



ELSEVIER

Contents lists available at ScienceDirect

## Organic Electronics

journal homepage: [www.elsevier.com/locate/orgel](http://www.elsevier.com/locate/orgel)

# Efficient solution-processed blue phosphorescent organic light-emitting diodes with halogen-free solvent to optimize the emissive layer morphology



Lihui Liu <sup>a,b</sup>, Xuejing Liu <sup>a,b</sup>, Keqi Wu <sup>a,b</sup>, Junqiao Ding <sup>a</sup>, Baohua Zhang <sup>a,\*</sup>, Zhiyuan Xie <sup>a,\*</sup>, Lixiang Wang <sup>a</sup>

<sup>a</sup> State Key Laboratory of Polymer Physics and Chemistry, Changchun Institute of Applied Chemistry, Chinese Academy of Sciences, Changchun 130022, PR China

<sup>b</sup> University of Chinese Academy of Sciences, Beijing 100039, PR China

## ARTICLE INFO

## Article history:

Received 20 December 2013

Received in revised form 18 March 2014

Accepted 4 April 2014

Available online 24 April 2014

## Keywords:

Organic light-emitting diodes

Solution process

Halogen-free solvent

Film morphology

## ABSTRACT

Efficient solution-processed blue phosphorescent organic light-emitting diodes (OLEDs) featuring with halogen-free solvent processing are fabricated in this study. The organic molecule 3,6-bis(diphenylphosphoryl)-9-(4'-(diphenylphosphoryl) phenyl)-carbazole (TPCz) that possesses good solubility in halogen-free polar solvents is selected to serve as the host of blue phosphorescent iridium(III) [bis(4,6-difluorophenyl)-pyridinato-N,C<sup>2</sup>]-picolinate (Flrpic) dopant. The morphology of the TPCz:Flrpic emissive layer prepared with different polar solvents including chlorobenzene (CB), n-butanol (ButA) and isopropanol (IPA) and the effect on their electroluminescent performance have been investigated in detail. It is found that the more polar halogen-free solvent IPA restrains the Flrpic aggregation and renders a more densely packed emissive layer as compared to the CB-processed counterpart, which results in the enhanced electroluminescent performance. The luminous efficiency and power efficiency of the blue phosphorescent OLEDs prepared with CB are merely 5.7 cd/A and 3.3 lm/W, respectively. When using more polar halogen-free solvent IPA, the efficiencies are enhanced to 22.3 cd/A and 15.6 lm/W, about 2.9 and 3.7-time increment, respectively. This work provides an approach to fabricate efficient solution-processed phosphorescent OLEDs with environmental-friendly solvents, which is highly required in large-scale solution-processed manufacturing.

© 2014 Elsevier B.V. All rights reserved.

## 1. Introduction

Vacuum-deposited organic light-emitting diodes (OLEDs) have come into commercial application in solid-state white lighting and flat-panel displays owing to the great progress achieved in past two decades on organic materials, device physics and device structures, etc. [1–3]. Vacuum deposition technology allows the fabrication

of complicated device structures toward achieving high device performance at the expense of the expensive vacuum deposition facilities and high organic material loss [4]. Alternatively, solution-processed OLEDs have drawn great research interest in recent years due to the low loss of expensive OLED materials and cost-effective large-area manufacturing via inkjet printing and screen printing, etc. [5–17]. In contrast to conjugated polymers, solution-processed OLEDs based on organic small molecules possess some advantages, such as excellent reproducibility of chemical synthesis and high purity of small molecules [5,6].

\* Corresponding authors.

E-mail addresses: [bhzhang512@ciac.ac.cn](mailto:bhzhang512@ciac.ac.cn) (B. Zhang), [xiezy\\_n@ciac.ac.cn](mailto:xiezy_n@ciac.ac.cn) (Z. Xie).

So far, significant progresses have been achieved for solution-processed OLEDs based on small molecules, including red/green/blue (R/G/B) and white OLEDs [7–19]. However, all these studies focused on tuning the components of the emissive layer (EML) in order to obtain balanced charge-transport and matched energy levels, and the corresponding film morphology issues were rarely concerned [11,20–22]. Lee et al. [11] prepared efficient blue fluorescent solution-processed OLEDs by doping fluorescent dye DPAVBi into the TBADN host matrix. Compared to the vacuum-deposited OLEDs counterpart, the solution-processed OLEDs with toluene or chlorobenzene solvent exhibited relatively low device efficiencies and lifetimes, which was ascribed to varied charge transport behaviors and exciton formation regions as a result of diverse film morphology. Especially, the packing density of solution-processed film was distinctly lower than that of the vacuum-deposited counterpart, which was supposed as the main possible underlying origin. Afterwards, annealing treatment was developed to increase the film density of the solution-processed blue EML to boost the device efficiencies and lifetimes [20]. Wang et al. [21,22] found that the injection/transport behaviors of vacuum-deposited and solution-processed fluorescent OLEDs with a multi-component single EML were quite different, which was attributed to circumstance effect, chemical interaction and interfacial states. Due to the differences in chemical structure, there is general phase-separation risk in solution-processed multi-component EML, e.g., hosts doped with phosphors, which remarkably deteriorates the corresponding device performance by aggregation-induced exciton-quenching effect, the frustrated energy transfer process, and the inefficient charge injection/transport [23–29] and so on. Besides, as mentioned above, it was inferred that the aggregation-induced low packing density of the solution-processed small molecule film in regard to its vacuum-deposited counterpart is correlated with the shorter lifetimes of the solution-processed small molecule OLEDs [11,20]. Therefore, it is necessary to optimize the film morphology to increase the packing density of the solution-processed EML in addition to the improvement of the device efficiency.

