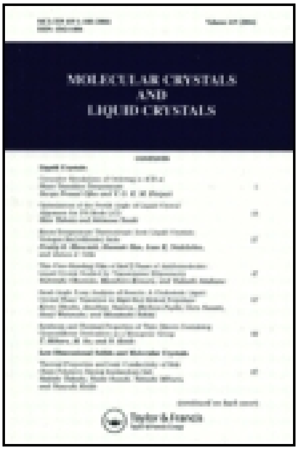

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Optimization of LCD Pixel Structure for Continuous Pinwheel Alignment (CPA) Mode

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In this article, we report our theoretical study on the electro-optical properties of continuous pinwheel alignment (CPA) mode. We performed three-dimensional finite element method (3D-FEM) simulations on various CPA electrode patterns and compared our simulation results with the conventional vertical alignment (VA) mode. Each CPA pixel pattern was carefully examined with respect to the transmission, dynamic response, and contrast ratio as well as viewing characteristics in an effort to optimize the electrode pattern. Our numerical study revealed that the optimum dimension for the thickness of the liquid crystal (△d) should be chosen as 2.9 μm where CPA mode can exhibit superior performance on VA mode in terms of transmission as well as viewing characteristics. Further, our numerical simulation demonstrated that the transmittance of CPA mode can be improved over VA mode by 81% while the viewing angle characteristics can be improved by 22%.

Keywords: finite element method; liquid crystal display; simulation

I. INTRODUCTION

Various kinds of LCD modes have extensively been investigated in an effort to enhance the electro-optical response of the LCD pixel such as

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wide viewing characteristics, high contrast ratio, excellent brightness, and good dynamic response. TN mode has been widely used due to a high transmittance, simple fabrication process, and uniform transmittance. TN mode, however, is considered to suffer from shortcomings such as the narrow as well as non-uniform viewing-angle characteristics. In the meanwhile, VA mode is considered to exhibit the better viewing-angle characteristics than TN mode. Various types of operating modes stem from the vertical alignment (VA) such as multi domain vertical alignment (MVA) mode and patterned vertical alignment (PVA) mode.

The MVA mode configures the electric field in the LC cell via protrusion of dielectric materials, which determines the boundary conditions of the surface anchoring directors. In the meanwhile, the electric field near the surface is determined by the electrode pattern for PVA mode. All the VA modes exhibit an excellent contrast ratio and eliminate the necessity of the rubbing process. However, VA mode has a technical limit in terms of light transmission because the presence of multi domains gives rise to domain walls which block the transmission of light.

Recently, continuous pinwheel alignment (CPA) mode was proposed by Sharp Co., Ltd. [1] CPA mode relies on VA technology simultaneously with TN mechanism. [1,3] In this article, we make a comparison of CPA mode with conventional VA mode in terms of electric optical properties by three-dimensional finite element method (FEM) simulation.

II. Operational Mechanism of CPA

Figure 1 is a cross sectional view of the liquid crystal cell structure under this study. Referring to Figure 1(a), we can notice that molecules of conventional VA mode exhibit homeotropic alignment in the off state. In Figure 1(b) is shown that molecules of negative LC tend to lie down in compliance with the vertical lines of the electric field, which is z-axis, over all in the on state. Referring to Figure 2(a), molecules of CPA mode seem to be aligned in a similar manner to the conventional VA mode in the off state. Figure 2(b) shows that molecules of CPA mode lie down to the vertical lines of electric field and rotate by 90 degrees starting from the bottom molecules to the top molecules.

As a consequence, the operation of CPA molecules is quite similar to that of TN mode. Referring to Figure 3, we note that the polarizer is set to lie down at 45 degrees while the analyzer lies down at 135 degrees. Figure 3(a) illustrates the condition for the conventional VA mode for the on state. If molecules lie in parallel with the polarizer

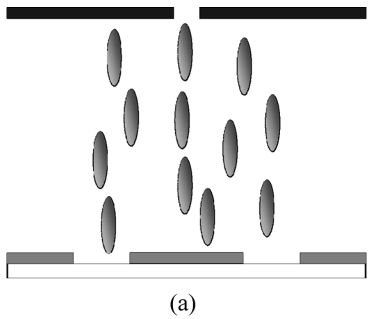


FIGURE 1 Cross-sectional view of liquid crystal cell for the VA mode at: (a) off state, (b) on state.

or the analyzer, domains B and D become dark state while the other domains become white state. CPA mode does not care about the direction of polarizer or analyzer in case of the on state. Since the orientation of light does not show dependence on the direction of polarizer or analyzer, and further oriented light rotates at 90 degrees, all the domains of CPA mode are to be white state.

