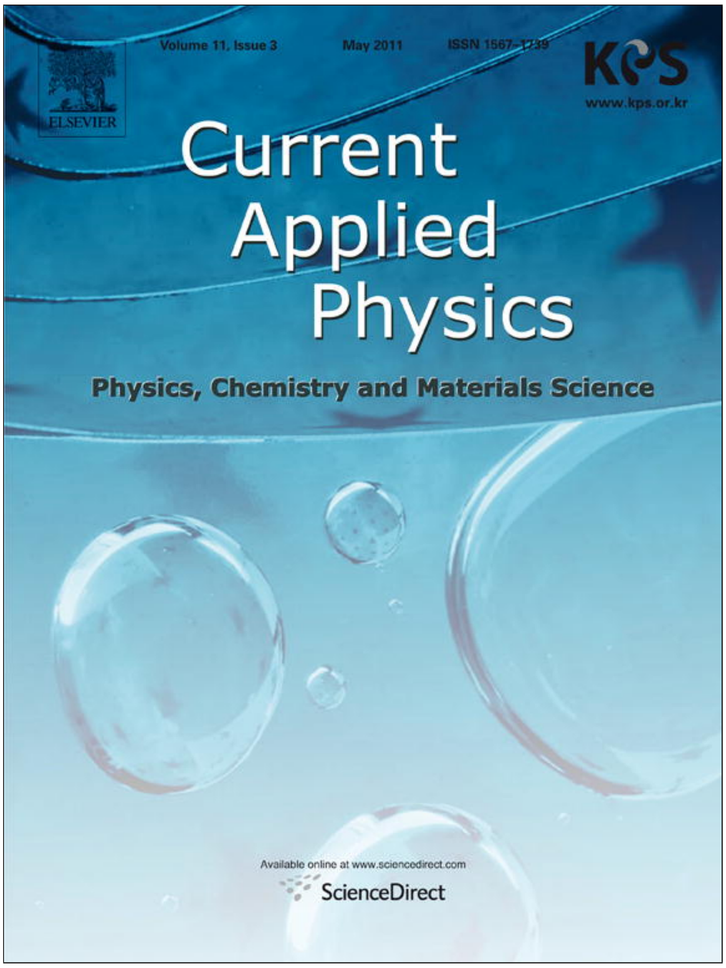
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Optimization of electrode structure to control liquid crystal director nearby domain boundary in a Z-shape patterned vertical alignment mode

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ABSTRACT

Various pixel structures have been proposed in the patterned vertical alignment (PVA) mode to improve transmittance and response time because collisions of the liquid crystal directors are inevitable near domain boundary region. One of them is well known as Z-shape structure, which shows multi-domain characteristic but low transmittance due to forming disclination lines at the domain boundary. This characteristic comes from the LC director that cannot tilt down to 45° with respect to the transmissive axis of crossed polarizers. In order to overcome this problem, we proposed a new pixel structure which improves transmittance while keeping the number of masks same as before. Consequently, the proposed structure improved transmittance up to 18% compared with conventional Z-shape structure.

1. Introduction

The liquid crystal display (LCD) market has many different liquid crystal (LC) modes in competition with each other. The conventional well known as twisted nematic (TN) mode [1,2] is mainly used in portable displays on account of its high transmittance and low power consumption. However, the TN mode shows a narrow viewing angle, and thus had led to development of many wide viewing angle liquid crystal modes such as in-plane switching (IPS) [3], fringe-field switching (FFS) [4–6], multi-domain vertical alignment (MVA) [7], and patterned vertical alignment (PVA) [8–11]. Among these modes, the PVA mode, which has been commercialized in LC-televisions and monitors, shows a very high contrast ratio at the normal direction because the LC is vertically aligned to the substrate so that phase retardation of the cell at normal direction is zero under a crossed polarizer, resulting in a good dark state. Nevertheless, LC reorientation is a major factor at on state in PVA mode.

In the normal PVA cell, the vertically aligned LC directors tilt down in four different diagonal directions by an oblique electric field generated by patterned electrodes on the top and bottom substrate. However, designing one pixel in real LCD, the horizontal electric field component of an oblique electric field cannot be generated as wanted. This causes that all LC directors are not tilted equally to 45° direction with respect to the transmissive axis of crossed polarizer. Accordingly, transmittance is low in this region due to the reason mentioned above.

