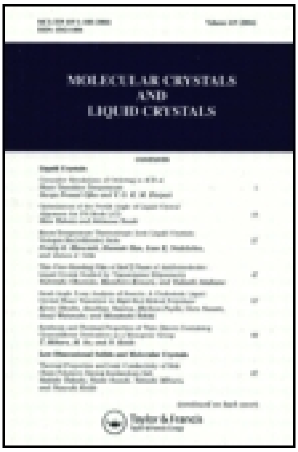

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2-Face Viewable Liquid Crystal Display by In-Plane Switching

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2-Face Viewable Liquid Crystal Display by In-Plane Switching

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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 2-domain mid-tilted liquid crystal, which is addressed by the in-plane switching.

Keywords In-plane switching; liquid crystal display; pretilt angle control; two-view

1. Introduction

One of the essential and indispensable elements in today's consumer electronics is the LCD. A large array of most common LCD-related products could be readily found in the market that runs the gamut of LCD televisions, laptop computers, digital cameras, cellphones etc. Recently, unlike the preceding LCD products, a small group of LCDs that are tailored to cater to some special requirements gradually gain ground in the market as well. Multi-view LCDs, among other things, are one of these typical examples aimed for specialty. As with such LCDs, different image or video content can be displayed simultaneously on a screen depending on the viewing direction. Courtesy of their multiple viewing angles, 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, digital signages in public places become able to showcase more than one advertisement as a passerby goes by. To date, only a few viable solutions have been proposed for this use. Parallax barrier [1], adopted in Sharp's proprietary two-way viewing-angle LCD, and lenticular lenses [2] are the commonly

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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 achieving multiple viewing angles is known as the vector error diffusion, a halftoning method [3]. Since this method involves the signal processing in imaging, the output multi-view effect is very limited and problematic. Motivated from the above issues, we propose a method for easily obtaining a 2-face viewable liquid crystal display (LCD) that is able to show different images on the same screen depending on the viewing perspectives.

2. Operational Principle

Figure 1 schematically depicts the operational principle of the proposed 2-face viewable LCD, where the LC alignment directions and transmission axes (TA) of the polarizers are explicitly indicated. It can be seen that a unit LC region is divided into two subpixels by means of a 2-domain alignment technique, such as ion-beam exposure [4] and ultra-violet irradiation [5]. When no voltage is applied, i.e., the turn-off state, LC directors are initially mid-tilted at a certain angle and oriented towards opposite ways. As a result, a disparity between the angular dependence of optical transmittance of two subpixels or domains will be obtained. In other words, two subpixels will contribute to two independent viewing cones, on which different display content varying with the observation directions [6–9] can be accommodated in one single device.

When a voltage is applied to the interdigital electrodes, i.e., turn-on state, LC directors will be forced to be aligned with the horizontal electrical field, lying in the plane of the substrate. Because of the superposition of LC directors and TA of the bottom polarizer, a dark state will be resulted. Yet, the vertical component of electrical field may exist in the region right above the electrodes, which can cause the palpable light leakage. From this consideration, the disposition of black mask is

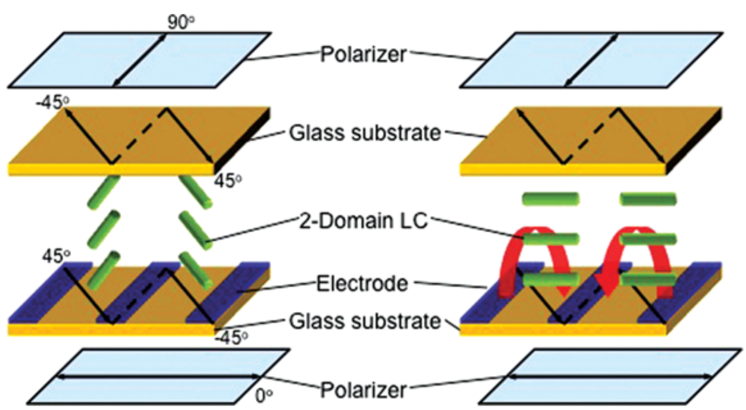

Figure 1. Operational principle: (a) turn-off state, and (b) turn-on state. (Figure appears in color online.)

quite necessary for keeping the light from leaking from the said region. Alternatively, this can be replaced by using the opaque metal electrodes instead of the transparent ITO electrodes.

To generate a mid-pretilt angle, several techniques can be employed, for example, the ion-beam exposure [4], mixing of planar and vertical polyimides [10], or stacked alignment layers [11]. Specifically, a special care should be paid to the selection of LC's pretilt angle $\theta_{pretilt}$, since it ultimately determines the optimal observation direction $\theta_{optimal}$ for each viewing cone. And it should satisfy the Snell's law, that is,

$$\frac{n_{air}}{n_{LC}} = \frac{\sin\theta_{refracted}}{\sin\theta_{incident}} = \frac{\sin(90^\circ - \theta_{pretilt})}{\sin\theta_{optimal}}. \tag{1}$$

3. Results and Discussion

3.1. *Simulation Parameters*

To calculate the viewing angle characteristics, we adopt ZLI-5070 as the LC material, which assumes the following cell parameters: $\Delta n = 0.1391$, $\Delta\varepsilon = +9.1$, $d = 2.9\,\mu m$, and a pretilt angle of 63.3°. As for the IPS electrode, the electrode width is 4 μm and the spacing in between is 10 μm. The LC's pretilt angle is chosen according to the Eq. 1, where we set the $\theta_{optimal} = 45^\circ$, thus $\theta_{pretilt} = 63.3^\circ$. Table 1 below summarizes the parameters used in our simulation tool (LCD Master).

