Organic Electronics 48 (2017) 271–275

Contents lists available at ScienceDirect

Organic Electronics

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

Triarylphosphine oxide–phenanthroline molecular conjugate as a promising doped electron-transport layer for organic light-emitting diodes

Ning-Ning Chen, Wan-Yi Tan, Jun-Zhe Liu, Jian-Hua Zhou, Dong-Yu Gao, Ling-Ling Chen, Jun-Biao Peng, Yong Cao, Xu-Hui Zhu*

State Key Laboratory of Luminescent Materials and Devices, Institute of Polymer Optoelectronic Materials and Devices, South China University of Technology (SCUT), Guangzhou 510640, China

ARTICLE INFO

Article history:
Received 26 April 2017
Received in revised form
7 June 2017
Accepted 11 June 2017
Available online 12 June 2017

Keywords:
n-Doping
Electron transport materials
Organic light-emitting diodes
Phenanthroline
Phosphine oxide

ABSTRACT

Over the past three decades, transparent high electron mobility molecular materials have attracted intensive research efforts for organic light-emitting diodes as electron-transport layer for the sake of low working voltage, high power efficiency and operational stability. However, developing high-performing electron-transport materials presents a demanding challenge owing to difficulties in synthesis, purification and/or processing. In this contribution, we show that *n*-doping a simple and facilely available phenanthroline derivative, namely 3-(6-diphenylphosphinylnaphth-2-yl)-1,10-phenanthroline **Phen-NaDPO** with a high T_g of 116 °C, is capable of greatly increasing the electron conductivity up to 3.3×10^{-4} S m^{-1}. The characterization of the blue sky fluorescent and green phosphorescent OLEDs involving this doped electron-transport layer **Phen-NaDPO**:50% wt Cs_2CO_3 revealed comparable performances to the analogue BPhen ($T_g \approx 66$ °C) OLEDs. For instance, the resulting sky blue fluorescent OLEDs provided ca. 15 cd/A, 13 lm/W @1000 cd m^{-2} & $t_{95} \approx 167$ h @1000 cd m^{-2}. The present finding shows that the doped **Phen-NaDPO** may be a robust electron-transport material for optoelectronics.

1. Introduction

Organic light-emitting diodes (OLEDs) find increasing applications in current flat panel displays and endeavor to be viable for next-generation eco-friendly lighting technology [1,2]. High mobility organic electron-transport materials are key to the success of OLEDs. A considerable number of small molecules with electron mobilities (μ_e) of up to 10^{-4}–10^{-3} cm^2 V^{-1} s^{-1} have been reported as electron-transport layers (ETLs) in OLEDs [3–23]. Such transparent materials exhibiting negligible absorption in the visible encounter frequently difficulties in synthesis/purification and poor solubility. Moreover, the potential halogen-containing impurities may create a source of operational instability of the resulting optoelectronic devices [24].

Recently we have attained a versatile electron-transport molecular compound 3-(6-diphenylphosphinylnaphth-2-yl)-1,10-phenanthroline (**Phen-NaDPO**, Fig. 1), which possesses facile synthesis and purification, a high T_g of 116 °C and attractive mobility of ~3.9×10^{-4} cm^2 V^{-1} s^{-1} @ $E = 8 \times 10^5$ V cm^{-1} based on time-of-flight technique [25]. The steric triarylphosphine oxide moiety renders **Phen-NaDPO** highly soluble in both weakly polar and polar solvents [26]. **Phen-NaDPO** appears to be a universal cathode modifier, greatly decreasing the work function of various substrates including Ag, ITO, HOPG and ZnO [25,27].

In this contribution, we studied **Phen-NaDPO** as a heavily n-doped electron-transport layer (**Phen-NaDPO**:50 wt% Cs_2CO_3) for OLEDs [28–30]. Similar to 4,7-diphenyl-1,10- phenanthroline (BPhen: $T_g \approx 66$ °C), n-doping improves largely the electron transport. Moreover, this heavy doping facilitates electron-injection and transport, and thus device fabrication. Under the same conditions, the *pin* sky blue fluorescent and green phosphorescent OLEDs involving **Phen-NaDPO** as the doped ETL offer comparable electroluminescent characteristics with the analogue BPhen diodes.

* Corresponding author.
E-mail address: xuhuizhu@scut.edu.cn (X.-H. Zhu).

http://dx.doi.org/10.1016/j.orgel.2017.06.021
1566-1199/

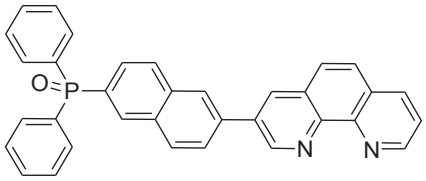

Fig. 1. Chemical structure of **Phen-NaDPO**.

