Light Leakage Comparison in a Homogeneously Aligned Nematic Liquid Crystal Display Depending on an Angle between Polarizer Axis and Optic Axis of a Liquid Crystal

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Abstract

We have studied 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 show 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.

1. Objectives and Background

Recently, the image quality of nematic liquid crystal displays (LCDs) has been greatly 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 are still not fast enough 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 is 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 T_0 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 ($\alpha + \beta = 90^\circ$): $\beta = 0^\circ$ (*E*-mode) and 90° (*O*-mode). With conditions of $\alpha + \beta = 90^\circ$, the same dark state is obtained irrespective of the *E*- and *O*-mode. At present, the polarizer is laminated on glass substrate, possibly resulting in alignment error between the optic axis of a HALC and the polarizer axis.

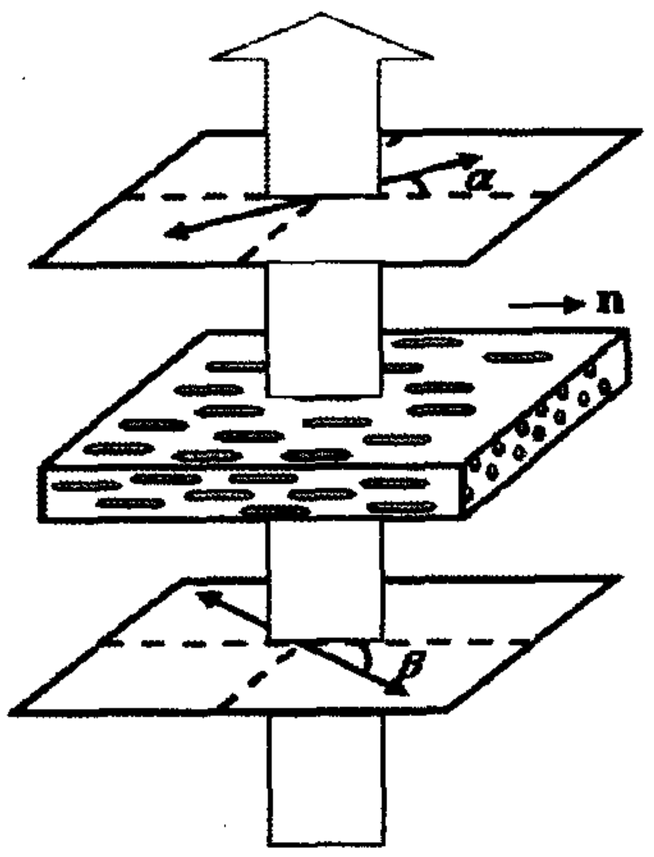


Fig. 1 Cell configuration of a homogenously aligned LC under two polarizers.

This paper, through calculation and experiment, examines the change in contrast ratio depending on the *E*- and *O*-mode when there is a deviation of the LC optic axis from the polarizer axis. The results can inform which mode is advantageous in manufacturing IPS or FFS cells.

2. Results

First of all, the transmittance for the *E*- and *O*-mode was calculated, assuming that the polarizers are crossed with each other and that there is only a small degree of deviation angle between the LC director, **n**, and the polarizer axis. In this case, the transmittance equation reduces to $T = T_o \{\sin^2(2\phi)\sin^2(\pi d\Delta n/\lambda)\}$, where ϕ is defined as the angle between crossed polarizers and **n**. Now 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 occurrence of effective birefringence Δn_{eff} since the linearly polarized light passing through the polarizer experiences a phase retardation when passing through the LC. Here, the Δn_{eff} can be defined as follows.

$$\Delta n_{eff} = n_e' - n_o = \left(\frac{n_e \times n_o}{n_e^2 \sin\phi + n_o^2 \cos\phi}\right)^{1/2} - n_o$$

