Single-Layer Fabry-Pérot Interferometric Display for Both Color and Intensity Modulations

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Abstract

We present an interferometric modulator display featuring a single layer of Fabry-Pérot filter using blue phase LC and a quantum-dot backlight. With this design, no polarizers and color filters are needed, and both color and intensity can be tuned by electrically controlling LC's birefringence. Based on simulations, device performance has been numerically studied.

Keywords

interferometric modulator display; Fabry-Pérot filter; blue phase liquid crystal; quantum dot

1. Introduction

Liquid crystal displays (LCDs) are nowadays ubiquitous in consumer electronics ranging from small handheld devices to large-size televisions [1]. However, in terms of light utilization, LCDs in nature are not an energy efficient solution, mainly suffering from polarizers and color filters, which could result in a low optical throughput typically around 5% [2]. To date, a number of approaches have been proposed to address the above issue. For instance, the replacement of absorptive polarizers with reflective polarizers enables the recycling of light in the backlight unit [3]. A special LC panel serving as a stencil mask to provide gray scale modulation is developed as a polarizer-free display [4]. Furthermore, field sequential color (FSC) driving scheme could eliminate the need for color filters, but the color breakup accompanying with moving objects is basically inevitable [5]. In order to develop an eco-friendly display other than LCDs, Iridigm *et al.* invented a reflective type display system based on interferometric modulation (IMOD) technology [6]. This system offers low energy consumption as well as color rendering, however the inherent bistable nature of micro-electro-mechanical systems (MEMS) greatly limits the resolution and color gamut of the display. In this paper, we propose an interferometric modulator display featuring a single Fabry-Pérot (FP) filter using blue phase liquid crystal (LC) and a quantum-dot (QD) backlight, which enables both color and intensity modulations. Its advantages are identified as simple structure, super-low power consumption, polarization independence, and fast response.

2. Operational Principle

Proposed Structure: Figure 1 is a schematic drawing of the cross section of the proposed structure, where blue phase LC is sandwiched in between two reflective, metallic electrodes to form an FP filter. The adoption of blue phase LC could save the alignment layers required by other types of LCs [7]. The top electrode is grounded, whereas the bottom electrode could be driven by thin film transistors (TFTs). Underneath the FP filter, a QD backlight is laminated to emit the unpolarized mixed white light, which incorporates red (R), green (G), and blue (B) spectra together, as shown in Fig. 2. The FWHM of QDs is preferably as narrow as possible, for the sake of color shift issue.

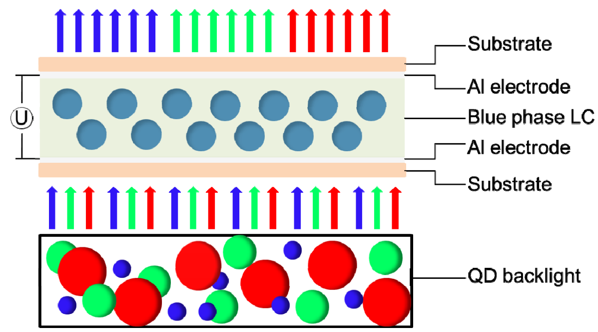

Figure 1. Principle of light absorption of E-type dye when in the off-state and (b) on-state.

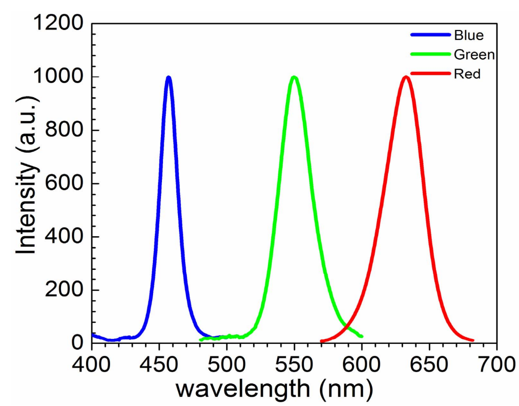

Figure 2. RGB spectra of quantum-dot backlight.

Color Modulation: To illustrate its operational principle, transmittance of a single FP filter with an LC interlayer can be expressed as the Airy function [8]

$$T = \frac{1}{1 + F\sin^2(\delta/2)} \quad (1)$$

where

$$F = \frac{4r^2}{(1-r^2)^2} \quad (2)$$

and

$$\delta = \left(\frac{2\pi}{\lambda}\right) 2 n_{LC} d \cos\theta_i \quad (3)$$

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Herein F is defined as fineness, which determines the transmission bandwidth of an FP filter. δ denotes the phase difference between two successive reflections. r is the reflectance of both the top and bottom electrodes. n_{LC} and d are the average refractive index and thickness of the LC interlayer, respectively, and θ_i is the incident angle. By applying a voltage to the blue phase LC interlayer, the refractive index n_{LC} of the LC can be tuned, so as to change the phase difference δ. As a result, the central wavelength of filter's bandwidth can be adjusted for achieving the color modulation.

