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Demonstration of highly efficient orange EL device and warm white OLED

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ABSTRACT

Exciplex is a well-known charge transfer excited-state complex formed between electron-donor and electron-acceptor molecules. The exciplex studied here is resulted from between the donor mCP and the acceptor PO-T2T, which acts as the host of orange emitting OLEDs. The emitter is orange phosphor Ir(pq)2acac. Our device based on the exciplex host and orange phosphor is very simple, but excellent EL performance was observed. That is, peak current efficiency of 35.3 cd/A, power efficiency of 31.0 lm/W and EQE of 18.7% at a 1.5 wt% orange phosphor, respectively. To date this is the highest orange OLED compared with other orange OLEDs with identical color performance. The better results were ascribed to reasonable device design and contribution from both singlet and triplet of exciplex host as well efficient energy transfer from exciplex host to the orange phosphor. The conclusion is based on the fact that exciplex emission comes from TADF process in which there is small $\Delta E_{s\text{-}t}$. This strategy enables to resolve the problem of the lower reverse intersystem crossing (RISC). Besides, warm white OLED was also achieved by lowering the dopant concentration, by which incomplete energy transfer from exciplex host to the orange phosphor could take place.

1. Introduction

Recent years, organic light emitting diodes (OLEDs) have attracted much attention owing to promising application of panel displays and solid-state lighting [1–4]. Thus, white OLED(WOLED) would be required. White OLED could be consisted of either three primary colors (R G B) or two primary colors with orange- and blue sub-emissive colors, which were referred to three or two primary color WOLED respectively [5–8]. The various emitters generally have been fabricated by doping a luminescent dye to host. For two primary color case, the effect of electroluminescent (EL) performance of the orange component on WOLED would be essential. Thus, highly efficient orange diodes have attracted a great deal of attention [9,10]. For a high strong EL orange emissive OLED, host materials are usually necessary in order to prevent triplet-triplet (T-T) annihilation because concentration quenching effect is easily happened for phosphorescence(PH) emitters. Therefore, carefully selecting suitable host should generally be important, i.e., the materials must possess suitable singlet (S_1) and triplet (T_1) state, so as to ensure efficient energy transfer from host to an orange phosphor emitter dopant [11–15]. To realize easily carrier injection from two electrodes and balance recombination of two carriers in the emitting layer (EML), a bipolar host would be required for reducing exciton quenching and injection barrier [10–15]. Recently, it is reported that phosphorescent OLEDs with exciplex as the host have exhibited high EL performance [1–4,9,13]. The exciplex can either emit itself or transfer energy to the dopant. In addition, on account of presence of small singlet-triplet energy difference thermally activated delayed fluorescence (TADF) exciplex, i.e., up-conversion process between singlet/triplet levels could be taken place [10,12,16–20]. The exciplex that derived from hole- and electron-transporting donor (D)/acceptor (A) pair usually presents the bipolar carrier transporting properties at an appropriate D-to-A-ratio, at such a molar ratio exciton recombination region of the exciplex host could be distributed throughout EML range, which can decrease the density of singlet- and triplet-exctions, so that the two kinds of exciton quenching would be lowered [21].

In this work, we demonstrated high effcient orange device in which exciplex and orange phosphor were as host and dopant. In exciplex host is formed between mCP(N,N′-dicarbazolyl-3,5-benzene) and PO-

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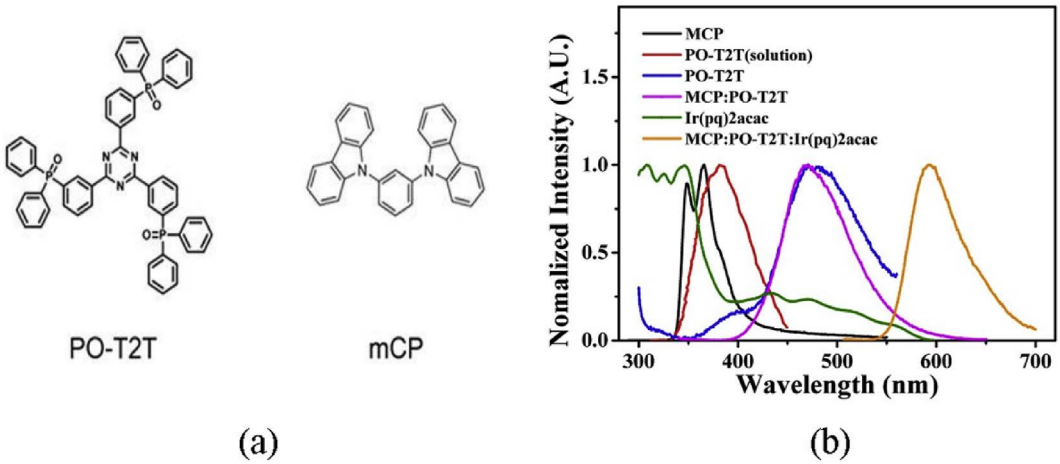

Fig. 1. a) Molecular structure of PO-T2T and mCP, b) Normalized PL spectra of mCP film and PO-T2T film and solution(PO-T2T is an excimer which has two peaks, one is the peak of PO-T2T itself coincides with the peak of PO-T2T solution in the figure, and the other is the peak of excimer), mCP:PO-T2T co-deposited film and mCP:PO-T2T:Ir(pq)2acac co-deposited film, as well the absorption spectrum of Ir(pq)2acac phosphor film green line). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

