Hybrid Full Color Micro-LED Displays with Quantum Dots

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Abstract

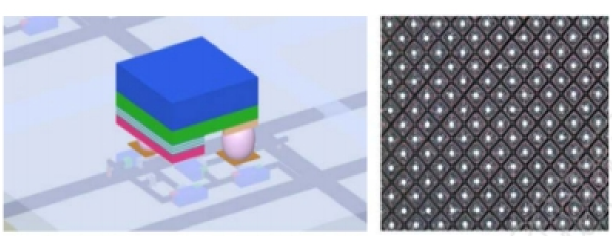
We propose a full color displays with high brightness blue Micro-LED array, using red and green photoluminescence quantum dot as the color conversion material, and successfully begin this study with using a Mini-LED array to excite red and green quantum dot to form a red and green picture.

Author Keywords

Blue Micro–LED Array; Quantum Dot; Full Color Displays

1. Introduction

High efficiency III-Nitride-based light emitting diodes (LEDs) have been used in a wide variety of applications such as flat-panel displays, solid-state lighting and striking signal lamp indications due to their excellent properties of self-illumination, low power consumption, high brightness, long life-time and wide spectral regions[1]-[3]. Recently, Micro-LED have been developed as a promising candidate for micro-display and micro-projection systems. The color-rendering property of Micro-LED is an important aspect in its applications[4,5]. Although a high color rendering index can be achieved by combining red, green, and blue (RGB) Micro-LED in an appropriate proportion, the drive circuit of such Micro-LED system is complicated and the full-color displays with red, green, and blue Micro-LEDs still suffers from the technical problems of high-density mass transfer. Moreover, because the degradation rates of RGB Micro-LEDs are different, it is difficult to maintain the color rendering index during operation. Furthermore, to enable emission of light colors, blue LEDs coated with phosphors were reported previously. However, as the particle size of phosphors is several micrometers and the size of the Micro-LED is dozens of micrometer, only a few phosphors particles can be coated onto the Micro-LED, and their color conversion efficiency is low. To solve the aforementioned problems, quantum dots (QD) are used as color conversion material[6]-[8].



(a) (b)

Figure 1. (a) Single Micro-LED Light Emitting Cell Structure (b) Micro-LED array device structure.

As one of the emerging and most promising new display technologies, quantum dot has the advantages of high quantum efficiency, narrow half-width and wide color gamut which can significantly improve the color gamut and reduce the power consumption. The applications of quantum dot display technology mainly includes two aspects, the quantum dot light-emitting diode display technology based on the electroluminescence quantum dot and the display technology based on photoluminescence quantum dot. Although quantum dot display has many advantages mentioned above, it still suffer from the problem of the lack of a more stable and efficient blue light materials and devices of quantum dot[9,10].

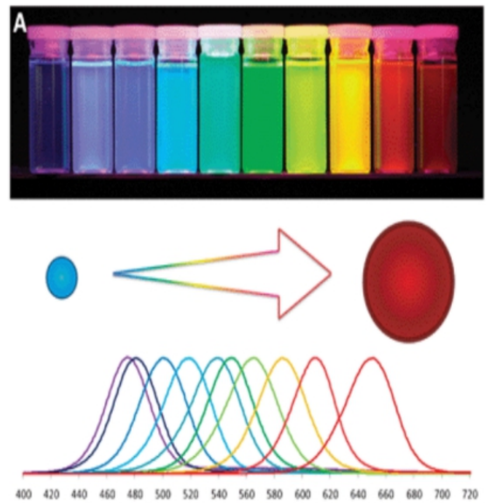


Figure 2. Unique photo-physical properties of Quantum Dot and narrow size-tunable light enables precise control over the color via varying the nanoparticle size.

In this article, we propose a full-color Micro-LED displays that uses blue-GaN Micro-LED to excite red and green photoluminescence quantum dots, which is shown in Figure 3. This will not only demonstrate the high efficiency, high brightness and good stability of GaN-based blue-light Micro-LEDs, avoiding the poor stability and low efficiency of blue quantum dot, but also play the advantages of narrow FWHM and wide color gamut of quantum dot.

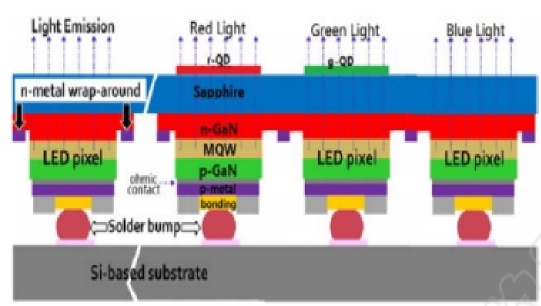


Figure 3. Full-color method for Micro-LED that uses blue-GaN Micro-LED to excite red and green photoluminescent quantum dot.

