Synthetic Metals 201 (2015) 49–53

Contents lists available at ScienceDirect

Synthetic Metals

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

High efficiency thermally activated delayed fluorescent devices using a mixed host of carbazole and phosphine oxide derived host materials

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ARTICLE INFO

Article history:
Received 25 November 2014
Received in revised form 19 December 2014
Accepted 22 December 2014
Available online 23 January 2015

Keywords:
Thermally activated delayed fluorescence
Mixed host
High quantum efficiency
Green device
Phosphine oxide

ABSTRACT

A mixed host of a carbazole type host and phosphine oxide type host materials was developed and used as the host for green thermally activated delayed fluorescent (TADF) device to obtain high quantum efficiency and to manage the emission color of the TADF device. Two mixed hosts, 1,3-bis(N-carbazolyl) benzene (mCP):diphenylphosphine oxide-4-(triphenylsilyl) phenyl (TSPO1) and mCP:9,9-spirobifluoren-2-yl-diphenylphosphine oxide (SPPO1) were used as the mixed hosts and the device characteristics of the mixed host devices were investigated. The electron transport type of the mixed host devices could manage the quantum efficiency and emission color of the TADF devices. High quantum efficiency of 27.5% was achieved in the green TADF OLEDs using the mixed host of mCP:TSPO1 and the emission peak wavelength could be shifted by more than 10 nm without sacrificing the quantum efficiency of the TADF devices.

1. Introduction

In recent years, thermally activated delayed fluorescent (TADF) devices have attracted great attention because of potentially high internal quantum efficiency of 100% by up-conversion of triplet excitons from triplet excited state to singlet excited state [1]. Although the quantum efficiency of the TADF organic light-emitting diodes (OLEDs) is not comparable to that of phosphorescent OLEDs [2–8], the TADF OLEDs are promising as high efficiency OLEDs which can replace phosphorescent OLEDs.

The most efficient TADF OLEDs were developed by Adachi group and the maximum quantum efficiency of the TADF OLEDs was close to 20% in green TADF OLEDs [1]. Donor-acceptor type (4s,6s)-2,4,5,6-tetra(9H-carbazol-9-yl)isophthalonitrile (4CzIPN) was synthesized as a green TADF emitter and 19.3% external quantum efficiency was demonstrated by doping the 4CzIPN dopant in 4,4′-di(9H-carbazol-9-yl)biphenyl (CBP) host1. In other works, 3,3-di(9H-carbazol-9-yl)biphenyl (mCBP) was used as the host material and 17.0% external quantum efficiency was obtained [2]. Although the quantum efficiency of the 4CzIPN based TADF OLEDs was high, the quantum efficiency could not be improved further by using the carbazole type host materials due to relatively poor electron transport properties of CBP and mCBP. Therefore, a host material which can facilitate electron injection from electron transport materials may improve the recombination efficiency in the emitting layer. It has been known that a mixed host of a hole transport type host and an electron transport type host can enhance the quantum efficiency of phosphorescent OLEDs [9–13] and TADF OLEDs [14]. In our previous work, we studied the effect of various hole transport type host materials of the mixed host on the device performances of the TADF OLEDs and carbazole type hole transport materials were effective as the hole transport type host materials of the mixed host [14,15]. However, no detailed study about the effect of electron transport type host materials was carried out.

In this work, a mixed host of a carbazole type host material and phosphine oxide type host materials were developed to investigate the effect of electron transport type host materials on the quantum efficiency and emission color of the 4CzIPN doped TADF OLEDs. It was demonstrated that the mixed host of 1,3-bis(N-carbazolyl) benzene (mCP) and phosphine oxide type host materials could enhance the quantum efficiency above 25% and manage the emission peak wavelength of the TADF OLEDs.

2. Experimental

The TADF OLEDs fabricated using the mixed host had a device structure of indium tin oxide (ITO, 50 nm)/poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS, 60 nm)/4,4′-cyclohexylidenebis[N,N-bis(4-methylphenyl) aniline] (TAPC, 20 nm)/mCP (10 nm)/host:4CzIPN (25 nm, 3%)/diphenylphosphine oxide-4-(triphenylsilyl)phenyl (TSPO1, 35 nm)/LiF(1 nm)/Al

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http://dx.doi.org/10.1016/j.synthmet.2014.12.025
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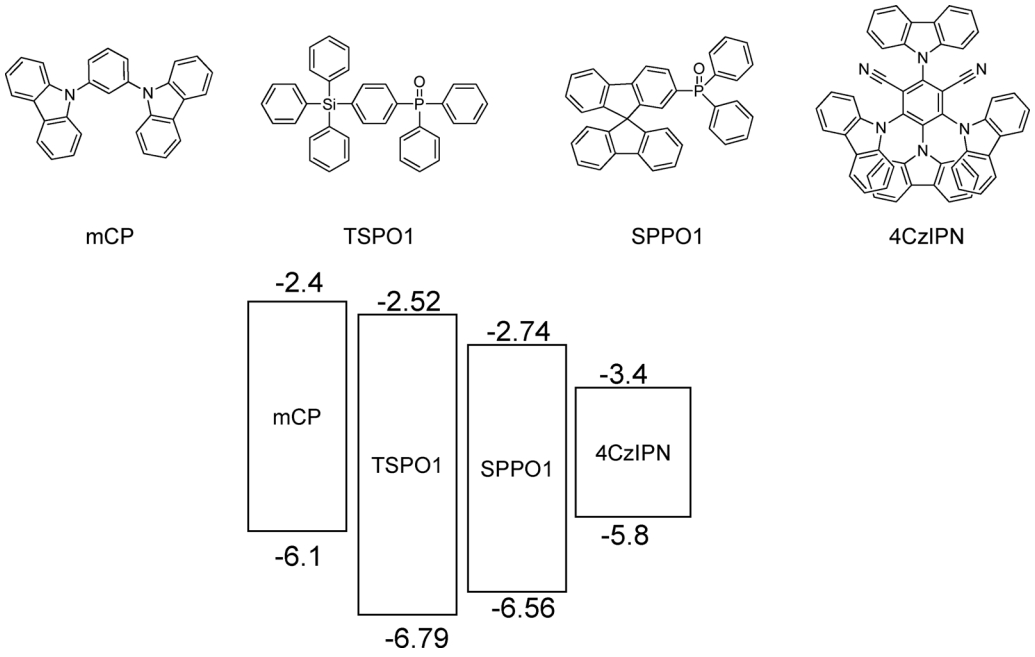

