Optical Structure of White OLED for 100% Color Gamut

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Abstract

We report a novel optical structure for bottom-emitting white OLEDs. The structure includes, reformulated color filter, dielectric mirror to enforce cavity resonance, and micro-scatterer to extract more light and diffuse the viewing angle dependency. With the new structure, the color gamut was 104% of that of NTSC, the combined transmission efficiency of the color filter was 83%/3 and the color shift at 45 ° was maintained below 0.02 in the 1976 CIE color space. The color performance of White OLED + color filter system can match comparably that of RGB OLED + microcavity system.

1. Introduction

For full color AMOLEDs, the RGB patterning method for the choice is thermal evaporation of small-molecules through fine metal shadow mask. Since this method is limited to small-size substrates, LITI (Laser Induced Thermal Imaging) [1], inkjet printing [2], and more recently, LIPS (Laser Induced Patternwise Sublimation) [3] were proposed for large substrates. However, the technologies are not yet fully proven to be reliable and dependable. The only "tested and true" method of patterning colors on large substrates is the use of color filters (CFs) with white OLED [4].

The combination of white OLED + CF has cost advantage from lower usage of EL material and shorter process time. The downside of this approach is lower efficiency resulting from absorption by CF and narrower color gamut. The first problem is alleviated significantly by the use of RGBW color system [5, 6, 7, 8]. Furthermore, for large displays drawing power from wall plug, the power efficiency may not matter at all once it falls below a certain level. However, the second deficiency can be more pronounced in the marketplace.

It is not a difficult task to match 72% of NTSC color gamut (sRGB) with white OLEDs. However, many AMOLEDs made with RGB monochromatic EL and microcavity are capable of displaying color gamut wider than the 100% NTSC. Although 100% color gamut can be achieved by thick CF [9], there is significant penalty on the efficiency, and consequently, life time of RGB subpixels.

We report a novel structure of OLED panel that enables more than 100% color gamut and 80% (R+G+B)/W ratio.

2. Color Filter

There are two main aspects of performance for a CF system. One is color gamut and the other is transmitting efficiency. For color gamut, we use the relative ratio of the gamut area to the NTSC gamut in the 1976 CIE space (u', v'). For transmission, we use a newly defined parameter called RGB/W ratio which is a ratio of the combined luminance from RGB-subpixels (W OLED + RGB CF) to the unfiltered luminance from a W-subpixel.

The transmission efficiency of CF affects the power consumption and the life time of RGB-subpixels. For RGBW OLED, the power consumption is given by

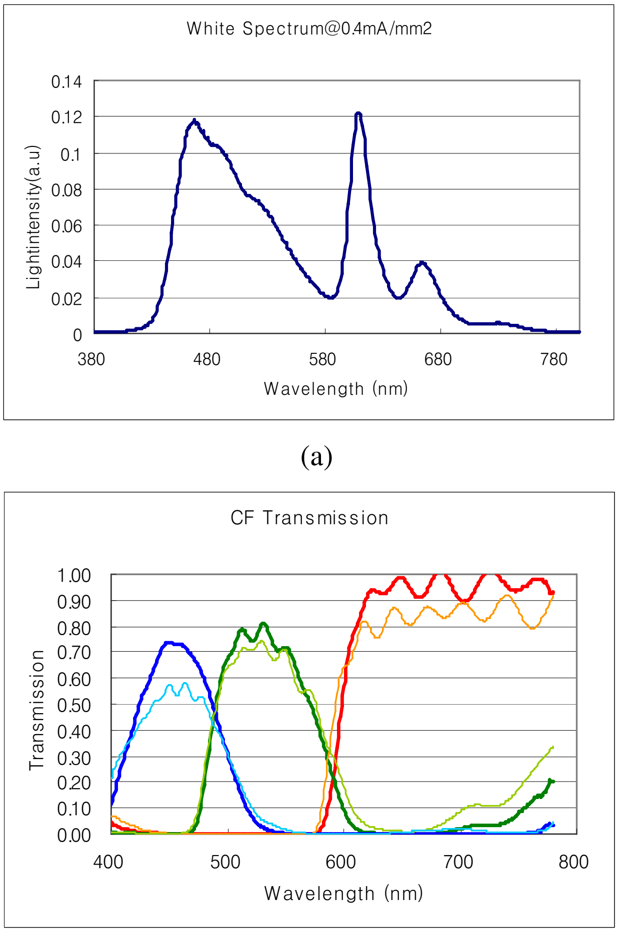
$$P = 3*S_{RGB}/(\text{RGB/W ratio}) + S_W \text{..................} \quad \text{(Eq. 1)}$$

where S_{RGB} and S_W are the average current stresses for RGB-subpixels and a W-subpixel, respectively. For the FC video, $S_{RGB} = 0.226$ and $S_W = 0.078$ [8]. The power P is normalized to the power consumption when only a W-subpixel is fully turned-on. When the RGB/W ratio is 100%, P = 0.75. CF with RGB/W ratio = 70%, for example, will increase the power consumption by 38% according to Eq. 1.