In Figure 4 is shown the electrode structure for the simulation of VA and CPA mode where we mark the direction of the polarizer and the analyzer. The size of simulation region is assumed to be 73 μm × 73 μm, μm, while the electrode structure being 58 μm × 58 μm. The thickness of liquid crystal layer (Δd) is 3 μm. The size of sub pixel structure is 29 μm × 29 μm. The common electrode is located on the CF substrate without any particular shape. We used a numerical simulator "TechWizLCD," which employs 3D finite element Method (FEM), in an effort to optimize the optical properties of the CPA modes [2].

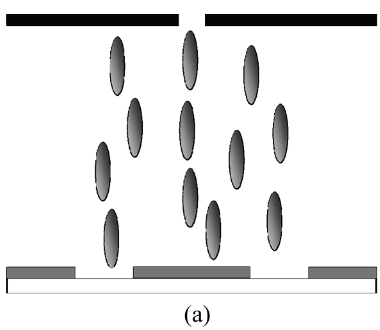


FIGURE 2 Cross-sectional view of liquid crystal cell for the CPA mode at: (a) off state, (b) on state.

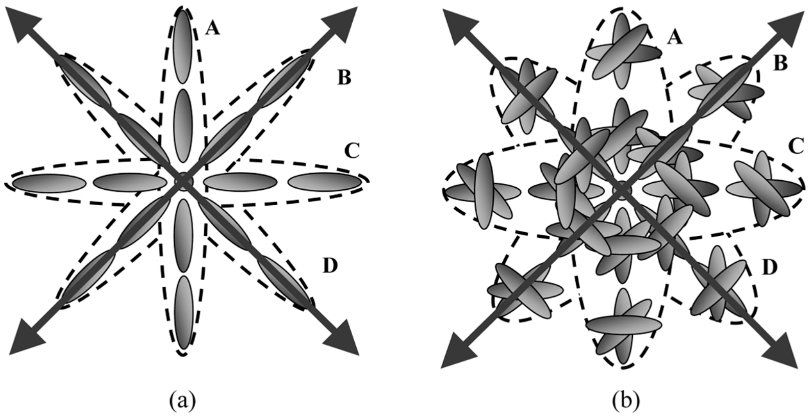


FIGURE 3 Top-view of liquid crystal cell (a) VA mode, (b) CPA mode where A, B, C, D mean observing domains.

Figure 5 illustrates that the conventional VA mode exhibits lines of dark regions in case of the on state. As aforementioned, the molecules tend to align with the direction of the polarizer for the dark region. In the meanwhile, CPA mode exhibits no dark region in the on state

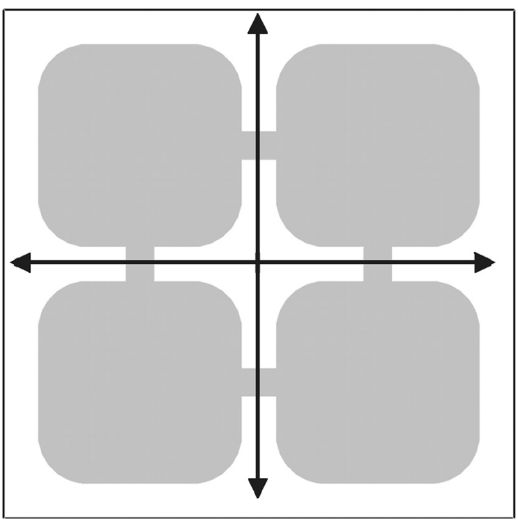
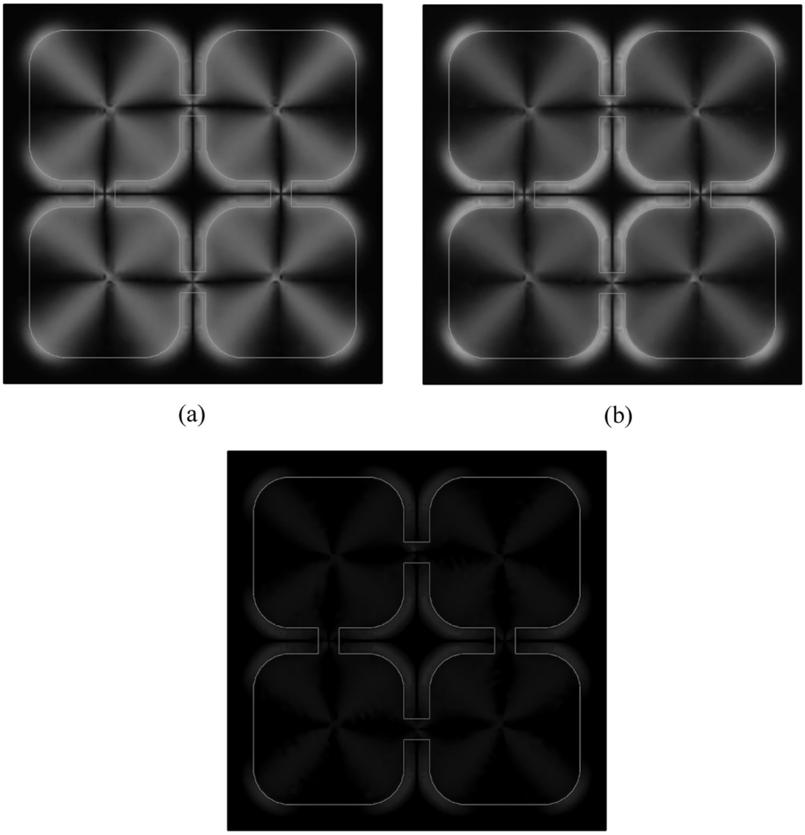


