Active Matrix OLED Displays with High Stability and Luminous Efficiency by New Doping Method

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Abstract

We have developed the active matrix OLED displays with a high efficiency red emission material which uses an emitting assist (EA) dopant system. The EA dopant (rubrene) did not itself emit but assisted the energy transfer from the host (Alq_3) to the red emitting dopant(DCM2). A stable red emission (chromaticity coordinates: x=0.64, y=0.36) was obtained in this cell within the luminance range of 100 - 4000 cd/m². By using EA dopant system, we can realize the reduction of the power consumption of the OLED display..

1. Introduction

Organic light-emitting diodes (OLEDs) have been expected to find application as a new type of display since Tang and VanSlyke first reported on high performance OLEDs[1]. They are able to produce various emission colors in accordance with a wide selection of organic fluorescent dyes. The green, yellow and blue OLEDs have high luminance, high efficiency and long life times [2][3][4]. However, red OLEDs with high emitting performance and pure red emission have not been reported.

Conventional red OLEDs have an emitting layer consisting of one material during their early development[5]. However, these devices are incapable of high luminance because of concentration quenching in the emitting layer. Recently, a doping system is often used in OLEDs in order to prevent this concentration quenching[6]. The doping system is composed of a host material and a red dopant. When the host layer is doped with a small quantity of the red dopant, which is a fluorescent dye, the red dopant emits with high luminance and without concentration quenching. Tris(8-quinolinolato) aluminum (Alq_3) is widely used as a host material because it features good carrier transporting characteristics, easy film formation and high stability.

However, the emission obtained from such a doping system is generally not red but orange. There is an emitting peak of Alq_3 in addition to the red peak in this doping system. Alq_3 exhibits strong green fluorescence (peak: 524 nm), and the red dopant shows fluorescence in the range of 600 - 650 nm. Therefore, the orange emission was the result of a mixture of the two emitting peaks. For this reason the doping system consisting of host material and red dopant cannot produce a pure red emission. The energy transfer from Alq_3 to the red dopant could not be made because the excitation energy of Alq_3 differs greatly from that of the red dopant.

In this paper, we propose a new doping system that can emit pure red with high luminance and its application to full colar displays. An additional dopant, called an emitting assist (EA) dopant, is used with a red dopant in order to prevent the emission from Alq_3. The EA dopant acts as an intermediary since its excitation energy lies between those of Alq_3 and the red dopant.

2. Experimental

OLED cells were fabricated on indium- tin oxide (ITO, anode) substrates. Organic layers and a cathode layer ($Mg_{0.9}In_{0.1}$) were deposited by conventional vacuum vapor deposition in 5×10^{-6} Torr. The emitting area was 2 x 2 mm. The cell structure used in this experiment was as follows:

[ITO / hole injection layer (20nm, CuPc) / hole transport layer (50nm, NPB) / emitting layer (40nm, Alq_3 + red dopant + EA dopant) / MgIn]. (CuPc: Copper(II) phthalocyanine, NPB: N, N'-Di(naphthalen-1-yl)-N, N'- diphenyl-benzidine) 4-

Dicyanomethylene-2-methyl-6-[2-(2,3,6,7-tetrahydro-1H,5H-benzo[ij]quinolizin-8-yl)vinyl]-4H-pyran (DCM2) was used as the red dopant[6], and rubrene was used as the EA dopant. Figure 1 shows the molecular structures of these materials. The photo-

luminescent (PL) peak of DCM2 and rubrene is 650 nm and 560 nm, respectively. Therefore, rubrene is an intermediary with an excitation energy between those of Alq_3 and DCM2. The doping concentration of DCM2 was 1wt% and 2wt% relative to the Alq_3 weight, and that of rubrene was 0wt%, 3wt% and 5wt% relative to the Alq_3 weight.