Figure 1a shows a white EL spectrum having a color coordinate of (0.299, 0.318) in the CIE 1931 space. With conventional CF (thin lines in Figure 1b), the color gamut was 73% and the RGB/W ratio was

71%. We developed a new CF (thick lines in Figure 1b) having color gamut of 89% and RGB/W ratio of 75%.

The new CF has higher transmission especially for blue light and slightly narrower bandwidths. However, it turned out that it affected the color gamut much more significantly than the transmission efficiency.



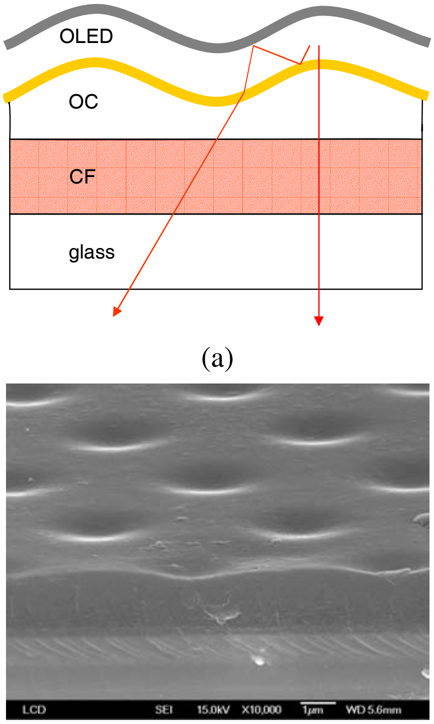
(a)

(b)

Figure 1. (a) White EL Spectrum. (b) CF Spectrum. Thick lines are new CFs.

3. Leaky Wave Guide

Secondly, we employed a novel optical structure, named Leaky Wave-Guide (LWG), to extract more light from OLED (Figure 2a). The photo-sensitive overcoat (OC) used to planarize the rough CF surface, was exposed to UV-light through a patterned mask, partially developed and cured at near the glass transition temperature to produce periodic and undulating structure (Figure 2b). More details on the structure will be published elsewhere. In LWG, the OLED waveguide is "leaky" and some of the otherwise trapped light escapes to air, improving the efficiency.



(a)

(b)

Figure 2. (a) Structure of LWG (Leaky Wave-Guide). (b) Scanning Electron Micrograph of LWG. The distance between the nearest neighbor is 5.0 um.

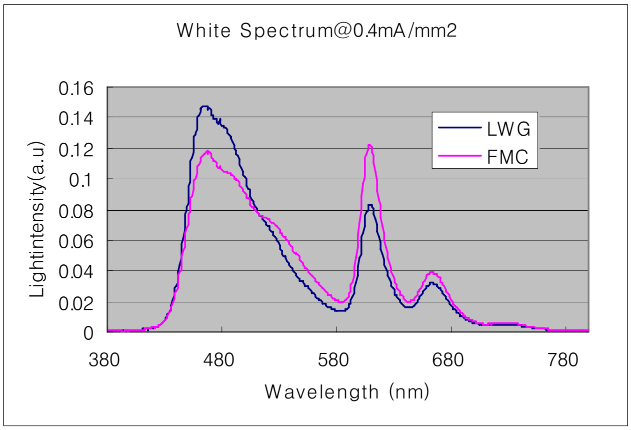
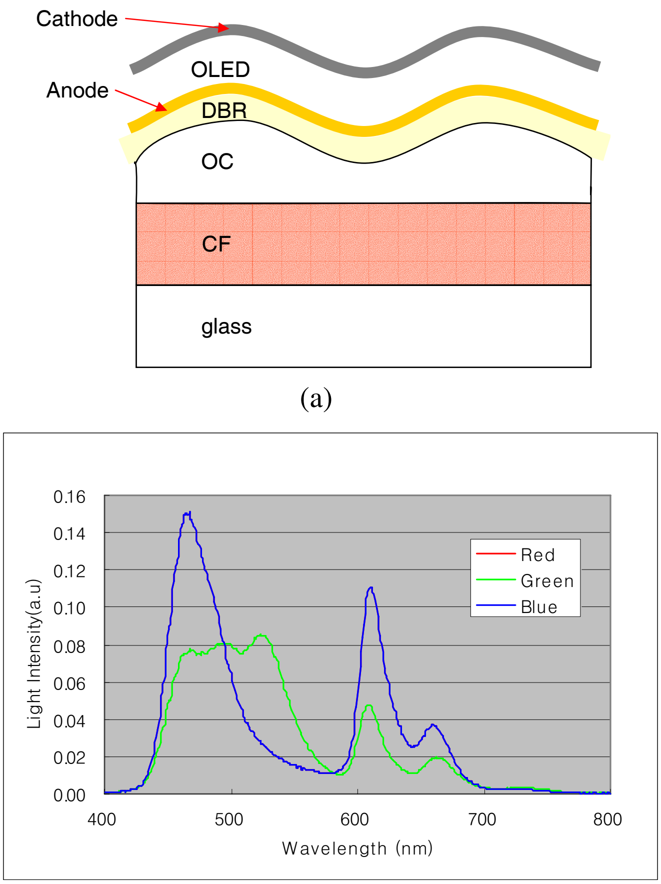


Figure 3. White spectra of LWG (dark blue) and the conventional structure (purple).

