 4 March 2017
Available online 6 March 2017

Keywords:
Delayed fluorescence
Lifetime
Blue device
Exciton
Polaron

ABSTRACT

Co-doping of a blue phosphorescent emitter in a thermally activated delayed fluorescent (TADF) emitter based emitting layer was developed as an approach to extend the lifetime of blue TADF devices by managing excitons and polarons in the emitting layer. The blue phosphorescent emitter was doped at a very low doping concentration below 1 wt% to suppress triplet-triplet and triplet-polaron quenching effect in the TADF emitting layer. The doping of the blue phosphorescent emitter led to great extension of the lifetime of the TADF devices by hole trapping effect of the blue triplet emitter which widened exciton formation zone in the TADF emitting layer. More than twice extension of the operational lifetime of the device was demonstrated by the co-doping approach irrespective of the doping concentration of the TADF emitter in the emitting layer.

1. Introduction

Lifetime and external quantum efficiency (EQE) are the most important device characteristics of organic light-emitting diodes (OLEDs) for practical application of OLEDs as a display panel [1–4]. Particularly, the lifetime and EQE of blue OLEDs are of crucial importance because the overall device performances of full color OLED displays are limited by those of blue OLEDs [5–13]. Therefore, the development of the long lifetime and high EQE blue OLEDs is the key topic to be studied in the field of OLEDs [13–20].

There have been a few candidates as the lifetime extending and EQE enhancing approaches of blue OLEDs and one of the candidates is to apply blue thermally activated delayed fluorescent (TADF) emitters in the emitting layer [20–30]. The TADF emitters can be as efficient as the Ir triplet emitters because all excitons formed by carrier injection can be harvested by fluorescence. Several TADF emitters validated the potential of the TADF emitters as the high EQE blue emitters although the EQE of the blue TADF device is not as high as that of blue phosphorescent OLEDs [25–34]. However, the lifetime of the blue TADF device is still very short compared to that of the commercialized blue fluorescent OLEDs due to several reasons. For instance, lack of stable high triplet energy host and charge transport materials and chemical instability of the TADF emitters are responsible for the poor lifetime of the blue TADF OLEDs. Moreover, little study has been carried out about device engineering to extend the lifetime of the blue TADF OLEDs. Therefore, a device approach to assist stable operation of the blue TADF device would be essential in addition to material study.

In this work, a device engineering method of blue TADF device was developed to increase the device lifetime by introducing a triplet exciton and polaron managing emitting layer. A blue Ir emitter was doped at a low doping concentration in the TADF emitting layer to control triplet excitons and polarons in the emitting layer, which stabilized the device operation and extended the lifetime by more than twice. In particular, the blue Ir emitter doping method afforded lifetime extending effect without sacrificing the efficiency of the TADF devices.

2. Results and discussion

It has been known that triplet-triplet annihilation (TTA) and triplet-polaron annihilation (TPA) are main routes of degradation of phosphorescent OLEDs [35–37], and the TTA and TPA processes are

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http://dx.doi.org/10.1016/j.orgel.2017.03.003
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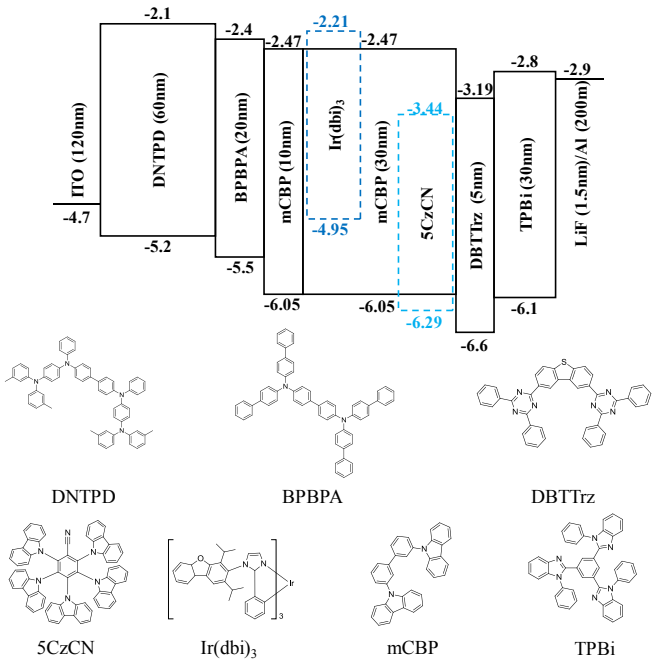

Fig. 1. Chemical structure of materials and device structure.

also responsible for the degradation of the TADF OLEDs because triplet excitons with long excited state lifetime are involved in the light-emission process. Therefore, a device engineering to suppress the TTA and TPA processes happening in the TADF emitting layer may increase the lifetime of blue TADF OLEDs. As the TPA degradation of the TADF device is caused by strong electron trapping effect of TADF emitters, a device structure compensating the electron trapping effect would extend the lifetime of the TADF device. In addition, the TTA process can also be suppressed if the electron trapping effect is properly managed. As a device approach of reducing the TTA and TPA effect simultaneously, a co-doping of hole trapping Ir emitter in the TADF emitting layer was tried because the hole trapping dopant would decrease TPA by decreasing polaron density and TTA by widening the recombination zone. Blue TADF emitter, 2,3,4,5,6-penta(9H-carbazol-9-yl)benzonitrile (5CzCN), was used as a blue TADF emitter for lifetime study [38,39] and blue triplet emitter, tris(2-(1-(2,4-diisopropyldibenzo[*b*,*d*]furan-3-yl)-1H-imidazol-2-yl)phenyl)iridium (Ir(dbi)$_3$), was doped in the TADF emitting layer to relieve TPA in the emitting layer. The device

