A study on the simplified fabrication structure for the multi-color OLED display

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Abstract
We proposed a simplified fabrication structure and method which can provide separate Red (R), Green (G), Blue (B), and White (W) OLED pixels with 2 metal-mask changes in emitting layer fabrication inspired from the structure of multi-layer white OLED and carrier blocking mechanism. A red emission layer for the R and W pixel with 1st mask, and then a blue emission layer with hole blocking layer for the B and W pixel with 2nd mask, and finally a common green emission layer were deposited sequentially. We expect that this concept would be very useful to the actual fabrication of multi-color OLED display although additional optimization is needed.

1. Introduction
Full color organic light emitting diodes (OLEDs) are regarded as the most attractive next generation flat panel display due to its thin and light form factor and high display qualities as well. However, relatively complicated process step is needed to achieve full color display especially in making separate color sub-pixels such as Red (R), Green (G) and Blue (B) due to limited shadow-mask alignment accuracy. Another way to achieve full color OLED in relatively simple way is combining a color filter matrix and white OLED backplane [1]. Recently RGBW color sub-pixel OLEDs with unique color signal pre-processing are reported as a way to increase the efficiency of a color filter matrix [2] and reduce the complexity of defining pixels [3]. However, they are inherently less efficient than the devices with separate sub-pixels. Here, we propose a simplified fabrication structure and method which can provide separate Red (R), Green (G), Blue (B), and White (W) OLED pixels with 2 metal-mask changes in emitting layer fabrication inspired from the structure of multi-layer white OLED [4, 5] and carrier blocking mechanism usually used in phosphorescent device [6].

2. Results and discussion
Fig. 1 shows the 1st device structure of proposed R, G, B, W pixel respectively. A layer for red emission is composed of 4,4'-Bis(2,2-diphenyl-ethen-1-yl)-diphenyl (DPVBi) doped with 0.3 % rubrene and 4-(Dicyanomethylene)-2-methyl-6-(julolidin-4-yl-vinyl) -4H-phran (DCM2) each. A layer for green emission is composed of tris-(8-hydroxyquinoline) aluminum (Alq_3) doped with 0.1 % 10-(2-benzothiazolyl)-2,3,6,7-tetramethyl-1H,5H,11H-(1)-benzopyropyrano (6,7-8-i,j)quinolizin-11-one (C545T) and DPVBi single layer is used as a blue emission layer.

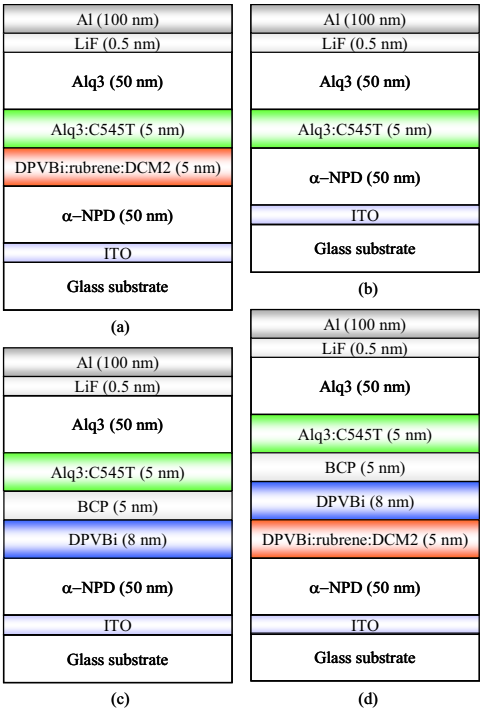

Figure 1. The 1st device structure of the devices for; (a) Red pixel, (b) Green pixel, (c) Blue pixel, and (d) White pixel

As you can see from Fig. 1, they require only 2 mask change while fabricating whole emission layer of R, G, B, W pixels. A red emission layer for the R and W pixel with 1st mask, and then a blue emission layer with BCP hole blocking layer for the B and W pixel with 2nd mask, and finally a common green emission layer was deposited sequentially with common Alq_3 electron transporting layer and α-NPD hole transporting layer.

All devices are fabricated by thermal evaporation under the vacuum of 10^{-6} Torr on the pre-patterned ITO substrate. The ITO substrate was ultrasonically cleaned with IPA (isopropyl alcohol), acetone, and methanol successively and dried in 120°C oven. All electro-optical measurement was conducted in the vacuum cryostat.