FIGURE 4 Pixel electrode structure used in the simulation of VA and CPA mode wherein directions of polarizer and analyzer are also shown.



(c)

FIGURE 5 Transmittance for VA mode when 5 V is applied to the pixel electrode; (a) the result of using the red CF, (b) the result of using the green CF, and (c) the result of using the blue CF.

as shown in Figure 6, which leads to the improvement in aperture characteristics and light transmission.

In Figure 7 is shown the light transmission as a function of voltage wherein the circle-dotted line represents the VA mode and the rectangle-dotted line for the CPA mode. The transmittance was calculated by the integration over a pixel and the transmittance is shown in an arbitrary unit. The light transmittance for the CPA mode is approximately twice as high as the conventional VA mode at 5 V. We can also observe the improvement in the light transmission for a wide range of viewing angles.

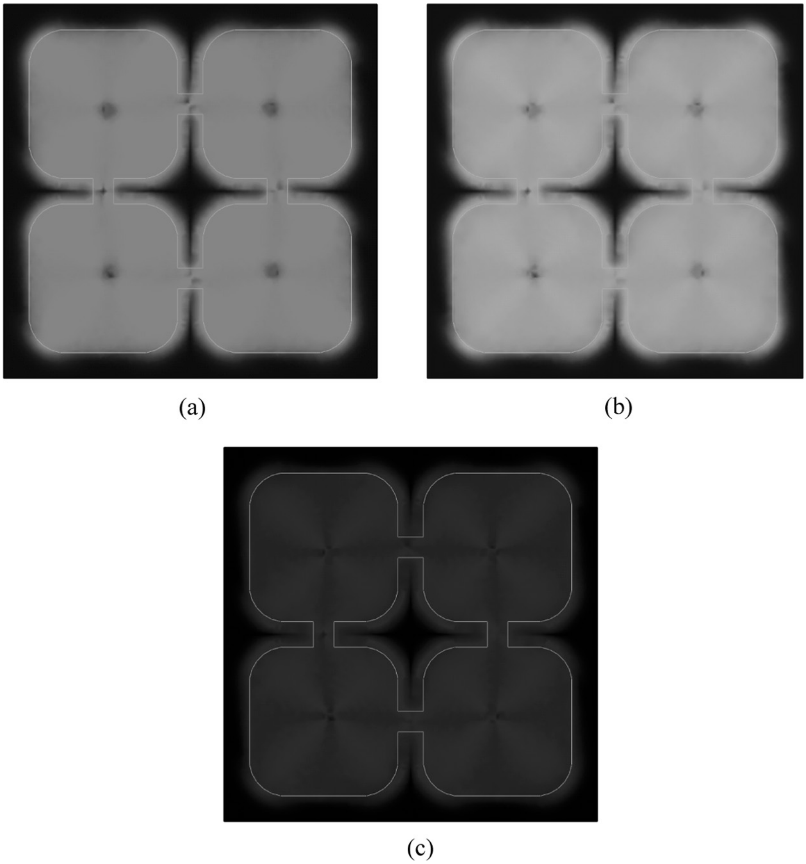


FIGURE 6 Transmittance for CPA mode when 5 V is applied to the pixel electrode; (a) the result of using the red CF, (b) the result of using the green CF, and (c) the result of using the blue CF.

Figure 8 is a plot illustrating the transmittance as a function of time for conventional VA and CPA mode. In this figure, the rectangle-dotted line represents transmittance of CPA mode while circle-dotted line represents the transmittance of conventional VA mode. We applied 5 V to the pixel electrode for the duration of 50 ms. Thereafter, we applied 0 V to the pixel electrode for the next period of 50 ms. Response time (rising time and falling time) was defined as the time interval between 10% point and 90% point from the transmittance curves. There seems to be no appreciable difference, i.e. 1.21 ms, in the falling time between the conventional VA mode and the CPA mode.

