Ambient Contrast Ratio Study of QD-OLED Devices

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ABSTRACT

Quantum dots are promising color conversion materials to achieve high resolution full color display with wide color gamut and low cost. In this work, we studied the ambient contrast ratio of QD-OLED devices and demonstrated an optimal structure to realize high contrast displays.

1 INTRODUCTION

Quantum dots (QD) are attractive for displays because of many advantages, such as narrow emission spectrum, tunable color and low cost solution process. One mature application of QDs is used as color enhancement films for liquid crystal displays (LCD) and the color gamut is significantly enlarged. Besides, QD as color conversion layer is proposed for self-emissive monochromatic devices to achieve full color by placing pixelized quantum dots on the emissive layer [1-3]. For organic light emitting diodes (OLED) displays, the difficulty to fabricate high resolution large area display with a high production yield by fine metal method is a longstanding problem. It is relatively simple to realize a large area full color display by adding QDs on a blue OLED, and blue light excites the QDs to emit red and green respectively. Moreover, full color micro LEDs are more inaccessible because of difficult mass transfer, and this QD color conversion method is advantageous in terms of feasibility. However, there is a concern that the upper QDs are excited by the ambient light and may emit light even the bottom emissive layer is off, and the light leakage results in a low contrast ratio. In this work, we studied the reflection of QDs films and full color QD-OLED, and proposed an optimal structure to suppress the leakage and improve the contrast ratio of the display.

2 RESULTS

Blue OLED is fabricated on an IGZO TFT backplane by vacuum evaporation. Green and red QD (CdSe/ZnS) films are fabricated by coating process. To maximize the color conversion efficiency, the thickness of the QD films are designed as thick as 10 μm. The emission spectra of blue OLED and converted red and green by QDs are shown in Fig.1. The color gamut is as large as 93% BT2020 due to the narrow emission band width.

Theoretically, the contrast ratio of self-emissive display is infinite. However, the contrast ratio is influenced by the ambient light due to the reflection. The ambient contrast ratio is defined as [4]:

$$\mathrm{ACR} = \frac{L_{on} + R * L_{ambient}}{L_{off} + R * L_{ambient}}$$

where L_{on} and L_{off} are the luminance of on state and off state of the display, respectively, $L_{ambient}$ is the ambient luminance, and R is the reflectivity. The reflection is measured by spectrophotometer CM2600d (KONICA MINOLTA, INC), and the individual reflection spectra are demonstrated in Fig.2. The reflectivity of the blue OLED is up to 53%, which is due to the strong reflection of the metal electrode, and the reflection for the whole spectrum is relatively same. The metal's reflection can be well solved by a circular polarizer. However, the mechanism of reflection of the QDs is different, which is actually the photoluminescence excited by the ambient light. Therefore, the reflection from 400 nm to 500 nm is weak for green QDs, which is mainly absorbed by the QDs, and strong reflection is exhibited within their emission spectrum. Similar phenomenon is shown for the red QDs. The overall reflection of the green and red QDs are 57.9 % and 18.7 %, which is a serious issue. To cut off the exciting light, corresponding color filters are added on the QDs, and a significant decrease of the reflection is obtained. However, the cutoff wavelength of the color filter doesn't exactly match the absorption of the QDs and part of the exciting light is leaked, resulting in the residual reflection.

The structure of the full color QD-OLED is demonstrated in Fig.3. Normal RGB color filters are fabricated by photolithography and a thick BM is patterned as the bank for QDs after the planarization. The Inkjet printing process is a simple and low cost process to fabricate large area QD display with high resolution [5,6]. Green and red QD inks are printed into the banks and the blue pixels are filled with colorless inks with scattering particles. Afterwards, the upper QD side are aligned with the bottom blue OLED and the QD-OLED is sealed with UV curable adhesive. A 6.6 inch full color QD-OLED device is exhibited in Fig.4. The optical microscope image of the RGB sub-pixels is shown in Fig.5.

The reflection spectra of the QD-OLED is exhibited in Fig.6. Due to the limited aperture ratio, the reflection of the full color QD-OLED is less serious than the QD films, but the reflectivity is still high. Even under a low intensity ambient light, the contrast ratio of the display is just 667. By adding a circular polarizer, the reflection is significantly suppressed and the contrast ratio is improved to 3670. Therefore, it is optimal to add a circular polarizer for the QD-OLED to achieve the high contrast ratio. The difference of contrast ratios between the two structures are demonstrated in Table 1. In the case of a high intensity ambient light, the contrast ratio of the optimal structure is 918, which is much higher than that of the normal structure.

