2-Face Viewable Display Using Dye-Doped Liquid Crystal

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Abstract

We present a liquid crystal display that allows two faces of the display viewed at opposite directions to show different image/video content simultaneously. This device is characterized by a dye-doped liquid crystal, which can eliminate the need for polarizers and offer a very low crosstalk between two separated viewing angles.

Keywords

multi-view; 2-face viewable; liquid crystal; dye-doped; multi-domain; low crosstalk

1. Introduction

2-face viewable liquid crystal display (LCD) devices [1-4] are an ingenious solution that accommodates two distinct viewing cones together in one display. As with multiple viewing angles, different image or video contents can be displayed simultaneously on a screen depending on the viewing direction. Courtesy of this franchise, this technology offers many possibilities that were previously not possible or at least difficult. Picture two persons sitting in a car. One could observe the global positioning system (GPS) map on the navigator from driver's seat, whereas the other could enjoy a soap opera from passenger's seat. Likewise, signages in public places become able to showcase more than one advertisement as a person goes by.

To date, only a few viable solutions have been proposed for this use. Parallax barrier, adopted in Sharp's proprietary three-way viewing-angle LCD [5], and lenticular lenses [6] are the commonly used physical means to route light from the subpixels to each independent field of view. However, both of them indeed demand an add-on device to assist a major LCD panel in order to fulfill their function. This inevitably will be accompanied by a sophisticated process of production, resulting in a decrease in the yield. Besides, a noticeably raised cost due to the parallax barrier or lenticular lens would not appeal to many manufacturers and consumers. Another approach to achieve multiple viewing angles is known as the vector error diffusion [7], a halftoning method. Since this method involves the signal processing in imaging, the output multi-view effect is very limited and problematic.

2. Principle of Guest-Host LC

Guest-host (GH) LC, best known for its application in the polarizer-free displays [8], is a mixture acquired by doping a host LC with a few percent (1-5 wt%) of guest dichroic dye. The impressive ability of dichroic dye to absorb light strongly along the principal molecule axis, that is, the absorption axis (AA), and to transmit light easily along the perpendicular direction lends itself to modulating the light intensity. By invoking the Beer-Lambert law [9], under the condition of a dilute solution, the normalized transmittance of a homogeneous GH cell can be given by

$$T_{//} = \exp(-\alpha_{//} cd), \tag{1}$$

$$T_{\perp} = \exp(-\alpha_{\perp} cd), \tag{2}$$

where $T_{//,\perp}$ and $\alpha_{//,\perp}$ represent the transmittance and absorptivity (the absorption coefficients) parallel and perpendicular to the incident plane of the light, characteristic of the material, respectively, c is the dye concentration and d is the cell gap. The dichroic ratio (DR), a measure of the dye's absorptive anisotropy, is defined as

$$DR = \frac{\alpha_{//}}{\alpha_{\perp}}. \tag{3}$$

Referring to Fig. 1, once LC and dye materials are blended together, the movement of dye molecules will follow that of LC directors in a sense that their optical axes always align in a line. In this regard, only the LC director is shown to represent the LC-dye mixture as a unity. When in the off-state, that is no external voltage being applied, assume that LC and dye are together positioned at a certain angle. The incoming unpolarized light is incident from the directions indicated by the wavevectors k at normal and k' at oblique. Thereafter, the p-(parallel) and s-(perpendicular) wave components of incident light will be converted into as E-wave and O-wave, respectively, upon entering into the anisotropic medium of LC-dye mixture. For every incident direction, the s-wave is going to experience pronounced attenuation brought by the O-wave absorption nature of E-type dye, as the s-wave is all the time orthogonal to the dye's optical axis. The p-wave, on the other hand, is to be more or less transmitted as long as there is a non-zero portion of E-wave component after its conversion. In particular, when the incident direction of wavevector is normal to the LC director, a maximum transmittance of p-wave will be acquired.

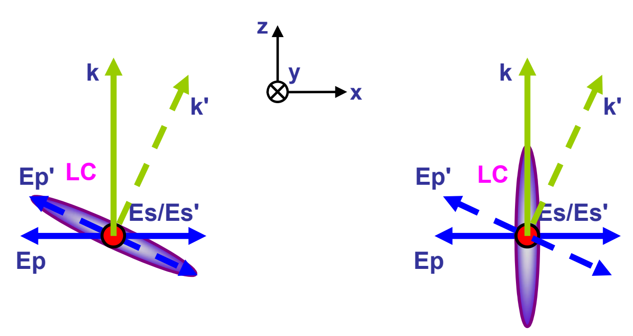

Figure 1. Principle of light absorption of E-type dye when in the off-state and (b) on-state.

