Fluorescent RGB and White OLEDs with High Performance

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Abstract

We developed highly efficient fluorescent dopants for full-color OLEDs. For blue, green and red OLEDs, current efficiencies of 8.7cd/A, 20.5 cd/A and 11.4 cd/A at 10mA/cm² were achieved, respectively. Lifetime of the blue device was estimated to be 23,000hours at an initial luminance of 1,000 cd/m². Moreover, long lifetime over 100,000 hours was estimated in the green and red devices. Furthermore, we obtained a three-component white OLED by using these new fluorescent materials. This white OLED shows a current efficiency of 16.1cd/A with extrapolated lifetime over 70,000 hours at 1000cd/m², and more excellent color reproducibility for full-color displays with color filters and general lighting, compared to previous fluorescent white OLEDs.

1. Introduction

Numerous materials for organic light-emitting diodes (OLEDs) have been developed since Tang and Van Slyke reported an OLED with a stacked structure [1]. Recently, a phosphorescent OLED made a breakthrough over the theoretical limit of fluorescent OLEDs and it was found that the internal quantum efficiency reached to 100% [2]. Especially the very high efficiency of a phosphorescent green OLED was established [3]. On the other hand, a fluorescent green OLED with a power efficiency of 26 lm/W and a lifetime of 25,000 hours was reported [4]. Fluorescent OLEDs still have a possibility to solve a lifetime problem for OLEDs. In addition, there are many advantages in the simple device structure and the material cost.

Our objective is to develop highly efficient fluorescent materials for full-color OLEDs with long lifetime especially in blue emission. Blue emission most greatly influences power consumption and lifetime compared to other primary colors. We have already reported that a combination of a blue host and a green dopant, GD-206 showed the high efficiency of 20.5 cd/A at CIE coordinates of (0.32,0.62) and a long lifetime of 40,000 hours at an initial luminance of 1,000 cd/m² in 2004 [5].

In recent years, OLED full-color displays have been actively developed and commercialized by several corporations. Three types of full-color systems for OLED were reported, i.e. RGB emitters fabricated by using a shadow mask, white emitter on the color filter (CF) array and blue emitter on the color changing mediums (CCM).

White-CF system has a great advantage of not using fine shadow masks. On the other hand, there is a challenge to realize a high efficiency, a long lifetime and emission spectrum suited for color filters simultaneously. Several groups have developed white OLEDs with some emitter types such as two-component and three-component types. We also reported a white OLED by using a red dopant of RD001, a green dopant of GD206 and a blue dopant of BD-052 [6]. However, the coverage of NTSC through CF with this white OLED was low with 62% and didn't meet the performance for the white-CF system because the pure red part of the EL spectrum in the luminance from RD001 was weak.

In this study, we developed new blue and red fluorescent materials for the high performance OLEDs having high efficiency and long lifetime. Furthermore, we fabricated a three-component white OLED by using these materials to improve the device efficiency, the lifetime and the coverage of NTSC.

2. Results and Discussion

2.1 Blue Devices

In order to realize highly efficient blue dopants with long lifetime, we tried to make the blue shift of the EL spectrum by modifying the molecular structure of GD-206. Consequently, new blue-emissive dopants, BD-1, BD-2 and BD-3 were obtained. We fabricated blue OLEDs with Idemitsu host material, NBH and these blue dopants. The device structure was glass/ITO/HIL/HTL/NBH:new dopant/Alq3/LiF/Al.

The performances of the devices with new blue dopant are shown in Table 1. The current efficiency and CIE coordinates of the device employing BD-2 are 8.7 cd/A and (0.13, 0.22), respectively. The lifetime at an initial luminance of 1,000 cd/m^2 was estimated to be 23,000 hours. Figure 1 shows the current density-L/J characteristics of the devices. All of the new blue dopants show higher current efficiency in the wide range of current density than that of our dopant, BD-052 reported before [7].

Table 1. EL characteristics for the devices with new blue dopants.

Dopant	CIE(x,y)	L/J(cd/A)	Lifetime (hr) @L_0=1000cd/m^2
BD-1	(0.14, 0.20)	7.9	17,000
BD-2	(0.13, 0.22)	8.7	23,000
BD-3	(0.14, 0.16)	7.2	12,000

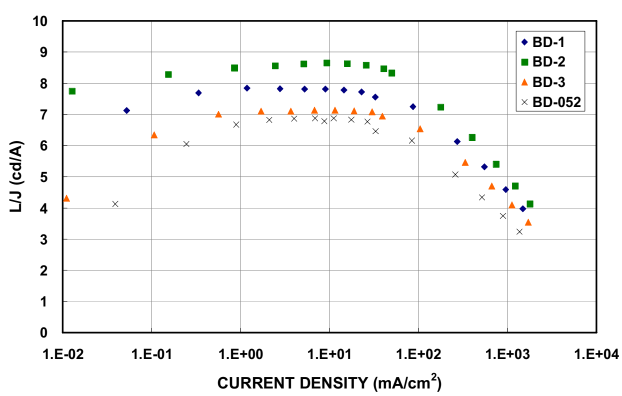

Figure 1. J-L/J characteristics for the devices with new blue dopants.

