P-185: Single Cell Gap Single Mode Transflective Liquid Crystal Display with High Optical Efficiency

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Abstract

A transflective liquid crystal display with single cell gap single mode structure is reported. Electrically controllable birefringence (ECB) mode is applied at both reflective (R) and transmissive (T) regions. With optimized orientation of only two compensation films, very high brightness is achieved for both R and T regions. At the same time, the dark state has nearly no color dispersion. High contrast ratio is achieved. Moreover, the electro-optical characteristics of R and T regions match with each other well. The fabrication process is also very easy.

1. Introduction

Transflective liquid crystal displays (LCDs) have attracted great interest especially for mobile applications because they combine the advantages of both transmissive and reflective LCDs: good visibility in any environmental light conditions and low power consumption.

In general, the design of the transflective LC cell is classified into two types. One is that the pixels of the transflective LCDs are separated into R and T sub-pixels. Cell gap of R sub-pixels is different from that of the T sub-pixels [1, 2]. The other type is that the transflective LCDs having the same cell gap [3, 4]. The double cell gap approach obtains good optical characteristics, since R and T parts can be optimized separately. However, it requires complex fabrication processes. In the single cell gap configuration, since R region and T region has different optical paths, two different LC modes were proposed, in order to compensate the optical path difference. However, different LC modes will lead to different response time of R and T parts. Moreover, the electro-optical characteristics of R and T parts would not match with each other. Thus, different driving schemes must be employed for the R and T parts. Besides, fringe-field switching (FFS) mode was proposed [5], in which the rotation angle of the LC director in the T region is double that in the R region. However, it also generates different voltage-dependent transmission and reflectance curve.

In this paper, we propose a single cell gap single mode tranflective LCD. There is no separate LC mode required for R and T regions. ECB mode is applied in both R and T regions. Patterned retarders are utilized for improving the optical performance of ECB mode. Patterned retarder can be realized experimentally by using SD1 as alignment layer [6]. The result shows a high optical efficiency in both R and T area. At the same time, it has nearly no color dispersion. So very high contrast ratio is achieved. The electro-optical curve of T and R part matches with each other well. So, only one driving circuit is necessary. Moreover, the proposed configuration can be easily fabricated.

2. Device configuration

The cell structure of film compensated single cell gap single mode transflective LCD is shown in Figure1. The reflective part and transmissive part share the same layer configuration, which including a top-polarizer, a LC layer sandwiched between 2 compensation films. The only difference is that a patterned mirror is placed on the top of bottom-polarizer at the R part.

We use ECB as the LC mode. Because the cell gap is the same for both R part and T parts, optical path difference exists. It should be compensated by additional retardation films. Otherwise, efficiency of T region bright state would be very low. And, only a-plate is tried here for our optimization because of its low cost and easy fabrication. The slow-axis of a-plates at R and T parts can be different from each other. It can be realized by the in-cell retarder technology [7] using SD1 as alignment layer.

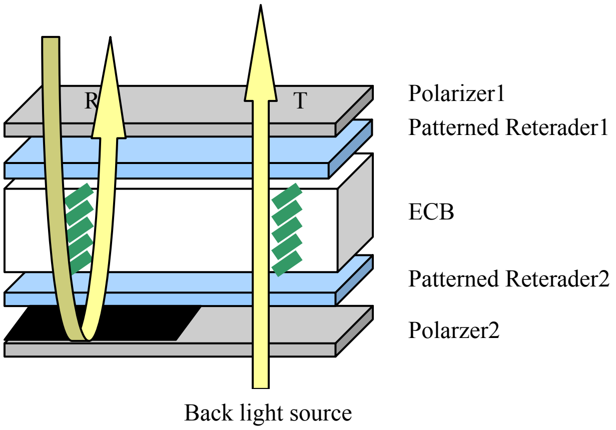

Figure 1 Schematic cell structure of film compensated single cell gap transflective LCD

3. Optimization

Before optimize the compensation film layer, suitable retardation value of ECB layer should be determined first. Here, we choose 283nm at wavelength of 550nm as the LC layer retardation (Δnd). Because, larger retardation value at LC layer will cause larger retardation difference between R and T regions, which will make it more difficult to get a matched transmission-voltage curve (TVC) and reflection-voltage curve (RVC). On the other hand, too small retardation value at ECB layer will not be enough to get high efficiency bright states, especially for the transmissive region.