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When in the on-state, that is a non-zero voltage being applied, LC and dye are both rotated to the right angle. The foregoing situation becomes different in that not just s-wave but p-wave will be attenuated due to the O-wave component decomposed normal to the dye's optical axis. Apparently, the amount of light absorption is dependent on the incident direction, in other words, the viewing direction, and also on the LC-dye orientation. Therefore, the viewing-angle-dependent light modulation becomes feasible through the electrical control of the LC-dye orientation.

3. Design of 2-Face Viewable Display

Figure 2 outlines the proposed structure for 2-face viewable display, where the LCD panel consists of glass substrates, a color filter array layer, a common ITO electrode, alignment layers, an LC-dye layer with a uniform cellgap in between, a pixel ITO electrode, and a TFT array layer. In particular, it should be noticed that there are no polarizers and compensation films required for this optical system.

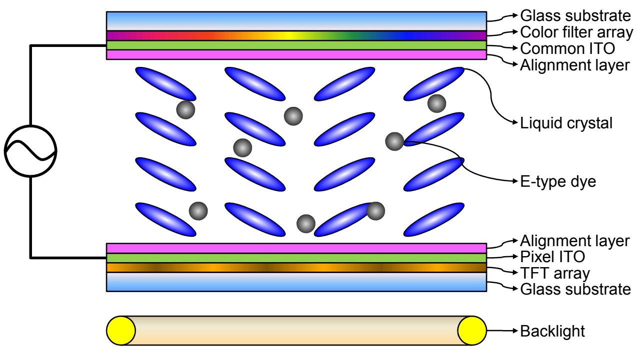


Figure 2. Schematic view of 2-face viewable LCD panel.

In the LC-dye layer, an E-type dichroic dye as a guest is doped into the liquid crystal as a host medium. The E-type dye has a larger light absorption coefficient ($\alpha_{\perp}$) traverse to the optical axis of dye than that ($\alpha_{//}$) along the optical axis of dye. Thus, the E-type dye has a greater absorption when its optical axis is positioned in parallel with a light path as compared to when its optical axis is perpendicular to the direction of light path.

In order to realize the multiple viewing angles, i.e. the multi-face viewable mode operation, it is urged that a multi-directional alignment be carried out onto the alignment layers. For top and bottom substrates, different alignment directions are necessary to segment the whole panel region into a multitude of different domains, within each of which, the LC alignment is homogeneously uniform and pointing to a certain direction. To explain this more thoroughly, the implementations of 2-face viewable and 4-face viewable modes are given as examples, where only four domains, with others omitted for the sake of clarity, are shown in Fig. 3. For 2-face viewable mode, two different domains are formed because of two different alignment directions (left and right). Especially, the alignment directions on the top and bottom substrates are oriented antiparallely. For 4-face viewable mode, four different domains are formed because of four different alignment directions (left, right, up, and down). It is obvious that the number of different domain is equal to the number of viewable faces. In addition to 2- and 4-face viewable modes, more options of other integer numbers are technically possible. To achieve this multi-directional alignment in practice, several techniques can be considered, such as conventional rubbing method with shadow mask [10], ion-beam alignment [11], and photo alignment [12]. Besides, while the number of viewable faces can be increased, the loss in the resolution as well as crosstalk effects merits special cares.

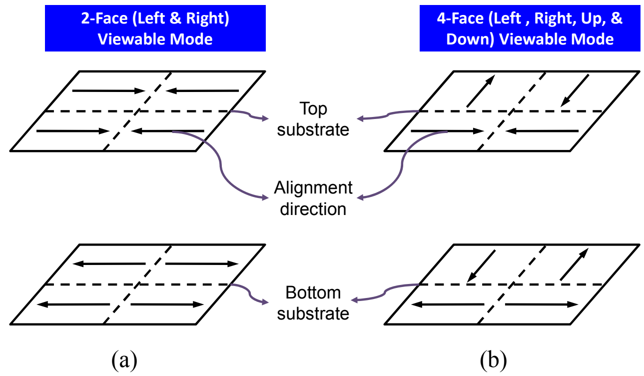


Figure 3. Multi-directional alignment for (a) 2-face and (b) 4-face viewable display.

4. Simulations

In the numerical calculation, LC parameters are chosen as ZLI-4792 (Merck) having the dielectric anisotropy $\Delta\varepsilon$=5.2 ($\varepsilon_{//}$=8.3, $\varepsilon_{\perp}$=3.1), refractive anisotropy Δn=0.0989 (n_o=1.4816, n_e=1.5805), and a pretilt angle of 26.57°. Specifically, the physical properties of E-type dye are idealized as the absorption coefficient $\alpha_{//}$ for E-wave is set as zero. However, by far, some practical E-type dichroic dye materials are available from OPTIVIA Inc. (US) and NIOPIK (Russia) [13]. The cellgap is set as a variable ranging from 3 to 8 μm. A more detailed list of parameters is given in Table 1.