In order to resolve this problems in PVA mode, a number of researches were proposed such as Z-shape [12], chevron [13] and A4 [14] structures and so on. Despite these efforts, the low transmittance remains challenges to solve for high performance LCD. In this research, we proposed pixel structure of Z-shape PVA mode and optimized pixel structure to minimize disclination regions, and its electro-optical characteristics have been compared with that of conventional Z-shape PVA mode. Some detailed descriptions on the proposed cell structure as well as the cell design for high transmittance have also been discussed.

2. Switching principle of PVA mode and proposed cell design

The normalized transmittance equation for the PVA mode can be defined as follows

$$T/T_0 = \sin^2(2\theta)\sin^2\left(\frac{\Delta n_{eff} d(V)}{\lambda}\right) \quad (1)$$

where θ is an angle between transmissive axis of crossed polarizers and LC director, Δn_{eff} is effective birefringence of the LC, d is the cell

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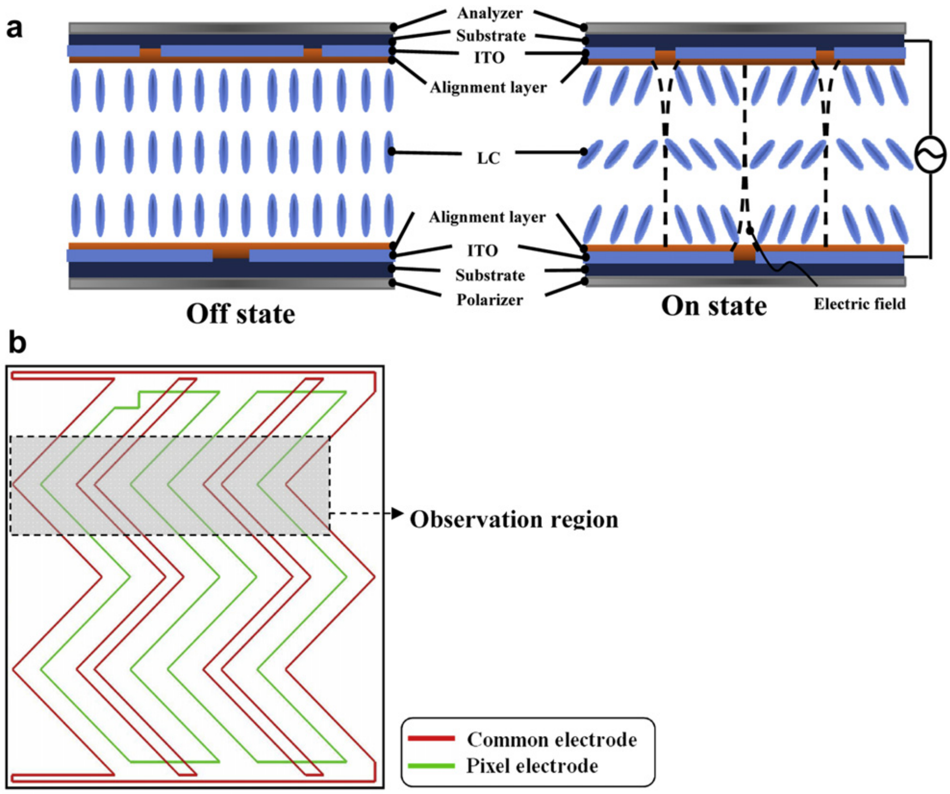

Fig. 1. (a) Cross-sectional view of the PVA mode cell structure; voltage off and on state, and (b) Top view of the electrode structure of Z-shape PVA mode.

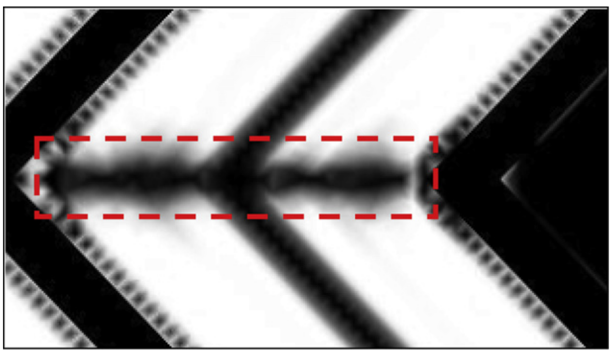

Fig. 2. Transmittance distribution of conventional Z-shape PVA structure in the observation area of Fig. 1(b). The dark region is associated with collision between LC directors and also undefined azimuthal orientation of LC directors.

gap, and λ is the wavelength of an incident light. To maximize the transmittance, θ and the effective phase retardation of cell ($d\Delta n_{eff}$) should be 45° and $\lambda/2$, respectively.

