High efficiency and long lifetime green OLED with a new electron transport material and a three-component RGB white OLED for full-color display applications.

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Abstract
We achieved a highly efficient green OLED with an efficiency of 30cd/A by using a new electron transport material and optimizing the device structure. The luminous efficiency was 16.8lm/W at 3000cd/m^2 and the lifetime was over 60,000hr at an initial luminance of 1000cd/m^2. Furthermore, we obtained a three-component RGB white OLED by using the highly efficient green material. This RGB white OLED shows more excellent color reproducibility for full-color displays with color filters, compared to a two-component white OLED.

1. Introduction
In 1987, Tang and VanSlyke reported an OEL with a stacked structure [1]. However, because the OLED at the time was fluorescent type, there was an upper limit originated from spin statistics. On the other hand, a phosphorescent OLED made a breakthrough over the theoretical limit of fluorescent OLEDs and it was found that the internal quantum efficiency arrived at 100% [2].The very high efficiency of a phosphorescent green OLED was well established. Universal Display Corporation demonstrated a phosphorescent green OLED with an efficiency of 29cd/A and a lifetime of 20,000hours at an initial luminance of 1,000 cd/m^2 by using a phosphorescent dopant of GD33 in SID04 [4].

However, the efficiency of phosphorescent green OLEDs with a long lifetime was not so surprisingly high compared to a fluorescent OLED. For instance, a fluorescent green OLED with a power efficiency of 26 lm/W at 1,000 cd/m^2 and a lifetime of over 25,000 hours was reported by Canon in SID04 [5]. This high efficient and durable fluorescent OLED is superior to the reported phosphorescent OLED with a long lifetime. Especially, fluorescent OLEDs still fully have the possibility to solve a lifetime problem for OLEDs. It should be emphasized that there is much accumulation of expertise in molecule design and device structures through vigorous research and development of several groups in the past [1], [3], [5].

Here, we reported that a green OLED with a fluorescent green dopant of GD-206 showed a high efficiency of 30cd/A and a long lifetime of over 60,000hours at an initial luminance of 1,000cd/m^2. Furthermore, the external quantum efficiency exceeded 7% near the theoretical limit of fluorescent OLEDs. We believe that this high performance green OLED will contribute to the progress of full-color OLED displays.

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 change 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 2-component and 3-component types. We also reported a long lifetime and a high efficiency for the white OLED by using a red dopant of RD-001 and a blue dopant of BD-102 in 2002. However, this white OLED was classified in two-component type with a blue-green and an orange emission. There was a small green component in EL spectrum of the white OLED so that there still was necessary of improvement for emission spectrum for high efficient white-CF display.

2. Green device

We reported that a combination of a blue host and the green dopant, GD-206 showed the efficiency of 19cd/A, a CIE coordinate of (0.32,0.63) and a lifetime of 26,000hours at an initial luminance of 1000cd/m^2 in 2003 [6]. A key-point of the high efficiency and the long lifetime was an excellent host and the dopant materials. Additionally, we found a new host BH-215 and a lifetime of 40,000hours for green OLED with green dopant GD-206 was successfully obtained in 2004.

However, the device structure has not been optimized in the view of an optical interference effect. Consequently, we selected thickness of ITO and HIL in the device structure based on an optical simulation developed by our group [7]. Additionally we decreased a driving voltage with a new electron transporting material instead of a conventional tris(8-hydroxyquinoline)aluminum(Alq).

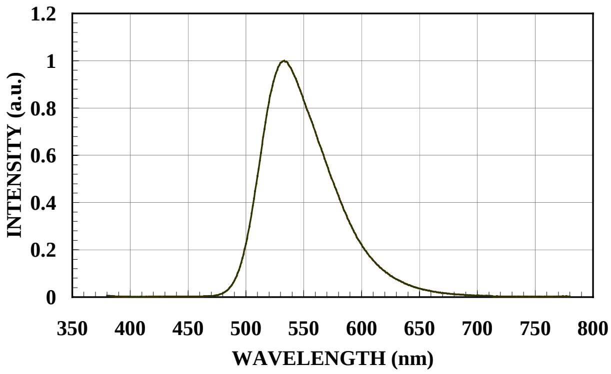

Figure 1. EL spectrum of green OLED

Therefore, we obtained a green OLED with an efficiency of 30cd/A at 3,000cd/m^2. The luminous efficiency was 16.8 lm/W at 3,000cd/m^2 .The lifetime at an initial luminance of 1,000cd/m^2 was estimated to be 60,000 hr. EL spectrum of the OLED is shown in Fig.1. Energy of excitation of host molecules sufficiently transferred to GD-206 so that there was very few component of emission from the blue host material in the EL spectrum. Luminance-Voltage characteristics for the devices with Alq and the new ETM are shown in Fig.2.