Where n_e and n_o are extraordinary and ordinary refractive index of the LC, respectively. The same degree of deviation from the *E*- and *O*-mode in the first term gives rise to the same value irrespective of the mode (the *E*- or *O*-mode). However, the values of Δn_{eff} are different depending on the initial configuration such as the *E*- and *O*-mode. 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 of the deviation angle to 5°. This indicates that when there is misalignment of 1° between bottom polarizer and the short or long axis of the LC, a cell in the *O*-mode at initial configuration shows less light leakage than in the *E*-mode. To confirm the results, a test cell with homogenous alignment was evaluated. Here, the cell retardation value was 0.25μm with the LC Δn of 0.1 at 550 nm, and the pretilt angle of the LC was 1°. The transmittance as a function of the deviation angle and measured the *CR* defined as the ratio of T_{max} to T_{min} at a normal direction for the *E*- and *O*-mode has been measured, where the T_{max} is defined as the transmittance obtained when two polarizers along with the LC director are parallel to each other; the T_{min} is defined as the transmittance obtained when two polarizers are crossed with each other. As shown in Fig. 3, the transmittance increases with an increase of the deviation angle. In other words, 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.

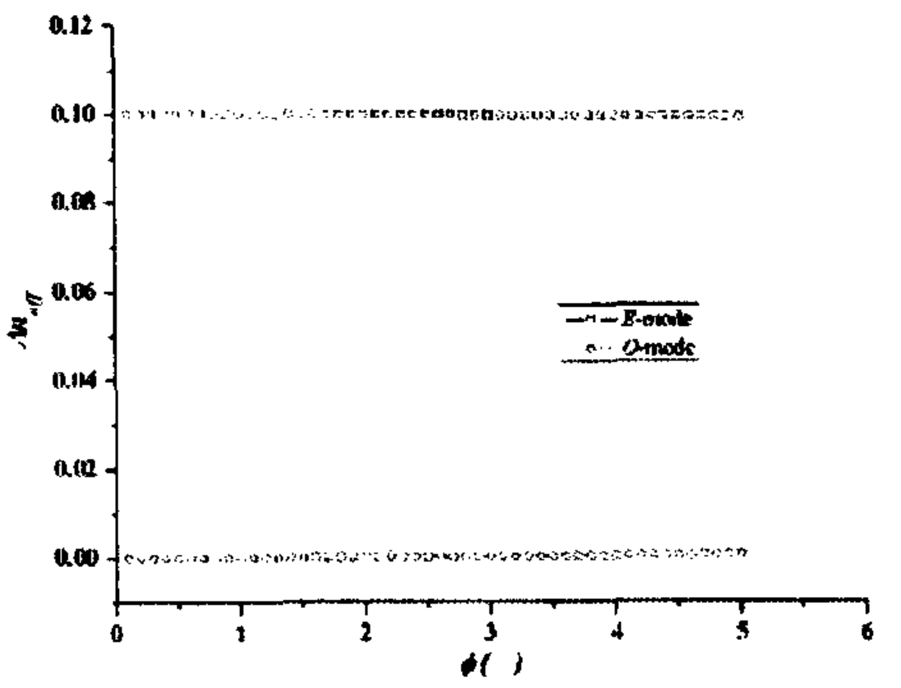


Fig. 2 Calculated effective Δn_{eff} as a function of deviation angle for the cell with the *E*- and *O*-mode.

