Top emission full color active matrix quantum dot light emitting display by overlay process

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Abstract

Top emission display is a widely used technology in OLED, due to its high open area, thus long lifetime and high brightness. But in quantum dot light emitting device, especially photo-lithography device, it is rarely reported. Here, we constrict the top emission device based on bottom emission device. The efficiency and lifetime are increased obviously. Then the red, green and blue top emission devices with overlay process are developed, which show negligible residue in each device. Finally, a 1.42' full-color top emission active matrix display is demonstrated with overlay process. This is the world's first paper to systematically illustrate from single color device to full color display.

Author Keywords

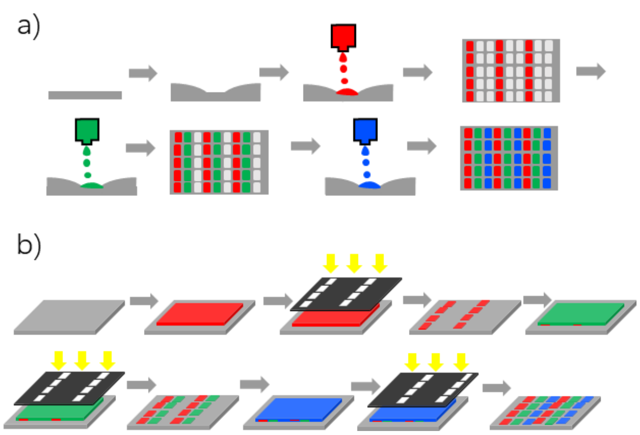
Top emission; Full color; (active matrix quantum dot light emitting device) AMQLED; photo-lithography

1. Introduction

Quantum dot light emitting diode (QLED) has attracted more and more attention due to its high luminance, long lifetime and feasibility to wet process thus low cost. Several processes were developed in academic and industrial area, such as ink-jet printing (IJP) [1], transfer printing [2], electrophoretic deposition [3], photo-lithography [4] and so on. Among them, ink-jet printing is most well-developed, especially the ink-jet printing OLED has been commercialized recently. However, the pixel pitch index (PPI) of ink-jet printing is limited by the align accuracy of the print head, bandwidth of the bank and the diameter of the droplet. Though there are several demo of ink-jet printing beyond 300 PPI, it is hard to be large scaled mass production. So the application of IJP is limited to middle to large size display, for example monitors, TVs and even notebooks.

Photo-lithography is known as a high resolution pattern process, see scheme 1. Thanks to the organic ligands of quantum dot, photo sensitive groups are easy to be modified to attach to quantum dot or mix into the ink. So the photo-lithography quantum dot can be realized by the crosslinking of the ligands. And a PPI of more than 2000 is also obtained [5], manifesting its potential in full size displays. Bottom emission device and panel are first achieved, because of its simple requirement. Meanwhile top emission device has high open area in panel, so longer lifetime and higher luminance are reasonable. What's more, the efficiency of device also can be enhanced due to the micro-cavity in top emission device. Although top emission device has so many advantages, there is little reports to discuss performance of top emission photo-lithography quantum dot light emitting device.

Herein, we firstly utilize the crosslinking character of quantum dot to fabricate the bottom emission photo-lithography device. Then the top emission device is established based on the bottom emission device. To get full color display, overlay of RGB color is also developed and finally we integrated the device to the LTPS backplane, and successfully obtained the top emission display.



Scheme 1. Pattern process flow of a) inkjet-printing and b) photo-lithography.

2. Single Color Top Emission Device

There are several difference between photo-lithography device and non-lithography device. For example, the photo-sensitive groups would quench the photoluminescence of quantum dot and the developing process would damage the film of the device [6]. To avoid these influence, we carefully chose the photo-sensitive groups and optimized the developing process. Limited impact is achieved as reported before [7]. Then the top emission device is fabricated based on the photo-lithography device. As shown in table 1 and figure 1, the efficiency of the RGB device is increased, especially the red one which is about 2.46 times. Owing to the higher efficiency, the current density to meet the same brightness is decreased. According to the lifetime transfer formula, the lifetime of the device is sure to be enhanced.

Table 1. Relative efficiency and lifetime of bottom and top emission device

		Bottom emission	**Top emission**
R	*EQE*	100%	246%
	T95	100%	171%
G	*EQE*	100%	145%
	T95	100%	305%
B	*EQE*	100%	148%
	T95	100%	128%

Figure 2 also displays the difference J-V curves of Red bottom and top emission devices. The current density is reduced at the same voltage. It is because the total film thickness of top emission device is thicker than bottom one to guarantee the optical length of micro cavity. So the carrier transfer route is longer. This phenomenon is more obvious in red device because of the longer wavelength.

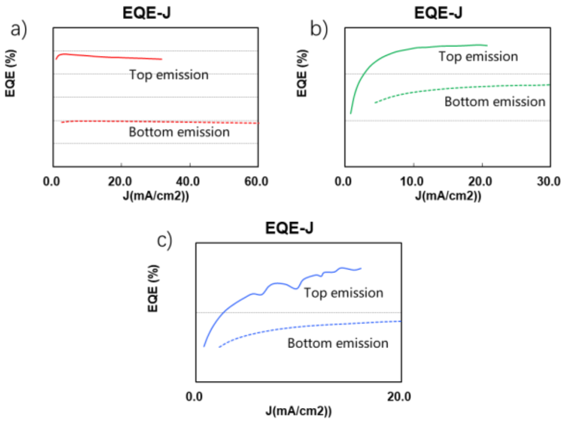


Figure 1, the EQE-J curves of top emission and bottom emission device. a) Red, b) Green, c) Blue.