It was found that LWG was especially effective in extracting blue photons. The spectrum of LWG is shown in comparison of that of conventional structure (flat mirco-cavity, or FMC) in Figure 3. With LWG, the color gamut increased to 92% largely because of the sharp blue emission.

4. Resonance Enhancement



(a)

(b)

Figure 4. (a) Structure of LWG + DBR. (b) Spectra for R and B (Blue line) and for G (Green).

Lastly, the distributed Bragg reflector (DBR) [10] was introduced as dielectric mirror to enforce the cavity resonance (Figure 4a). Use of dielectric mirror is advantageous in two ways: it has higher transmittance than metal mirrors and the reflectivity can be changed arbitrarily.

The combination of DBR with LWG enables the individual tuning of spectrum peaks without an additional process. A common DBR was formed in all R, G, and B subpixels (except for the W-subpixel). The RGB-subpixels were individually tuned for the optimal optical conditions by varying the shape of the OC. More dosage of UV light produces deeper undulation and larger slope angle of the overcoat layer. Therefore, by simply controlling UV exposure for each R, G, and B-subpixel, optimum conditions for red, green, and blue light can be individually obtained. This greatly simplifies the process steps. For this particular case, we used the same UV exposure for the red and blue subpixels. For the green subpixel, the irradiation of UV was three times higher. The corresponding cavity modes were m = 1 for red, m = 1 for green, and m = 2 for blue. Figure 4b shows the individually tuned spectra for R, G, and B subpixels. The DBR and white EL are common for the all subpixels. Only the shapes of the underlying OC are different.

The drawback of cavity resonance is its strong dependency on viewing angle. The dependency is much more severe for white OLEDs. The LWG structure acts as micro-scatterer and diffuses the angle dependency. Without LWG, we obtained color gamut of 114%. However, the value decreased to a mere 73% at 45°. The white point moved by 0.071 (Δu'v') and the blue primary moved by 0.100. With LWG, the color gamut decreased slightly to 104%. However, it was still 97% at 45°. The white point moved by 0.015 and the largest shift was 0.018 for the red primary, which was still below 0.02 (Figure 5). The RGB/W ratio was enhanced to 83% because the spectral peaks matched well with the transmission peaks of the CF.

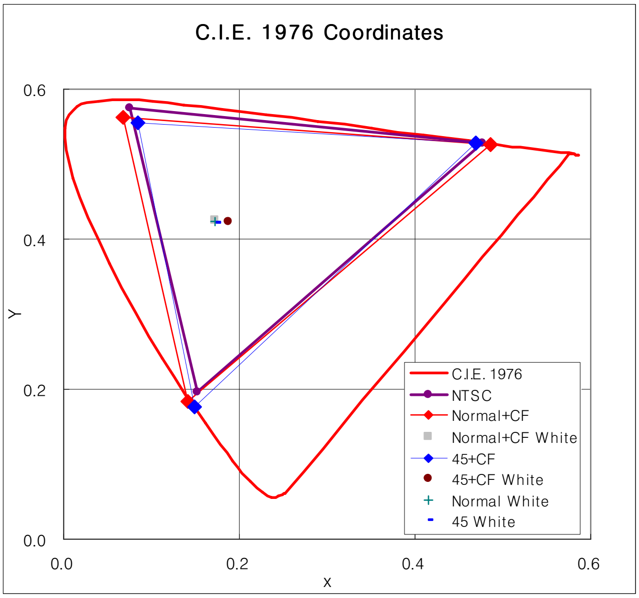


Figure 5. Color gamut of LWG + DBR. Red: Normal direction. Blue: 45°. Purple: NTSC.

5. Conclusion

In summary, the new optical structure significantly enhanced the color performance of white OLED + CF system. The color gamut increased from 73% to 104% and the transmission efficiency increased from 71% to 83%. There were no appreciable color shifts for all R, G, B, and W colors.

It was generally conceived that the white OLED + CF system was inferior to the RGB monochromatic OLED system in color performance, which drove many researchers in search of new RGB patterning methods for large substrate. However, these methods typically result in increased cost, non-uniformity, and sometimes, reduced efficiency and life time. White OLEDs do not have these problems. With the new structure, we demonstrated that it can equally match the color performance of RGB OLEDs with micro-cavity. We believe the simpler structure, lower material usage, and higher yield of white OLED are quite advantageous for large-size AMOLEDs.

5. References

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