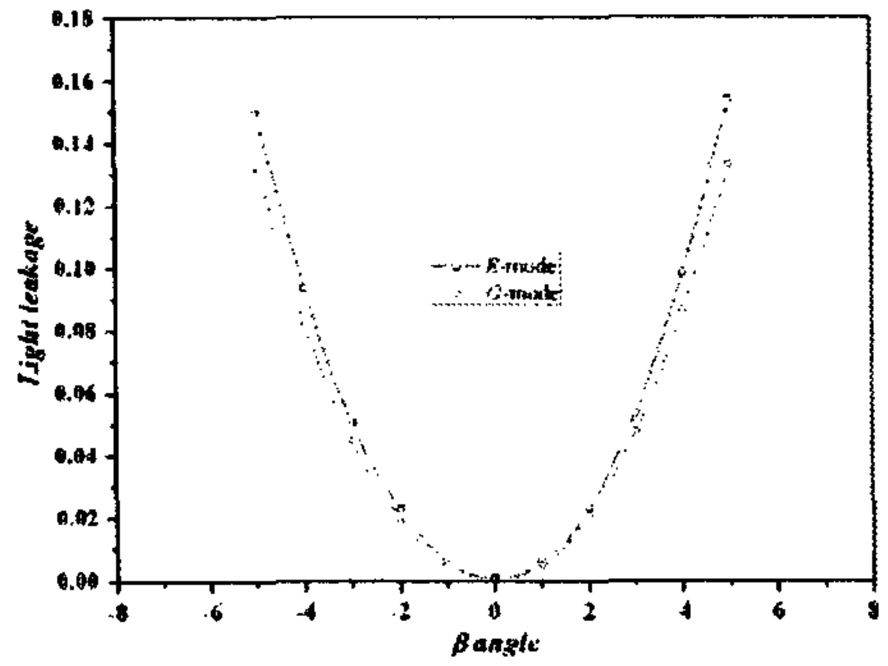


Fig. 3 The measured light leakage as a function of deviation angle for the director of cell with the *E*- and *O*- mode.

Also, the *CR* decreases with an increase of the deviation angle as shown in Fig. 4. Consequently, the CR of 1510 with a deviation angle of 0° is the same for both the *E*- and the *O*-mode, however, with a deviation angle of 1° it drops to 503 for the *E*-mode and to 604 for the *O*-mode, which is about a 20% higher value than 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 clear advantages for achieving a high *CR* at a normal direction.