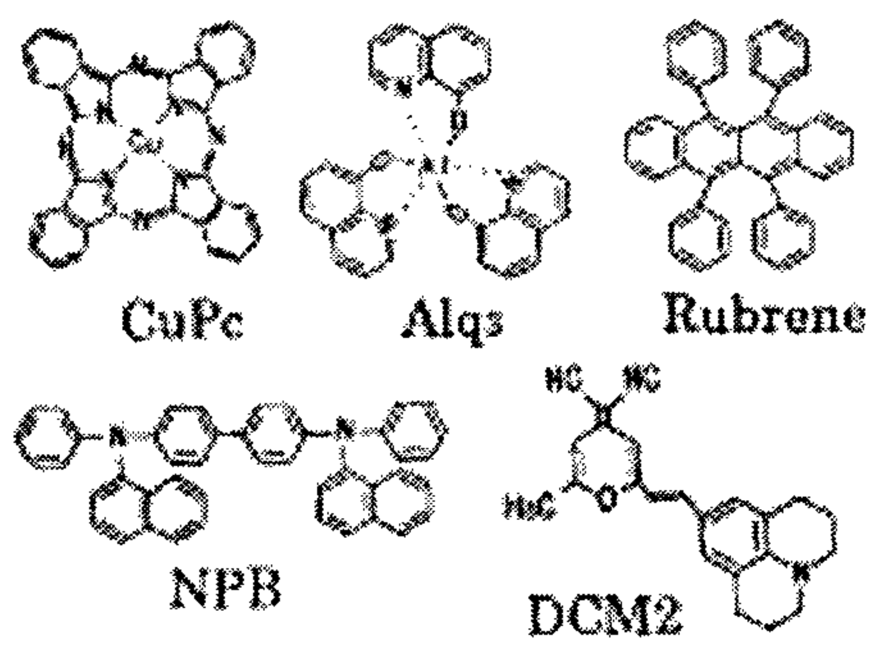

Fig.1The molecular structure of the materials.

3.High Efficiency Red Emission Material

The chromaticity coordinates of these cells at luminance values of 100, 1000 and 4000 cd/m^2 are shown in Table 1 [7]. The OLED containing 2wt% DCM2 was more suitable for obtaining red emission compared to the OLED with only 1%wt%.

In particular, the [2,3] cell (DCM2: 2wt%, rubrene: 3%) and the [2,5] cell exhibited good red color

Table 1 The change of chromaticity coordinates in red OLEDs with luminance in the range of 100-4000cd/m2

DCM2 (%)	Rubrene (%)	Luminance (100 cd/m^2)	Luminance (1000 cd/m^2)	Luminance (4000 cd/m^2)
1	0	x=0.57, y=0.42	x=0.54, y=0.44	x=0.54, y=0.44
	3	x=0.62, y=0.38	x=0.60, y=0.39	x=0.60, y=0.40
	5	x=0.59, y=0.41	x=0.57, y=0.42	x=0.56, y=0.43
2	0	x=0.62, y=0.38	x=0.62, y=0.38	x=0.60, y=0.39
	3	x=0.65, y=0.35	x=0.64, y=0.36	x=0.64, y=0.36
	5	x=0.64, y=0.36	x=0.64, y=0.36	x=0.64, y=0.36

(x=0.64, y=0.36). The distinctive feature of cells using an EA dopant is that no change in chromaticity coordinates is observed within the luminance range of 100 - 4000 cd/m^2. On the other hand, when the EA dopant is not used, the change in chromaticity coordinates is large. Although the [2,0] cell had reddish emission (x=0.62, y=0.38) at a low luminance of 100 cd/m^2, it had orange emission (x=0.60, y=0.39) at a high luminance of 4000 cd/m^2.

Figure 2 shows the luminance – voltage curves of the [2,0], [2,3] and [2,5] cells.

The maximum luminance of all three cells was almost the same ([2,0] cell: 7130 cd/m^2, [2,3] cell: 7840 cd/m^2 and [2,5] cell: 7780 cd/m^2). However, only the luminance – voltage curve of the [2,5] cell shifted toward the low-voltage region in comparison with those of the [2,0] and [2,3] cells. The turn-on voltage (at 1 cd/m^2) of the [2,5] cell was also the lowest of all cells ([2,0] cell: 6.5V, [2,3] cell: 6.3V and [2,5] cell: 4.8V). This decrease in voltage was due to the increase in the concentration of rubrene.