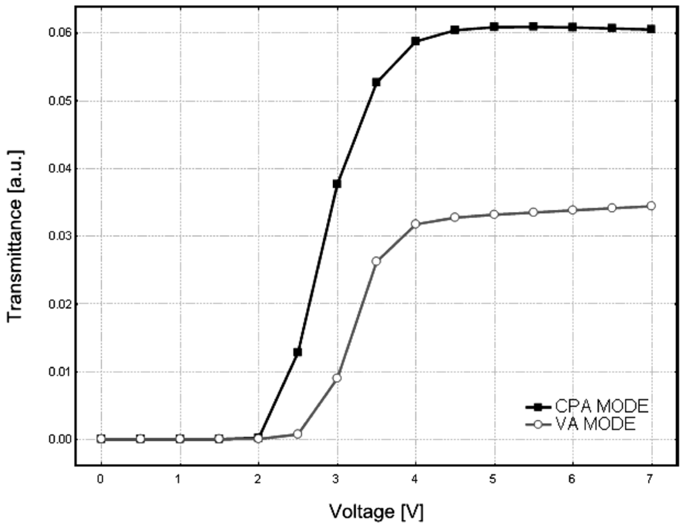


FIGURE 7 Transmittance as a function of voltage for VA and CPA mode.

At a first glance, we may conclude that the rise time was raised by 10.31 ms if CPA mode is driven. However, the deterioration of rise time can be compensated if we take the improvement of the absolute

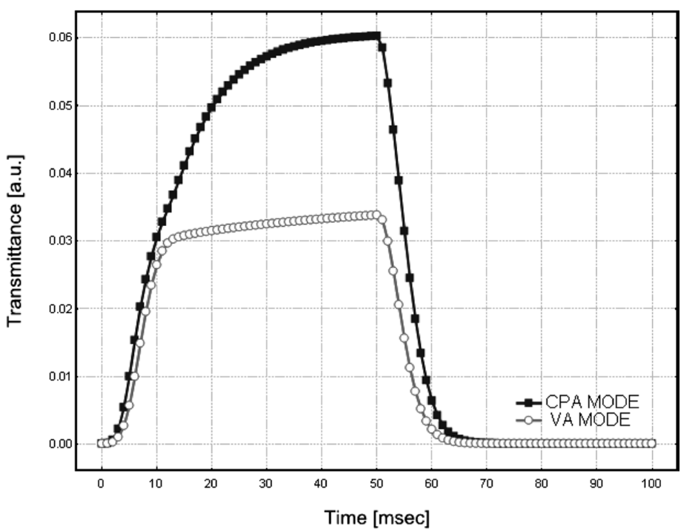


FIGURE 8 Transmittance as a function of time for conventional VA and CPA mode.

TABLE 1 Transmittance as a Function of Time for Conventional VA and CPA Mode

	10%	90%	90%–10%
VA mode rising time	4.24 ms	13.59 ms	9.35 ms
VA mode falling time	51.84 ms	58.96 ms	7.12 ms
CPA mode rising time	4.41 ms	24.57 ms	20.16 ms
CPA mode falling time	51.81 ms	60.14 ms	8.33 ms

transmittance into account. The physics is that molecules of liquid crystal in CPA mode have chiral dopant, which makes the molecules take time for the rotation and subsequently lying down when a DC voltage (5 V) is applied to the pixel electrode. When the voltage at the pixel recovers to ground potential, the molecules of liquid crystal in CPA mode behave in a similar manner to the conventional VA mode. Table 1 lists numerical values of response time for the conventional VA mode and CPA mode.

Figure 9 shows the contrast ratio for viewing angle in polar coordinate; conventional VA and CPA mode. We depicted a line at an angle of 45 degrees in the figure. This line means a contrast level corresponding to 10. We confirmed that viewing angle of CPA mode has been improved by more than 22%. Our numerical simulation revealed that transmission can be improved by 81% while viewing angle can be improved by 22% for CPA mode in comparison with VA mode.

III. SIMULATION RESULTS AND DISCUSSION

In this work, we tried various patterns for CPA mode. All the simulation conditions are identical except for the electrode structures. In this sections, we report the results on three trials, "pattern 1" in Figure 10(a), "pattern 2" in Figure 10(b), and "pattern 3" in Figure 10(c), respectively. "Pattern 1" in Figure 10(a) is the same structure as the one for the conventional VA mode. "Pattern 2" in Figure 10(b) has a protrusion in the common electrode, which includes a circle at the center of structure. "Pattern 3" in Figure 10(c) is the same structure as pattern 2 except the exclusion of protrusion. We estimated transmission, response time, and viewing angle.

