

High-Efficiency Blue Electroluminescence Based on Coumarin Derivative 3-(4-(anthracen-10-yl)phenyl)-benzo[5,6]coumarin

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Abstract The electroluminescent (EL) properties of a new coumarin derivative, 3-(4-(anthracen-10-yl)phenyl)-benzo[5,6]coumarin (APBC), were investigated. The results show that the EL devices comprised of vacuum vapor-deposited films using the derivative as dopant exhibited blue emission that is identical to the photoluminescence of the thin film. The electroluminescence device of ITO/2-TNATA (5 nm)/NPB (40 nm)/CBP : APBC (1.0 wt%, 30 nm)/PBD (30 nm)/LiF (1 nm)/Al (100 nm) gives a maximum luminous efficiency of 2.3 cd/A at the current density of 20 mA/cm², and maximum luminance of 5169 cd/m² at 16 V. The external quantum efficiency of the device is 1.85 %.

Keywords Coumarin derivative · Anthracene · Photoluminescence · Electroluminescence

Introduction

Light-emitting materials are the primary substance for organic light-emitting diodes (OLEDs) that generate electroluminescence (EL) in flat panel display applications. Fundamentally, EL originates from electron and hole recombination on the emitting materials in the thin film layer

structure of OLEDs [1]. OLEDs have attracted intensive attention and constitute a rapidly developing field due to their potential use in the development of energy-efficient, excellent tunability of emissive color by chemical structure modifications, lower direct current drive voltage, less power consumption, low-cost, full-color, flat-panel displays and other emissive products [2–6].

Coumarins are an important class of naturally occurring and synthetic compounds, which have been extensively investigated for electronic and photonic applications [7–11], such as fluorescence probe, charge-transfer agents, solar energy collectors, and nonlinear optical properties due to their characteristics of high emission yield, excellent photo-stability, extended spectral range, good solubility and their relative ease of synthesis. Coumarin dyes were always used as blue, green and red dopants in OLEDs [12–14]. However, coumarin dyes are easily self-quenched in high concentration due to the intermolecular interactions and aggregations, so as the light-emitting materials they are always doped in the host materials at appropriate concentration to fabricate OLEDs with reasonable, luminant efficiency [15–19].

Recently, we have synthesized a new coumarin derivative, 3-(4-(anthracen-10-yl)phenyl)-benzo[5,6]coumarin (APBC) (Fig. 1). The strategies for designing are to increase the rigidity of the molecule and enlarge the π - π^* conjugation that influence EL performance of the emitting materials. In this article, we fabricated the electroluminescence devices by vacuum vapor-deposited films with the coumarin derivative as emission material and investigated the EL properties.

Experimental

The multilayer OLEDs were fabricated by the vacuum deposition method. The ITO-coated glass with a sheet resistance

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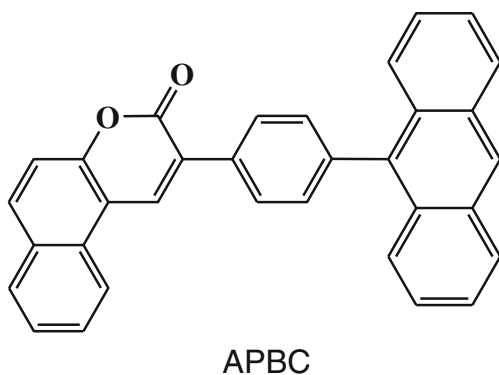
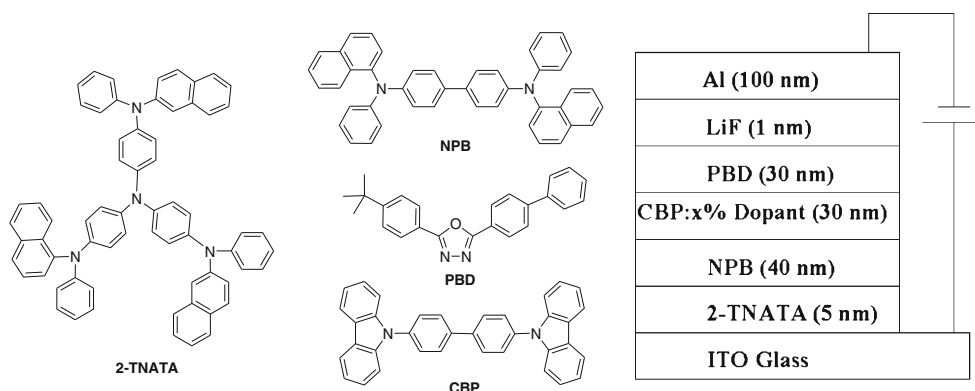