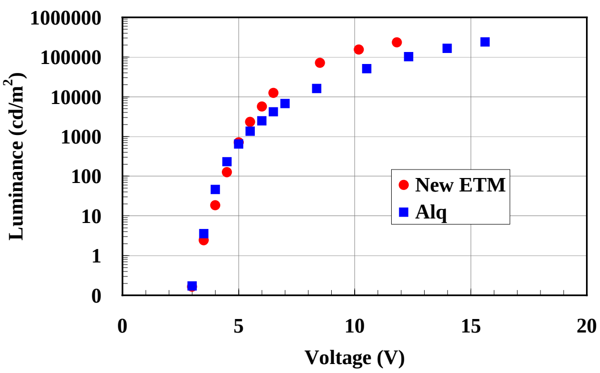

Figure 2. Luminance – Voltage characteristic of green OLED with Alq and new ETM

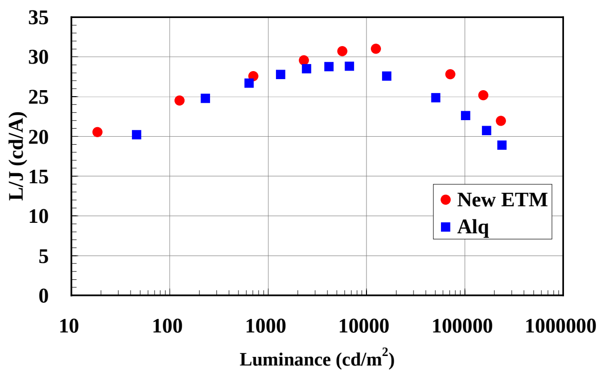

Figure 3. L/J efficiency characteristic of green OLED with Alq and new ETM

The new ETM especially decreased the driving voltage in the luminance range over 1,000cd/m^2 compared to Alq. The operating voltages at 10,000cd/m^2 and at 100,000cd/m^2 are 6 volts and 9 volts, respectively. The low voltage driving is caused by the high electron mobility of the new ETM. Furthermore, by taking advantage of the high electron mobility, we can improve electron-hole balance.

In the passive matrix range of over 10,000cd/m^2, the current efficiency of the new ETM as shown in Fig.3 was quite larger than that of Alq.

The value of current efficiency of 30cd/A is one of the highest in fluorescent OLEDs as far as we know.

A decay curve of the green OLED under the condition of DC constant current driving and room temperature is shown in Fig.4. A half lifetime in Fig.4 is found to be about 5,400hours. By using our empirical acceleration factor, this lifetime was estimated to be over 60,000hr at an initial luminance of 1,000 cd/m^2. The new ETM enables us to obtain OLEDs with the low driving voltage and the long lifetime.

As these data indicate, this green OLED opens up great possibilities for full color displays with fluorescent OLEDs. Then, we have confidence that a philosophy of our molecular designing shall advance higher efficiency and longer lifetime in fluorescent OLEDs.

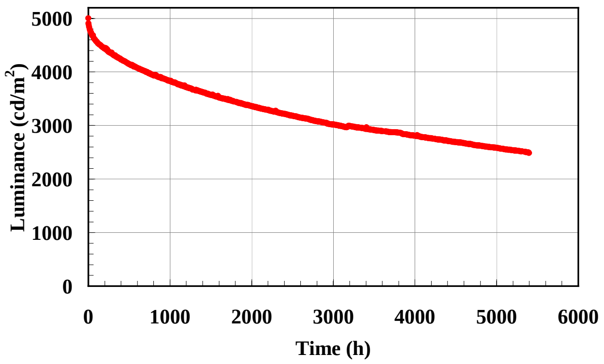

Figure 4. Lifetime of green OLED under the condition of DC constant current driving and room temperature

3. White device

We fabricated a 3-component white OLED by using the GD-206 and a pure blue dopant BD-052 instead of the light blue dopant BD-102 in order to improve the color balance. The emitting layers of the 3-component white OLED consisted of stacked-layers with BH-215 as a common host for each RGB emitters. Therefore, it becomes easy to fabricate the stacked-layers for mass-production not requiring different hosts for each RGB emitters. Furthermore, although RD-001 is red dopant, it has a unique property that an effective energy transfer from the blue host to the red dopant occurs without a co-host system. An orange OLED with BH-215:RD-001 had an efficiency of 13cd/A, a CIE coordinate of (0.57,0.42) and an external quantum efficiency of 5.6%. The EL spectra of the 2-component and the 3-component white OLEDs at a current density of 10 mA/cm^2 are shown in Fig.5.

The 3-component white OLED showed the CIE coordinate of (0.283, 0.338), the high color temperature of 8139 K and the color rendering index (CRI) Ra of 79. On the other hand, the 2-component white OLED showed smaller CRI Ra of 67 than the 3-component OLED, because of less intensity in range of 450nm and 550nm.

