

In-plane Switching Liquid Crystal Cell with a Mixed Bent Electrode Structure for Fast Response Time

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Abstract

A bent electrode structure is proposed in the super in-plane switching (S-IPS) liquid crystal (LC), as it can re duce the response time without loss of transmittance in the bright state. The electrode angle in each position of th e bent electrode was optimized to simultaneously achieve high transmittance and fast response time. The electro-opt ical characteristics of the proposed LC cell structure were experimentally compared with those of the conventional cell. It was observed that the response time became over 8% shorter without loss of transmittance when the propos ed bent structure was applied.

Keywords : liquid crystal, electrode, response time, transmittance

1. Introduction

Recent liquid crystal display (LCD) technologies have rapidly progressed to satisfy demand for high-quality TV applications. Various kinds of advanced liquid crystal modes such as the patterned vertical alignment (PVA) mode [1], the multi-domain vertical alignment (MVA) mode [2], and the fringe field switching (FFS) mode [3, 4] have been developed because they can provide a high contrast ratio, a wide viewing angle, and a fast response time. Despite these efforts, however, the qualities of LCDs are still insufficient, as they are still unable to display moving pictures that require fast response time. The S-IPS mode [5, 6] is one of the best LCD modes for TV applications because it is suitable for high frame rate operation (120Hz operation), which is one of the key technologies for fast LCD response to improve motion blurring, in addition to a wide viewing angle. The response time of the S-IPS mode has significantly improved because of the development of low-viscosity LC materials and the enlargement of the process window for the low cell gap configuration. On the other hand, these technologies also show some disadvantages such as low processing capability and decreased transmittance.

In this paper, a mixed bent electrode structure is proposed for the S-IPS LC cell that can reduce the response time without loss of transmittance. The bent electrode was optimized using the software *Teckwiz LCD* (SANAYI Systems Co., South Korea). To verify the effect of the bent electrode structure, the response time and the optical transmittance of the proposed S-IPS LC cell with the optimized electrode structure were experimentally measured, and compared with those of the conventional S-IPS LC cell.

2. Effects of the Electrode Angle of the S-IPS LC Cell on the Transmittance and Response Time

Fig. 1 shows the structure of the typical S-IPS LC cell. The indium/tin oxide (ITO) layer was deposited on the bottom substrate for the interdigital electrodes. The LC was injected between the two substrates after anti-parallel rubbing to obtain a homogeneously aligned liquid crystal cell. θ represents the angle between the electrode and the rubbing direction, which implies the optical axis of the LC director at the initial zero-voltage state, as shown in Fig. 1.

In the absence of an electric field, the optical axis of the LC layer coincided with the polarization axis of the polarizer,

Manuscript received August 5, 2008; accepted for publication September 19, 2008.
This paper was supported by the Dong-A University Research Fund in 2008.
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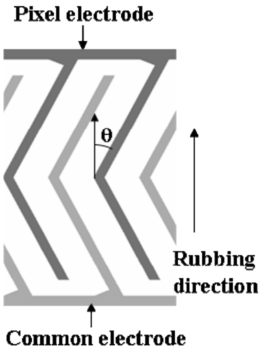

Fig. 1. Schematic diagram of the S-IPS cell structure from the top view.

so that the polarization state of the incident light after the light passed through the LC layer did not change and permitted a dark state. For the bright state, the optical axis of the LC directors, that experienced half-wave retardation, rotated to 45° for maximum transmittance. The LC directors in the cell did not rotate to 45° all together, however, because of the surface anchoring effect. Therefore, the optimized cell structure that can make the retardation effective must be found, and the effective optical axis of the LC director orientations must be made half-wave and 45°, respectively, when the voltage is applied. The normalized transmittance of the LC cell that has been placed between a pair of crossed polarizers can be written as follows [7]:

$$T / T_o = \frac{1}{2} \sin^2 (2\phi) \sin^2 (\frac{\pi d \Delta n}{\lambda}), \qquad \text{Eq. 1}$$

wherein ϕ is the angle between the transmission axis of the polarizer and the optical axis of the LC director, T_0 is the intensity of the transmitted light through a pair of parallel polarizers, d is the cell gap, Δn is the birefringence of the LC, and λ is the wavelength of the incident light.