Blue Phase LC: In the voltage-off state, blue phase LC is optically isotropic and this refractive index can be given by [9]

$$n_{iso} = \sqrt{(2n_o^2 + n_e^2)/3} \qquad (4)$$

where n_o and n_e are the ordinary and extraordinary refractive indices of the LC composite, respectively. If exposed to an external electric field E, n_o and n_e will be subject to the following changes [10]

$$n_o(E) = n_{iso} - \frac{\lambda K E^2}{3} \qquad (5)$$

$$n_e(E) = n_{iso} + \frac{2\lambda K E^2}{3} \qquad (6)$$

where K stands for the Kerr constant and E is the amplitude of the electric field. Since the LC molecules are stretched along the vertical electric field, for the case of normal incidence, either s-wave or p-wave encounters the same refractive index $n_o(E)$. In other words, this device is independent of the polarization.

Color Modulation: As for intensity modulation, by controlling the overlapped area between filter's spectrum and QD's spectra, the intensity of the transmitted light can be modulated as well. Moreover, as the blue phase LC is optically isotropic and its index ellipsoid is stretched along the direction of electric field that is perpendicular to the substrate, the modulation of light is actually independent of polarization, which can greatly improve the light utilization. In addition, the fast response of blue phase LC would even make possible the field sequential color, which may triple the display resolution.

3. Results and Discussion

In our simulations, the reflectance of the metallic electrode is set as 80% and the thickness of the FP filter as 500 nm. A more detailed list of parameters is given in Table 1. Figure 3 plots the spectrum of FP filter in the visible regime, when the LC's refractive index equals to 1.65. In this case, there are two peak wavelengths of FP filter, one of which matches with the central wavelength (λ=550 nm) of the green color of QD backlight. In this sense, one can also say that the green color is selected. By superimposing FP's spectrum with QD's, the final spectrum of the emerging light from the device is calculated as in Fig. 4. If the color is fixed at 550 nm but to change its intensity, we could vary the LC's refractive index from 1.4 to 2.0, as shown in Fig. 5. As can be seen, the contrast ratio of our device—the ratio of the maximum transmittance to the minimum one—can hit over 100:1 as long as the LC's refractive index change could be greater than 0.24, which is, as a matter of fact, technically available.

Table 1. Parameters used in the simulation.

Reflectance of electrode	80%
n_o	1.580
n_e	1.782
Δn	0.202
n_{iso}	1.650
Cellgap	500 nm

4. Conclusions

In conclusion, we have demonstrated an interferometric modulator display with a novel structure featuring a single-layer FP filter using blue phase LC and QD backlight, which can enable both color and intensity modulations. Its operational principles are briefly described, followed by simulation results. This type of display is typically suitable for green display applications for requiring no polarizers and color filters. In addition, compared with other LC-based FP filters, our solution is independent of polarization, which could double the light utilization.

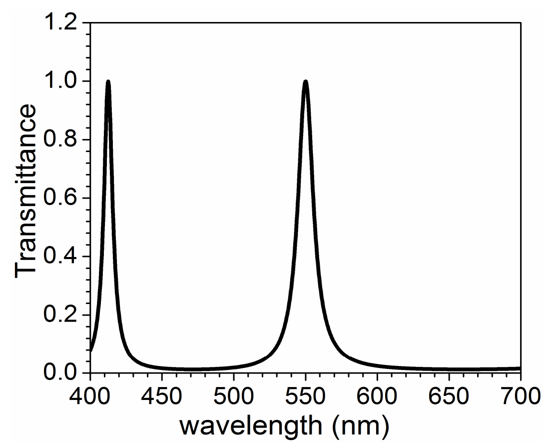

Figure 3. Spectrum of the blue phase LC FP filter when n_{LC}=1.65.

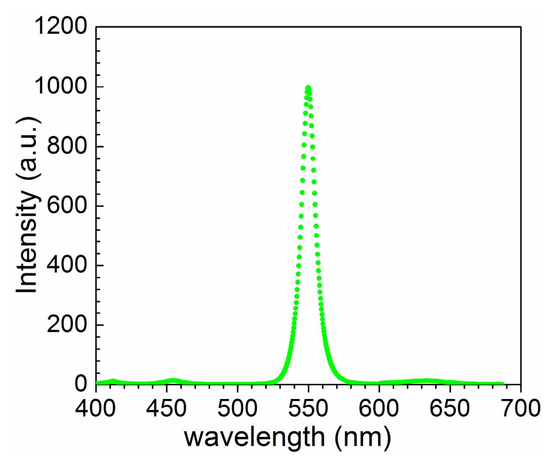

Figure 4. Spectrum of the emerging light from the device when n_{LC}=1.65.

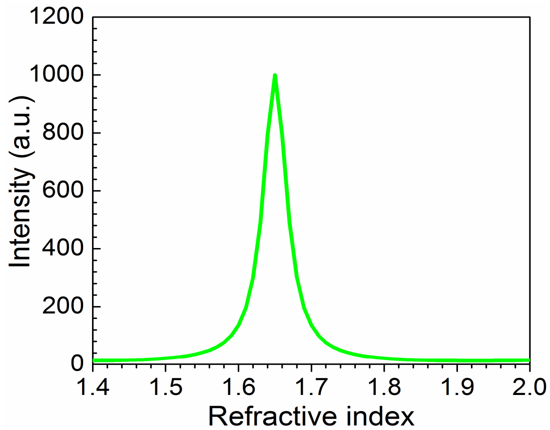

Figure 5. Intensity modulation through the variation of LC's refractive index.

5. Acknowledgements

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