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Table 1 Orientations of different layers.

Layer	Angle
Polarizer1	45°
Patterned retarder 1	45°(30° for R region)
ECB layer	0°
Patterned retarder 2	-75° (–40° for R region)
Polarizer2 (for T only)	-40°

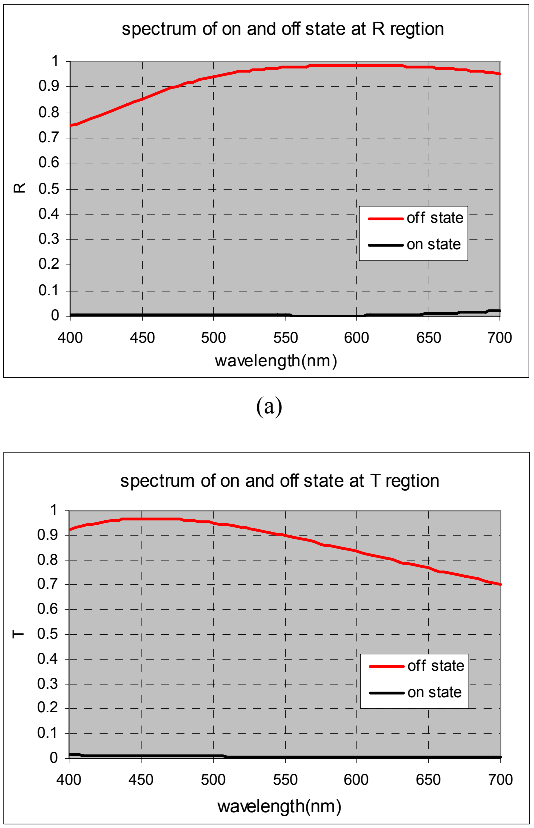
Once the device configuration and the LC layer retardation value are fixed, compensation films should be optimized in order to achieve high efficiency at both R and T regions, and high contrast display.

Table1 gives the orientations of different layers. The rubbing direction of ECB mode is along x-axis and set to be to zero degree. The LC layer is shared by R and T regions. For T region, one retardation layer (retarder2) with slow axis along -75degree, and retardation value 69nm, is applied for optimization. The slow axis of retarder2 at R region is 35degree away from that at T region. An additional compensation film (retarder1) is attached on the top LC layer at R region, with slow axis along -30degree, and retardation value 205nm.

For T region, there is no additional retarder on the top of ECB layer. For the purpose of easy fabrication, we can apply a retardation layer with slow axis along 45degree (same as polarizer1 absorption angle) and sharing the same retardation value as in the R region. This patterned in-cell retarder can be realized by photo-alignment, using SD1 as alignment layer. Moreover, the input polarizer (polarizer1) and output polarizer (polarizer2) are not crossed. This arrangement is in order to decrease the dark state residual retardation and achieve high contrast ratio for transmissive mode.

4. Results

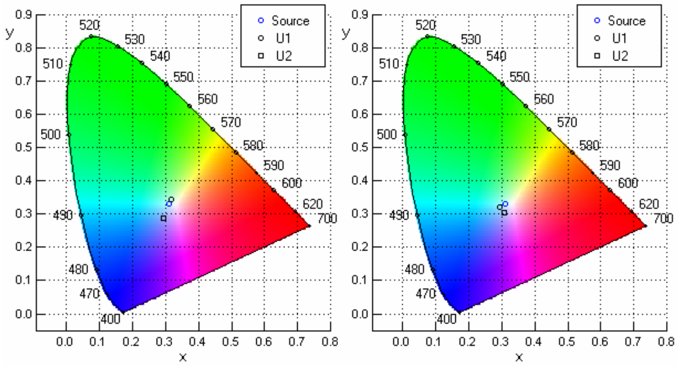
Basically, ECB mode shows large color dispersion, because the transmission or reflection is related to $\frac{\Delta nd}{\lambda}$, which is wavelength dependent. In our device, with one to two properly oriented compensation layers, the color dispersion is greatly suppressed. The calculated spectrum of reflective and transmissive mode is shown in Figure2. The dark states of both R and T regions are almost flat and zero for whole visible light range. At the same time, the bright state efficiency is very high. For the incident light at the λ of 550nm, both transmission and reflection are above 90% (not considering the absorption of polarizers). So, very high contrast ratio is achieved in our design. In addition to color dispersion, the contrast ratio is also limited by surface reflection, especially for the reflective mode display. So, antireflection layer is suggested to be attached on the top of polarizer1.



