High efficiency LCDs using Quantum Dot Films

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Abstract

By incorporating quantum dot films into the backlight, new-generation LCDs can achieve significantly higher power efficiency. For displays with sRGB color gamut, 20% higher power efficiency can be obtained. For wide color gamut, quantum dot film extends color space by 50% to 100% of the Adobe RGB 1998 standard while delivering the same brightness as current sRGB displays.

Author Keywords

Backlight; color gamut; color saturation; quantum dot; nanocrystal; quantum dot film; RGB; LED; display

1. Objective and Background

Most of today's LCDs use white LEDs as the backlight illumination source. These white LEDs have a blue LED chip combined with a broad-band yellow phosphor, e.g., Ce-doped YAG [1]. The red, green and blue primary colors required by the LCD are achieved by using color filters with band-pass in the red, green, and blue spectral region, respectively [2]. Inherently, yellow phosphor is not well-suited for green and red primary colors due to the low spectral weights in the green and red regions. For current main-stream products that utilize the sRGB color gamut, relatively narrow-band color filters are used that have low optical transmission and this results in lower power efficiency (Figure 1). For mobile products where battery life is critical, the color gamut of LCDs has been running short of sRGB as a result. Only in the past two years did the leading mobile displays catch up in color performance and conform to the sRGB standard. For higher color gamut standards, e.g., Adobe-RGB and DCI-P3, LCD solutions remain elusive even for wall-plug applications.

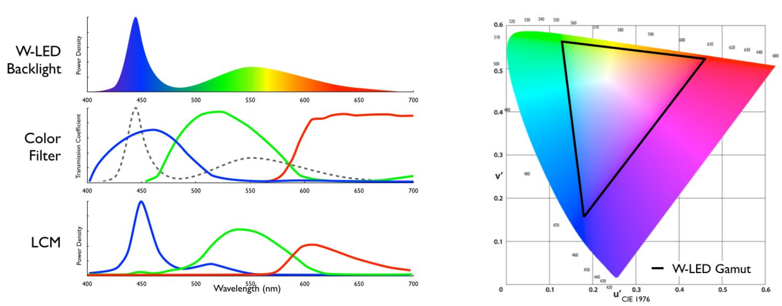

Figure 1 White LED backlight spectrum requires narrow-band color filters with low optical transmission to achieve sRGB gamut

The advent of quantum dots [3], a new emitter material, can significantly boost the power efficiency of LCDs and enable high color gamut displays. Quantum dots are synthesized in solution chemistry with narrow size distribution at relatively low temperatures, <350C. These quantum dots have narrow emission linewidths, less than 35nm in FWHM and tunable wavelengths (500nm to 650nm) (Figure 2). In the last couple of years, they have improved in quantum efficiency to >90%, increased lifetime to >50,000 hours in backlight applications, and lowered in cost [4]. As a result, quantum dots are beginning to be adopted in main-stream display applications. Furthermore, quantum dot films offer simple display integration by replacing the bottom diffuser in the backlight film stack.

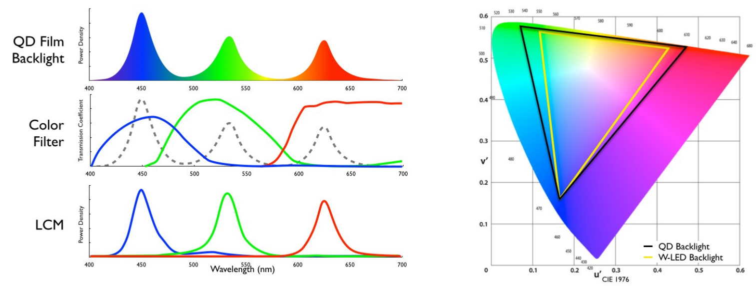

Figure 2 Quantum dot film backlight spectrum achieves wide color gamut with highly transmissive color filters due to it's narrow line-width spectrum

In this paper, we will first discuss how quantum dot films can improve the power efficiency of existing sRGB displays through the use of higher transmissivity color filters. Then we will show that quantum dot films, when combined with the current mainstream CF72 color filters, can deliver wide color gamut standards (e.g., Adobe-RGB and DCI-P3) while maintaining brightness compared to white LED solutions at the sRGB color gamut. In other words, quantum dot films offer "free" color saturation.

2. Results

(2-A) Power efficiency of sRGB solution with quantum dot film.

