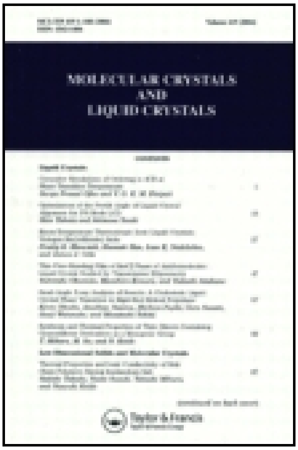

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Numerical Study on Electro-Optical Characteristics of the LCD Modes: VA, CPA, and OCB

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Version of record first published: 05 Oct 2009

To cite this article: Sang Young Cho, Seung Su Yang & Taeyoung Won (2009): Numerical Study on Electro-Optical Characteristics of the LCD Modes: VA, CPA, and OCB, Molecular Crystals and Liquid Crystals, 511:1, 360/[1830]-368/[1838]

To link to this article: http://dx.doi.org/10.1080/15421400903054477

Mol. Cryst. Liq. Cryst., Vol. 511, pp. 360/[1830]–368/[1838], 2009

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400903054477

Numerical Study on Electro-Optical Characteristics of the LCD Modes: VA, CPA, and OCB

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In this paper, we report our finite element method (FEM) study on the electro-optical characteristics as well as dynamic molecular behavior for the three liquid crystal modes; vertical alignment (VA), continuous pinwheel alignment (CPA), and optically compensated bend (OCB). Our numerical study revealed that the CPA mode is very promising in view of light transmittance and wide viewing angle characteristics over the VA modes and the OCB mode exhibits an excellent dynamic response behavior over the VA and CPA modes.

Keywords: CPA; finite element method; numerical calculation; OCB; simulation; VA

I. INTRODUCTION

TN mode has been widely used for the application in the LCD market due to high transmittance, simple fabrication process, and uniform transmittance. TN mode, however, is considered to suffer from shortcomings such as non-uniform viewing-angle characteristics. Consequently, a great deal of research efforts has been made on the development of novel LCD modes. VA mode is considered to exhibit the better viewing-angle characteristics than TN mode. However, there are still problems to be overcome such as motion blur.

In order to resolve the issue of motion blue, it is necessary to realize a fast liquid crystal molecule response time. Recently, optically compensated bend (OCB) attracted a great deal of attention because

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this novel scheme resolves not only the viewing angle problem but also the response time issue [1,2]. Moreover, continuous pinwheel alignment (CPA) mode, which was proposed by Sharp Co., Ltd. [3,4], seems to be promising because it relies on the VA technology simultaneously with merits of TN mechanism. Therefore, we undertook a numerical comparative study on the CPA mode, VA mode, and OCB mode in terms of the electro-optical properties with a three-dimensional finite element method (FEM) simulator.

II. OPERATIONAL MECHANISMS OF THE LC MODES UNDER THIS WORK

We looked into the dynamic response of the LC molecules, i.e., director configuration, as a function of time for various types of LC modes. Figure 1 is a cross sectional view of the LC cell structure under this study. Since the directors of the vertically aligned (VA) cell are perpendicular to the surfaces of the cell, the light propagates along the z-axis whereas the electric field is perpendicular to the z axis. Figure 1(a) shows the so-called “homeotropic state”, off state, wherein the directors at the top and bottom region points to the vertical direction.

