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LETTER TO THE EDITOR

High colour rendering index non-doped-type white organic light-emitting devices with a RGB-stacked multilayer structure

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Abstract

A non-doped-type white organic light-emitting device with high colour rendering index has been reported. The structure of the device is ITO/NPB (50 nm)/TPBI (3 nm)/Alq3 (d nm)/DCM2 (0.1 nm)/TPBI (40 − d nm)/Alq3 (10 nm)/LiF/Al, where NPB is N,N′-bis-(1-naphthyl)-N,N′-diphenyl-1,1′-biphenyl-4,4′-diamine, TPBI is 2,2′,2-(1,3,5-phenylene)tris(1-phenyl-1H-benzimidazole), Alq3 is tris (8-hydroxyquinoline)aluminium, DCM2 is [2-methyl-6-[2-(2,3,6,7-tetrahydro-1H,5H-benzo[ij]quinolizin-9-yl)ethenyl]-4H-pyran-4-ylidene] propane-dinitrile. Through the optimization of d, pure white emission with CIE coordinates of (0.3198, 0.3400) at 9 V was obtained, at which the colour temperature and colour rendering index were 6080 K and 97, respectively. The CIE coordinates of the device change from (0.4552, 0.3867) at 4 V to (0.2864, 0.2865) at 19 V that are well in the white region. Its maximum luminance was 10 855 cd m\(^{-2}\) at 19 V and maximum power efficiency was 1.31 lm W\(^{-1}\) at 5 V.

1. Introduction

White organic light-emitting devices (WOLEDs) are considered as low-cost alternatives for backlights in liquid-crystal displays and illumination purposes. Generally speaking, doping is usually utilized to obtain white emission [1–8]. This technique has been used to obtain white light from small-molecule and polymer devices and the devices have high efficiency and luminance. However, the control of the doping concentration was difficult. Delta-doping, in which a thin layer of the dopant material alone is incorporated in the device, has been used to determine the position of the recombination zone [9, 10]. Currently, non-doped-type WOLEDs using delta-doping technique have been reported by Tsuji et al and Xie et al [11–13]. The simple device structures and excellent reproducibility make them well suited to low-cost lighting applications.

From the lighting perspective, light quality refers primarily to the colour and the colour rendering index (CRI) of the light. The CRI of a white light source is a measure of the colour shift that an object undergoes when illuminated by the light source as compared with the colour of the same object when illuminated by a reference source of comparable colour temperature [14]. Acceptable illumination sources require a CRI of higher than 80. WOLED with the CRI of 93 is reported by Duggal et al [15]. To our knowledge, there are presently no reports on the CRI of the non-doped-type WOLEDs. The CRI of the earlier reported non-doped-type WOLEDs [11–13] should be low because it utilizes two complementary colours to obtain white emission. From the point of view of colour
rendering, a three-component white device is required. In this letter, we report a high-CRI non-doped-type WOLED with a RGB-stacked multilayer structure.

2. Experimental detail

Figure 1 shows the chemical structures of organic materials used in this work, the structure of the device and the energy level of the device.

Figure 1. The chemical structures of organic materials used in this work, the structure of the device and the energy level of the device.

<table>
<thead>
<tr>
<th>LiF/Al</th>
<th>Alq3 (10 nm)</th>
<th>TPBI (40 nm)</th>
<th>Alq3 (d nm)</th>
<th>TPBI (3 nm)</th>
<th>NPB (50 nm)</th>
<th>ITO</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>DCM2 (0.1 nm)</td>
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</table>

Table 1. A multilayer structure for devices A–C.