Fig. 1 shows the cross-sectional and top view of the Z-shape PVA mode cell structure. Without applying an electric field in the cell, the LC director is vertically aligned so that the polarization state of linearly polarized light passed through a polarizer does not change while propagating through the LC, and thus the light is blocked by an analyzer. When bias voltage is applied to the cell, LC directors tilt downward in two different directions by oblique electric field and the transmittance becomes maximum when $\theta = 45°$ and $d\Delta n_{eff} = \lambda/2$. Electrode design as presented in Fig. 1(b) is commonly known as Z-shape PVA mode. The LC directors tilt down in four different directions by oblique electric field generated by chevron electrode structure. In this approach, molecular reorientation in the region marked with rectangular dashed line is observed because collision of LC directors in the domain boundary region is inevitable when the voltage is applied.

In this study, the LC with negative dielectric anisotropy was used for the simulation. The dielectric anisotropy and refractive index were −4.2 and 0.079, respectively. The pretilt angle of LC molecules was 90° on bottom and top substrates. Transmission axis of polarizer at the bottom substrate was 0° whereas analyzer axis on the top substrate was 90°. The cell gap and $d\Delta n$ were 4 μm and 0.316 μm, respectively. Pixel and common electrodes are biased by 12 V and 6 V, respectively, so that potential difference 6 V is applied to LC molecules. To simulate the electro-optic characteristics of the PVA mode, three-dimensional finite element method (FEM) module of TechWiz LCD (Sanayi System, Korea) was used. The optical transmittance was calculated using the 2 × 2 extended Jones matrix.

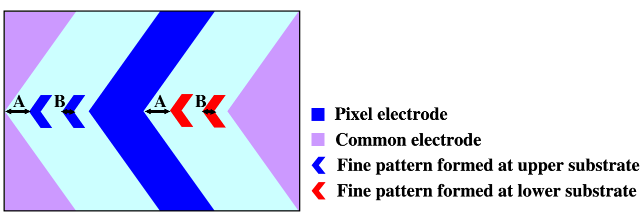

Fig. 3. Fine patterned electrode structure of electrode near the observation area.

Table 1
Optimized width of fine pattern on common and pixel electrodes.

	A	B
Pattern width on common electrode	6.6 μm	4.1 μm
Pattern width on pixel electrode	7.0 μm	3.5 μm

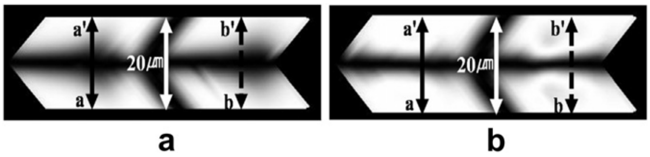

Fig. 4. Simulated result of transmittance distribution: (a) conventional and (b) proposed electrode structure.

3. Results and discussion

The Z-shape PVA mode has low transmittance region associated with disclination line near domain boundary because LC directors do not tilt down to 45° with respect to the crossed polarizer axes as shown in red box of the Fig. 2. The main reasons for low transmittance are that the horizontal component of an oblique electric field is not in diagonal direction so that the LC directors do not tilt down as wanted, and at the same time, the LC directors collide with each other because the LC directors in the upper and the lower sides of bent region in domain boundary tilts down to −45° and +45° with respect to the horizontal axis, respectively. In order to increase the transmittance, collisions between the LC directors should be minimized or field direction of an oblique electric field should be optimized. Besides, solution should be made without an additive process or cost.

Fig. 3 shows the proposed structures of fine patterned Z-shape PVA mode. Fine patterns were formed on the pixel and common electrode, respectively. Shapes of the fine patterns were the same as chevron structure and the angle of these patterns was formed ±45° to the transmissive axis of polarizers. Through this structure, we could expect that LC directors in the disclination region could be reinforced by oblique electric field generated by chevron pattern.

