Method to Enhance Color Gamut up to 89 % in Bottom Emission Active-Matrix Organic Light Emitting Device

Hwa Kyung Kim *, Hong Seok Choi, Dong Hee Yoo, Woo Chan Kim, Jong Geun Yoon, Joong Whan Yang
OLED Gr. Digital Display Research Lab. LG Electronics, Seoul 137-724, KOREA
Phone: +82-2-526-4963, E-mail: hinter@lge.com

Keywords : AM-OLED, Bottom Emission, Microcavity, and Color Gamut

Abstract

Though bottom emission AM-OLED has advantages in respect of mass production, the bottom emission type is underrated due to its low aperture ratio and low color gamut, compared with top emission type. In this paper, we demonstrate that the color gamut up to 89 % can be simply achieved by depositing dielectric multilayers, whose thicknesses are determined using an optical simulation program, prior to formation of Si layer.

1. Introduction

Bottom emission-type OLED (organic light emitting device) has manifested its simplicity in manufacturing process through successful launching of passive matrix OLED to small-sized display for mobile. At this time when top emission active matrix (AM)-OLED employing low temperature poly-silicon (LTPS) substrate has just been emerged to market, bottom emission AM-OLED is challenged due to its relatively low aperture ratio and low color gamut, and struggles to find out breakthroughs to resolve the two significant issues.

In this study, to enhance the color gamut in the bottom emission AM-OLED, we suggest a simple method in which buffer layer is fabricated with multi-layers of low refractive index layer and high refractive index layer, before the deposition of Si layer. Each buffer layers are engineered with an optical simulation program. Since the buffer layers undergo no process such as photolithography and etch, this method can be applied to mass production with minimum cost increase. The result of this study demonstrates the competitiveness of our bottom emission AM-OLED which should survive in a race in respect of display quality and cost as well, against TFT-LCD holding strong market share.

2. Results

Figure 1 shows a cross-sectional structure at a pixel area proposed in this study for enhancing color gamut, compared to the conventional bottom emission AM-OLED. In the LTPS process, the buffer layer plays a critical role in maintaining the electrical properties of TFT such as mobility and threshold voltage (V_{th}), by preventing impurity ions in the glass substrate from diffusing into Si layer at the stage of crystallization with a strong excimer laser. Previously, the buffer layer was composed of single layer of SiO_2 fabricated by PECVD. In contrary, our buffer layer is made by depositing high refractive index layer of SiN_x and low refractive index of SiO_2 by two times. Our structure is called quadruple buffer in this paper.

Figure 2 compares the electroluminance (EL) spectra between the conventional single buffer

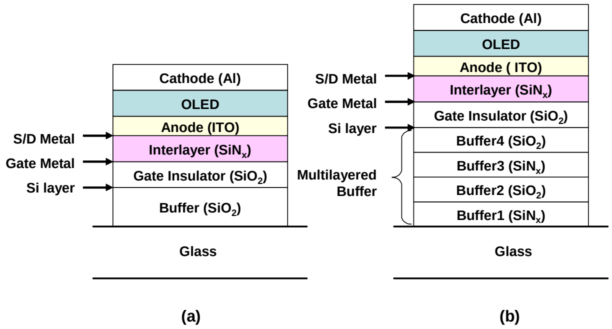


Figure 1 Cross-sectional Diagrams at pixel area (a) conventional structure for bottom emission (single buffer) and (b) structure proposed in this study for enhancing color gamut. (quadruple buffer)

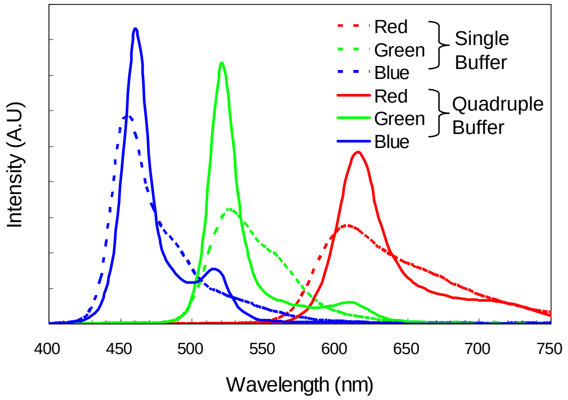


Fig. 2. Electroluminance spectra of red, green, and blue mono-colors for the single buffer and the quadruple buffer structures

structure and the quadruple buffer structure. The spectra are normalized by the electric current. The RGB EL spectra for the single buffer have broad curve shapes strongly dependent on photoluminance (PL) spectra of each emission layers.