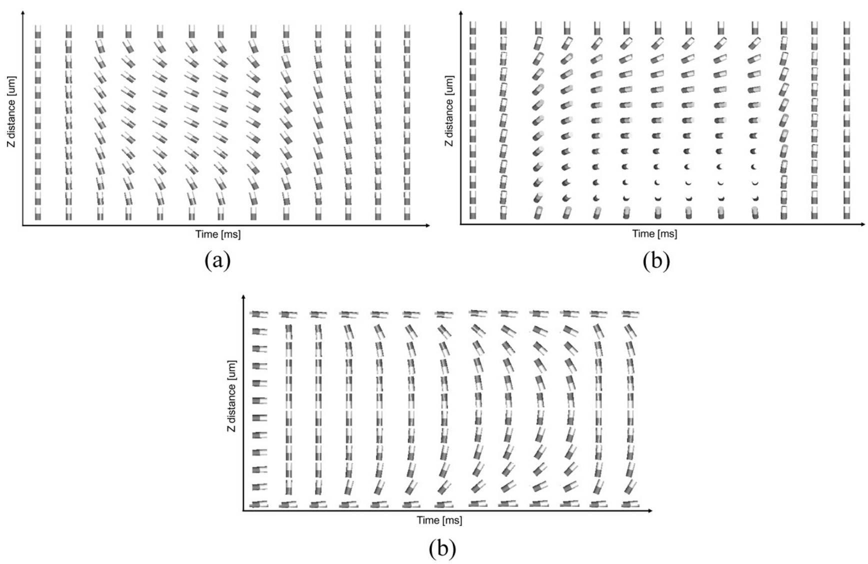


FIGURE 1 The results of calculated director configurations. (a) cross sectional diagram of the VA mode (b) cross sectional diagram of the CPA mode (c) cross sectional diagram of the OCB mode.

If the electric field is applied to the cell, LC molecules tend to tilt toward the center of the electrode. Chiral dopants are assumed to exhibit viscous behavior as shown in Figure 1(b). The OCB cell is based on the nematic liquid crystal in which the molecular director bends symmetrically through the cell. The splay state is defined as the state wherein the pre-tilt angle is 5 degree at the bottom and the pre-tilt angle is – 5 degree at the top as shown in Figure 1(c).

Referring to Figure 1(a), we can see that molecules of VA mode exhibit homeotropic alignment in the off state. Molecules of negative LC tend to lie down in compliance with the vertical lines (z-axis) of the electric field over all in the on state. Referring to Figure 1(b), molecules of CPA mode seem to be aligned in a similar manner to the conventional VA mode in the off state. The difference in operating mechanism between the two LC modes is 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.

The unique feature of the OCB mode is that it exhibits the splay state at a very low voltage while it exhibits the bend state at the higher voltage. Since the optical switching of an OCB cell should be performed in the bend state, it is necessary to be able to apply a voltage above a critical value if we want to make transition from the splay state to the bend state. Since these states are topologically different form each other, the transition between the splay state and the bend state inevitably accompanies the bend nucleus [5].

III. SIMULATION RESULTS AND DISCUSSION

Table 1 illustrates material parameters such as dielectric constants, elastic constants, and pre-tilt angles which were utilized in this study. The thickness d of the cell is 4.5, 2.9, and 10 μm, for VA, CPA, and OCB, respectively. In Figure 2 is shown the electrode structure for

TABLE 1 Parameters Used in the Simulation Cells

Parameter	VA	CPA	OCB
Cell thickness d	4.5 μm	2.9 μm	10 μm
Perpendicula dielectric constant $\varepsilon_{\parallel}$	3.6	3.9	5.0
Perallel dielectric constant $\varepsilon_{\perp}$	7.8	8.9	10.0
Splay elastic constant K_{11}	16.7	14.7	10.6 pN
Twist elastic constant K_{22}	7.3	7	5.09 pN
Bend elastic constant K_{33}	18.1	16.8	11.3 pN
Pretilt angle	—	—	5°

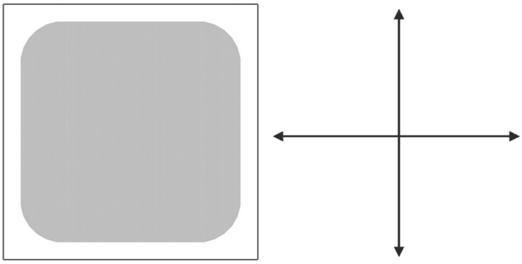
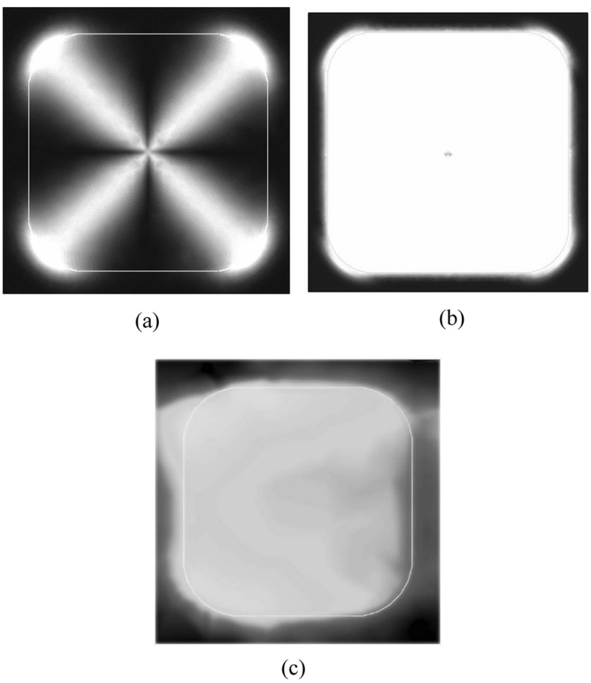