Fig. 1 Chemical structure of 3-(4-(anthracen-10-yl)phenyl)-benzo[5,6]coumarin (APBC)

$R_{\square} \sim 20 \Omega/\square$ was cut into 3×3 cm plates and etched in dilute hydrochloric acid for 20 min. Then the ITO substrates were routinely cleaned by ultrasonic treatment in solvents and then cleaned by exposure to an UV-ozone ambient. All organic layers were sequentially deposited without breaking vacuum (2×10^{-4} Pa). Thermal deposition rates for organic materials, LiF and Al were $\sim 2 \text{ \AA/s}$, $\sim 1 \text{ \AA/s}$ and 10 \AA/s , respectively. The active area of the devices was 12 mm^2 . The EL spectra were measured on a Hitachi MPF-4 fluorescence spectrometer. The characterization of brightness–current–voltage (B–I–V) were measured with a 3645 DC power supply combined with a 1980A spot photometer and were recorded simultaneously. All measurements were done in air at room temperature without any encapsulation.

The molecular structures of the materials and the structure of devices used in this work are shown in Fig. 2. CBP : APBC was employed as the emitter, 2-TNATA, NPB, and PBD were used as hole injection, hole transport and electron transport materials, respectively. LiF was used as the electron-injection layer.

Fig. 2 The molecular structures of the materials and the structure of EL device



Results and Discussion

The devices with the configuration of ITO/2-TNATA (5 nm)/NPB (40 nm)/CBP : APBC (x wt%, 30 nm)/PBD (30 nm)/LiF (1 nm)/Al (100 nm) were fabricated.

Figure 3 shows the EL spectra of the devices with APBC doped at concentration of 1.0 wt% at different driving voltages. The intensities and spectral features of EL emissions do not change with increasing the driving voltages. All devices exhibit blue emissions with the maximum peaks at 460 nm.

The photoluminescent behavior of APBC doped in poly (methyl methacrylate) (PMMA) was also investigated in Fig. 3. The mixed system of APBC with PMMA was prepared by dissolving APBC with a certain weight ratio into acetone. The sample for spectroscopy was fabricated by spin-coating the acetone solution onto clean quartz substrates. From Fig. 3, it can be seen that the EL spectra of APBC are identical to the PL spectrum of its thin film. The result indicates that the same excitation state was involved, i.e., the light is resulted from the derivative molecule.

Figures 4 and 5 show the representative luminance–voltage–current density (L – V – I) characteristics of the devices doped APBC with various concentrations. Bright blue emission could be seen easily under normal light conditions. The L – V – I curves of the devices revealed excellent diode behavior, i.e., under the forward bias, the luminances and current densities increased with the increase of applied voltage after surpassing the turn-on voltage. The turn-on voltages of the devices at the doped concentrations of 1.0 wt% and 2.0 wt% were 8 V. Moreover, under reverse bias, no obvious increase of current was observed when the applied voltage was increased. The luminance and the current density of the device (1.0 wt%) are higher than those of the device (2.0 wt%). The maximal luminances were 5169 cd/m^2 at 16 V for the device doped concentration of 1.0 wt% and 3867 cd/m^2 at 18.5 V for the device doped concentration of