In case of the quadruple buffer structure shown in Fig. 2, the EL spectra have narrow width, resulting in the improvement of color purity and color gamut. The narrow spectra shape is due to micro-cavity effect between the quadruple buffer and Aluminum cathode.[1]

As well known, the top emission AM-OLED can realize the color gamut more than 100%, also using the microcavity effect. In the top-emission type, one more OLED layer besides the RGB emission layer should be deposited with different thicknesses for the subpixel of each color to enhance the microcavity effect. Such a process needs the pixelized shadow mask like as in the fabrication of the emission layer, and needs more number of evaporation chamber. Since our bottom emission AM-OLED fabricates only RGB emission layer with the pixelized shadow mask, it has advantage over the top emission type, in terms of production cost and process simplicity.

There is distinctive difference in microcavity effect between bottom emission and top emission. In case of top emission where the microcavity effect comes from interference between highly reflective metals, the emittance curve determined by optical environment has single peak in the visible range. But in our bottom emission where the microcavity effect comes from interference between dielectric multilayer and reflective metal, the emittance curve can become the multi-peak curve which is determined by thicknesses of each layer in the multilayered buffer.

Our strategy in optical design of the quadruple buffer is to make the simulated emittance curve bear three peaks whose wavelengths correspond to the peak wavelength of the PL of RGB emitting layer, as shown in Fig. 3. The simulated emittance curve is determined by optical constant (n, k) and thickness of each layers consisting in TFT and OLED, but is irrespective of PLs of emitting layers. Our optical design program brings out the expected EL spectra, multiplying the PL of RGB emitting layer by the simulated emittance. According to the simulation, the EL spectra in our structure become narrower and the color gamut is enhanced drastically, compared to the single buffer structure, owing to the elaborately designed emittance.

The color points of the single buffer and the

Table 1 Color points and color gamut ratio (%) of the single buffer and the quadruple buffer structures

Buffer type	Color	Color Point	Color gamut (%)
Single Buffer	Red	0.629, 0.367	70.7
	Green	0.298, 0.655	
	Blue	0.146 , 0.111	
Quadruple Buffer	Red	0.663 , 0.335	89.1
	Green	0.242, 0.694	
	Blue	0.139, 0.112	

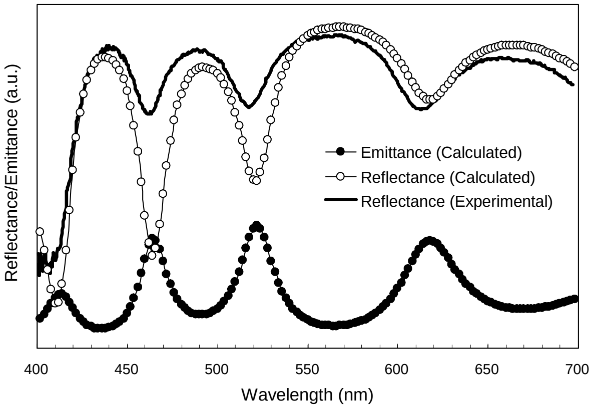
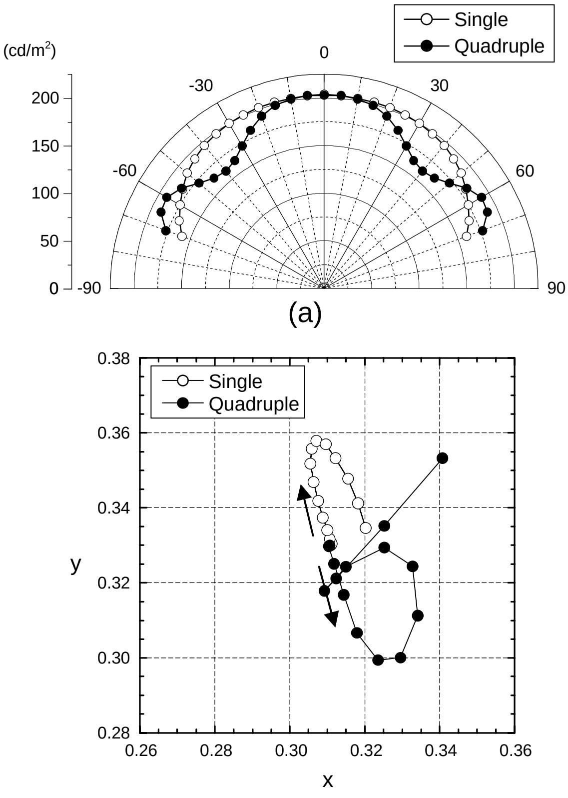