Fig. 2 shows that the spectrum of device for R, G, B, W pixel described in Fig. 1 measured at 500 uA driving current. These spectrums correspond to the CIE1931-xy coordinate of (0.254, 0.625) for G, (0.193, 0.291) for B, (0.365, 0.435) for W respectively while R pixel turned out to be a kind of yellow pixel with the CIE1931-xy color coordinate of (0.385, 0.489). This yellow-like property in R pixel is attributed to the more widely-distributed exciton recombination zone than expected in R pixel structure.

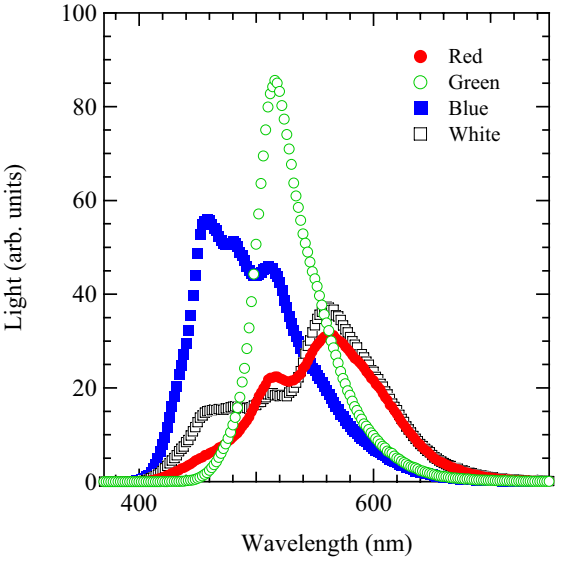

Figure 2. The spectrum of fabricated R, G, B, W pixel in 1st proposed structure.

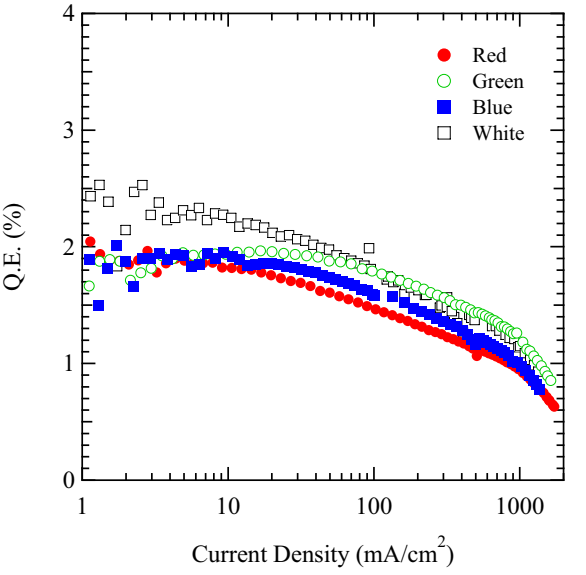

Figure 3. The external quantum efficiency as a function of current density in 1st proposed structure.

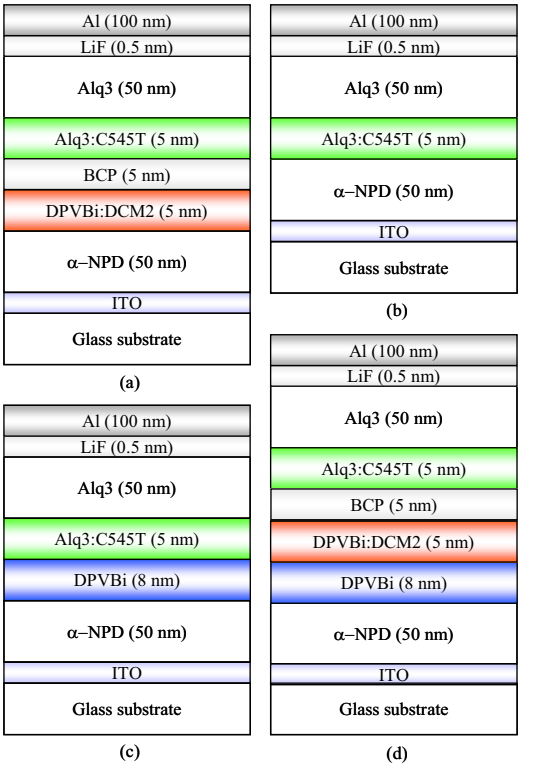

Figure 4. The 2nd device structure of the devices for; (a) Red pixel, (b) Green pixel, (c) Blue pixel, and (d) White pixel

Fig. 3 shows the external quantum efficiency (EQE) of R, G, B, W pixel structure. Every R, G, B, W showed similar EQE of near 2 %. These properties indicate that there is more room for additional improvement.