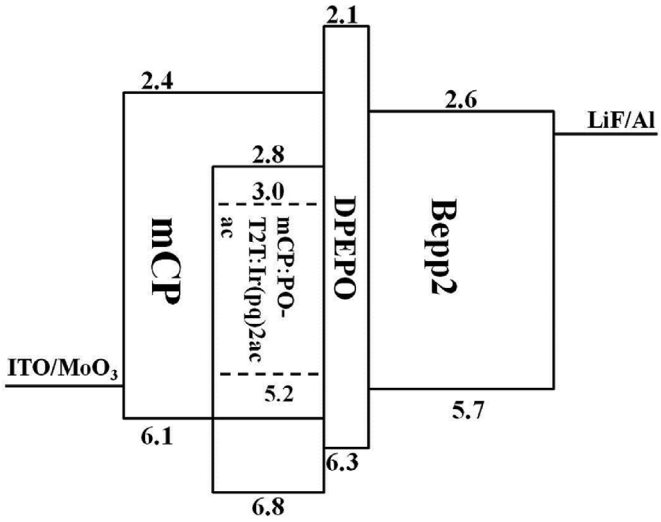

Fig. 2. Schematic device structures in this study, the numbers on LUMO and under HOMO depict the LUMO- and HOMO-levels (eV) of each molecule, respectively.

T2T((1,3,5-triazine-2,4,6-triyl)tris(benzene-3,1-diyl) tris(diphenylphosphine oxide)) which serve respectively as the electron-donor- and acceptor components, as well orange phosphor is (iridium (III)bis(1phenylquinoline)-acetylacetonate Ir(pq)2acac)). By comparing it is observed that the T_1 level is lower for the exciplex (2.64 eV) than for either mCP (2.94 eV) or PO-T2T (2.99eV), and higher than that of phosphor Ir(pq)2acac (2.2 eV) [1,22–25]. Thus, we dope different concentrations of Ir(pq)2acac into the exciplex host in which mCP:PO-T2T ratio also was tuned. As a result, high EL performance based several orange emitting OLEDs were successfully achieved, therein, orange OLED with maximum efficiency was developed, That is, at a concentration of 1.5 wt% maximum current- and power-efficiency are respectively 35.3 cd/A and 31.0 lm/W, as well EQE reaches up to 18.7%. It is also observed that as the quantity of orange phosphor was further lessened in exciplex host, WOLED was successfully constructed, which is attributed to an incomplete energy transfer from the exciplex host to the phosphor dopant and presence of blue emission derived from the exciplex host. For the purpose of hybrid WOLED by overlapping blue exciplex TADF emissive spectrum with orange emitting band of the phosphor, an interlayer would be required, because such an interlayer can prohibit mutual energy transfer and exciton quenching [26,27]. However, if our device structure contains interlayer, the EL efficiency would be lowered. Note that blue phosphor emission has generally a poor stability which restricts its application [5–8]. Thus, in this manuscript we use the blue exciplex with a small singlet-triplet splitting to realize high efficiency OLED by utilizing reverse intersystem crossing mechanism from T_1 to S_1. In addition, broad EL spectrum of the exciplex also facilitates to fabricate WOLED. Optimal WOLED provides a current-efficiency of 15.55cd/A, a power-efficiency of 13.69 lm/W, as well an EQE of 7.49%, as a result, WOLED with highly simple structure was obtained as the phosphor concentration is 0.1 wt% in exciplex host.

1.1. Experiments methods

All OLED devices were fabricated on indium tin oxide (ITO) coated glass substrates with a sheet resistance of 10 Ω/sq. The ITO processes were carried out, and finished the deposition of organic layers, Al/LiF compound cathode was deposited in the end with a shadow mask, which defined the device an area of $3 \times 3\,mm^2$. The photoluminescence (PL) spectra were measured with a FluoroMax-4 fluorescence spectrometer (HORIBA Jobin Yvon). The UV–visible absorption spectrum was recorded with a Hitachi U-3900 scanning spectrophotometer. EL spectra were measured through a PR-655 spectra scan spectrometer with computer controlled. The current-voltage-luminance curves were measured with a Keithley 2400 power supply combined with a ST-900M spot photometer. EQE was calculated from the current density-voltage-luminance curve and spectra data. All the organic materials were procured commercially without further purification. All the measurements were carried out at room temperature and under ambient conditions without any protective encapsulation, The substrates were cleaned firstly with acetone, deionized water, acetone and then treated by ultraviolet-ozone for 10 min, after that the ITO substrates were loaded into a high vacuum chamber and a vacuum reaches up to 5.0×10^{-4} Pa and then deposition.

2. Results and discussion

Fig. 1(a) shows the molecular structures of mCP and PO-T2T which are respectively used as electron-donor and -acceptor material in the exciplex system. PL spectrum of mCP:PO-T2T(molar ratio 1:1) is obviously red-shifted compared with that of pure mCP and PO-T2T ones (see Fig. 1(b). Interestingly, the mCP:PO-T2T co-deposited film shows a broad PL spectrum with a peak of 471 nm (2.64 eV), which is close to the energy difference between the $[HOMO]_{mCP}$ and $[LUMO]_{PO\text{-}T2T}$ level, it is referred to PL blue emission of the exciplex [11]. In addition, it is also noted that the PL spectrum of the exciplex overlaps with the