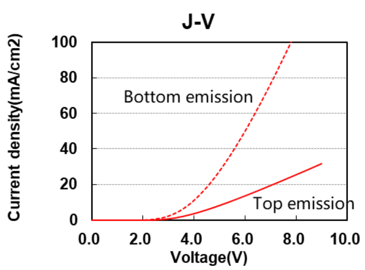


Figure 2, the J-V curve of red top emission and bottom emission device.

3. Full Color Overlay Top Emission Device

Three color integration is a key route to full-color display. Different from ink-jet printing, one color is deposited on another color's pixel area in overlay process. Though the developing process is performed, color residue is still occurred. And multi film deposition and developing steps would also influence the film quality and the film interface of the device [8]. After carefully optimized the overlay process, we got a decent device performance as shown in table 2. We can see the efficiency is almost consistent from single color to three color device while the lifetime is dropped seriously, especially the green device. Thanks to the high resolution of photo-lithography process, the open area of the display can be larger than fine metal mask deposition OLED and ink jet printing QLED. Thus the lifetime requirement is reduced for photo-lithography. Figure 3 shows the lifetime we obtained in three color device with overlay process is compared to demand of the smart phone. The red and green lifetime is larger enough for smart phone while the blue is lacking. Therefore, enhancing the intrinsic lifetime of blue QLED and the transfer efficiency of lifetime from single to three color are both important.

The Chroma of the device can signal the residue of quantum dot during the overlay process. The spectra of red, green and blue devices before and after overlay process are presented in figure 4 and its corresponding Chroma is summarized in table 3. The red, green and blue spectra are neat without the other two color residue. The main peak of the spectra is a little shift because of the micro cavity. These results indicate that the Chroma of device are not variable after overlay process. The color gamut of three color devices can reach to 87% BT2020.

The above results manifesting photo-lithography of quantum dots light emitting device is a feasible solution to display.

Table 2. Relative efficiency and lifetime of single and three color devices

		Single color	Three color
R	*EQE*	100%	95%
	T95	100%	77%
G	*EQE*	100%	99%
	T95	100%	34%
B	*EQE*	100%	103%
	T95	100%	68%

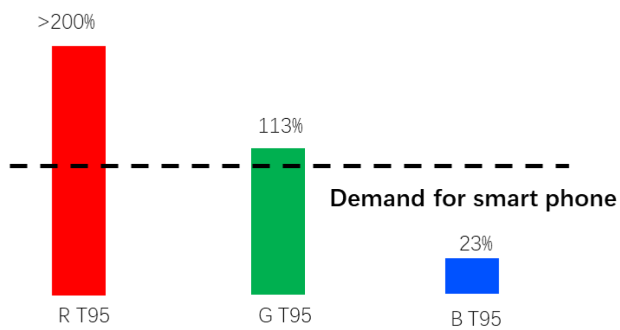


Figure 3, lifetime of Red, Green and Blue with overlay compare to the demand for smart phone.

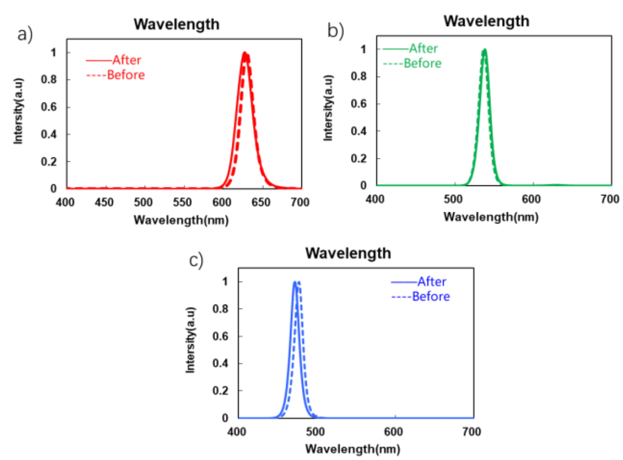


Figure 4, the spectra of the devices before (dot line) and after (solid line) overlay process. a) Red, b) Green, c) Blue.

Table 3. The Chroma of red, green and blue devices before and after overlay process

	Before overlay	After overlay
R	(0.700, 0.298)	(0.694, 0.304)
G	(0.208, 0.767)	(0.222, 0.756)
B	(0.108, 9,101)	(0.122, 0.070)

4. Full Color Overlay Top Emission Display

After we got the full color overlay top emission device, we integrated this device system to low temperature poly-silicon (LTPS) backplane to fabricate the display [9]. Compare to bottom emission, the light output pathway needn't considered for top emission. So the area for lighting and circuit is increased which is more flexible to pixel and circuit design. We have demonstrated the 1.42inch top emission wearable display based on overlay process. All the functional and emitting layers are optimized to obtain the correct Chroma and high luminance. The image of the display is shown in figure 5.

Figure 5. Image of 1.42inch full color AMQLED display panel with overlay process.

5. Summary

To enhance the performance of quantum dot light emitting display, we developed top emission technology from device to display. Specifically, we constrict the top emission device based on bottom emission device. And the efficiency and lifetime are increased obviously. Then the red, green and blue top emission devices with overlay process are prepared, which show negligible residue in each device. Finally, a 1.42' full-color top emission active matrix display is demonstrated with overlay process. All this manifest that top emission overlay quantum dot light emitting display is a feasible solution to high performance application.

6. References

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