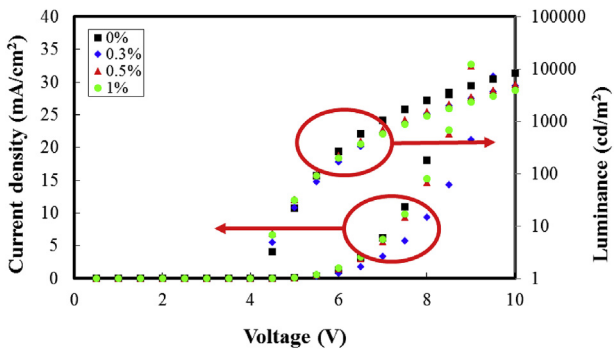

Fig. 2. Current density and luminance plots against driving voltage of the 5CzCN blue TADF OLEDs according to doping concentration of Ir(dbi)$_3$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

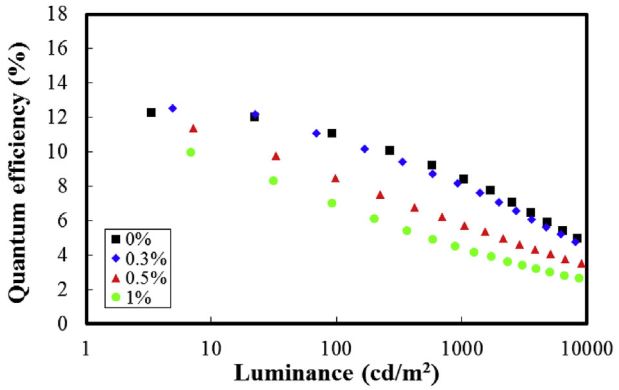

Fig. 3. Quantum efficiency plots against luminance of the 5CzCN blue TADF OLEDs according to doping concentration of Ir(dbi)$_3$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

structure of the TPA managing device by co-doping method is shown in Fig. 1 in addition to the chemical structure of 5CzCN and Ir(dbi)$_3$.

The device characteristics of the 5CzCN and Ir(dbi)$_3$ co-doped TADF devices are summarized in Fig. 2 according to Ir(dbi)$_3$ doping concentration. The Ir(dbi)$_3$ doping decreased the current density (**J**) of the TADF device by hole trapping effect caused by large highest occupied molecular orbital (HOMO) level gap between 3,3-di(9*H*-carbazol-9-yl)biphenyl (mCBP) host and Ir(dbi)$_3$. The reduced **J** also affected the luminance (**L**) of the TADF device in a similar way.

EQE data of the TADF devices are shown in Fig. 3 according to **L** of the devices. The 0.3% doping of Ir(dbi)$_3$ had little influence on the EQE of the device, but 1.0% doping decreased the EQE of the TADF device. Judging from the reduced **J** of the TADF device by Ir(dbi)$_3$ doping, the EQE should not be degraded due to better charge balance. Therefore, the efficiency reduction at 1.0% Ir(dbi)$_3$ doping may be due to other reasons.

To examine the EQE degradation of the 5CzCN device by Ir(dbi)$_3$ at 0.5 and 1.0 wt% doping concentrations, electroluminescence (EL) spectra of the 5CzCN device were compared in Fig. 4. Main emission of the 5CzCN devices appeared at the same wavelength range in all devices, but there was slight difference of the EL spectra at long wavelength around 580 nm. The long wavelength emission was not observed in the Ir(dbi)$_3$ free 5CzCN device, but it was detected in the Ir(dbi)$_3$ doped 5CzCN device. This can be

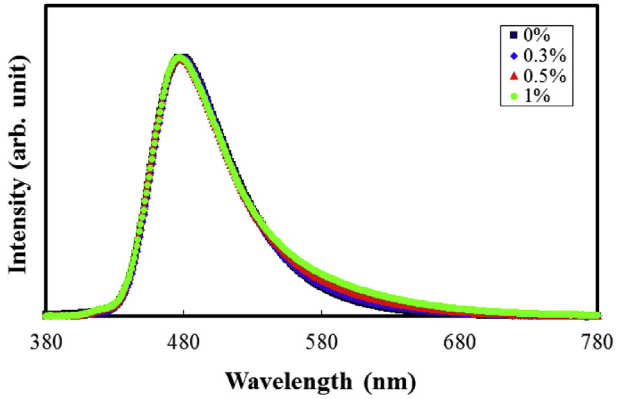

Fig. 4. EL spectra of the 5CzCN blue TADF OLEDs according to doping concentration of Ir(dbi)$_3$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)