PAPER *Special Issue on Electronic Displays*

# Dual Domainlike, Vertically Aligned Nematic Liquid Crystal Display Driven by In-Plane Field

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**SUMMARY** A homeotropic liquid crystal display utilizing a liquid crystal with positive dielectric anisotropy, 13.3" XGA TFT-LCD, has been fabricated. The rubbing-free device, appears black in the absence of electric field. When an electric field generated by interdigital electrodes is applied, a bend deformation of molecular director to the direction of the field occurs and thus the cell transmits light, showing brightness uniformity in all directions owing to the dual domainlike director configuration. With an addition of negative-birefringent film, this device shows excellent viewing angle characteristics.

***key words:** homeotropic liquid crystal display, interdigital electrodes, wide viewing angle*

## 1. Introduction

At present, twisted nematic (TN) and super twisted nematic (STN) liquid crystal displays (LCDs) are dominantly used for personal notebook computers. However, they show narrow viewing angle, which hinders to replace the CRTs in the monitor and TV markets. Therefore widening the range of viewing angle and high-speed response time are prerequisite to compete with the CRTs. Recently, a new concept of the LCDs exhibiting a wide viewing angle such as the in-plane switching (IPS) mode [1]-[3], the vertical alignment (VA) with negative [4], [5] and positive [6]-[8] LCs, and optically compensated mode (OCB) [9] have been suggested. The IPS mode shows wide viewing angle comparable to the CRT displays, but the cell gap margin is narrower and the response time is rather slower than those of the TN mode. The VA mode with negative-birefringent film shows the range of viewing angle greater than 70° in polar angle for all azimuthal directions and very fast response time of less than 25 ms. However in order to show the wide viewing angle, the fabrication of the dual domains or four domains is further necessary. This inevitable step needs an additional process like mask rubbing, photoalignment, or surface protrusion, rendering this mode less practicable. Moreover, most of the LCDs being currently used need a rubbing process, which causes contamination by dust and electrostatic charges that may damage thin film transistors. Therefore the fabrication of the LCDs with rubbing-free process and wide viewing angle is most desirable if possible.

Here, we suggest a rubbing-free dual-domainlike VA (DDVA) LCDs associated with the deformed transition from vertical alignment induced by the in-plane field switching. This device with an addition of negative birefringent compensation film, shows very wide viewing angle comparable to the existing divided-domain VA mode.

Manuscript received February 12, 1998.
Manuscript revised June 12, 1998.

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## 2. Electro-Optic Characteristics of the DDVA Cell

### 2.1 Switching Principle of the DDVA Cell

Figure 1 shows the schematic structure of the DDVA cell with an interdigital electrode and molecular director configuration in the voltage-off and -on state. For the voltage below Freedericksz transition threshold, $V_{th}$, the LC molecules are anchored homeotropically on both alignment layers so that the polarization state of the incident light through the polarizer remains unchanged. Consequently the light is blocked by the analyzer, giving rise to a complete dark-state. However, the light leakage at off-normal directions occurs,

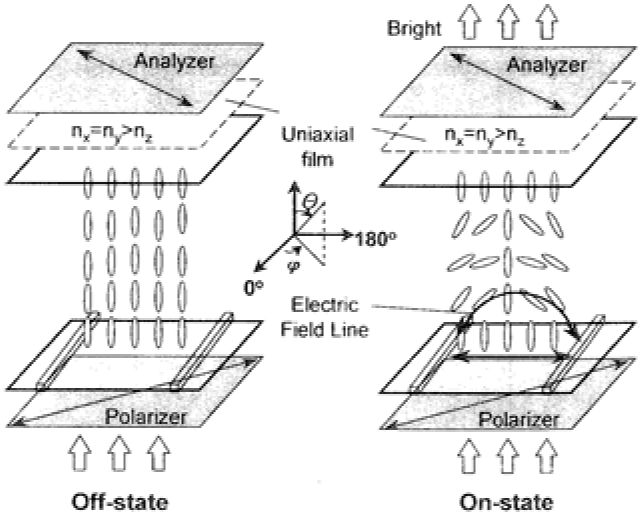


**Fig. 1** The schematic diagram of the DDVA cell with the molecular director configuration in the off- and on-state. The negative-birefringent film is inserted between the analyzer and the top substrate.

resulting in low contrast ratio. This light leakage can be reduced with an addition of negative-birefringent film [10]. In on-state, an electric field generated by the interdigital electrodes is applied and a bend deformation of molecular director towards center from electrodes along the field direction occurs due to the positive dielectric anisotropy of the LCs, whereas the liquid crystal molecules at the center line remain unchanged as shown in Fig. 1.