FIGURE 2 The electrode structure of conventional VA and CPA mode and the direction of polarizer and analyzer.

VA, CPA and OCB modes wherein the direction of the polarizer and the analyzer are also illustrated in the figure. It should be noted that we chose a flat electrode structure which does not have a specific shape or pattern in order to perform a fair comparative study on threes modes of operation (VA, CPA, OCB). In case of OCB mode,



(a) (b) (c)

FIGURE 3 Transmittance distributions of simulation results for various type of liquid crystal mode (a) VA mode (b) CPA mode (c) OCB mode.

we rotate the direction of the polarizer and the analyzer by 45° in an effort to minimize the light leakage. The simulation region is 73 μm × 73 μm, while the electrode structure being 58 μm × 58 μm The common electrode is located on the CF substrate without any particular shape. We utilized a numerical simulator "TechWizLCD," which is based on three-dimensional finite element method (FEM).

Figure 3 is a diagram which illustrates the lines of dark regions for the VA mode in case of "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, which enhances the aperture characteristics as well as the light transmission. In the meanwhile, OCB mode exhibits a good aperture ratio while the transmittance is blurred around the area of the pixel electrode.

In Figure 4 is a schematic diagram illustrating the light transmission as a function of voltage wherein the circle-dotted line represents the VA mode, the rectangle-dotted line representing the CPA mode, and the triangle-dotted line represents the OCB mode. The light transmittance was calculated through the integration over the pixel and is illustrated with an arbitrary unit in the figure. The light transmittance for the CPA mode is approximately twice as high as the VA mode at 5 V. In case of OCB mode, it is marked from 2 V to 7 V. We started the OCB mode in the splay state with applying 12.5

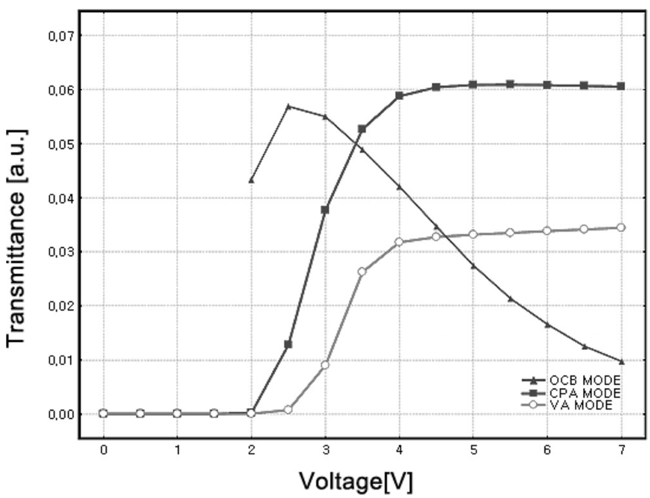


FIGURE 4 Transmittance as a function of voltage for VA, CPA and OCB mode.

volts at the initial stage for splay-to-bend transition. The transmittance for the OCB mode was found to be 0.058 at 2.5 V.