We simulated 8 trials from 2.5 μm to 3.2 μm for the purpose of finding the optimized thickness of CPA mode. Figure 11 illustrates the dependence of transmittance on the applied voltage wherein the thickness of CPA mode is set to be 2.9 μm in which the transmittance

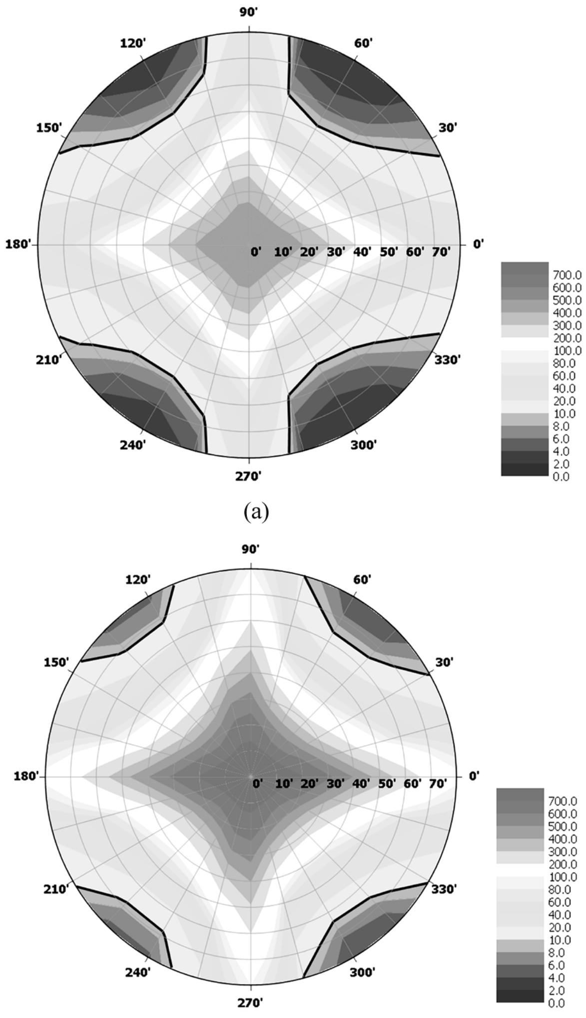


FIGURE 9 Contrast ratio for viewing angle in polar coordinate; (a) conventional VA mode (b) CPA mode.

exhibits the peak value at 5 V. Further, the transmittance does not show fluctuations for other voltages when the thickness of CPA mode is set to 2.9 μm. However, the transmittance when the thickness of CPA mode is 2.5 μm is less than that when the thickness of CPA mode is 2.9 μm at all voltages. In case when the thickness of CPA mode is

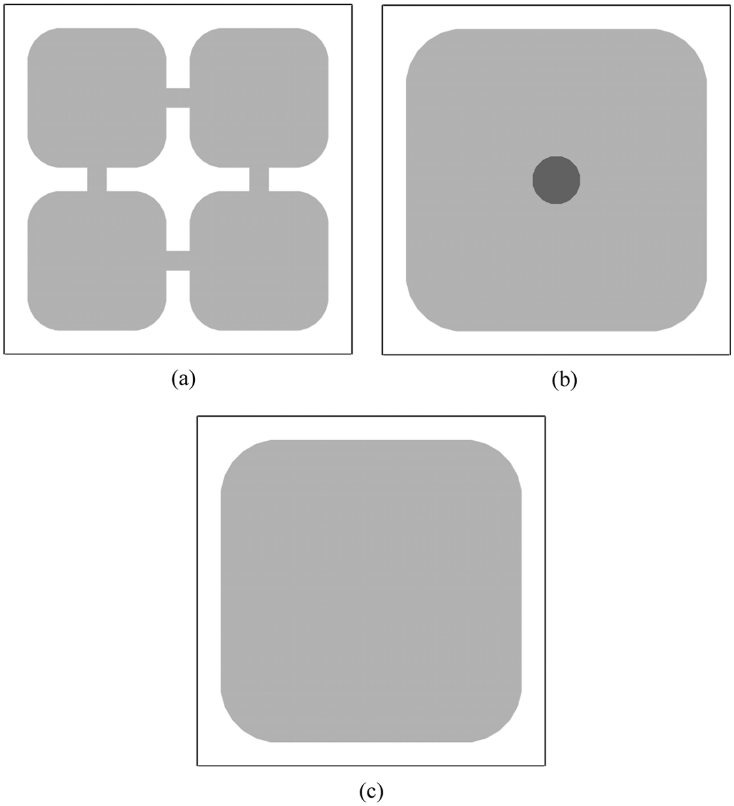


FIGURE 10 Electrode structures of CPA mode for comparing electro optical properties (a) pattern 1, (b) pattern 2, and (c) pattern 3.