Table 1. Parameters used in the simulation.

LC host	ZLI-4792
Δn	0.099
n_o/n_e	1.482/1.581
$\Delta\varepsilon$	+5.2
$\varepsilon_{//}$ / $\varepsilon_{\perp}$	8.3/3.1
Absorption coefficient (ideal)	$\alpha_{\perp}$ = 0.0004/nm; $\alpha_{//}$ = 0/nm
Dye concentration	4%
Pretilt	26.57°
Cellgap	3/4/5/6/7/8 μm

Among the above parameters, the pretilt angle $\theta_{pretilt}$ of LC-dye molecules plays a crucial role in our device, and it should be determined from Snell's law,

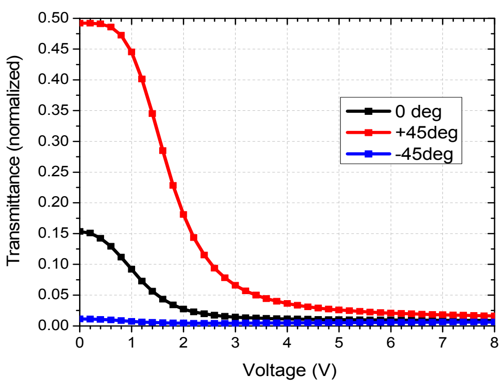
$$\frac{n_{air}}{n_{LC-dye}} = \frac{\sin\theta_{refracted}}{\sin\theta_{incident}} \rightarrow \frac{1}{n_e} = \frac{\sin\theta_{pretilt}}{\sin\theta_{best}}, \qquad (4)$$

where θ_{best} stands for the angle, for which a maximum transmittance for E-wave can be obtained. It is also the same direction for achieving the highest contrast ratio (CR). For this reason, it can be seen as the best viewing direction as it is named. In practice, the value choice of θ_{best} is based on the panel specification. By way of example only, if θ_{best} = 45° and n_e = 1.581, $\theta_{pretilt}$ = 26.57°.

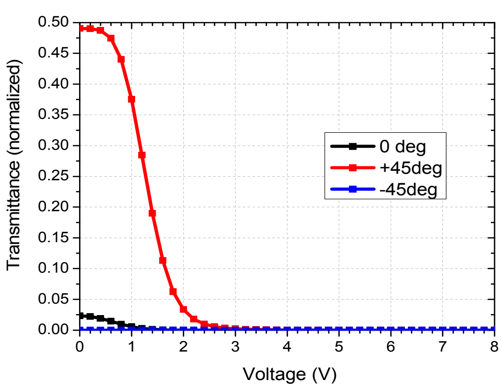
5. Results and Discussion

We shall mention that the following results are all calculated merely with right-view pixel, while the left one is omitted for the sake of clarity. Figures 4(a) and 4(b) are graphs showing the voltage-transmittance (V-T) curve for an LC-dye layer with cellgaps of 3 and 8 μm, respectively. These curves are observed for viewing directions of 0° (front), +45° (45° on the right), and −45° (45° on the left), of which, the +45° direction demonstrates a continuous change from the maximum to the minimum transmittance. This is in an agreement with the statement earlier discussed. By comparing the V-T curves of +45° and −45°, it also can be said that the present invention is free of crosstalk [14], as the light emitted from the opposite direction (−45°) is far below the level of viewable direction (+45°). Technically, this is quite advantageous to be applied as a multi-face viewable display device. Table 2 summarizes the figure of merits with respect to the six different cellgap conditions from 3 to 8 μm. As can been told, the large the cellgap, the better the CR as well as crosstalk. The selection of cellgap for a real device should depend on the actual physical properties of E-type dye and also on the performance requirement.

Figures 5(a) to 5(f) are a series of iso-luminance contours showing how the luminance changes in response to the variation of an applied voltage, when the LC-dye layer has a cellgap of 6 μm. At 0 V, the bright state or the maximum brightness is obtained and its area is primarily limited to the right half of the entire viewing cone, as expected. With an increase in the voltage, both the level and area of luminance are gradually scaling down to a dark state at 8 V.