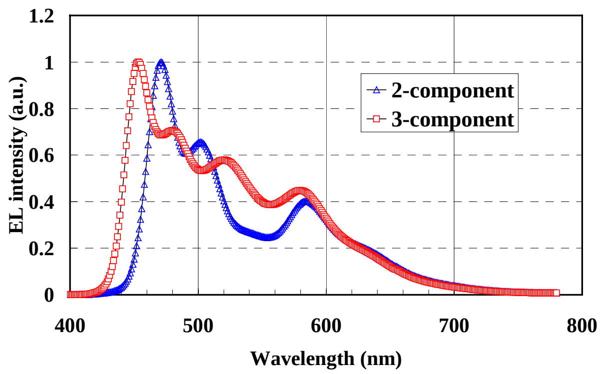

Figure 5. EL spectrum of white OLED

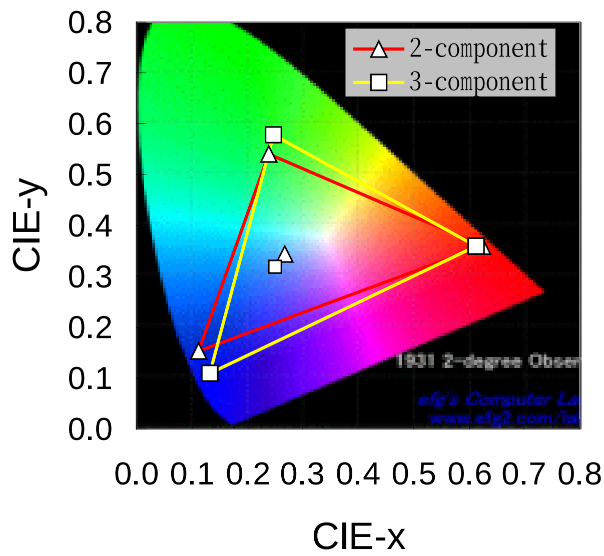

Figure 6. CIE coordinate of white OLED through color filter

We calculated the CIE coordinate and the transmission spectra through CF by using this 3-component white OLED. The CIE coordinates for RGB are shown in Fig.6.

The 2-component and the 3-component white OLEDs showed the NTSC ratio of 54.6 % and 62.0%, and the white efficiency of RGB through CF of 3.7cd/A and 3.4cd/A, respectively.

At a current density of 10mA/cm^2 for the 3-component white OLED, the voltage is 6.87V, and the efficiency is 11.4cd/A.

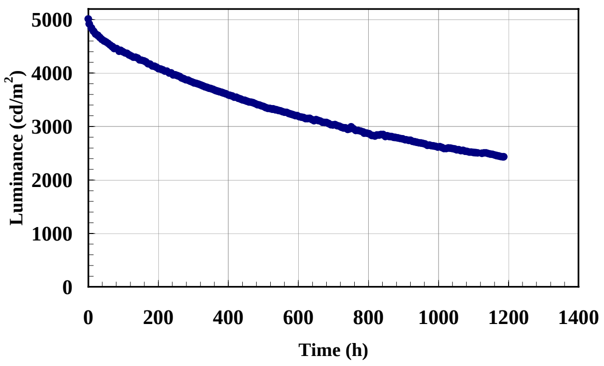

Figure7. Half lifetime of white OLED

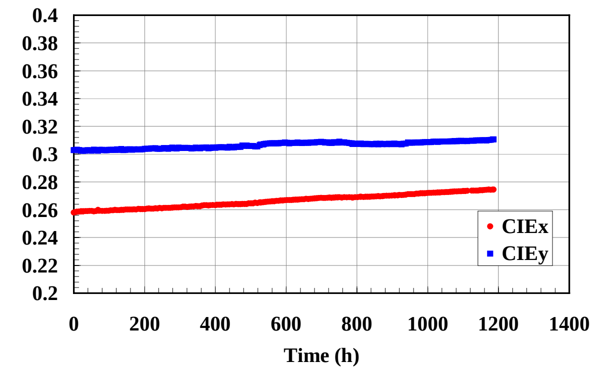

Figure 8. CIE shift at lifetime test of white OLED

The luminous efficiency and the external quantum efficiency were estimated to be 5.2lm/W and 5.0% at a current density of 10mA/cm^2. A pure blue emitter with BD-052 has a high external quantum efficiency of 5% .

Therefore, We succeeded in obtaining both high color temperature and the high external quantum efficiency for the white OLED.

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 Fig.7. According to our empirical acceleration factor, the lifetime was estimated to be over 12,000hr at an initial luminance of 1000 cd/m^2. The shift of the CIE coordinate at the lifetime test is shown in Fig.8.

The shift in this test was found to be less than 0.02 at the time of the half initial luminance. This result indicates that active full color displays with the white luminance of 200 cd/m^2 and the half lifetime about 10,000 hr can be realized on the basis of our reported white OLED by taking into the account of a moderate pixel fill factor, CF transmittance and 50%-on driving.

4. Conclusion

We obtained a green fluorescent OLED with both a high efficiency of 30cd/A and a long lifetime of 60,000hr by using an optical simulation and a new ETM. According to this performance, the green device could be applied to the full color display with fluorescent OLEDs.

We found that a three component fluorescent white OLED with the simple device structure showed a high efficiency, a high color temperature and a long lifetime. Although each RGB dopants have different properties, the shift of CIE coordinates at the half lifetime was found to be quite small.

5. Acknowledgement

RD-001 as a red dopant was developed in the program of technology in Japan Petroleum Energy Center.

6. References

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