The response time of the S-IPS LC cell can be derived with an equilibrium equation in which the elastic, electric, and viscous torques are expressed as follows [8-10]:

$$\gamma_1 \frac{\partial \phi}{\partial t} = K_{22} \frac{\partial^2 \phi}{\partial z^2} + \varepsilon_0 |\Delta\varepsilon| E^2 \sin\phi \cos\phi . \qquad \text{Eq. 2}$$

Here, γ_1 represents the rotational viscosity, ε_0 represents the permittivity of the free space, $\Delta\varepsilon$ represents the dielectric anisotropy, and K_{22} is the twist elastic constant of the LC. By solving the above equation, the optical on/off time for switching the LC cell can be determined as follows [11]:

$$\tau_{off} = \frac{\gamma_1 d^2}{\pi^2 K_{22}}, \quad \tau_{on} = \frac{\gamma_1}{\varepsilon_0 |\Delta\varepsilon| (E^2 - E_{th}^2)}, \qquad \text{Eq. 3}$$

wherein E_{th} represents the electric field that occurs in an optical threshold, and τ_{on} and τ_{off} represent the on/off time in the switching time.

It can be observed in equations (1) and (3) that the transmittance of the S-IPS LC cell strongly depends on angle ϕ in the active area, and that the response time also strongly depends on E_{th}. In general, the material parameters or geometrical structure can be manipulated to control the optical threshold voltage E_{th}. Therefore, τ_{on} can be reduced by decreasing E_{th}, which can be achieved by observing the relation between the electrode structure and E_{th}. The relation between the threshold electric field E_{th} and the angle θ was investigated in this study, and angle θ, which can reduce E_{th}, was optimized so that a fast response time could be realized without changing the LC material parameters.

Fig. 2 (a) and (b) show the calculated azimuth angle of

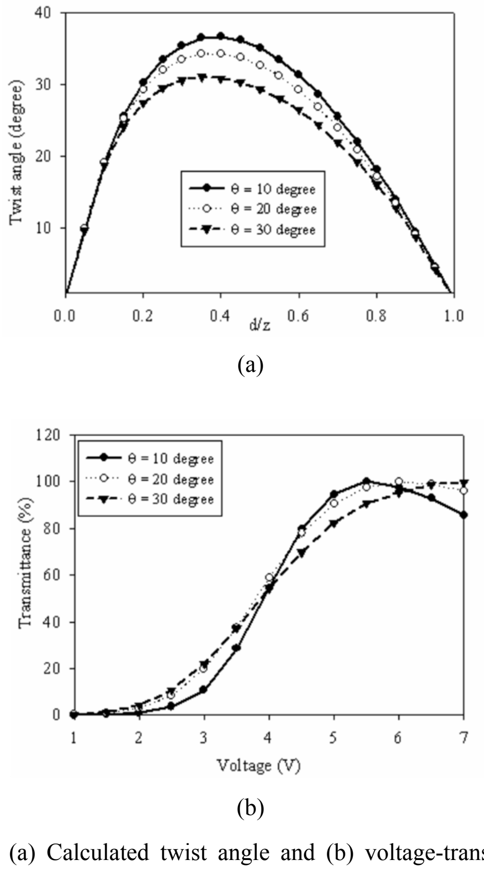

Fig. 2. (a) Calculated twist angle and (b) voltage-transmittance curve of the S-IPS LC cell as a function of the electrode angle *θ*. *d/z* represents the normalized position in the cell gap in the z-direction.

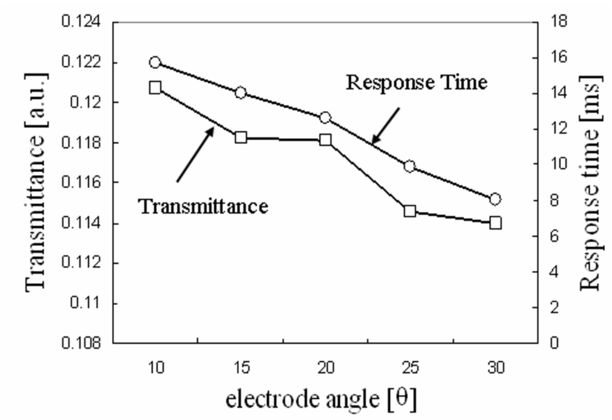

Fig. 3. Calculated transmittance and response time as a function of the electrode angle θ.