Table 1 shows electrode structure with optimized numerical value of interval and width of fine patterns. The interval and width of fine patterns at the pixel electrode were 7.5 μm and 3.5 μm, respectively. Whereas the interval and width of fine patterns at the common electrode were 6.6 μm and 4.1 μm. The height of all the fine patterns were 10 μm. Fig. 4 shows the simulated results of transmittance distribution between conventional and proposed electrode structures. As presented, the size of dark regions seems to be reduced in the proposed structure. Maximum transmittance has been increased 18% from 0.0096 to 0.01134 in the proposed structure. In order to analyze the transmittance distribution in detail, we define an angle β, defined as an angle of LC molecules against transmissive axis of polarizers and it is calculated within the range of 7 μm from the center of bent region. Fig. 5 shows distribution of the angle β within the 7 μm range from mid-position of the bent region. As indicated in this figure, more LC directors have β values close to 40–45° in the proposed structure than those of conventional structure. Accordingly, we could expect that transmittance will be increased in the proposed structure. Fig. 6 shows comparison of transmittance distribution within ±10 μm from mid-position of bent region at two electrode positions a and a', b and b' indicated in Fig. 4. From Fig. 4, we know that the width of disclination region in proposed structure is much narrower than that of conventional structure without fine pattern. As expected, the transmittance in the proposed structure increased in the cross-sectional positions a–a' as well as b–b', compared to that in the conventional structure. This clearly informs that the oblique field direction which makes LC director tilt down to 45° with respect to

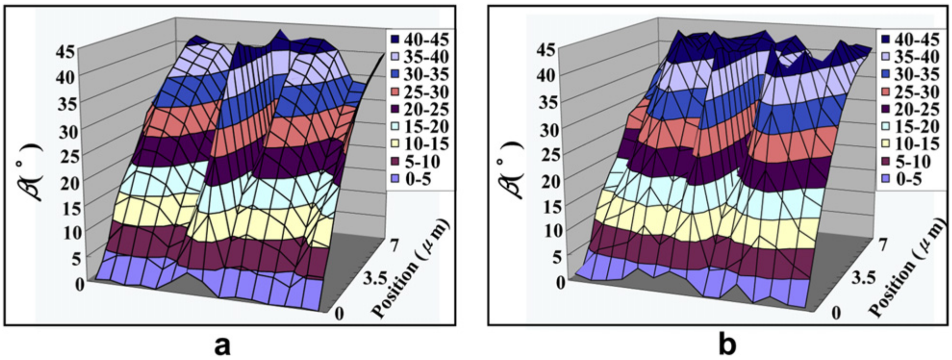

Fig. 5. Distribution of β within the 7 μm range from mid-area of bend region: (a) conventional and (b) proposed structures.

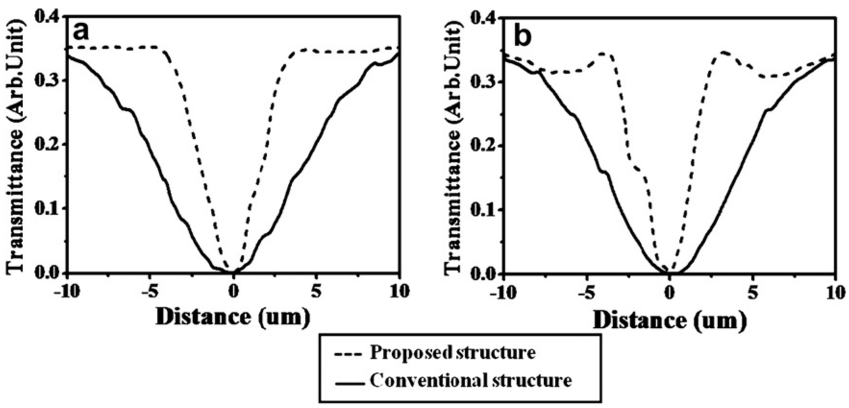

Fig. 6. Comparison of transmittance distribution within ±10 μm from mid-position of bent region along the cross-sectional lines (a) a–a′ and (b) b–b′, defined in Fig. 4.

transmissive axis of polarizers is reinforced near domain boundary by fine patterning electrode.

4. Conclusion

We have studied how to improve transmittance in the Z-shape PVA device. A proposed electrode structure with fine pattern leads to improvement of transmittance up to 18% nearby LC collision region because LC directors are controlled well toward 45° direction with respect to transmissive axis of polarizer owing to oblique electric field generated by fine pattern. Especially, the improvement was achieved without any additional process or cost.

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