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Research paper

Effects of acceptor on the performance of exciplex-based OLED

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ABSTRACT

In this work, exciplex-based OLEDs (ExOLEDs) are fabricated with 1,1-bis((di-4-tolylamino)phenyl)cyclohexane (TAPC) as the donor and a series triazine derivatives, e.g., 2,4,6-tris(biphenyl-3-yl)-1,3,5-triazine (T2T), 2,4,6-tris(3-(1H-pyrazol-1-yl)phenyl)-1,3,5-triazine (3P-T2T), and 2,4,6-tris(m-(diphenylphosphinoyl)phenyl)-1,3,5-triazine (PO-T2T), as the acceptors. With different acceptors and mole ratios of donor:acceptor, the effects of the photoluminescence quantum yield (PLQY), charge carrier balance, and exciton lifetime on the EQE and efficiency roll-off are systematically investigated. It is found that the external quantum efficiency (EQE) of the ExOLEDs is primary determined by the PLQY of the mixed donor:acceptor film and tuned in a certain extent by the charge carrier balance. Furthermore, the efficiency roll-offs of different ExOLEDs are all less than 20%, which are simultaneously determined by the photoluminescence (PL) lifetime and the charge carrier balance.

1. Introduction

Thermally activated delayed fluorescence (TADF) organic light-emitting diodes (OLEDs) have attracted great attention in the past few years for their applications in next generation display and lighting [1–12]. TADF is a promising mechanism to use non-radiative triplet excitons for light emission by efficient reverse intersystem crossing (RISC) via thermal activation. Thus, OLEDs based on TADF emitters can attain 100% internal quantum efficiency in theory, which are the same as phosphorescent OLEDs [13,14]. To achieve efficient RISC, a small energy difference between the singlet and the triplet excited states ($\triangle E_{ST}$) is required. Organic intramolecular TADF materials are composed of electron donor and acceptor groups in a molecule to attain efficient TADF, which are hard to design. In addition to intramolecular TADF materials, small $\triangle E_{ST}$ can be realized by exciplex formation via intermolecular charge transfer between donor and acceptor molecules [15–19]. However, there are few exciplex-based OLEDs (ExOLEDs) reported with high external quantum efficiencies (EQEs) [20–28]. Besides, the efficiency roll-off is another figure-of-merit factor for an ExOLED. To attain a high EQE with a low efficiency roll-off, it is necessary to understand which factors that limited these parameters of an ExOLED.

2. Methods

The photoluminescence quantum yield (PLQY) was measured with F900 fluorescence spectrometer (Edinburgh Instruments Ltd) and the system combined with an integrating sphere, a Xe lamp (as the excitation source) and a multichannel spectrometer (as the optical detector). The mobilities were measured by steady-state space-charge limited currents (SCLC) method. The structures of hole and electron only devices were ITO/MoO_3 (20 nm)/test layer (100 nm)/MoO_3 (20 nm)/Al (100 nm) and ITO/C_{60} (20 nm)/test layer (100 nm)/C_{60} (20 nm)/Al (100 nm), respectively. ITO coated glasses were pre-cleaned and treated with ultraviolet-ozone for 15 min before fabrication of OLEDs. All layers were thermally evaporated in a vacuum chamber under about 4×10^{-4} Pa. All organic materials were purchased without further purification. Absorption spectra were measured on a Shimadzu UV-3101PC spectrophotometer. Steady-state photoluminescence (PL) and electroluminescence (EL) spectra were obtained from a Shimadzu F7000 and OPT-2000 spectrophotometers, respectively. Transient PL decay was measured with FL920 (Edinburgh Instruments Ltd). The electrical properties of devices and mobility of blended layers were measured with a Keithley 2400 source meter under ambient condition. EQE was calculated from the current density, luminance, and EL spectrum, assuming a Lambertian distribution.

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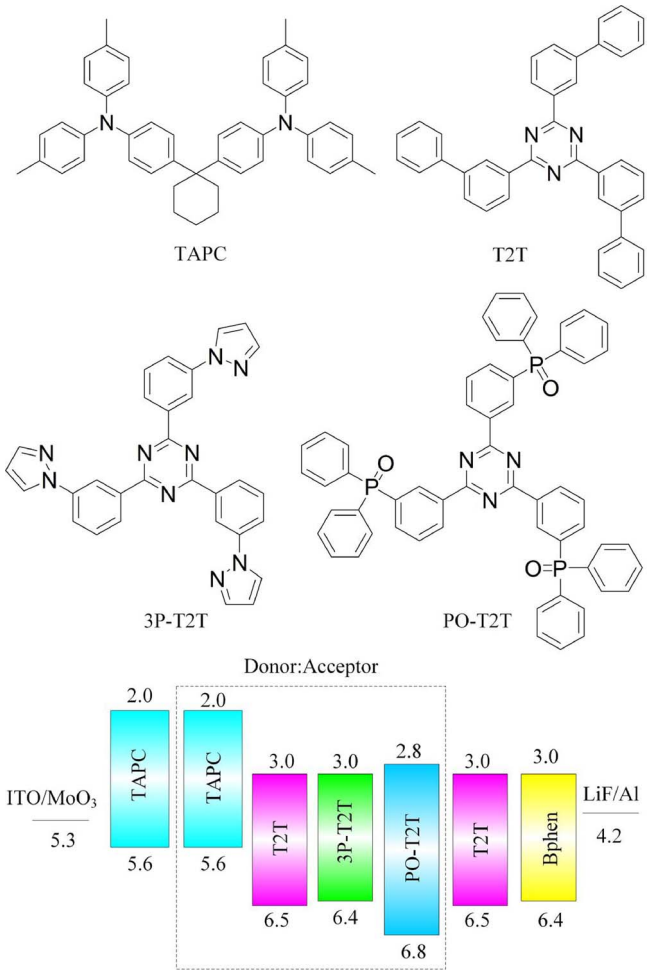

Fig. 1. Molecular structures of the materials and the schematic energy level diagram of the device.