3.0 μm and 3.2 μm, respectively, the transmittance peak is higher than that when the thickness of CPA mode is 2.9 μm. However, the transmittance when the thickness of CPA mode is 3.0 μm and 3.2 μm exhibits decrease from 6 V to 7 V. As a consequence, we finally adjusted the thickness of CPA mode to 2.9 μm.

Figure 12 is a schematic diagram illustrating the light transmission for three trial structures (a) pattern 1, (2) pattern 2, and (c) pattern 3, respectively, under the condition when 5 V is applied to the pixel electrode. The light transmission of the pattern 1 is poor when compared with those of patterns 2 and 3. However, the aperture ratio of pattern 1 is better that those of the other two trials. We can observe a dark area at the center, which is due to the disclination at the protruded electrode.

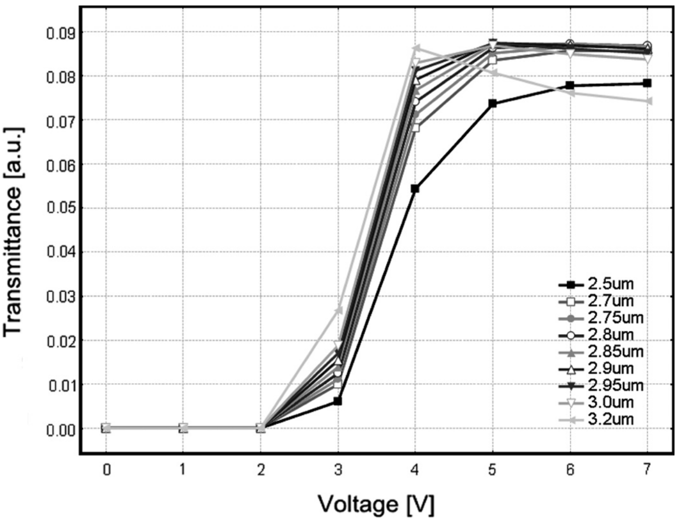


FIGURE 11 Transmittance as a function of voltage for optimizing the thickness liquid crystal layer of CPA mode.

Figure 13 is a V-T curve illustrating the transmittance as a function of voltage for the three trial patterns of CPA mode. In this figure, the rectangle-dotted line represents the transmittance of pattern 1, while the triangle-dotted line stands for the transmittance for pattern 2. Furthermore, the circle-dotted line represents the transmittance for pattern 3. Our numerical simulation reveals that the transmittance of the white state for pattern 1 is inferior to those of pattern 2 and pattern 3 by more than 8%, which is due to the fact that the effective area of the pixel electrode of pattern 1 is smaller than that of patterns 2 and 3.

Figure 14 is a T-T curve for the three trial patterns which illustrates transmittance as a function of time. It is assumed that a voltage step of 7 V is sustained for 50 ms and subsequently the voltage is dropped to zero. Response time was defined as the time interval between the initial 10% value and 90% value in order to make a fair comparison among those three trials. The response times from the white state to the dark state when the voltage step is 7 V are 14.45 ms for pattern 1, 15.27 ms for pattern 2, and 15.95 ms for pattern 3, respectively. According to our numerical simulation, it seems that the pixel structure of pattern 1 provides a better control of LC molecules for the fast switching.

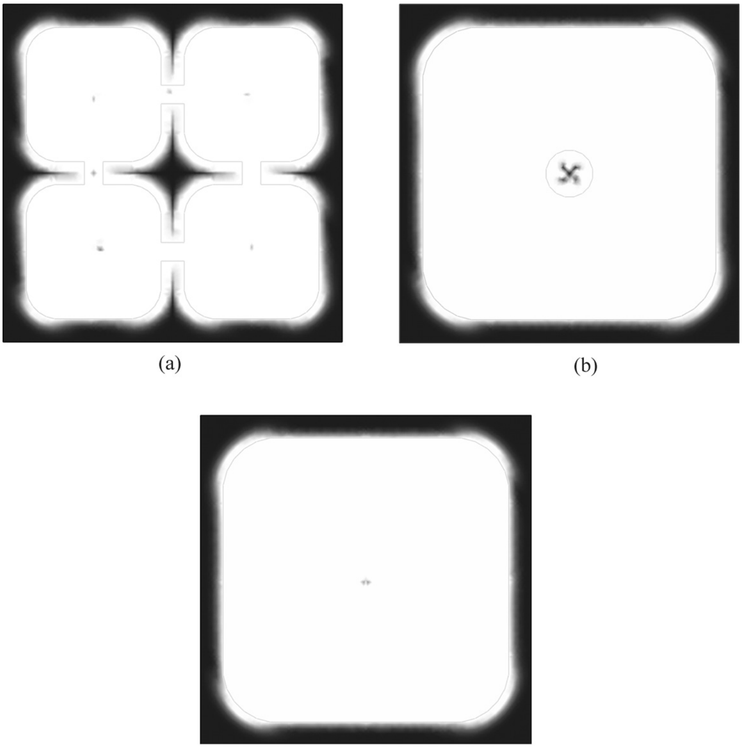


FIGURE 12 Transmittance for three type of CPA mode (a) pattern 1, (b) pattern 2, and (c) pattern 3 when 5 V is applied to the pixel electrode.