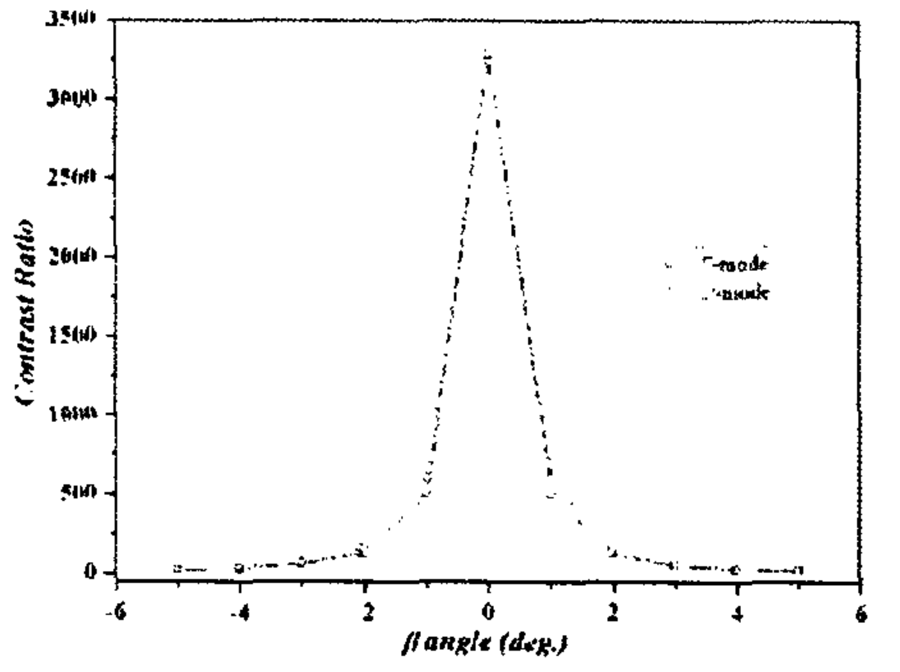
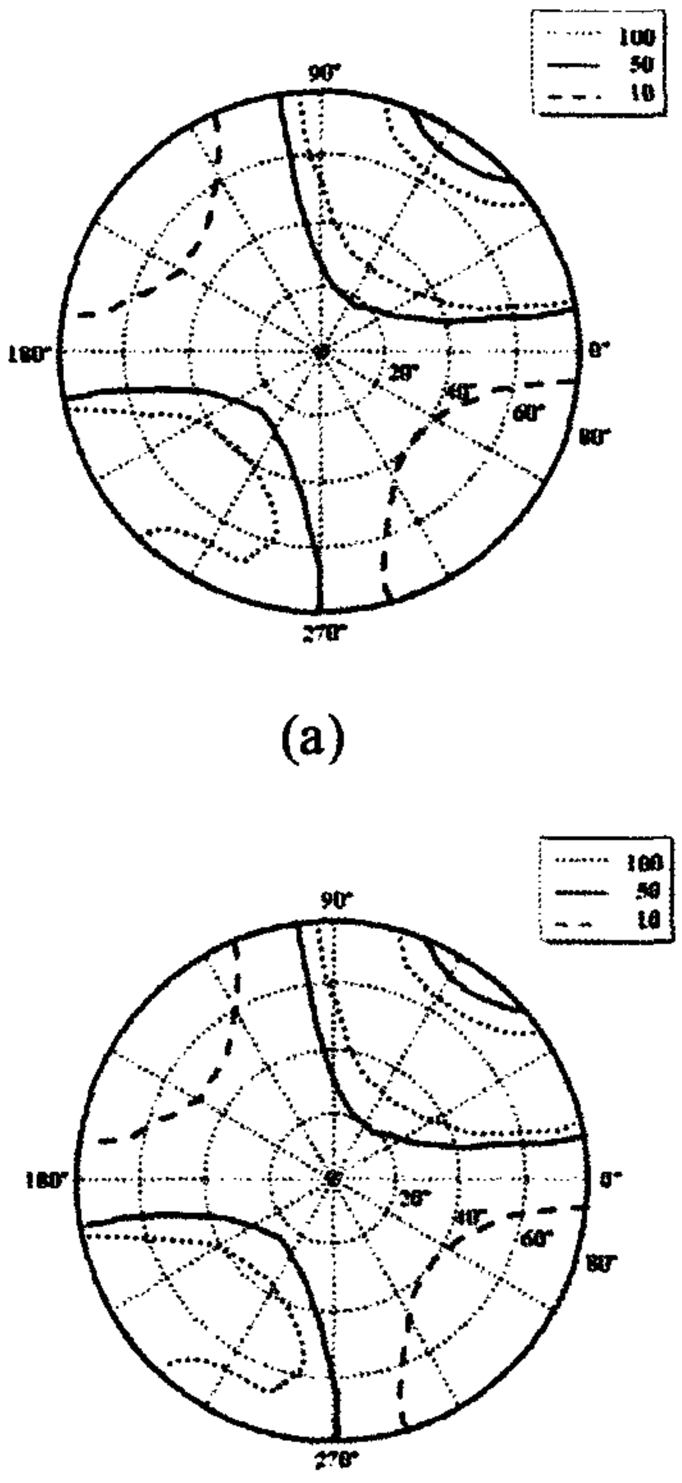


Fig. 4 The measured CR as a function of deviation angle for the cell with the *E*- and *O*-mode.

We have also investigated the viewing angle dependency of *CR* for the *O*- and *E*-mode.



(a)

(b)

Fig. 5 The calculated iso-CR contour with (a) the *E*- and (b) *O*-mode when the LC director initially deviates from 5°.

Fig. 5 shows Iso-CR contour when the LC director initially deviates from 5°. As shown in Fig 5, the results show almost the same Iso-CR contour.

3. Conclusion

In summary, how the cell configurations in the *E*- and *O*-mode 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 the cell in *O*-mode has distinct advantages over that of the cell in *E*-mode.

4. Acknowledgements

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5. References

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