The transmission of the vertically aligned liquid crystal layer placed between crossed polarizers can be given by

$$T = T_0 \sin^2(2\Phi)\sin^2(\pi d\Delta n/\lambda)$$

where $\Phi$ is an angle between the LC director and the transmission axis of the polarizer, $d$ is the cell gap, $\Delta n$ is the birefringence of the LC, and $\lambda$ is the wavelength of incident light. Therefore, when the tilted LC directors make an angle of 45° from the polarizer transmission axes given $d\Delta n$, the polarization state of incident light through the polarizer becomes elliptic due to the phase retardation and thus the light transmits through the analyzer, showing brightness uniformity in horizontal directions owing to the dual domain-like director configuration.

## 2.2 Voltage-Dependent Transmission Characteristics

In the DDVA cell, the lowering driving voltage and control of dark lines existing between electrodes are the key technologies for low power consumption and high quality TFT-LCD.

Figure 2 shows the voltage-dependent transmittance curve depending on $d\Delta n$ at normal direction. For a panel condition, a liquid crystal with a positive dielectric anisotropy $\Delta\varepsilon$(10.4, 1 kHz) and a birefringence $\Delta n$(0.078, 589 nm) is used and the distance ($l$) between electrodes is 9.7 µm. Two different cell gaps with 3.8 µm and 4.8 µm were tested. As can be seen, the light transmittance starts to occur above 3 V and saturates at 10 V for large $d\Delta n$ cell. For a cell of which $d\Delta n \fallingdotseq \lambda/2$, the transmission will keep increasing with further increasing voltage. The threshold voltage depends on $l$, cell gap, and the value of the dielectric anisotropy and the bend elastic constant ($K_3$) of the liquid crystal i.e., $V_{th} = \pi l/d\,(K_3/\varepsilon_0\Delta\varepsilon)^{1/2}$. Therefore, in order to lower the driving voltage, small value of the ratio $l/d$, high $\Delta\varepsilon$ and low $K_3$ are necessary. The cell gap strongly influences the driving voltage. As can be seen, increasing the cell gap by about 1 µm, the voltage at which transmittance starts to occur, decreases by 1 V. However, normally in the VA mode, large $d\Delta n$ causes a response time to be slow as well as renders the range of the viewing angle become narrow and the color shift occur as the viewing direction changes. Therefore, the optimization of $d\Delta n$ in the DDVA cell is very important and unlike the LCs for IPS cell, lowering $K_3$ of LCs is also key for lowering operational voltage.

Transmission pattern by the polarizing microscope was observed for a test cell. Before the voltage is applied below the threshold, the cell shows complete darkness except the region near the sphere spacers. As the voltage increases above the threshold, the transmittance starts to occur at the region near the electrodes and the transmission region extends to the whole space, as shown in Fig. 3. Disclination lines exist at the center between electrodes because the LC layers do not move through the whole cell gap at the center, i.e., the directors are pushed towards the center from both sides. These lines are very stable, and not disturbed even in the very high voltage for the test cells. However, the disturbing fields from gate and source bus line exist, resulting in instability of disclination lines so that the optimized design to control them is further required [11].