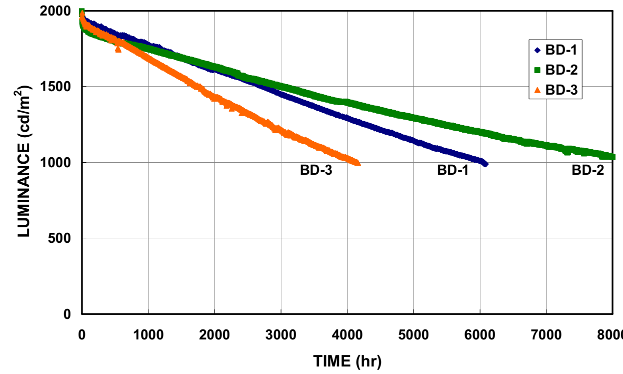

Figure 2. Luminous decay curves for the devices with new blue dopants.

Figure 2 shows the luminous decay curves for the blue devices under DC constant current driving at room temperature. The half lifetime of BD-2 at an initial luminance of 1,000 cd/m^2 is 8,000 hours, as shown in Figure 2. By using our empirical acceleration factor (1.5th power), the lifetime was estimated to be 23,000 hours. To the best of our knowledge, this lifetime is one of the longest values of the blue OLEDs. Moreover, Figure 3 shows that BD-2 also decreased driving voltage compared to the other new dopants. BD-2 fulfills the requirement for the top-emitting full-color OLED displays improved the CIE coordinates with the microcavity effect.

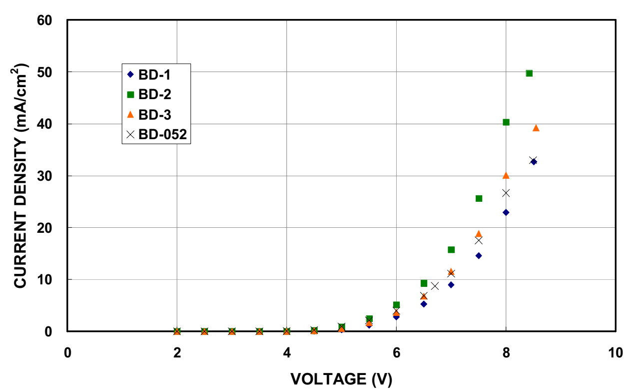

Figure 3. J-V characteristics for the devices with new blue dopants.

The device having BD-1 also shows the high efficiency of 7.9 cd/A at the CIE coordinates (0.14, 0.20) In Table 1 and the long lifetime was 17,000 hours at an initial luminance of 1,000 cd/m^2 in Figure 2. On the other hand, BD-3 succeeded in the improvement of lifetime with pure blue emission. The CIE coordinates are (0.14,0.16) and the lifetime at an initial luminance of 1,000 cd/m^2 is estimated to be 12,000 hours.

2.2 Red Devices

We recently developed red fluorescent materials, RH-1 and RD-2. The RD-2 is a pure red dopant. We fabricated red devices with these materials. The device structure was glass/ITO/HIL /HTL/RH-1:RD-2/ETM/LiF/Al. Alq_3 or Idemitsu new electron transporting material (NET) were used as ETM. The initial performances of the devices are shown in Table 2.

Table 2. EL characteristics for the devices with new red materials.

ETM	CIE(x,y)	Voltage(V)	L/J(cd/A)
Alq_3	(0.64, 0.35)	4.9	7.2
NET	(0.67, 0.33)	4.1	11.4

The NET decreased a driving voltage compared to a conventional Alq_3. Therefore, we obtained a pure red OLED with a current efficiency of 11.4 cd/A and a power efficiency of 8.6 lm/W at 10 mA/cm^2 in CIE coordinates of (0.67, 0.33). In order to estimate the external quantum efficiency (E.Q.E.), we measured emission pattern from the red device in Figure 4. The pattern is approximately Lambertian. Consequently, the value of E.Q.E. from emission pattern was estimated to be 8.4 %.

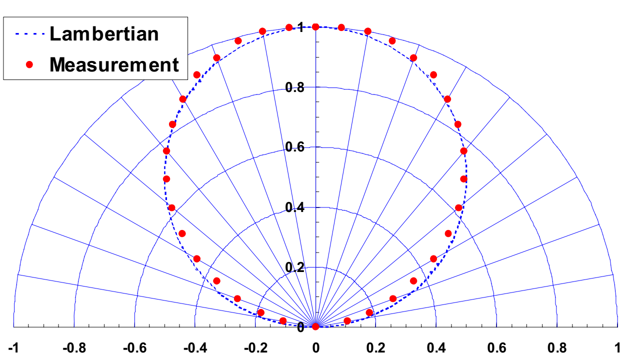

Figure 4. Emission pattern for the device with new red materials and NET. Dotted line is Lambertian surface.