Fig. 1. Chemical structures and energy levels of the organic materials used in this work.

(200 nm). The mixed host structures used for the device fabrication were mCP:TSPO1 (1:1) and mCP:9,9-spirobifluoren-2-yl-diphenylphosphine oxide (SPPO1) (1:1). Chemical structures and energy levels of mCP, TSPO1, SPPO1 and 4CzIPN are shown in Fig. 1. PEDOT:PSS film was coated on the ITO substrate by spin coating from aqueous dispersion of PEDOT:PSS and other organic materials were deposited by vacuum thermal evaporation at a vacuum pressure of 1.0×10^{-6} torr. The mixed host composition was controlled by managing the deposition rate of each host material. Devices were encapsulated with a glass lid and sealed with an ultraviolet curable epoxy resin for device performance measurement using Keithley 2400 source measurement unit and CS2000 spectroradiometer. Photoluminescence (PL) measurement of the vacuum evaporated film was carried out using Hitachi F-7000 fluorescence spectrometer.

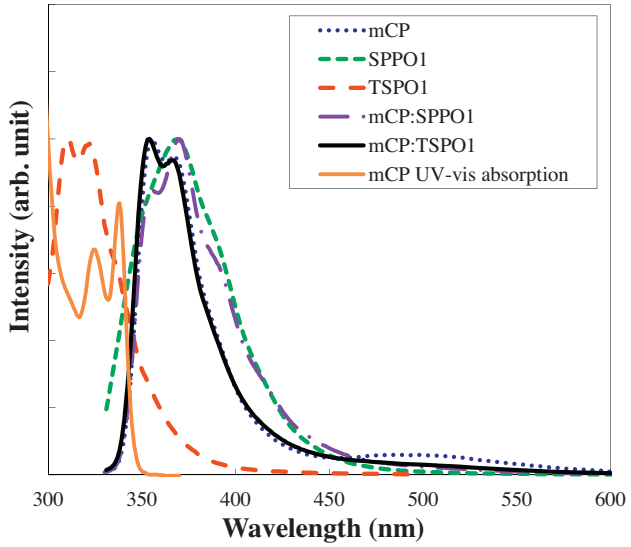

Fig. 2. Solid PL spectra of mCP, SPPO1, TSPO1, mCP:SPPO1 and mCP:TSPO1 films.

3. Results and discussion

The phosphine oxide based host materials, SPPO1 and TSPO1, have been used as the electron transport type host materials or electron transport materials in the phosphorescent OLEDs because of electron withdrawing character of the diphenylphosphine oxide unit [16,17]. A mixed host of SPPO1 and a carbazole type host material was reported to be effective to improve the device performances of blue phosphorescent OLEDs [16]. Therefore, the phosphine oxide based SPPO1 and TSPO1 can be used as the electron transport type host materials for the green TADF devices.

PL spectra of the mCP:SPPO1 and mCP:TSPO1 solid films were analyzed to investigate the energy transfer from the mixed host to 4CzIPN. Excitation wavelength was 310 nm in all PL measurements. PL spectra of mCP, SPPO1, TSPO1, mCP:SPPO1 and mCP:TSPO1 are presented in Fig. 2. The mCP:SPPO1 mixed host exhibited combined emission of mCP and SPPO1. Long wavelength emission

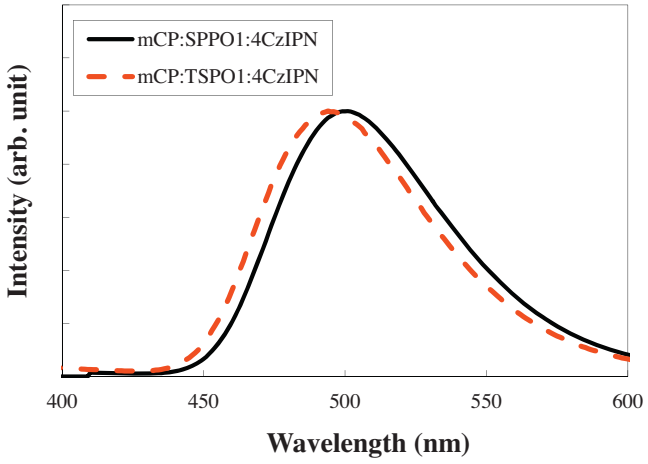

Fig. 3. PL spectra of mCP:SPPO1:4CzIPN and mCP:TSPO1:4CzIPN films after excitation by 310 nm light source. Doping concentration of 4CzIPN was 3%.