(a)

(b)

Figure 2 Calculated on and off state spectrum at (a) R region, (b) T region



(a)

(b)

Figure 3 Color coordinates on CIE 1931 chromaticity diagram of on and off states (a) R region, (b) T region

In our calculation, parameters of MLC-6080 from Merck are applied. Its Δn value is 0.2024. The dielectric anisotropy and elastic constants are $\Delta\varepsilon = 7.2$, $K_{11}=1.44*10^{-6}$N, $K_{22}=7.1*10^{-7}$N and $K_{33}=1.91*10^{-6}$N respectively. Assuming D65 ((x, y) =

(0.313, 0.329)) is applied as the light source for both transmissive mode and the reflective mode, the color coordinates of both bright and dark states at R and T regions are calculated. Table2 gives the values in detail and Figure3 shows the coordinates on the CIE 1931 color space chromaticity diagram.U_1 and U_2 refer to bright state voltage (0V) and dark state voltage (3.4V) respectively. It can be seen that the color coordinates are close to each other and shows very small color dispersion.

Table 2 Calculated color coordinates

	Bright-state U_1		Dark-state U_2	
	x	y	x’	y’
Reflection	0.3193	0.3431	0.2962	0.2859
Transmission	0.2954	0.3198	0.3079	0.3031

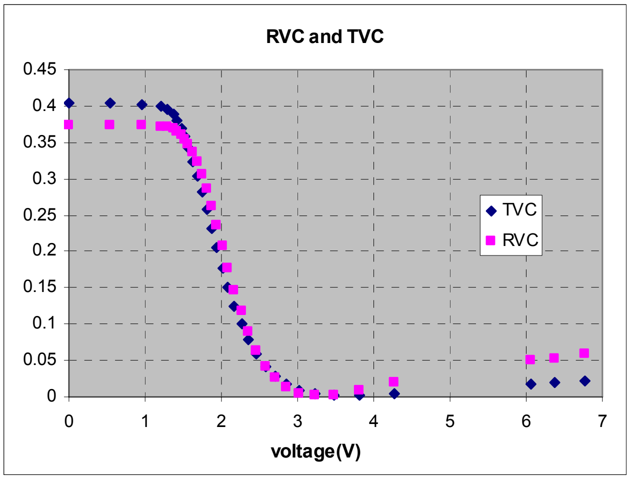


Figure 4 Electro-optical characteristics of R and T regions.

For transflective displays, electro-optical characteristic is another key issue for evaluating device configurations optimization. Matched TVC and RVC are preferred. That makes it easy for circuit and driver design. Otherwise, two separate drivers are required for R and T parts respectively, which also increase the cost. Figure4 shows the voltage-dependent reflectance and transmittance of our cell configuration listed in Table1. And polarizer absorption is considered. These two curves match with each other mostly. So images can be generated with a single driving circuit.

5. Conclusion

In summary, a transflective LCD with single cell gap and single mode configuration is studied. It shows high optical efficiency in both reflective and transmissive region. The color dispersion is greatly depressed by proper orientation of the optical retarders. Very high contrast and suitable color coordinates for black and white display are achieved. The electro-optical curves match with each other well. The R and T parts can be driven at the same time by single circuit one gamma curve. The cell structure we proposed could be fabricated easily.

6. References

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