Figure 5 shows the luminous decay curves for the red devices under DC constant current driving at room temperature. The half lifetime of the NET device was estimated to be over 10,000 hours. Therefore, the lifetime at an initial luminance of 1,000 cd/m^2 was estimated to be over 100,000 hours. The lifetime of red device was drastically improved by the use of the NET.

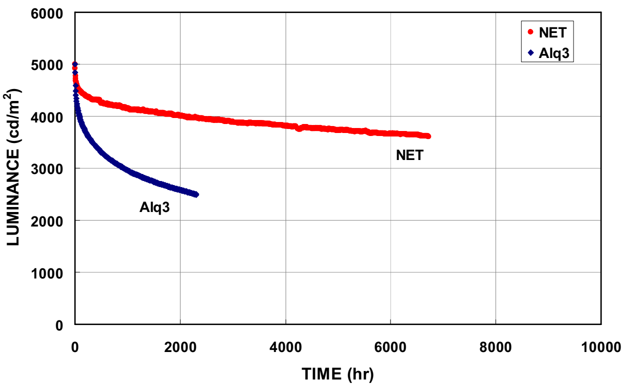

Figure 5. Luminous decay curves for the devices with new red materials.

2.3 White device

We fabricated a three-component white OLED by using new blue and red fluorescent materials to improve the efficiency, the lifetime and the color balance. The emitting layers of the white OLED consisted of the RH-1:RD-2 and the NBH doped with BD-1 and GD206.

The white OLED showed CIE coordinates of (0.33, 0.39), a color temperature of 5568 K and a color rendering index (CRI) Ra of 87. On the other hand, our previous reported white OLED having dopants with BD52, GD206 and RD001 showed smaller CRI Ra of 79 than this three-component white OLED, because of less intensity in range of pure red by using RD001[6].

We calculated CIE coordinates through RGB CF by using the three-component white OLED. The CIE coordinates for RGB are shown in Figure 6. The white OLED and the previous one show coverages of NTSC with 75.3% and 62.0%, and white efficiencies through the CF of 4.3cd/A and 3.4cd/A, respectively. At 10mA/cm^2 for the white OLED, the efficiency was 16.1cd/A and E.Q.E. was 7.5% in Table 3.

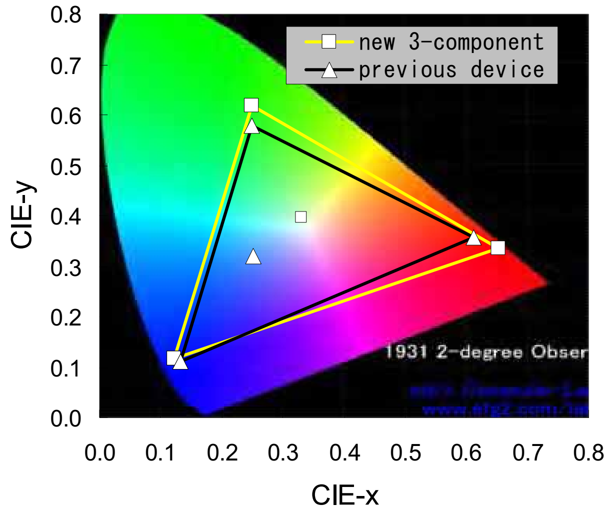

Figure 6. CIE coordinate of white OLEDs through color filter

Table 3. EL characteristics for the three-component white OLED.

CIE(x,y)	L/J(cd/A)	E.Q.E.(%)
(0.33, 0.39)	16.1	7.5

Luminance decay of the white OLED under the condition of DC constant current, room temperature and initial luminance of 5000 cd/m^2 is shown in Figure 7. According to our empirical acceleration factor, the lifetime was over 70,000hr at an initial luminance of 1000 cd/m^2.

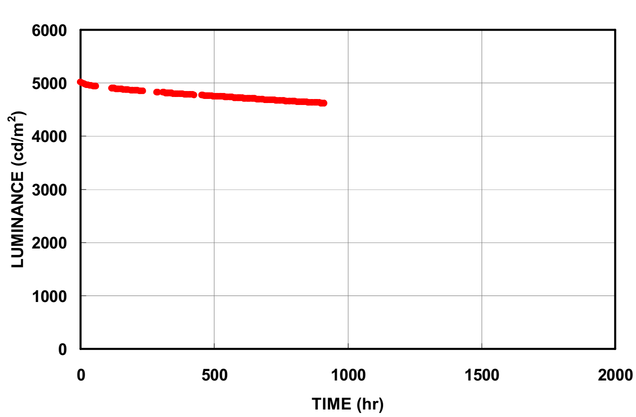

Figure 7. Luminous decay curves for the three-component white OLED.

3. Conclusion

We successfully developed highly efficient and stable fluorescent dopants for blue and red OLEDs. Furthermore, we found that a three-component fluorescent white OLED by using these materials showed a high efficiency, a long lifetime and a wide coverage of NTSC. We believe this highly efficient white OLED will provide a possible solution for the manufacturing of high resolution full color displays and general lighting for next generation.

4. Acknowledgements

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