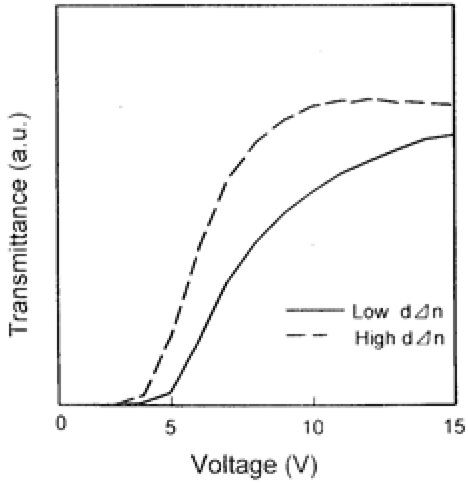


**Fig. 2** Voltage-dependent optical transmission curve.

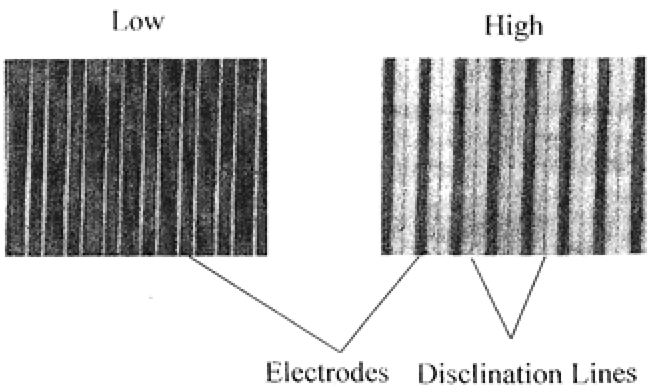


**Fig. 3** The transmittance pattern when an applied voltage is low and high.

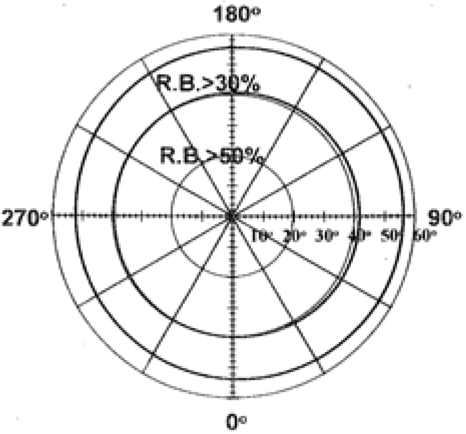


Fig. 4 The viewing angle dependence of light transmission. The reference is the light intensity when a transmission-maximum voltage is applied at normal direction. R.B. stands for relative brightness.

Table 1 Specification of the DDVA TFT-LCD.

| | |
|---|---|
| Display Size | 13.3" Diagonal |
| Number of Pixels | 1024 (X3) X 768 |
| Viewing Angle (CR>10) | > ±60° |
| Contrast Ratio at normal | > 300 |
| Response Time | < 30 *ms* |
| Panel Transmittance | > 3.5 % |

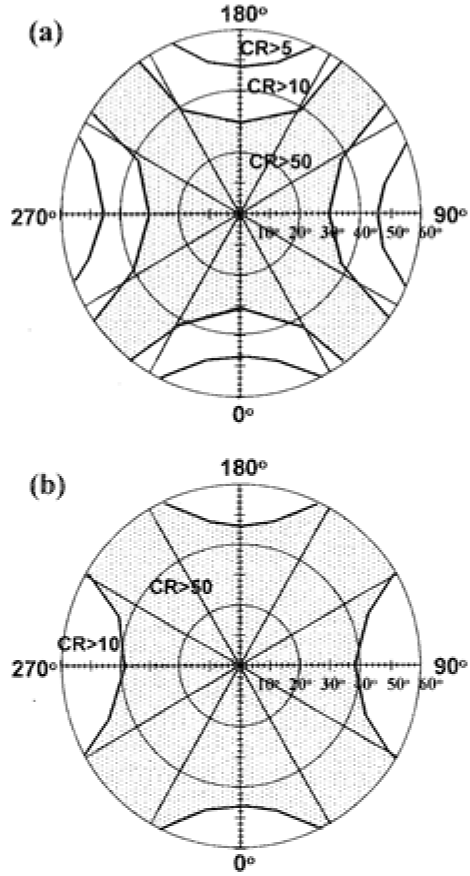


Fig. 5 The iso-contrast curves of the DDVA cell (a) without and (b) with compensation film.

## 2.3 Viewing Angle Characteristics and Response Time

Figure 4 shows the viewing angle dependence of brightness. The reference is the light intensity with transmission-maximum voltage at normal direction. As can be seen clearly from the figure, the uniformity in brightness is greatly improved compared with that of the conventional cell associated with a single domain in deformation of vertically aligned phase [4]. The luminance more than 30% is transmitted within a polar angle ($\theta$) of 60° in all directions. This results from the configuration of the dual-domainlike LC director by the in-plane switching.

Figures 5(a) and (b) show the iso-contrast plots of the DDVA panel without and with the negative-birefringent compensation film, respectively. Due to the self-optical compensation effects in the on-state, the brightness uniformity in horizontal direction is greatly improved and thus the region in which the contrast ratio is greater than 5 is about 60° in all directions for the DDVA panel. In addition, the film-compensated DDVA panel extends the range of the viewing angle range more than 60° in all directions. Especially the viewing angle characteristics in 45° diagonal directions are superb. We also measured the response time characteristics. The total response time is less than 30 ms which is faster than those of the IPS and the TN cells. Another great advantage of this device over the IPS cell is that high contrast ratio more than 300 can be easily obtained at normal direction. Table 1 summarizes the characteristics of 13.3" XGA TFT-LCD panel.

## 3. Conclusion

In summary, the vertically aligned nematic LCD using the liquid crystal with positive dielectric anisotropy whose on- and off-states are controlled by in-plane field, shows wide viewing angle and fast response time. This device does not require even rubbing of alignment layers, thus saving cost and processing steps in mass production of active-matrix LCDs. We expect that this new concept of device puts a step forward for application to the wide viewing angle active-matrix LCDs and also four domainlike VALCD showing super color characteristics as well as wide viewing angle is under preparation.

**Acknowledgements**

We are deeply grateful to the TFT production team for the support of manufacturing TFT-LCD panels, and to Prof. Young Hee Lee for his valuable comments on this paper.

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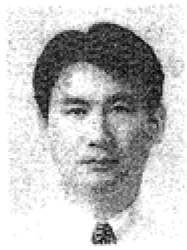

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