3 CONCLUSIONS

In this work, we have analyzed the mechanism of the reflection of the QDs, and show effective reduction of the reflection by using the color filters to cut off the exciting light. Besides, we have fabricated a full color QD-OLED device by inkjet printing process, and proposed an optimal structure to suppress the reflection. The ambient contrast ratio of the QD-OLED is significantly improved with a circular polarizer.

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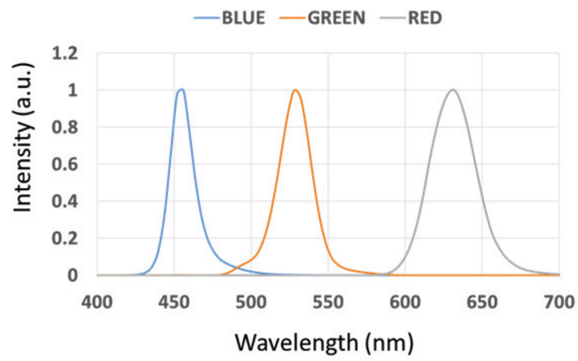

Fig. 1 The RGB emission spectra

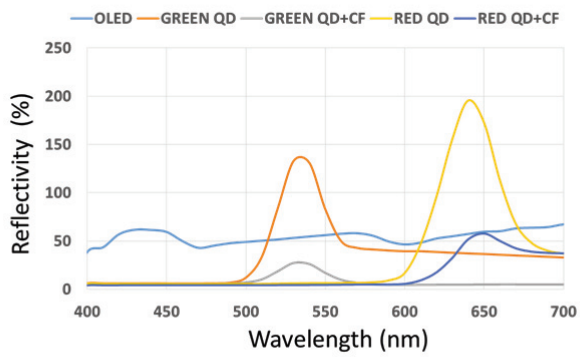

Fig. 2 The reflection spectra

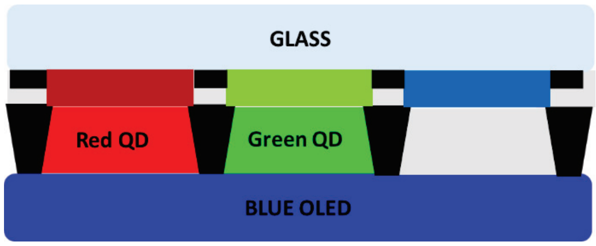

Fig. 3 The structure of full color QD-OLED

Fig. 4 The image of a 6.6 inch full color QD-OLED

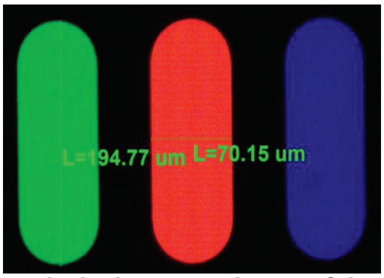

Fig. 5 The optical microscope image of the QD-OLED

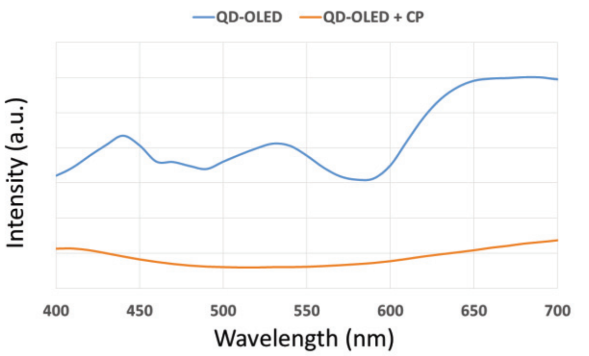

Fig. 6 The reflection spectra of QD-OLED w/o circular polarizer

Table 1. The reflectivity and ambient contrast ratio of full color QD-OLED w/o circular polarizer

		Full color QD-OLED	Full color QD-OLED with circular polarizer
ACR	Low intensity ambient light	665	3670
	High intensity ambient light	167	918