Figure 5 is a polar diagram which illustrates the contrast ratio (CR) for the viewing angle; VA, CPA and OCB mode. In Figure 5, we provide CR contours for each mode under the respective maximum transmittance voltages at three different wavelengths ($\lambda = 565$ nm, 530 nm, 430 nm). We designated a line at an angle of 45 degree in the figure, which denotes a contrast level of 10. Our numerical calculation revealed that the viewing angle of CPA mode has been improved by more than 22% over the conventional VA mode. Our numerical simulation also revealed that transmission can be improved by 81% while viewing angle can be improved by 22% for CPA mode in

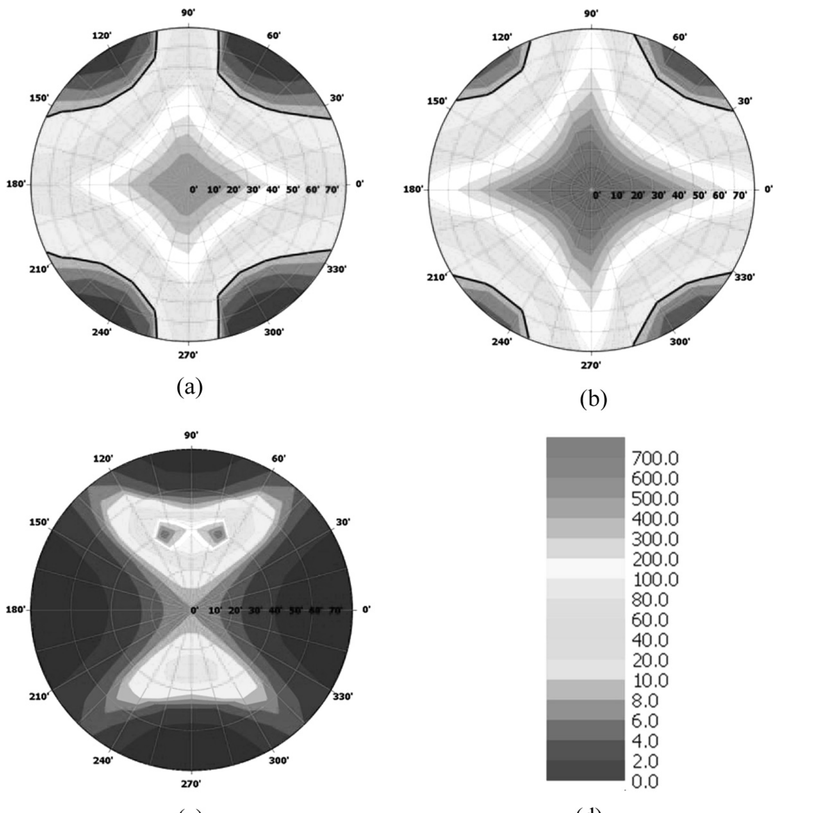


FIGURE 5 Contrast ratio for viewing angle in polar coordinate; (a) VA mode (b) CPA mode (c) OCB mode (d) legend of contrast ratio.

comparison with the VA mode. We can also note that the OCB mode exhibits the narrower viewing angle than the other two modes. The OCB mode exhibits the contrast ratio of 280:1. The OCB mode requires the compensation for the retardation between LC at the black state and Re value of negative c-plate. In this work, it should be noted that we did not optimize the properties of the retardation film for the reduction of the light leakage.

Figure 6 is a T-T curve for the LC modes in this work, which illustrates the light transmittance as a function of time. It is assumed that a voltage step of 5 V is sustained for the duration of 50 ms and subsequently the voltage is dropped to zero. The response time is defined as the time interval between the initial 10% value and the final 90% value. This definition was made in order to make a fair comparison among those three trials. In case of OCB mode, it is necessary to have high voltage at the early stage for the splay-to-bend transition. Consequently, we applied zero volt for the bend state of the liquid crystal molecules. As far as the rising time is concerned, there seems to be a minor difference of 2.02 ms between the VA mode and the CPA mode. However, we can see a noticeable difference of 5.98 ms between the VA mode and the CPA mode in the falling time.