2. Experiment

In order to study the feasibility of full-color method for Micro-LED shown in Figure 3, we first used a Mini-LED array to excite quantum dot instead of using a Micro-LED array as it could provide us a larger display area and a more obvious display effect. The Mini-LED array we prepared has a peak wavelength of 455nm, its full width at half maximum (FWHM) is less than 15 nm. The resolution of the array was 32 × 32 and the pixel pitch of the Mini-LED array was 0.6mm. The monochromatic LED chip was directly bonded onto a custom-designed printed circuit board which is made of flexible and transparent substrate. We also prepared some quantum dot with red and green color.

2.1 Mini-LED array with red and green quantum dot film

In the first experiment, we used the array to respectively excite red quantum dot and green quantum dot. The concentration of these quantum dot solution were both 10mg/ml. The emission peak of the red quantum dot was 632 nm, the quantum yield was 78.8% and the full width at half maximum (FWHM) was 34.1 nm. For the green quantum dot, the emission peak was 523 nm, the quantum yield was 90.6% and the FWHM was 25.6nm. The emission and absorption spectrum of red and green quantum dot are shown in the following pictures.

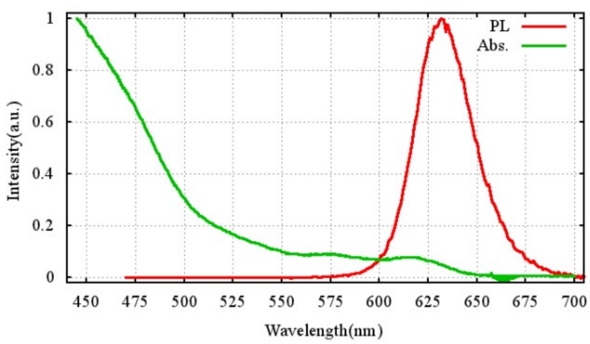


Figure 4. The Abs and PL of red quantum dot.

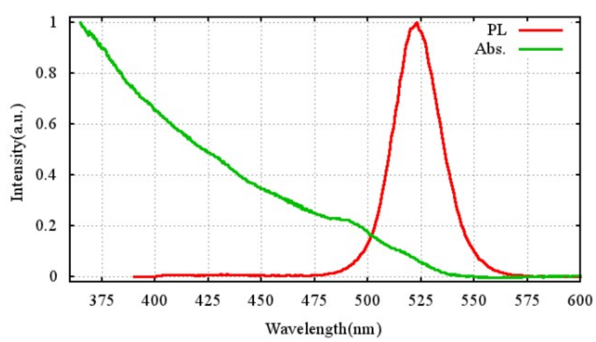


Figure 5. The Abs and PL of green quantum dot

We dropped the quantum dot solution on a 0.15 mm thin round glass sheet through a pipette. The diameter of the glass sheet was 3 cm, which was just enough to cover the Mini-LED array we prepared. The volume of the quantum dot solution was 400 microliters and the concentration of the red and green quantum dot solution were 10mg/ml. The glass sheet was then spin-coated on a spin coater with a rotation speed of 1000r/min and a spin-coating time of 40s. Thus, we obtained a thin layer of quantum dot film on the glass sheet, then placed the glass slide coated with quantum dot film right above the Mini-LED array, observing the color conversion effect, they are shown in Figure 6.

(a) (b)

Figure 6. (a) Color conversion effect of red quantum dot film. (b) Color conversion effect of green quantum dot film.

2.2 Mini-LED array with quantum Dot film and DBR

In this experiment, in order to decrease the blue light after exciting the red and green quantum dot, we used a DBR film to selectively reflect the blue light emitted by Mini-LED without reflecting the red or green light emitted by red or green quantum dot. The transmission spectrum of the DBR is shown in Figure 7.

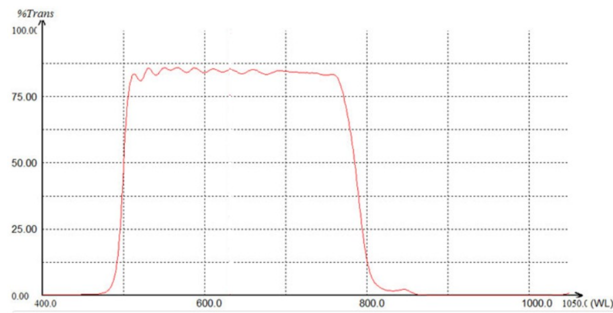


Figure 7. The transmission spectrum of the DBR.