3.2. *Voltage-Transmittance Curve*

During our calculation, we should mention that only the right subpixel is turned on while the other one is turned off. Voltage-transmittance (V-T) curves for three different observation directions are given in Figure 2, where 0°, 45°, and −45° denote normal, lower-right diagonal, and upper-left diagonal, respectively. The maximum contrast ratio (CR) for 45° is found out as 20:1 (0 V/11 V). It is crucial to be aware that the there is no concern needed for the crosstalk as the level of the light emitting from the opposite side (−45°) always stays below that of the light from the side of interest (45°).

Table 1. Parameters used in simulation

LC	ZLI-5070
Δn	0.1391
n_o/n_e	1.5025/1.6416
$\Delta\varepsilon$	+9.1
$\varepsilon_{//}/\varepsilon_{\perp}$	13.3/4.2
Pretilt	63.3°
Pretwist	135°
Anchoring energy	$1 \times 10^{-3}\,J/cm^2$
d	2.9 μm

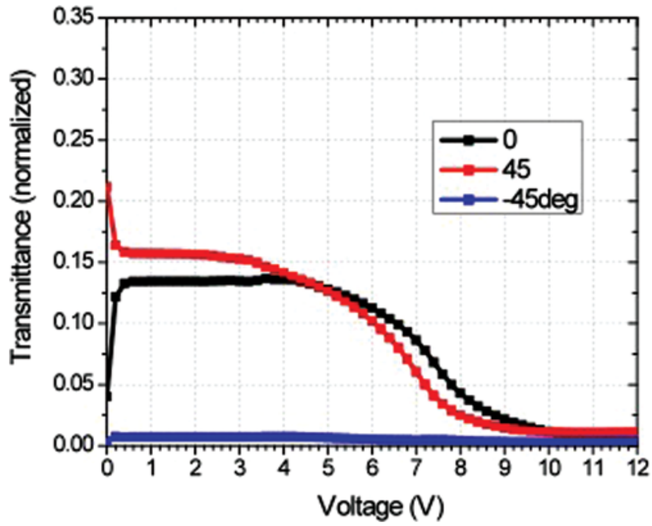

Figure 2. Voltage-transmittance curves for three observation directions (0°, 45°, and −45°).

3.3. *Viewing Angle Characteristics*

Figure 3 is a graph showing the iso-luminance contour of the bright state at 0 V, from which, we note that levels of 25% and 50% of luminance become converged and restricted within the lower-right half. Similarly, as shown in Figure 4, almost all the levels of contrast ratio (CR) (0 V/11 V) above 5:1 are located within the lower-right half area. Both the maximum luminance and CR are found at the direction about the 45°, which is in agreement of the foregoing discussion. To design optimal observation directions other than 45°, different pretilt angles should be determined. Owing to this angular dependence, if both subpixels are being addressed with different signals, the entire viewing cone could be split into two, with one covering the lower-right face and the other covering the upper-left face. In practice, even

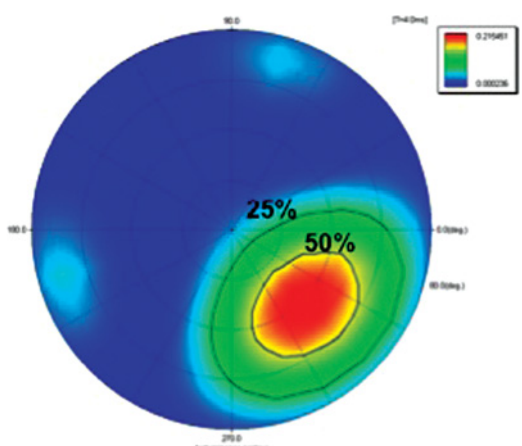

Figure 3. Iso-luminance contour of the bright state at 0 V. (Figure appears in color online.)

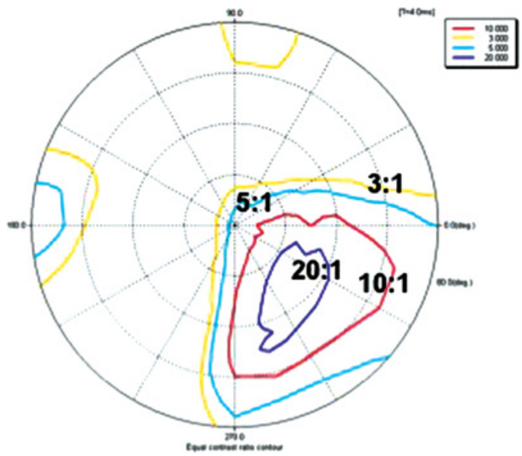

Figure 4. Iso-contrast ratio contour (0 V/11 V).

an autostereoscopic effect [12] would be generated to a viewer who sits in the middle, if the separation angle between two viewing cones could be sufficiently small. Finally, we shall mention that, for a given screen resolution, the two subpixels will divide the effective resolution in the horizontal direction. By way of example, if the total resolution of a display is 800×480, each viewable image would be 400×480.

4. Conclusions and Perspectives

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. In its own right, this device is especially useful for the application as digital signages. We are looking forward to its commercial potential in the diverse market of display not only for its versatile functions but also for its competitive manufacturing cost.

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