the LC director in the LC layer and the calculated voltage of the transmittance curve of the cell as functions of the electrode angle θ. For the calculations, an LC material from Merck Co. was used (K_{11} = 12.8, K_{22} = 5.8, K_{33} = 12.5, Δn = 0.0972, and $\Delta\varepsilon$ = 8.4). The width and the distance of the electrode were set at 3.5 μm and 11 μm, respectively. The cell gap was fixed at 3.4 μm. Fig. 2 (a) and (b) show that angle ϕ is closer to 45° and that the threshold voltage increases when the electrode angle θ is decreased. This implies that a high transmittance can be achieved in the bright state by decreasing angle θ, but that the response time will simultaneously become slower. Fig. 3 shows the calculated transmittance in the bright state and the response time of the LC cell as functions of the electrode angle θ. The inversely proportional relationship between the brightness and the response time as functions of the electrode angle θ can be easily found. The angle θ of 20° was applied in the S-IPS LC cell to achieve both the appropriate response time and the transmittance for the TV application.

3. A Mixed Bent Electrode in the S-IPS LC Cell to Improve the Response Time

To improve the response time without loss of transmittance from the simple electrode structure, a bent electrode structure was applied in the LC cell, as shown in Fig. 4. The bent structure applied, in the active area, three separate parts that had the same spatial length in the rubbing direction and three different electrode angles. θ_1, θ_2, and θ_3 represent the electrode angle of the edge area, the middle area, and the center area, respectively. Obviously, the transmittance in the

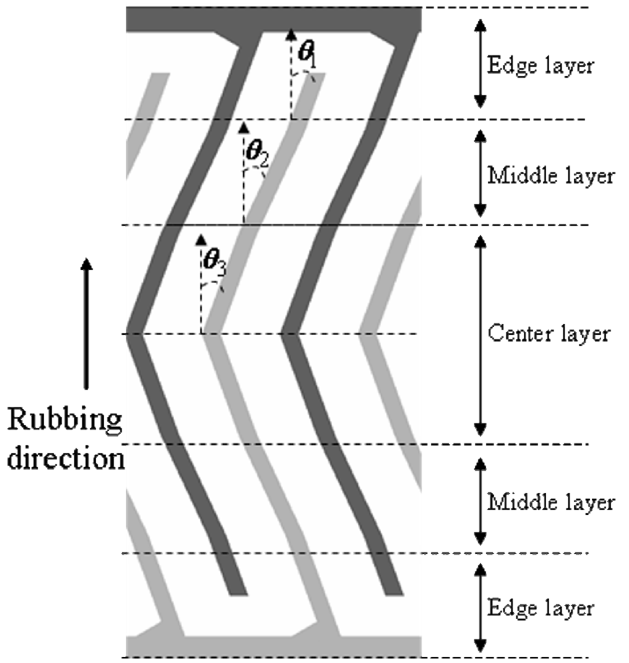

Fig. 4. Schematic diagram of the proposed mixed bent electrode structure.

bright state and the response time depended on the electrode angle θ, and they had an inversely proportional relationship to one another, as calculated in Fig. 3. In the bent electrode structure, however, the transmittance in the bright state was not always proportional to the electrode angle in each position because the aperture ratio, which could directly affect the transmittance, could be changed as a function of the electrode angle θ. Fig. 5 shows the calculated transmittance and the aperture ratio in each area of the LC cell as functions of angle θ in the bent structure. The calculated result shows that the aperture ratio in the middle area was maximized at θ_2 = 25°. The aperture ratio of the other areas was maximized when angles θ_1 and θ_3 were 20°. Fig. 5 further shows that the transmittance of the edge area was relatively low compared to that of the other areas despite the edge area's large aperture ratio. This was due to the defect generation from the non-uniform potential distribution in the edge area. Therefore, the calculated result shows that the maximum transmittance in each area occurred at (θ_1, θ_2, θ_3) = (20°, 25°, 20°). Furthermore, an angle of 25° for θ_2 in the middle area will clearly help decrease the response time of the cell compared to that of the conventional LC cell (θ_1, θ_2, θ_3) = (20°, 20°, 20°). Fig. 6 shows the calculated transmittance in the bright state and the response time as functions of the combined angle (θ_1, θ_2, θ_3). The result shows