To improve the R pixel property, we changed the device structures in Fig. 1 into those in Fig. 4.The major differences are red and blue emission layer position thereby the hole blocking layer is positioned right after the red emission layer. We also modified the red emission layer composition into DPVBi doped with 0.5% DCM2 to adjust the W pixel color property.

Fig. 5 shows that the spectrum of device for R, G, B, W pixel described in Fig. 4 measured at 500 uA. These spectrums correspond to the CIE-xy color coordinate of (0.388, 0.425) for R, (0.264, 0.580) for G, (0.201, 0.347) for B, and (0.250, 0.295) for W respectively. This time R pixel turned out to be a kind of white pixel. This yellowish-white property in R pixel might be originated from insufficient DCM2 doping concentration and exciton blocking property. There is only B pixel color property improvement in this 2nd proposed structure while W pixel property was blue-shifted compared to prior structure. In both structure, the W pixel spectrum showed kind of 2-wavelength system rather than originally intended 3-wavelength system.

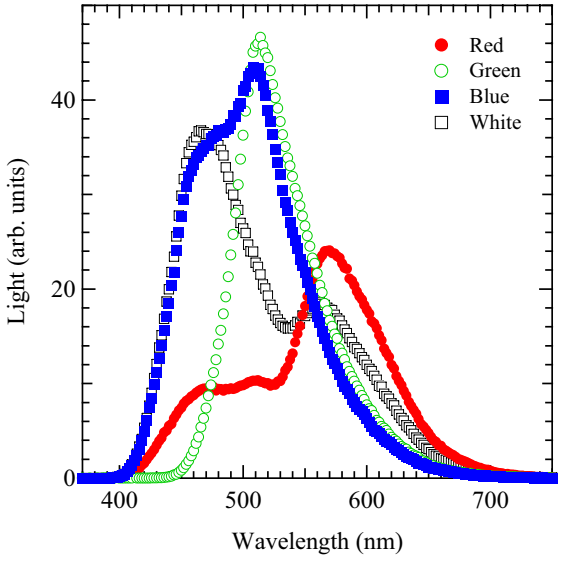

Figure 5. The spectrum of fabricated R, G, B, W pixel in 2nd proposed structure.

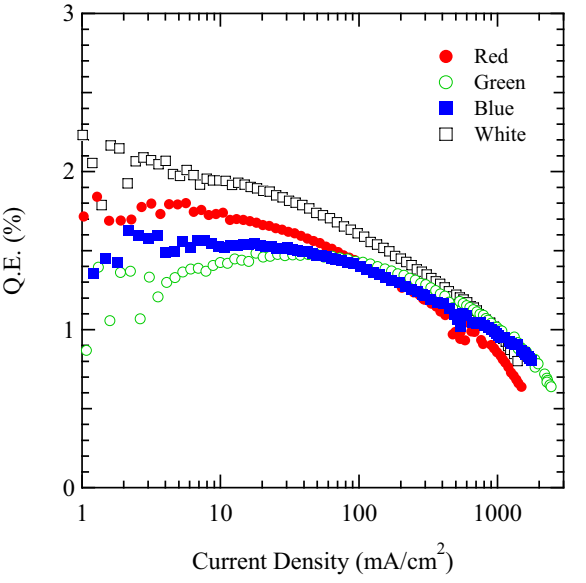

Figure 6. The external quantum efficiency as a function of current density in 2nd proposed structure.

So, if we use rather thick-BCP hole blocking layer might achieve somewhat improved R pixel property. In addition, we have to adjust the green emission layer characteristics to improve B pixel property more.

The external quantum efficiency of 2nd proposed structure was a bit lower than that of 1st proposed structure as shown in Fig. 6. However, there was no difference in G pixel device of both structures this is not inherent but problem in reproducibility.

Therefore, additional modification and sub-layer level optimization are needed to achieve proper color for each sub-pixel and white balance when every R, G, B, and W sub-pixel is turned ON for actual full color OLED application

3. Conclusion

We proposed a simplified fabrication structure and method which could provide separate R, G, B, W OLED pixels with 2 metal-mask changes in emitting layer fabrication. In conclusion, we acquired proper G, B, W characteristics with proposed structure but failed to acquire the proper red characteristics. However, this could be improved if additional optimization is performed.

4. References

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