Fig. 3. Emittance and Reflectance spectra on AM-OLED panel are calculated with the quadruple buffer, using our simulation program. Reflection curve measured with micro-reflectance spectrometer is added.

quadruple buffer structures are summarized in Table 1. Color points of red and green mono-colors are moved toward NTSC standard color points so that the gamut of the quadruple buffer structure is increased by 19%, compared to the single buffer. We expect more increase in the color gamut if new emitting dopant being developed by our group is applied.

The simulation of the emittance curve can be validated by comparing the calculated and the measured EL spectra, but cannot be verified directly. A simple method to confirm if each layers of the TFT and OLED in the real panels are deposited as same as the simulation condition is to measure reflectance at the pixel area. According to our simulation, the interesting fact is found that the maximum of the emittance is corresponding to the minimum of the reflectance, as shown in Fig. 3. This rule is also applied to the top emission OLED.[2]



(b)

Fig. 4. (a) Viewing angle versus luminance of white color which is set up to 200 cd/m^2 at the normal direction. (b) Color shift of white which is set to (0.31,0.33) at the normal direction, when varying the viewing angle from 0° to 70°.

Figure 3 shows the experimental reflectance curve, measured with a micro-reflectance spectrometer joined to an optical microscope. The detecting spot size of the spectrometer is reduced less than 20 μm. This method has the merit that we need not destroy the OLED panel to probe the layer structures. According to Fig. 3, it is found that the wavelengths of minimums in the experimental reflectance fall in with those in the simulated reflectance.

Figure 4 compares dependence of luminance and color point on the viewing angle between the single buffer and the quadruple buffer panels. The panel is set to the luminance of 200 cd/m^2 and the color point of (0.31,0.33) at the normal view. As shown in Fig. 4(a), one of the advantages of the bottom-emission type is the wide viewing angle. The luminance at 70° from the normal direction in the bottom type is dropped by less than 20%, irrespective of the buffer type. However, we measured that the luminance of the top-emission type panel at the same angle is dropped by more than 80%, which results in decrease in the contrast ratio at the wide viewing angle.

Regarding the color shift dependent on the viewing angle, the white color point of the quadruple buffer goes around with the puzzling pattern and in the broader range, contrary to the single buffer. As the viewing angle is increased, optical path is lengthened and the peak position of the emittance curve moves to the blue shift. The luminance and color point of RGB mono-colors are changed more drastically than in the single buffer, which results in such a color shift of white according to the viewing angle. We are trying to further reduce the color shift of white.

3. Summary

Our study shows that bottom-emission type AM-OLED can realize the high color gamut up to 89% by fabricating the multilayered buffer and has sufficient competitiveness in terms of production cost and color gamut, compared to not only TFT-LCD but also top emission AM-OLED.

4. Acknowledgement

The authors acknowledge researchers in LG Philips LCD for their supports by the preparation of LTPS substrate. This work was supported by MOCIE of Korea.

5. References

1. R. H. Jordan, L. J. Rothberg, A. Dodabalapur, and R. E. Slusher, *Appl. Phys. Lett.*, **69[14]**, 1997 (1996).

2. Naoki Tanaka, *Flat Panel Display 2005*, p128 (2005).