3. Results and discussion

In our previous study, we reported an ExOLED by using 1,1-bis((di-4-tolylamino)phenyl)cyclohexane (TAPC) and 2,4,6-tris(biphenyl-3-yl)-1,3,5-triazine (T2T) as the donor and acceptor, respectively [26]. This ExOLED shows an EQE of 11.6%, which is one of the highest among the reported ones [22–26]. In this study, ExOLEDs are fabricated with TAPC as the donor material and T2T, 2,4,6-tris(3-(1H-pyrazol-1-yl) phenyl)-1,3,5-triazine (3P-T2T), and 2,4,6-tris(m-(diphenylphosphinoyl)phenyl)-1,3,5-triazine (PO-T2T) as the acceptor materials, respectively. These three acceptor materials are selected because they have similar molecular structures with a triazine core in the molecules (Fig. 1) but different energy levels and electron mobilities. The structure of the ExOLEDs is ITO/MoO_3 (3 nm)/TAPC (25 nm)/TAPC:acceptor (15 nm)/T2T (5 nm)/Bphen (30 nm)/LiF (1 nm)/Al (100 nm). A schematic energy level diagram of the device is also shown in Fig. 1 with the energy level data cited from references [19,29–32]. Combining with the photoluminescence and charge carrier transporting properties, we systematically investigated the factors that limiting the EQE and efficiency roll-off of the ExOLEDs.

The current density-voltage-luminance characteristics of the ExOLEDs with different donor and acceptor mixing mole ratios are shown in Fig. S1. It can be found that these characteristics are significantly affected by the mixing ration. Fig. 2 presents the EQEs of the ExOLEDs, and the maximum EQEs derived from these curves are listed in Table 1. Among the three series devices, the devices based on TAPC:T2T show the highest EQE. The maximum EQEs are 11.6%, 6.5%, and 5.1%, respectively, for the TAPC:T2T, TAPC:3P-T2T, and TAPC:PO-T2T based devices.

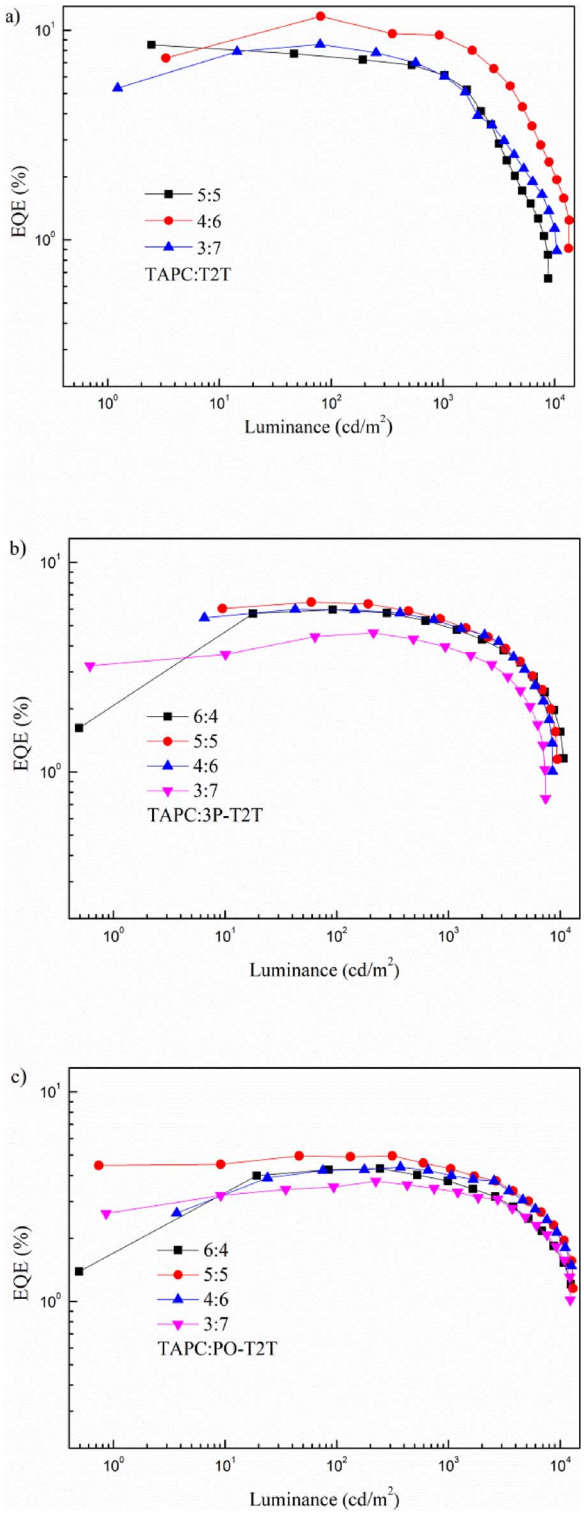

Fig. 2. EQE-luminance characteristics of (a) TAPC:T2T, (b) TAPC:3P-T2T, and (c) TAPC:PO-T2T based devices with different mixing ratios.

The theoretical EQE of an OLED can be calculated from equation:

$$EQE = \gamma \eta_r \eta_{PL} \eta_{OUT} \quad (1)$$

where γ is the ratio of the charge combination to the electron and hole transportation, η_r is the ratio of exciton formation for radiative transition, η_{PL} is the photoluminescence quantum yield (PLQY), and η_{out} is