To demonstrate the power efficiency of quantum dot films for sRGB color gamut, we took two identical tablets from the market and retrofitted the first one (unit 1-A) with white LEDs and the second one (unit 1-B) with blue LEDs combined with a quantum dot film. To ensure a proper power efficiency comparison both white and blue LEDs are sourced from the same vendor and have the same binned blue chips. The white LEDs are packaged the same way as the regular product with YAG phosphors and the blue LEDs have clear encapsulation instead. In the case of the quantum dot film retrofit, the bottom diffuser in the film stack is replaced by a sheet of quantum dot film. The green and red emission wavelengths for the quantum dot film are 545nm and 610nm, respectively. These particular wavelengths are chosen so that they, when matched up with the color filters in the display, can deliver the green and red primaries of sRGB precisely.

	White LEDs	White LEDs	QD film + Blue LEDs
Color Filter	CF60	CF72	CF60
Color Gamut (NTSC)	60%	72%	72%
Relative Brightness	100%	90%	110%

Table I: Comparison of LCD brightness with white-LEDs and QD films/blue-LEDs for sRGB color gamut.

Compared to the white-LED retrofit unit, the quantum dot film/blue-LED retrofit unit has 10% higher brightness as shown in table I. Both units have closely matching white point at D65, which is typical for these products. The color filters in the units are CF60. As a result, the white-LED retrofit unit has a 60% NTSC color gamut. The quantum dot film/blue-LED retrofit unit, in contrast has an improved 72% NTSC color gamut (sRGB). It is because of the narrow emission spectra of quantum dot film backlight, that when combined with CF60 color filter, produces a display that is capable of delivering sRGB color gamut. The reason that quantum dot film/blue-LED retrofit has higher brightness than the white-LED unit is the following. On the backlight level, the two retrofit units have comparable brightness. The quantum dot film spectra is designed so that the green and red peak wavelengths are closely matched to the transmission peaks of the green and red color filters. In contrast, the white LED spectrum has relatively low spectral weights in the green and red regions. Therefore, higher transmission is achieved with the quantum dot film/blue-LED retrofit unit than the white-LED retrofit unit. In essence, the spectral emission from the quantum dot film/blue LED-retrofit is better matched to minimize light loss when passing thru the color filter compared to the white-LED retrofit unit.

In order to compare the quantum dot film/blue-LED solution to white-LED solution at the same color gamut, we modeled the brightness of the white-LED solution by using a CF72 color filter. Our modeling results show that using a CF72 color filter reduces the LCD brightness by close to 10% compared to a CF60 color filter (see Table I). This is rather typical in LCDs. Therefore, a 20% net brightness improvement is obtained by using a quantum dot film/blue-LED backlight with CF60 color filter versus a white-LED backlight with a CF72 color filter when both displays have the same color gamut: sRGB.

(2-B) "Free" color at 100% coverage of Adobe 1998 using quantum dot films.

To demonstrate 100% coverage of Adobe 1998, we again took an existing LCD tablet product and retrofitted one unit with white LEDs (2-A) and another unit (2-B) with blue LEDs combined with a sheet of quantum dot film. In this case, the LCD product is designed for sRGB color gamut and therefore has a CF72 color filter. Compared to the retrofit unit 1-B, retrofit unit 2-B uses a sheet of quantum dot film with different a green wavelength, 530nm, while the red wavelength at 610nm is the same as used in the sRGB comparison above. These wavelengths are chosen such that when combined with the CF72 color filter, Adobe-RGB color primaries can be achieved. By using the same efficiencies described in the earlier sRGB comparison, the quantum dot film/blue LED unit provides “free” color by improving the color gamut to AdobeRGB while maintaining the same brightness as the white LED unit which is limited to achieve only sRGB color gamut.

	White LEDs	**QD Film/Blue LEDs**
Color Filter	CF72	CF72
Color Gamut (% NTSC1976)	sRGB, 72%	Adobe-RGB, 99%
Relative Brightness (%)	100%	102%

Table II: Comparison of white LEDs and QD film/Blue-LEDs on LCD displays with CF72 color filter.

As shown in table II, retrofit unit 2-B with quantum dot film/blue-LED delivers the same brightness as unit 2-A with white LEDs while significantly expanding the color gamut from sRGB to Adobe-RGB. Both units have white points at D65.

3. Impact

Quantum dot films, with narrow emission line-widths, tunable wavelength, and high quantum efficiency, offer the ideal backlight spectra for LCD displays. When combined with today's high efficiency blue LEDs, quantum dot films can enable 20% higher power efficiency for sRGB color gamut displays by using higher transmission color filters. Furthermore, quantum dot films are capable of delivering wide color gamut solutions (e.g., Adobe-RGB and DCI-P3) without any penalty in power efficiency compared to today's sRGB displays using white LEDs. The blue LEDs and the color filters that are needed to realize these gains are already available in the market to allow quick adoptions.

4. References

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