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Short Note

Contrast Ratio in Homogeneously Aligned Nematic Liquid Crystal Display Depending on Angle between Polarizer Axis and Optic Axis of a Liquid Crystal

Il Sub SONG[1], Hae Kyung WON[1], Do Sung KIM[1,2], Hoe-Sub SOH[2], Woo Yeol KIM[2] and Seung Hee LEE[1]*

[1]*School of Advanced Materials Engineering, Chonbuk National University, Chonju-si, Chonbuk 561-756, Korea*
[2]*Advanced Technology Development Team, LG-Philips LCD, Kumi-si, Kyungbuk 730-726, Korea*

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We have studied the contrast ratio of a homogeneously aligned nematic liquid crystal (LC) display as a function of the angle between the polarizer axis and LC director. The results showed that a cell configuration in which a polarizer axis facing a light source coincides with a short LC axis has a better process margin in terms of high contrast ratio than that of the cell coinciding with a long LC axis. [DOI: 10.1143/JJAP.43.4242]

KEYWORDS: contrast ratio, homogeneously aligned liquid crystal

Recently, the image quality of nematic liquid crystal displays (LCDs) has been markedly improved with the utilization of LC modes, such as in-plane switching (IPS),[1)] fringe-field switching (FFS)[2)] and multi-domain vertical alignment.[3)] Nevertheless, the response time[4–7)] of the LCDs is still not sufficiently fast to realize a perfect video image and the contrast ratio (CR) of the LCDs are still not satisfactory, which is basically due to the use of a polarizer.[8,9)] In the IPS and the FFS modes, the LCs are homogenously aligned (HA) under crossed polarizers with an optic axis coincident with one of the polarizer axes. In general, the transmittance equation where the uniaxial medium exists between two polarizers is given by

$$T = T_0\{(\cos^2(\alpha+\beta) + \sin(2\alpha)\sin(2\beta)\sin^2(\pi d\Delta n/\lambda)\},$$

where λ is an incident light, α and β represent angles defined as shown in Fig. 1, d is the cell gap, Δn is birefringence of the LC and λ is the wavelength of an incident light. Therefore, to realize a normally black mode where the LCD shows a dark state before applying a voltage, two different configurations are possible with crossed polarizers ($\alpha+\beta = 90°$) : $\beta = 0°$ (E-mode) and 90° (O-mode). With the conditions of $\alpha+\beta = 90°$, the same dark state is obtained irrespective of the E- and O-modes. At present, the polarizer is laminated on a glass substrate, possibly resulting in alignment error between the optic axis of a HALC and the polarizer axis. In this study, through calculation and experiment, we examined the change in contrast ratio depending on the E- and O-modes when there is a deviation of the LC optic axis from the polarizer axis. The results indicate which mode is advantageous in manufacturing IPS or FFS cells.

First, the transmittances for the E- and O-modes were calculated, assuming that the polarizers cross with each other and that there is only a small degree of deviation angle between the LC director, $\boldsymbol{n}$, and the polarizer axis. In this case, the transmittance equation becomes to $T = T_0\{(\sin^2(2\phi)\sin^2(\pi d\Delta n/\lambda)\}$, where ϕ is defined as the angle between crossed polarizers and $\boldsymbol{n}$. When ϕ varies from 0° to ±5° (E-mode) or from 90° to ±5° (O-mode), the transmittance occurs due to nonzero values of $\sin^2(2\phi)$ and also the occurrence of effective birefringence Δn_{eff} because the linearly polarized light passing through the polarizer experiences a phase retardation when passing through the

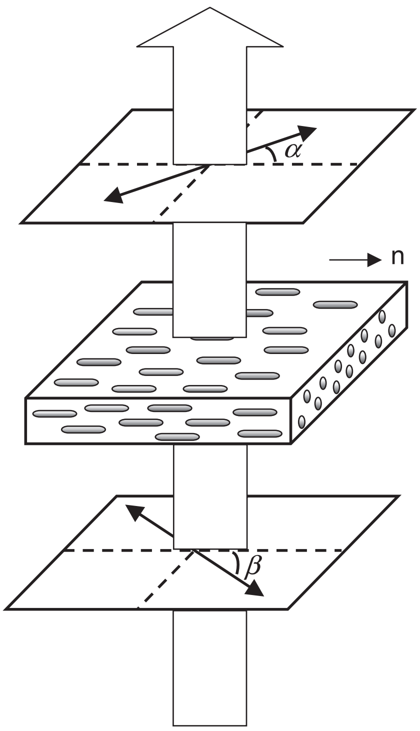

Fig. 1. Cell configuration of a homogenously aligned LC under two polarizers.

