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Pure white organic light-emitting devices with excellent color stability using a non-doped 4-aryloxy-1,8-naphthalimide derivative

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ABSTRACT

Pure white organic light emitting devices (OLEDs) with high color stability have been fabricated, using a 4-aryloxy-1,8-naphthalimide derivative FluONI as a non-doped blue emitting layer (EML) combined with orange emitting exciplex at the interface of electron donor/FluONI. Three kinds of hole transport materials consisting of amino groups with stepped highest occupied molecular orbital (HOMO) levels are introduced as electron donors for the modulations of exciplex emission band and hole injection barrier. As a result, pure white emission with a standard Commission Internationale de l'Eclairage (CIE) coordinate of (0.33, 0.33) is achieved by adopting *N,N′*-diphenyl-*N,N′*-bis(1-naphthyl)-1,1′-biphenyl-4,4″-diamine as an electron donor with a relatively deep HOMO level and a 30 nm-thick EML. Meanwhile, excellent color stability is also observed with a slight CIE coordinates shift of (0.01, 0.01) at a luminance range from 100 to 4000 cd/m^2. According to the systematic analyses on electroluminescence spectra, the pure white emission benefits from the broad emission bands of both FluONI and exciplex. The pure white emission with high color stability at different drive voltages are attributed to the sustainable equilibrium between FluONI intrinsic and exciplex emission. Our devices based on a single non-doped EML provide a simple way to realize color pure and stable white OLEDs.

1. Introduction

Organic light-emitting devices (OLEDs) have been achieved significant development in the last decades due to the impressive advantages of low drive voltage, high resolution, wide view angle, homogeneous large-area emission and potential application on flexible substrates [1–5]. Among them, white OLEDs (WOLEDs) have already attracted a great deal of interests owing to their extensive applications in full-color displays, back lighting of flat panel displays and solid-state lighting [6–10]. The color quality of a white lighting source is closely related to Commission Internationale de l'Eclairage (CIE) coordinate, which reflects the red/green/blue, blue/yellow or blue/orange emission component ratio. For instance, pure white emission requires CIE coordinate to be close to (0.33, 0.33), which means one emission composition proportion could be comparable to others [11]. Meanwhile, slight CIE coordinates shift in a large range of luminance is essential for high color stability. To realize the above requirements, three typical routes have been devoted to the fabrication of WOLEDs: (1) multiple emitting layers (MEMLs) structure; (2) single EML with multiple dopants (SEML-MDs); (3) single non-doped emitting material combined with intermolecular charge-transfer excited-state complex, which means exciplex or excimer. Since dopants possess different electrical properties and degradation processes, the employment of MEMLs or SEML-MDs always suffers voltage dependent emission and color-aging effects, which result in poor color stability. Consequently, the color stable WOLEDs based on MEMLs or SEML-MDs are generally obtained through complex device structures and/or precisely controlled fabrication processes [12,13]. For instance, Zhang and Lee et al. have reported highly efficient hybrid WOLEDs based on SEML-MDs with extremely low dopant concentrations of green and red phosphors, in which the thermally activated delayed fluorescence exciplex as host and blue emitter can avoid triplet energy loss on the non-radiative triplet states through reverse inter-system crossing [14]. Meanwhile, the device with optimum doping concentration ratio between different dopants achieves color stability at different luminance. However, the absolutely precise control of the co-deposition rate of four kinds of materials and extremely low dopant concentration in physical vapor deposition procedure is quite complex. Since the complex device structures and fabrication processes raise the production cost and decrease reproducibility, they may be challenging for commercial mass