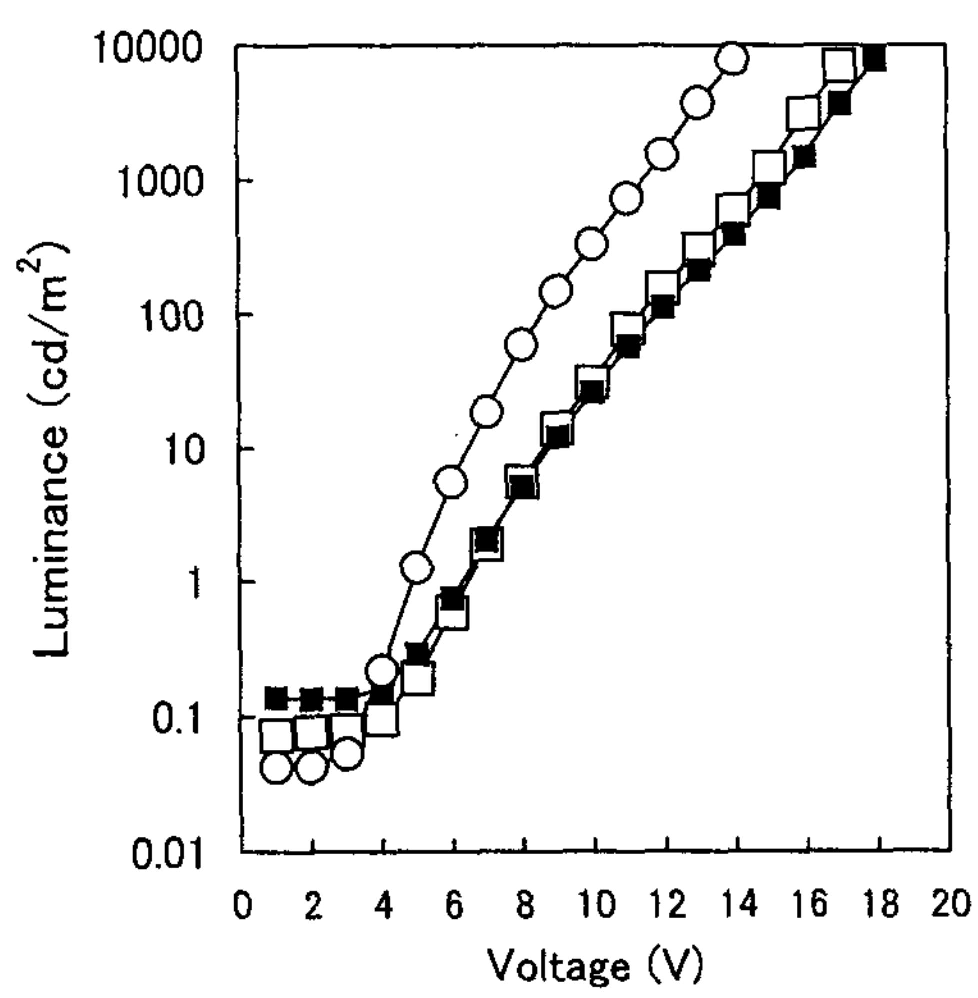

Fig.2 The luminance-voltage characteristics of [2,0], [2,3] and [2,5] cells

□ [2,0] cell, ■ [2,3]cell and ○[2,5] cell

4. Application to Active Matrix OLED Displays

Utilizing EA doping method, we developed full color displays on the low temperature poly-si TFT substrates. These displays are shown in Fig.3. The specifications are shown in Table 2.