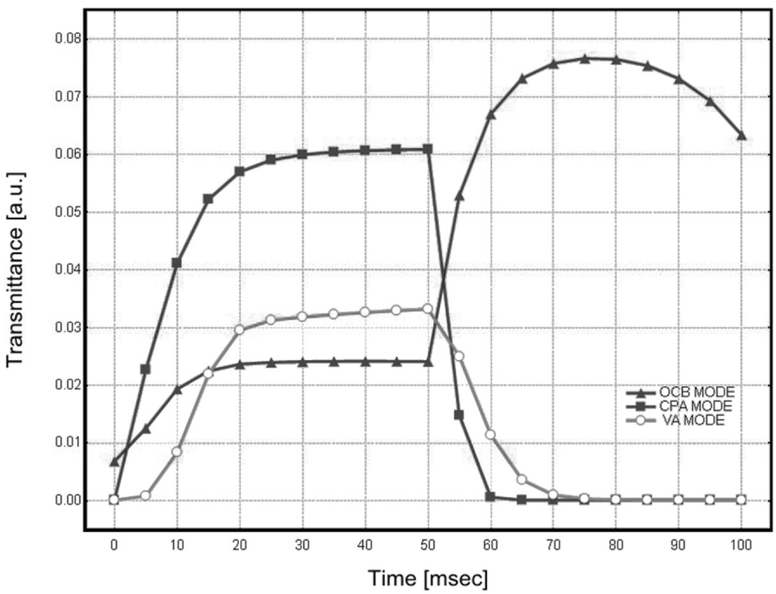


FIGURE 6 Transmittance as a function of time for VA, CPA and OCB mode.

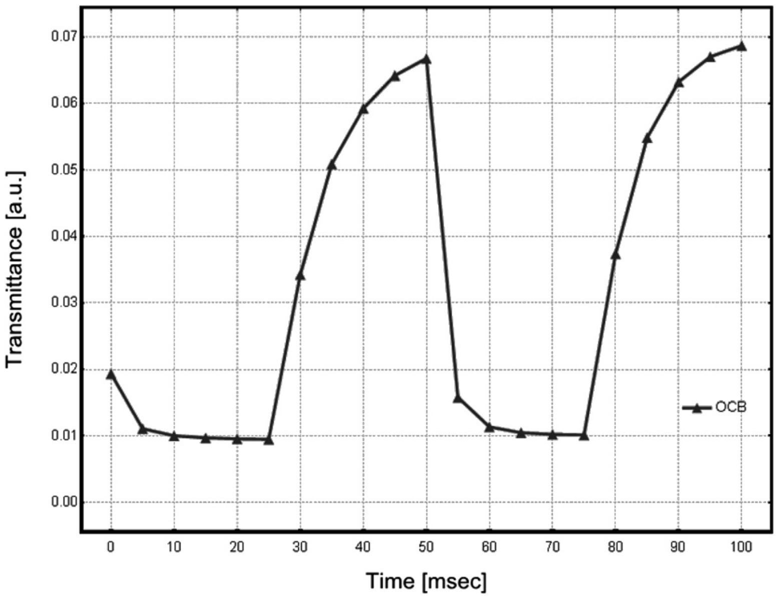


FIGURE 7 Transmittance as a function of time for OCB mode.

For the OCB mode, we applied voltages from zero to seven volt with a voltage step of 25 ms and subsequently decreases down to 2 V. In Figure 7 is shown the transmittance as a function of time. Table 2 is a table illustrating the numerical values of response time for the VA, CPA, and OCB mode, respectively. According to Table 2, VA mode exhibits the fastest response time of about 2ms in the rising step. However, VA mode exhibits a remarkably fast response time in the falling stage over the other modes. If we look into the overall response time, the OCB mode exhibits the fastest response behavior.

TABLE 2 Transmittance as a Function of Time for VA, CPA, OCB Mode

	10% (ms)	90% (ms)	90%–10% (ms)
VA mode rising time	6.70	21.02	14.32
VA mode falling time	52.00	65.36	13.36
CPA mode rising time	1.34	17.68	16.34
CPA mode falling time	50.65	58.03	7.38
OCB mode rising time	26.19	43.56	16.37
OCB mode falling time	50.39	55.42	5.03

IV. CONCLUSION

In this paper, we report our numerical study on the VA, CPA, and OCB mode for the comparative investigation on the electro-optical characteristics. Our simulation revealed that CPA mode exhibits the better performance than the VA mode in terms of transmission as well as viewing characteristics. According to our numerical simulation, the transmittance of CPA mode is higher than VA mode by 81%. In addition, the viewing angle of the CPA mode can be improved by 22%. Our numerical study implies that OCB mode exhibits a fairly good response time. However, OCB mode has a unique feature of exhibiting the splay state at the lower voltage and the bend state at the higher voltage with the retardation film.

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