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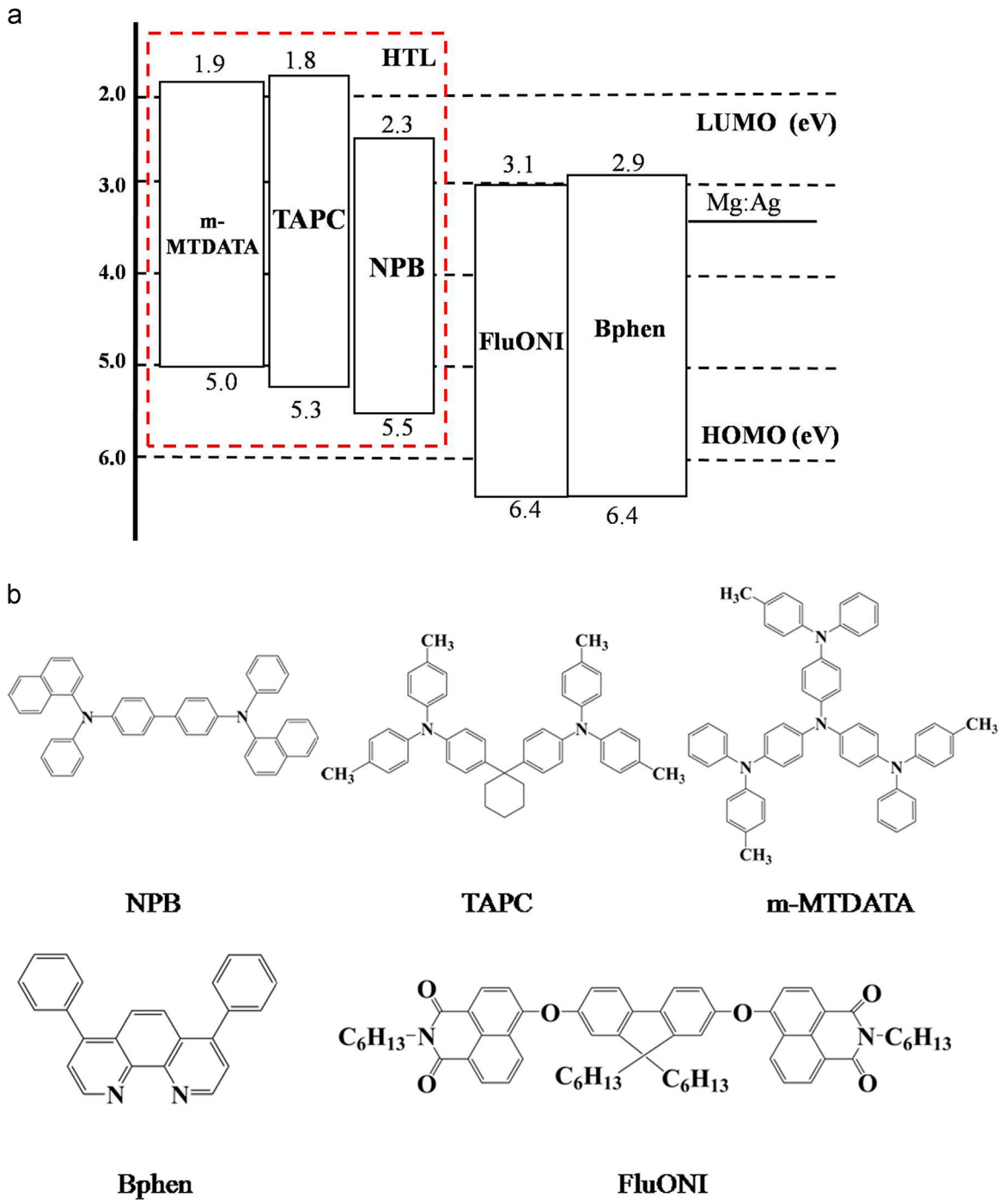

Fig. 1. (a) Schematic energy level diagram of the OLEDs with different hole transport layers. (b) Chemical structures of employed organic functional materials.

production. In contrast, warm WOLEDs realized by a single non-doped EML and exciplex have been reported [15]. Moreover, Lavrentovich and Skabara et al. recently have demonstrated a new interface engineering method for WOLEDs by embedding an ultrathin non-doped EML in interface exciplex [16]. The device structure is highly simplified, but the device efficiency should be further improved. It is noteworthy that, this kind of WOLED has the potential of realizing high efficiency, pure white emission and maintaining color stability at different drive conditions. What's more, it will significantly simplify device structure and fabrication process, which makes the fabrication highly reproducible and cost effective.

As well known, excimer is formed between a pair of chemically identical molecules charged by electrons and holes, but exciplex is formed at the interface between chemically different molecules, which are named by electron donor (D) and electron acceptor (A) [17–19]. To date, OLEDs with exciplex emission are mainly based on D/A planar structure or D:A blends, in which hole and electron transport materials are widely used as electron donors and acceptors, respectively [20,21]. Besides, some newly synthesized fluorophores are adopted as not only emitters but also electron donors or acceptors for exciplex formation [22–24]. The energy of exciplex emission maximum depends critically on the difference between the highest occupied molecular orbital (HOMO) level of electron donor and the lowest unoccupied molecular orbital (LUMO) level of electron acceptor [25]. In both electroluminescence (EL) and photoluminescence (PL) spectra, exciplex emission always exhibits a red-shift and broad spectrum profile