In this study, we successfully fabricated efficient solution-processed blue phosphorescent OLEDs by optimizing the processing solvent to restrain the aggregation tendency in the blended EML and promote the packing density of solution-processed small molecule films. The organic molecule 3,6-bis(diphenylphosphoryl)-9-(4'-(diphenylphosphoryl)phenyl)-carbazole (TPCz) was previously developed as a promising host for blue phosphorescent dyes, and has been successfully used as a host to fabricate efficient blue phosphorescent OLEDs owing to its sufficient high triplet level ( $E_T$ ) of 3.07 eV and bipolar transport characteristic [18,30,31]. Herein, a range of polar solvents including chlorobenzene (CB), *n*-butanol (ButA) and isopropanol (IPA) are employed to prepare the EML based on the TPCz:iridium(III) [bis(4,6-difluorophenyl)pyridinato- $N,C^2$ ]-picolinate (Flrpic) ( $E_T$  = 2.65 eV) and fabricate blue phosphorescent OLEDs. The influence of the processing solvents on the TPCz:Flrpic EML morphology and its optoelectronic properties have been investigated in detail. It is found that the

polar solvent not only can restrain the molecule aggregation to obtain the more closely packed film, but also can balance the charge transport in EML, rendering the light-emitting efficiency of the solution-processed blue phosphorescent OLEDs increased from 3.3 to 15.6 lm/W.

## 2. Experimental

The chemical structures of the organic materials used in this study are shown in Fig. 1. Poly(ethylenedioxythiophene):poly(styrene sulfonate) (PEDOT:PSS) (Baytron PAI 4083) was purchased from H.C. Starck. Poly(*N*-vinyl carbazole) (PVK) with an average molecular weight ( $M_w$ ) of 90,000 was purchased from Acros Organic Co. and used as received without further purification. TPCz, (5,9-di(diphenylphosphine oxide)-9,9'-spirofluorene (SPPO13), and blue phosphorescent Flrpic were synthesized in our lab according to the literatures [7,8,30,31].

A range of polar solvents including CB (polarity index = 2.7), ButA (polarity index = 3.7) and IPA (polarity index = 4.3) were selected to prepare the TPCz:Flrpic (9/1, w/w) solutions. The solvents were purchased from Aldrich (purity > 99.8%) and used as received without further purification. The films were prepared via spin-coating from their solutions and then annealed at 80 °C for 30 min in nitrogen-filled glove box. Topography images of the films were collected by SPI3800N atomic force microscopy (AFM) instrument (Seiko Instrument Inc.) in a tapping mode with a 2 N/m probe and at a scan rate of 1 Hz under ambient conditions. Transmission electron microscopy (TEM) measurements were carried out on a JEOL JEM-1011 TEM operated at an acceleration voltage of 100 kV. The samples for TEM were prepared by loading the sample films on copper TEM grid. The refractive index of the films was measured using spectroscopic ellipsometry (Horiba Jobin Yvon). The photoluminescence (PL) spectra were recorded using a Perkin–Elmer LS 50B spectrofluorometer.

The solution-processed OLEDs have a structure of indium tin oxide (ITO)/PEDOT:PSS(40 nm)/PVK(10 nm)/TPCz:Flrpic(30 nm)/SPPO13(40 nm)/LiF(1 nm)/Al(150 nm), and the proposed energy level diagram of the devices are shown in Fig. 1. The hole- and electron-only devices have the device configurations of ITO/PEDOT:PSS(40 nm)/PVK(10 nm)/TPCz:Flrpic(30 nm)/SPPO13(40 nm)/MoO<sub>3</sub>(5 nm)/Al(150 nm) and ITO/LiF(1 nm)/PVK(10 nm)/TPCz:Flrpic(30 nm)/SPPO13(40 nm)/LiF(1 nm)/Al(150 nm), respectively. The PEDOT:PSS layer was spin-coated onto the pre-cleaned and UV-ozone treated ITO substrate and then baked at 120 °C for 45 min. Subsequently, the samples were transferred to nitrogen-filled glove box. The hole-transporting PVK layer was spin-coated onto the PEDOT:PSS layer from its toluene solution and then annealed at 180 °C for 30 min, finally spin-rinsed by toluene solvent to remove the dissolvable part. A thickness of ~10 nm and uniform PVK layer can be achieved [32]. The rinse experiment of pure CB, ButA and IPA for PVK samples confirms that spincoating the EML from these solvent did not dissolve the underlying PVK layer. The EML of the TPCz:Flrpic blend was deposited onto the hole-transporting PVK layer from different solutions, followed by thermal evaporation of the SPPO13 (40 nm)/LiF(1 nm)/

Download English Version:

<https://daneshyari.com/en/article/10566273>

Download Persian Version:

<https://daneshyari.com/article/10566273>

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