LC. Here, the Δn_{eff} can be defined as follows

$$\Delta n_{eff} = n'_e - n_o = n_e n_o/(n_e^2 \sin\phi + n_o^2 \cos\phi)^{1/2} - n_o$$

where n_e and n_o are extraordinary and ordinary refractive indices of the LC, respectively. The same degree of deviation from the E- and O-modes in the first term gives the same value irrespective of the mode (E- or O-mode); however, the values of Δn_{eff} are different depending on the initial configuration such as the E- and O-modes. Figure 2 shows the calculated results of Δn_{eff} as a function of the deviation angle, where the n_e and n_o of a LC was assumed to be 1.6 and 1.5 at 550 nm, respectively. As indicated, the values of Δn_{eff} in the O-mode are much smaller than those in the E-mode, and in addition, it remains almost zero with an increase in the deviation angle to 5°. This indicates that when there is misalignment of 1° between the bottom polarizer and the short or long axis of the LC, a cell in the O-mode at the initial configuration exhibits less light leakage than in the E-mode.

*To whom correspondence should be addressed.
E-mail: lsh1@moak.chonbuk.ac.kr

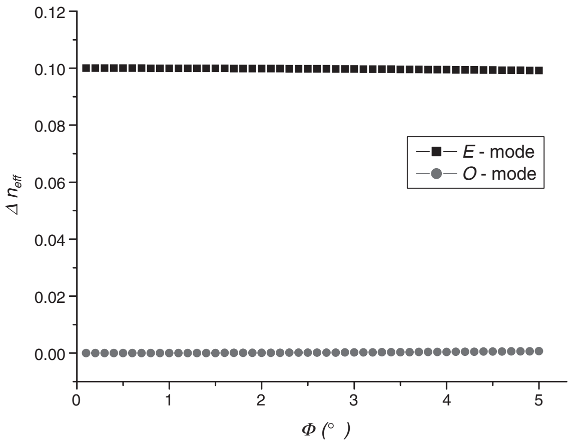

Fig. 2. Calculated effective $\Delta n_{\rm eff}$ as a function of deviation angle for the cell with the E- and the O-modes.

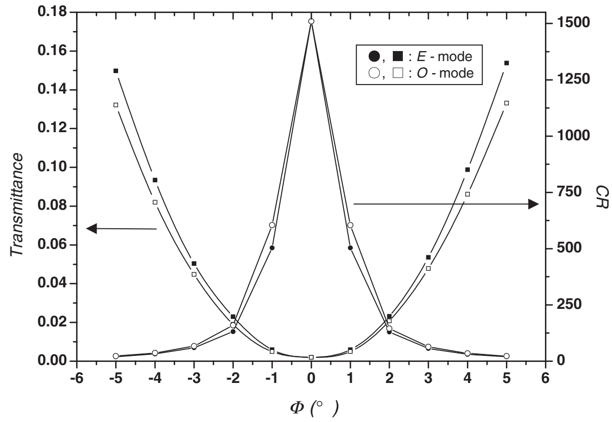

Fig. 3. Measured transmittance and contrast ratio as a function of deviation angle for the cell with the E- and the O-modes.

To confirm the results, a test cell with homogenous alignment was evaluated. Here, the cell retardation value was 0.25 μm with the LC Δn of 0.1 at 550 nm, and the pretilt angle of the LC was 1°. Transmittance as a function of deviation angle and measured CR defined as the ratio of $T_{\rm max}$ to $T_{\rm min}$ in the normal direction of the E- and O-modes have been determined, where the $T_{\rm max}$ is defined as the transmittance obtained when two polarizers along with the LC director are parallel to each other; the $T_{\rm min}$ is defined as the transmittance obtained when two polarizers cross with each other. As shown in Fig. 3, the transmittance increases and the CR decreases with an increase in the deviation angle. That is, the light leakage in the dark state is larger for the cell with the E-mode than that with the O-mode whenever there is a misalignment. Consequently, the CR of 1510 with a deviation angle of 0° is the same for both the E- and the O-modes; however, with a deviation angle of 1° it decreases to 503 for the E-mode and to 604 for the O-mode, which is about a 20% higher than that of the cell with the E-mode. This indicates that when manufacturing the LC cell, misalignment between the polarizer and the LC axis is inevitable. However, cell configurations employing the O-mode have distinct advantages for achieving a high CR in a normal direction. We have also investigated the viewing angle dependency of CR for the O- and E-modes and the results show almost the same iso-CR contour. We have also investigated the case in which the alignment angle between the upper and lower substrates is not equal to each other. We consider misalignment angle of up to 5° and the light leakage of the O-mode is smaller than that of the E-mode. Therefore, the O-mode is superior to the E-mode in the process margin such as in the alignment angle between the upper and lower substrates.

In summary, how the cell configurations in E- and O-modes affect the contrast ratio in a homogenously aligned LC cell have been investigated with respect to the cell manufacturing process. The results show that whenever there is misalignment between the polarizer axis and the LC axis and a misalignment angle between the upper and lower substrates, the cell in O-mode has distinct advantages over that of the cell in E-mode.

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