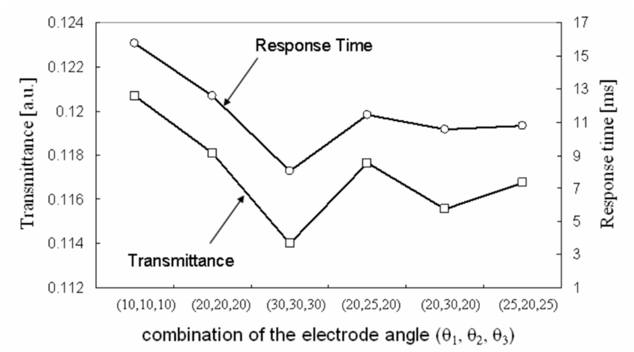

Fig. 5. Calculated transmittance and aperture ratio in each area as functions of the electrode angles θ_1, θ_2, and θ_3.

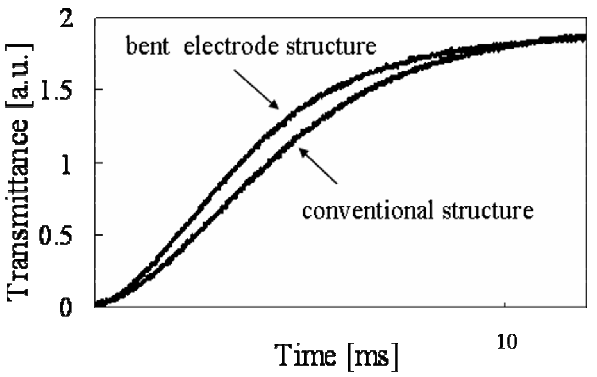

Fig. 6. Calculated transmittance in the bright state and response time as functions of the combined angles θ_1, θ_2, and θ_3.

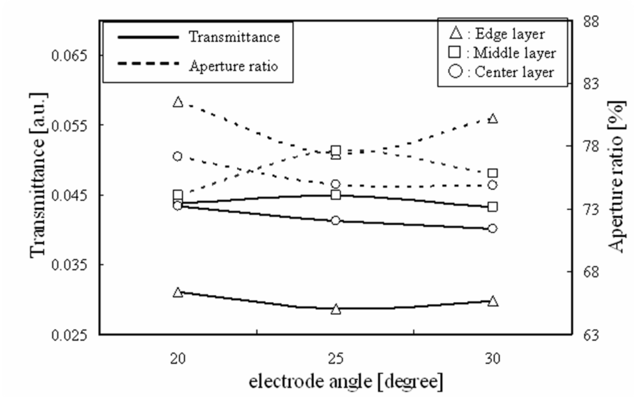

Fig. 7. Comparison of the measured dynamic response time of the proposed and conventional S-IPS LCD.

that the condition (θ_1, θ_2, θ_3) = (20°, 25°, 20°) provided the largest decrease in the response time without decreasing the transmittance.

To verify the calculation result, the electro-optical characteristics of the proposed LC cell and the conventional LC cell were experimentally compared. Fig. 7 shows the measured dynamic response time of the conventional LC cell and the proposed S-IPS LC cell, with (θ_1, θ_2, θ_3) = (20°, 25°, 20°). The measured response times of the proposed cell and the conventional cell were 13.2 ms and 14.4 ms, respectively. The measured transmittance values of the proposed cell and the conventional cell were 2.02 (a.u.) and 2.03 (a.u.), respectively. Therefore, an over 8% improvement in the response time (τ_{on}) and almost the same transmittance between the proposed LC structure and the conventional structure were observed.

4. Conclusions

In this study, the S-IPS LC cell with a mixed bent electrode structure was proposed. The structure of the bent electrode was optimized to simultaneously achieve high transmittance and fast response time. The experimental results showed good agreement with the simulated results. The proposed electrode structure of the S-IPS LC cell may be suitable for TV application, which demands a fast response time.

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