New structures for highly-efficient and robust blue organic light-emitting devices

Meng-Ting Lee, Chi-Hung Liao, and Chin H. Chen

A new structure for organic light-emitting devices (OLED) can provide high electroluminescent efficiency, a long operational lifetime of 10,000 hours at an initial luminance of 100cd/m², and strong saturated color for the vitally-important, but elusive, blue emitter.

OLEDs have considerable advantages over today’s ubiquitous liquid crystal displays (LCDs) in terms of the higher efficiency, lower power consumption, and faster response times. With the ability to be self-emissive and both extremely thin and light, they are particularly suitable for flexible display applications. They are thus one of the most promising new display technologies today.

Three kinds of pixelation scheme have been demonstrated for fabricating full-color OLED displays: discreet lateral RGB emitters; blue emitters with a color-conversion layer; and white emitters with color filters. All of these require a robust blue emitter with high electroluminescent (EL) efficiency and long operational lifetime. In additional, the color of a blue OLED also needs to be saturated, preferably with a y-value of less than 0.15 on the Commission Internationale d’Eclairage coordinate (CIE_y) scale, to significantly reduce the power consumption of a full-color display (see Figure 1).

An OLED consists of a series of organic thin films sandwiched between two conductive electrodes. The choice of organic materials and the layer structure determine the device performance: such as emissive color, operating lifetime, and EL efficiency. It is well-known that the guest-host-doped emitter system can significantly improve the device performance and modify the color. Furthermore, the modification of the anode/cathode contact or hole/electron transport layer has been shown to improve charge balance and recombination, as the injected hole is usually more mobile than the injected electron under the same electric field in conventional OLED. However, to date, blue-doped emitter systems with all the desirable attributes of high EL efficiency, long operational lifetime, and saturated blue color are still rare.

We have successfully demonstrated an anthracene-based blue host material, 2-methyl-9,10-di(2-naphthyl)anthracene (MADN), which can form a stable thin-film morphology upon thermal evaporation. When fabricated as an OLED, the device achieved an EL efficiency of 1.4cd/A with a CIE_x,y color coordinate of [0.15, 0.10]. Subsequently it was discovered that—by using a novel composite hole transport layer (c-HTL) composed of copper phthalocyanine (CuPc)/N, N'-bis(1-naphthyl)-N,N’-diphenyl, 1, 1’-biphenyl-4, 4’-diamine (NPB) at a specific ratio—the EL efficiency was boosted by more than a factor of two to 3.0cd/A. The increased EL efficiency is attributed to an improved balance between hole and electron currents arriving at the recombination zone due to the c-HTL layer. This can efficiently reduce hole mobility, a notion that has been supported by the hole-only devices we reported previously.

We found the EL efficiency of blue OLEDs can be further improved by judicious selection of a matching guest ma-
terial for efficient Förster-energy transfer. This is highly dependent on the spectral overlap between the emission of the host and the absorption of the guest. For instance, the di(styryl)amine based light-blue dopant—p-bis(p,N,N-diphenyl-aminostyryl)benzene (DSA-Ph)—possesses a high fluorescence quantum yield at a λ_{max} of 458nm, and a well-matched spectral overlay between the guest DSA-Ph and the host MADN. Thus, this blue-doped emitter\textsuperscript{12} achieved a high EL efficiency of 9.7cd/A with a greenish-blue color of CIE\textsubscript{x,y} [0.16, 0.32], and a long operational lifetime of 46,000h at a initial brightness of 100cd/m\textsuperscript{2}. However, the color saturation is far from adequate for full-color OLED displays.

To achieve saturated-blue OLED, a deeper-blue dopant with a more hypsochromic (blue) shift of the emission from the DSA-Ph is needed. From the material-design and synthetic point of view, the most straightforward approach is to shorten the conjugation length (chromophore) of the di(styryl)amine-based material to the mono(styryl)amine-based core. By modifying the substituents attached to the nitrogen as well as to the styrene part of the molecule, it is possible to obtain emissions in the deeper-blue visible region between 430–450nm. When doped in the host and the absorption of the guest. For instance, the spectral overlap between the guest DSA-Ph and the host MADN, gave two key factors in producing high-EL-efficiency OLEDs.

Carrier recombination and the balance of holes and electrons are two key factors in producing high EL-efficiency OLEDs. Incorporating the c-HTL layer in our sky-blue and deep-blue emitter systems with DSA-Ph and BD-1 in host MADN, gave devices with very high EL efficiency of 17cd/A and 5.4cd/A and blue color coordinate of CIE\textsubscript{x,y} [0.14, 0.28] and [0.14, 0.13], respectively.\textsuperscript{11,13} These devices with c-HTL showed twice the EL efficiency with comparable device operational lifetimes to those without c-HTL (see Figure 2).

To the best of our knowledge, the EL performance of our sky-blue and deep blue OLEDs using c-HTL represent some of the best reported to date, making them suitable for use in full color OLED displays.

### Author Information

**Meng-Ting Lee and Chi-Hung Liao**

Department of Applied Chemistry
National Chiao Tung University
Hsinchu 300, Taiwan

**Chin H. Chen**

Display Institute
Microelectronics and Information Systems Research Center
National Chiao Tung University
Hsinchu 300, Taiwan

### References


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