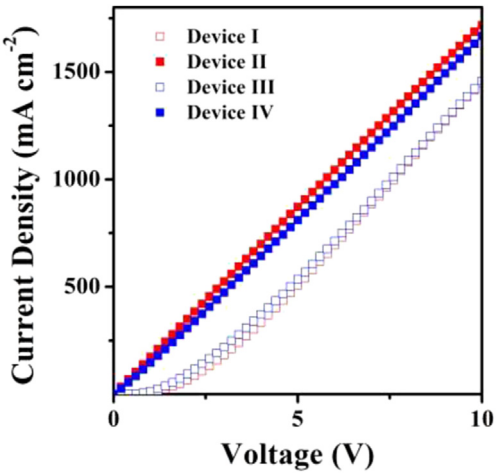

Fig. 2. *J*–*V* characteristics of the electron-only devices: ITO/BPhen:50 wt % Cs_2CO_3(20 nm)/ETL(150 nm)/BPhen:50 wt % Cs_2CO_3(20 nm)/Al(200 nm). ETL = **Phen-NaDPO** (Device I), **Phen-NaDPO**:50 wt % Cs_2CO_3 (Device II), BPhen (Device III) and BPhen:50 wt % Cs_2CO_3 (Device IV).

2. Experimental

2.1. OLED fabrication and characterization

Phen-NaDPO was prepared according to our early procedure [25] and studied as a heavily doped electron-transport layer in green phosphorescent OLEDs. Patterned indium-tin oxide (ITO, 15 Ω/square)-coated glass substrates were cleaned with distilled water, acetone, detergent, distilled water and 2-propanol successively in an ultrasonic bath. All organic and metal layers were thermally deposited through a mask in vacuum (<2 × 10^{-7} Torr) with the deposition speed and thickness monitored by a thickness/rate meter. In the deposition of the doping layers, deposition rates of both host and guest were controlled by their correspondingly independent quartz crystal oscillators. The devices were encapsulated immediately after preparation under a nitrogen atmosphere using epoxy glue and glass lids. The emission area of the devices is 9 mm^2 as defined by the overlapping area of the anode and cathode. The electroluminescent (EL) spectra and Commission International de l'Eclairage (CIE) color coordinates of packaged devices were obtained by a Konica Minolta CS2000 spectra system. The current density (*J*)–voltage (*V*)–luminance (*L*) characteristics were recorded simultaneously, using a computer-controlled source meter (Keithley 2400) and multimeter (Keithley 2000) with a calibrated silicon photodiode. All the measurements were carried out at room temperature under ambient conditions.

Single carrier electron-only devices (ITO/BPhen:Cs_2CO_3(20 nm, 50%)/ETL(150 nm)/BPhen: Cs_2CO_3(20 nm)/Al(200 nm)) were fabricated to evaluate the electron mobility of **Phen-NaDPO**, **Phen-NaDPO**:Cs_2CO_3, BPhen and BPhen:Cs_2CO_3.

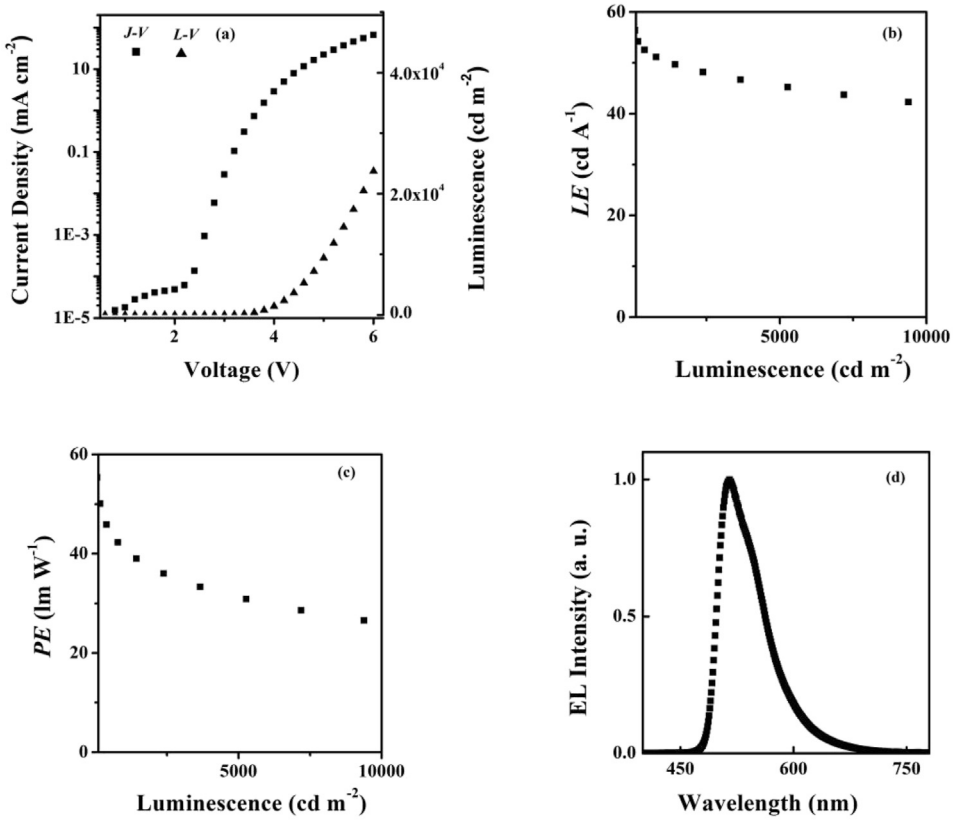

Fig. 3. EL characteristics of the green PHOLED: (a) *J*–*V*–*L*, (b) *LE*–*L*, (c) *PE*–*L* and (d) EL spectra.