Figure 2 shows the EL spectra of devices A–C at 9 V. The emissions from NPB (440 nm), Alq3 (520 nm) and DCM2 were observed. From the energy level of the device as shown in figure 1, the emission from the NPB and Alq3 is predictable. A 3 nm thick TPBI layer inserted between the NPB and Alq3 can block some holes and the excitons will form at the NPB/TPBI interface. (40 − d) nm thick TPBI will block other holes and the excitons will form at the Alq3/TPBI interfaces. Then, the emission from the NPB and Alq3 was observed. The excitons formed at the Alq3/TPBI interface will transfer their energy to the ultrathin DCM2 layer inserted between the Alq3/TPBI interface and the emission from DCM2 was observed. With the increase of d, the emission from the Alq3 increases. It indicated that the larger d is, the more the excitons will form at the Alq3/TPBI interface. Thus, the emission from the Alq3 increases.

Figure 3 shows the CIE coordinates of devices A–C at different voltages. The CIE coordinates of the three devices are all within the white region. From the figure we can see that device B has the best colour purity among the three devices. The CIE coordinates of device B change from (0.4552, 0.3867) at 4 V to (0.2864, 0.2865) at 19 V. And the pure white emission with the CIE coordinates of (0.3198, 0.3400) at 9 V was obtained that is closest to the equi-energy white point (0.33, 0.33) in all three devices.

Figure 4 shows the normalized EL spectra of device B at different voltages. The emission spectra strongly depend on the current density. With the increase of the current density, firstly, the contribution from the DCM2 decreases and the emission from the Alq3 increases; then the emission from the Alq3 decreases. This result indicated that at low current density most excitons will form at the Alq3/TPBI interface and transfer their energy to DCM2. With increasing current density, the recombination will mostly occur in Alq3.
and NPB. The shift of the peak intensity from DCM2 to Alq3 to NPB as the voltage increases can be explained by the movement of the emission region. And the width of the emission region depends on the displacement or diffusion of excitons before recombination and the distance travelled by injected carriers before exciton formation [10]. The latter will increase with operating voltage. As a result, the recombination region will broaden and shift to Alq3 to NPB with increasing voltage.

The applied voltage (V) dependence of (a) current density (I) and luminance, and (b) the EL and power efficiencies of device B, are shown in figure 5. The maximum luminance of 10 855 cd m$^{-2}$ is achieved at 803 mA cm$^{-2}$ when the voltage is 19 V. For the luminance of 1000 cd m$^{-2}$, $I = 44.81$ mA cm$^{-2}$, $V = 8.23$ V, the EL and power efficiencies are 2.24 cd A$^{-1}$ and 0.86 lm W$^{-1}$, respectively. The maximum EL and power efficiencies of device B are 2.32 cd A$^{-1}$ at 7 V and 1.31 lm W$^{-1}$ at 5 V.

The colour rendering indices of device B at different voltages are shown in figure 6. The correlated colour temperatures (CCT) were calculated by the CIE coordinates using the formula reported by McCamy [16]. And the CRI were calculated from the EL spectra of the device by the CIE CRI method [14]. The CIE coordinates of device B at 4 V are (0.4552, 0.3867), CCT = 2560 K and the CRI is 85. The CIE coordinates of device B at 9 V are (0.3198, 0.3400), CCT = 6080 K and the CRI is 97. And the CIE coordinates
of device B at 14 V are (0.2947, 0.3055), CCT = 8020 K and the CRI is 97. Our WOLED has excellent CRI in the red, green and purple regions. This is due to the broad EL spectra covering the range from 380 to 780 nm and three primary peaks at 440 nm (blue), 520 nm (green) and ∼608 nm (red).

4. Conclusion

In conclusion, a high-CRI non-doped-type white organic light-emitting device with a RGB-stacked multilayer structure has been reported. Pure white emission with the CIE coordinates of (0.3198, 0.3400) at 9 V was obtained, at which the colour temperature and colour rendering index were 6080 K and 97, respectively. The CIE coordinates of the device change from (0.4552, 0.3867) at 4 V to (0.2864, 0.2865) at 19 V that are well in the white region. Its maximum luminance was 10 855 cd m$^{-2}$ at 19 V and maximum power efficiency was 1.31 lm W$^{-1}$ at 5 V.

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