(a)

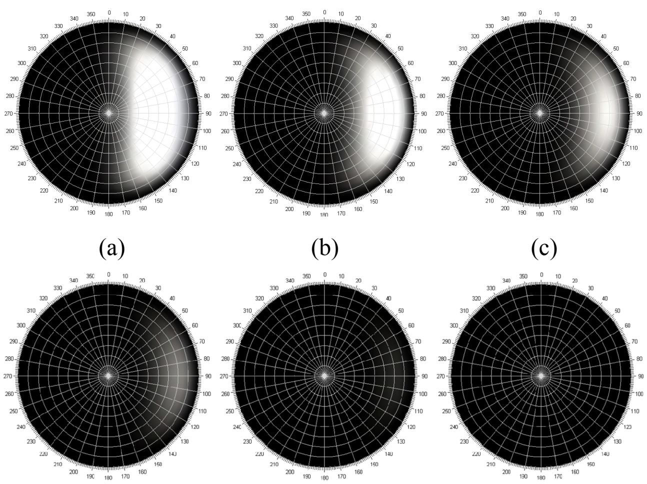


(b)

Figure 4. V-T curves for cellgaps of (a) 3 μm and (b) 8 μm.

Table 2. Figure of merits with respect to different cellgaps.

	d=3μm	d=4μm	d=5μm	d=6μm	d=7μm	d=8μm
T(0V)@+45°	0.4919	0.4905	0.4902	0.4902	0.4902	0.4902
T(8V)@+45°	0.01626	0.004777	0.001437	0.000438	0.000135	4.15E-05
T(0V)@-45°	0.01124	0.002837	0.000733	0.000192	5.09E-05	1.35E-05
T(8V)@-45°	0.006394	0.001269	0.000255	5.18E-05	1.06E-05	2.19E-06
Crosstalk(0V)	2.3%	0.6%	0.1%	0.0%	0.0%	0.0%
Crosstalk(8V)	39.3%	26.6%	17.7%	11.8%	7.9%	5.3%
CR@+45°	30.3	102.7	341.1	1119	3631	11812

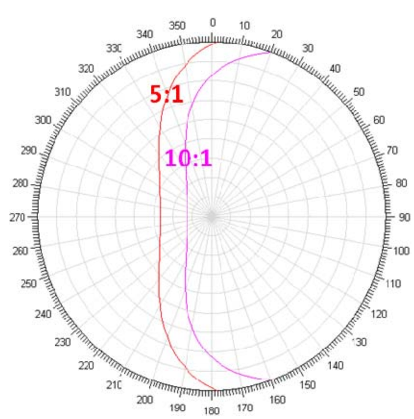


(a) (b) (c)

(d) (e) (f)

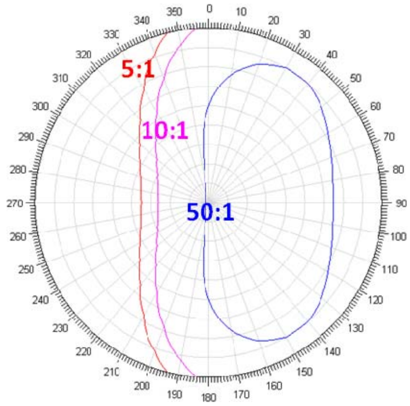
Figure 5. Iso-luminance contours of a dye-doped LC cell of 6 μm at voltages of (a) 0, (b) 1.2, (c) 1.6, (d) 2.0, (e) 2.6, and (f) 8.0 V.

As shown in Fig. 6, three contours compare the CRs of three different cellgaps (3, 4, and 8 μm), from which, it can be seen that high levels of CR are mainly confined to the right half of the entire viewing cone. Moreover, the best viewing direction for right-view pixels will be at 45° as it is optimized. Even though CRs over 5:1 can intrude some of the left half region, the transmittance level is still way too low to display any discernible information.

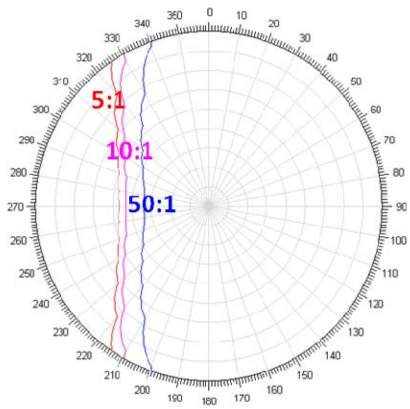


(a)

Figure 6a



(b)



(c)

Figure 6. Iso-CR contours of a dye-doped LC cell with the cellgaps of (a) 3 μm and (b) 4 μm, and (c) 8 μm.

6. Conclusions

In conclusion, we have demonstrated a 2-face viewable LCD device that is capable of allowing simultaneous displays of two independent image or video contents on the same screen. The proposed structure features a multi-domain dye-doped LC cell, which in its own right can eliminate the use of polarizers. Incidentally, we have found out that E-type dye outrivals O-type dye in terms of the viewing angle splitting [15]. This device is typically useful for the application as digital signages, not only for its unique function but also for its competitive manufacturing cost.

7. Acknowledgements

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