In Figure 15 are shown CR (contrast ratio) polar plots for the three trial patterns which illustrate the calculated contrast ratio for each viewing angle direction. In Figure 15 is also shown the locus in solid line for designating the 10:1 contrast ratio. We can observe that the 10:1 locus for pattern 3 as shown in Figure 15(c) locates in the outer region that the other two cases corresponding to Figure 15(a) and Figure 15(b). The CR curve of pattern 2, corresponding to Figure 15(b), is the worst among the three trial cases and this seems to be due to the fact that there exists a protrusion at the center of the electrode which blocks the effective control of light transmission.

Figure 16(a) and Figure 16(b) are CR (contrast ratio) plots for those three trial patterns as a function of theta angle when phi (azimuth) angle is (a) 0 degree, (b) 45 degree. Figures 16(a) and (b) reveal that

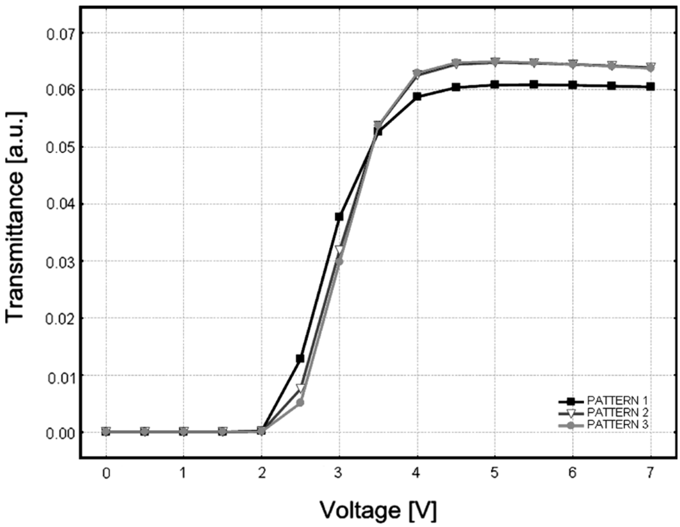


FIGURE 13 Transmittance as a function of voltage for three type of CPA mode (a) pattern 1, (b) pattern 2, and (c) pattern 3.

pattern 3 exhibits a superior performance to the other patterns with respect to contrast ratio for relatively wide range of viewing angles. Poor viewing angle characteristics of pattern 2 seem to be due to the

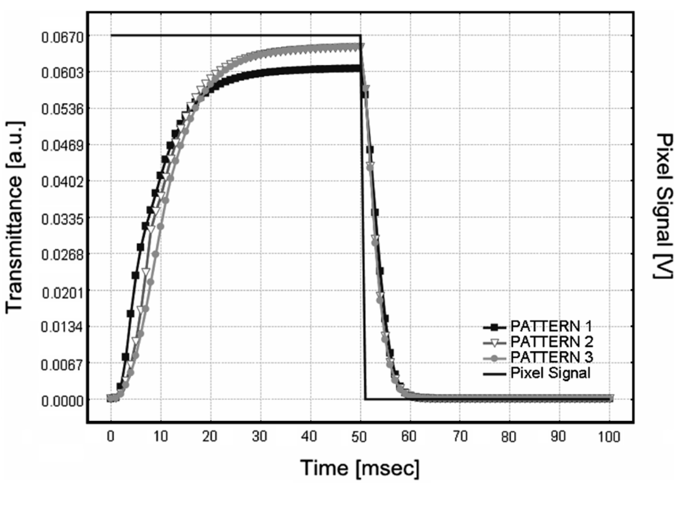


FIGURE 14 Transmittance as a function of time for three type of CPA mode (a) pattern 1, (b) pattern 2, and (c) pattern 3.