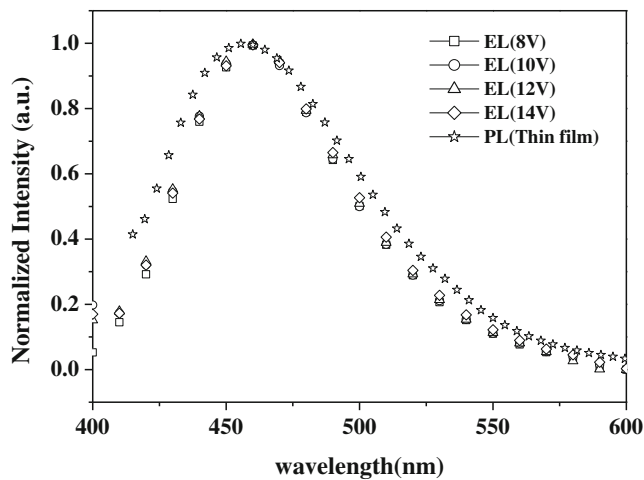


Fig. 3 PL and EL spectra of the devices with the configuration of ITO/2-TNATA (5 nm)/NPB (40 nm)/CBP : dopant (1.0 wt%, 30 nm)/PBD (30 nm)/LiF (1 nm)/Al (100 nm) at different applied voltages

2.0 wt%, respectively. From Figs. 4 and 5, we can see that the device (2.0 wt%) needs higher drive voltage than the device (1.0 wt%). In other words, it was thought that the increasing doped concentrations suppressed the luminance of the devices, indicating that strong charge trapping occurred in present device structures. It is obvious that the better APBC concentration in the CBP host is 1.0 wt%.

We achieved the maximum brightness at a current density of 466 mA/cm² for the device doped concentration of 1.0 wt% and at a current density of 413 mA/cm² for the device doped concentration of 2.0 wt% (Fig. 6).

Figure 7 gives the relationships between the current efficiency and the current density in the devices with various APBC doping concentrations, which shows the maximal current efficiencies at the doped concentrations of 1.0 wt%

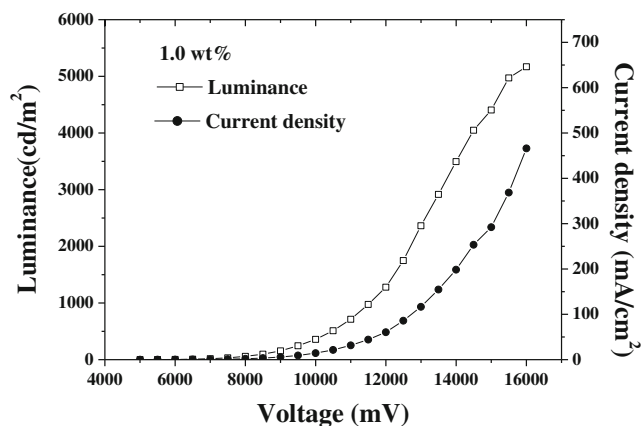


Fig. 4 The luminance–voltage–current density characteristics of the device with the derivative (1.0 wt %)

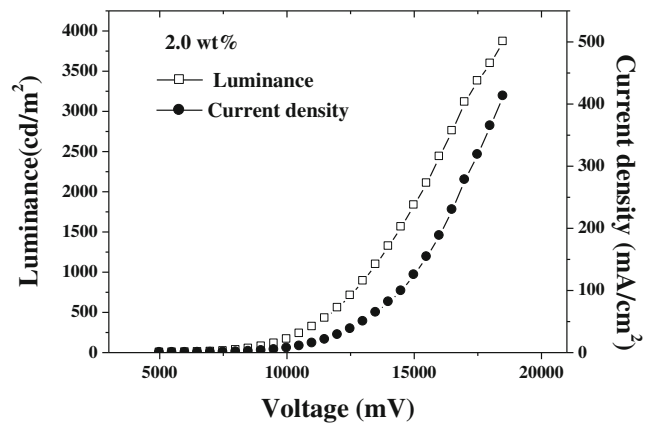


Fig. 5 The luminance–voltage–current density characteristics of the device with the derivative (2.0 wt %)