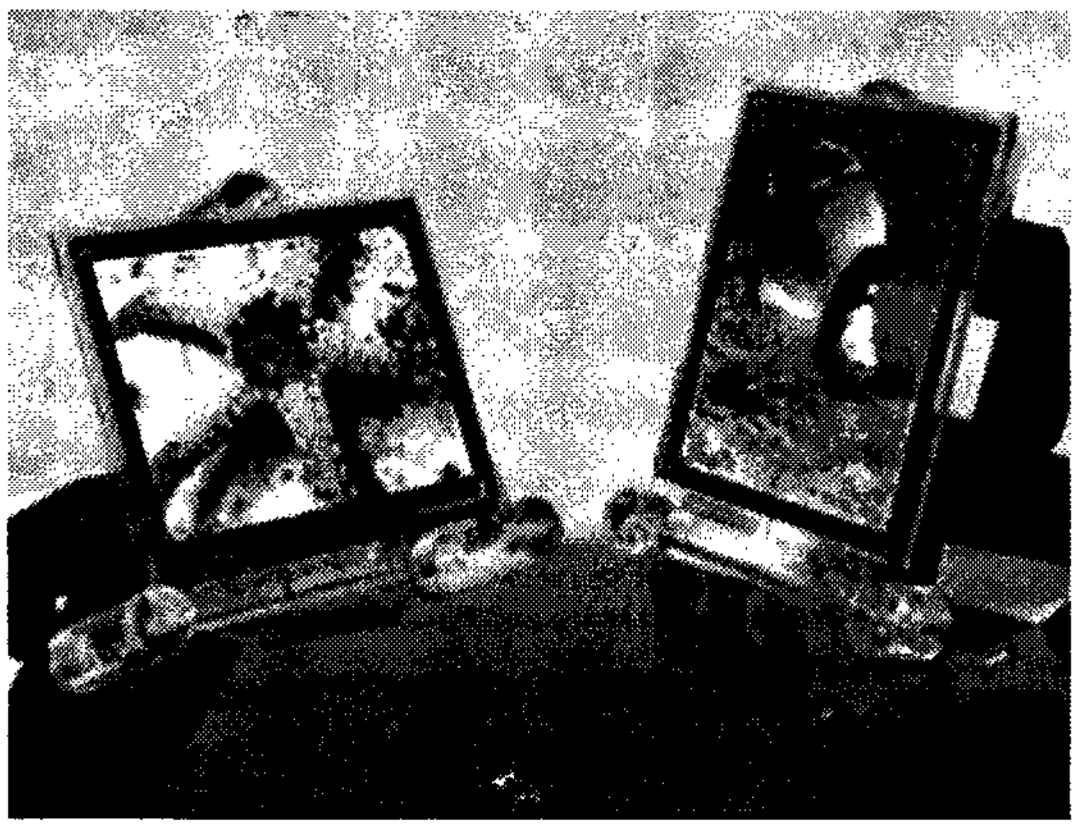

Fig.3 Active matrix OLED displays

Table 2. The specifications of active-matrix full color OLED display.

Dot counts (HxV)	521 x 218
Dot pitch (HxV)	0.084x0.151 mm
Color arrangement	RGB Delta
Number of color	Full color
Active area (HxV)	43.806 x 32.918mm (2.16?
contrast ratio	500 : 1

By using EA doping method, pure red emission and higher luminous efficiency is achieved. As shown in Table 3 each color achieved excellent efficiency and as well as chromaticity.

Table 3 The luminous efficiencies and RGB CIE coordinates in the each sub-pixel of active-matrix full color display

	luminous efficiency (cd/A)	CIE coordinates (X,Y)
Red	3.0	(0.64,0.36)
Green	6.0	(0.28,0.68)
Blue	6.0	(0.16,0.19)

4.Conclusion

We have developed the active matrix OLED displays with a high efficiency red emission material.

We proposed an emitting assist (EA) dopant system for obtaining organic light-emitting diodes (OLEDs) with pure red emission. The EA dopant (rubrene) did not itself emit but assisted the energy transfer from the host (Alq_3) to the red emitting dopant (DCM2). A stable red emission (chromaticity coordinates: x=0.64, y=0.36) was obtained in this cell within the luminance range of 100 - 4000 cd/m^2. When the cell was not doped with rubrene, the emission color changed from red to orange as the luminance increased. By using EA dopant, we can realize the reduction of the power consumption of the OLED display. The EA dopant system would improve the performance of other OLEDs.

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