We respectively put a DBR film on the top of red quantum dot film and green quantum Dot film, then placed the red and green quantum dot film right above the Mini-LED array, observing the conversion effect. The display effect of quantum dot film with DBR are shown in the following picture.

Figure 8. (a) The conversion effect of red quantum dot film with DBR. (b) The conversion effect of green quantum dot film with DBR.

3. Result and Discussion

As can be seen in the Figure 6, since the quantum dot film that we obtained was thin, its absorption rate of the blue light emitted by Mini-LED was extremely low, and the light emitted through the quantum dot film contains many blue light. However, we never want a thick quantum dot film covering on a display when we desire to get a thin displays. In addition, some other experiments showed that even a quantum dot film with thickness of 2 mm could not completely absorb the blue light as well.

For the experiment in 2.2, it showed that by using a DBR that can selectively reflects blue light, the exitance of blue light from quantum dot film would significantly decrease and the color conversion effect would be much better, this experiment showed a significant way to decrease the blue light that excites the red and green sub-pixel quantum dot in the method of using blue-light Micro-LEDs to excite red and green quantum dots to realize full-color display. However, how to reduce the exitance of blue light more effectively is still an important problem in the method of using blue light Micro-LED and red, green quantum dots to achieve full color displays.

For the next research of using Micro-LED and quantum dots to achieve full color displays. we will try to form the red and green sub-pixels with a patterned quantum dot film, and we will also design a better DBR with suitable structure to selectively reflect the blue light without reflecting the red and green light, then we will make a hybrid full color Micro-LED Displays with quantum dot.

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5. References

[1] M. R. Krames et al., "Status and future of high-power light-emitting diodes for solid-state lighting," J. Display Technol., vol. 3, no. 2, pp. 160–175, Jun. 2007.

[2] K. Chilukuri, M. J. Mori, C. L. Dohrman, and E. A. Fitzgerald, "Monolithic CMOS-compatible AlGaInP visible LED arrays on silicon on lattice-engineered substrates (SOLES)," Semicond. Sci. Technol., vol. 22, no. 2, pp. 29–34, 2007.

[3] H. X. Jiang, S. X. Jin, J. Li, J. Shakya, and J. Y. Lin, "III-nitride blue microdisplays," Appl. Phys. Lett., vol. 78, no. 9, pp. 1303–1305, 2001.

[4] Z. Gong et al., "Efficient flip-chip InGaN micro-pixellated light-emitting diode arrays: Promising candidates for micro-displays and colour conversion," J. Phys. D Appl. Phys., vol. 41, no. 9, ap. 1459–1469, 2008.

[5] Z. J. Liu, W. C. Chong, K. M. Wong, and K. M. Lau, "360 PPI flip-chip mounted active matrix addressable light emitting diode on silicon (LEDoS) micro-displays," J. Display Technol., vol. 9, no. 8, ap. 678–682, Aug. 2013.

[6] Z. J. Liu, W. C. Chong, K. M. Wong, and K. M. Lau, "360 PPI flip-chip mounted active matrix addressable light emitting diode on silicon (LEDoS) micro-displays," J. Display Technol., vol. 9, no. 8, ap. 678–682, Aug. 2013.

[7] Z. Liu, W. C. Chong, K. M. Wong, and K. M. Lau, "GaN-based LED micro-displays for wearable applications," Microelectron. Eng., vol. 148, pp. 98–103, Dec. 2015.

[8] S. Kishwar, K. Ul Hasan, N. H. Alvi, P. Klason, O. Nur, and M. Willander, "A comparative study of the electrodeposition and the aqueous chemical growth techniques for the utilization of ZnO nanorods on p-GaN for white light emitting diodes," Superlattices Microstruct., vol. 49, no. 1, pp. 32–42, Jan. 2011.

[9] H.-Y. Lee, Y.-C. Lin, I.-H. Chen, and C.-H. Chao, "Effective color conversion of GaN-based LEDs via coated phosphor layers," IEEE Photon. Technol. Lett., vol. 25, no. 8, pp. 764–767, Apr. 15, 2013.

[10] K.-J. Chen et al., "Resonant-enhanced full-color emission of quantum-dot-based display technology using a pulsed spray method," Adv. Funct. Mater., vol. 22, no. 24, pp. 5138–5143, Dec. 2012.