and 2.0 wt% were 3.2 and 5.2, respectively. It is indicated that all doped devices have higher efficiencies at low current densities, and then the efficiencies fall off fleetly at higher current densities. The 1.0 wt% doped device has a maximum luminous efficiency of 2.3 cd/A at the current density of 20 mA/cm², whereas the 2.0 wt% doped device has a maximum luminous efficiency of 2.0 cd/A at the current density of 20 mA/cm². The external quantum efficiencies of the devices are 1.85 % and 1.55 %, respectively.

The above results indicate that the electron–hole recombination may not be effective under high current density, revealing that the host CBP might not be an optimal host material. The present device performance could be further improved by substituting other host candidates.

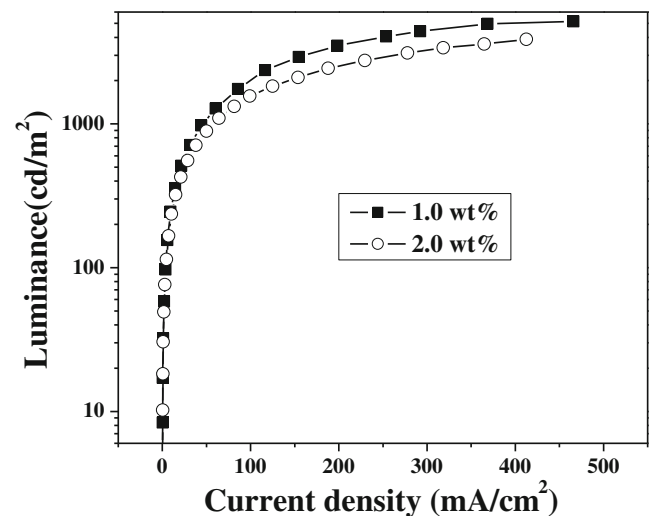


Fig. 6 Luminance–current characteristics of the doped devices with the various derivative concentrations

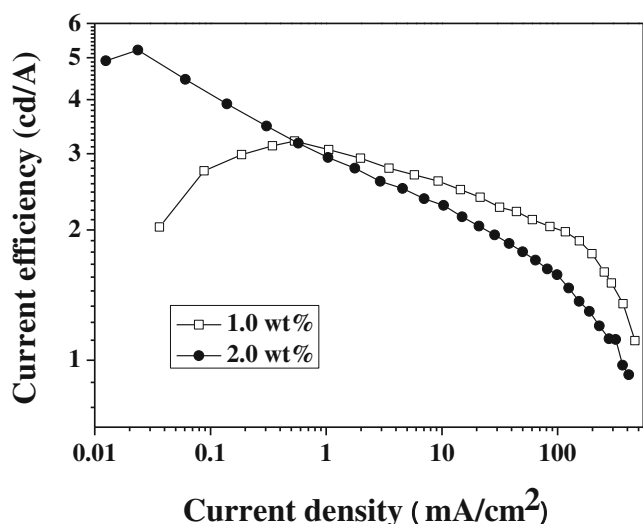


Fig. 7 Current efficiency-current density characteristics of the doped devices with the various derivative concentrations

Conclusion

The electroluminescent (EL) properties of a new coumarin derivative, 3-(4-(anthracen-10-yl)phenyl)-benzo[5,6]coumarin, were investigated. The EL devices comprised of vacuum vapor-deposited films using the derivative as dopant shown blue emission that is identical to the photoluminescence of the thin film. The electroluminescence device of ITO/2-TNATA (5 nm)/NPB (40 nm)/CBP : dopant (1.0 wt%, 30 nm)/PBD (30 nm)/LiF (1 nm)/Al (100 nm) gives a maximum luminous efficiency of 2.3 cd/A at the current density of 20 mA/cm², and maximum luminance of 5169 cd/m² at 16 V. The external quantum efficiency of the device is 1.85 %.

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