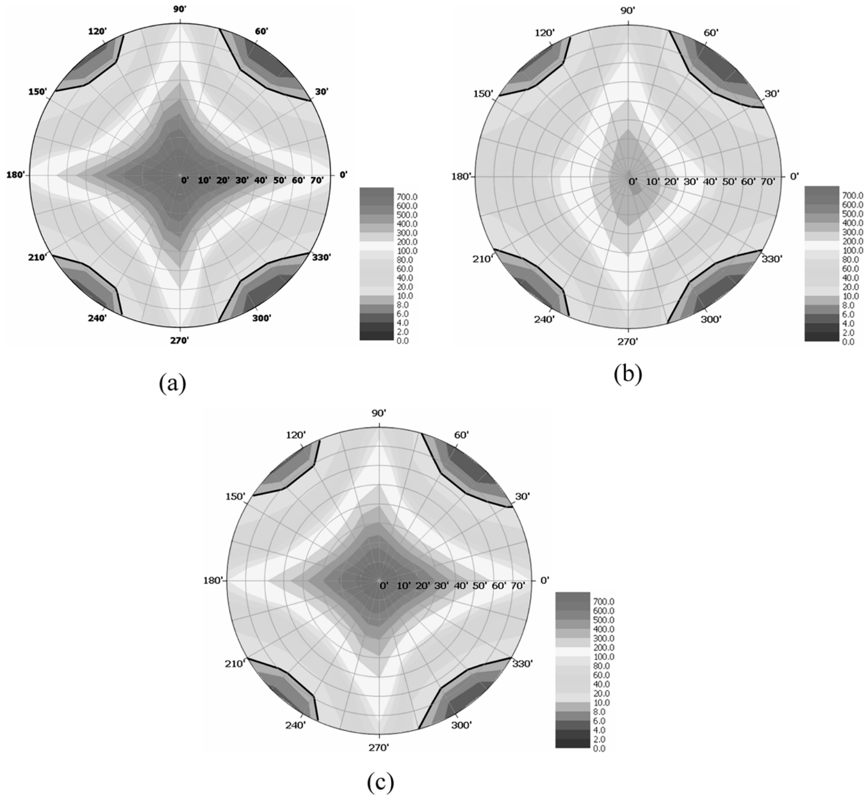
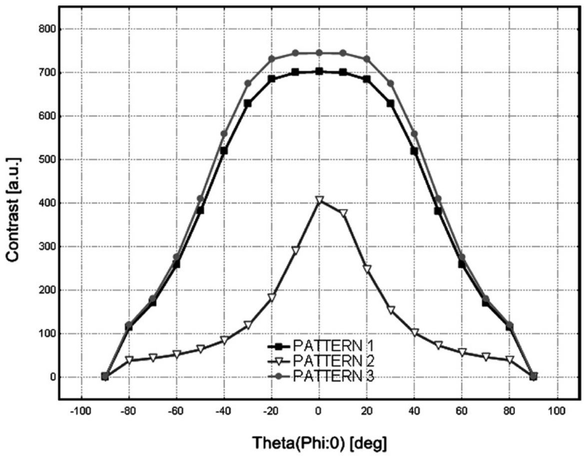


FIGURE 15 Contrast ratio for viewing angle in polar coordinate about three type of CPA mode (a) Pattern 1, (b) Pattern 2, and (c) Pattern 3.

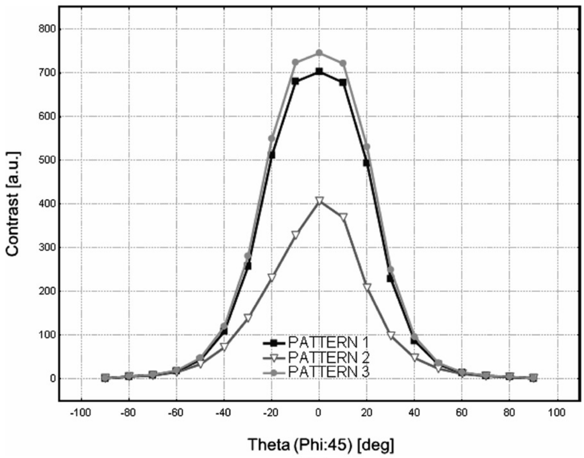
presence of protrusion at the center of structure. The simulation implies that the contrast ratio of pattern 3 can be improved by more than 6.5%over pattern 2. Maximum contrast ratio of pattern 3 is higher than that of pattern 2 by more than 81%.

IV. CONCLUSION

In this article, we report our numerical study on the CPA mode for the feasibility and optimizing purposes. We also compared the electro-optical properties of the CPA mode with those of the conventional VA modes. We confirmed that CPA mode can exhibit better performance than VA mode in terms of transmission as well as viewing



(a)



(b)

FIGURE 16 Calculated contrast ratios as a function of theta angle for three test patterns of CPA structures when phi (azimuth) angle is (a) 0 degree, (b) 45 degree.

characteristics. According to our numerical simulation, transmittance of CPA mode is higher than VA mode by 81%. In addition, viewing angle of the CPA mode can be improved by 22%. Furthermore, we simulate various patterns for CPA mode. We came up with an optimized electrode structure by comparing electro optical properties in terms of transmission, response time, and contrast ratio.

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