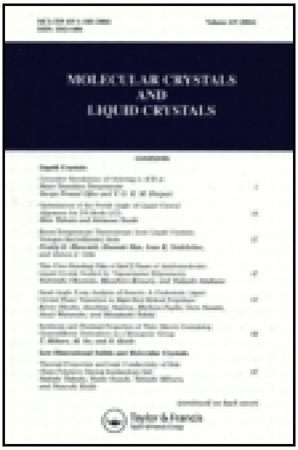

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A Simulation Study of Improving Viewing Angles Using Composite Uniaxial Compensation Films in Optically Compensated Bend Liquid Crystal Displays

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In this study, we use the commercial simulation software, DIMOS2.0, to study improvement of viewing angle performance. Based on concepts of optical phase compensation, optimized conditions of composite uniaxial compensation films are achieved in optically compensated bend (OCB) liquid crystal displays (LCDs). In conditions of D65 illumination for compensated cells, it shows that viewing angles with contrast ratio over 10 are in the ranges of horizontal 100° and perpendicular 130°. No gray scale inversion occurs within polar angle of 70° at horizontal direction. According to definition of CIE 1931, color coordinate of white point in non-compensated and compensated simulated cells are (0.29634, 0.32592) and (0.27143, 0.29306) at on-axis viewing direction, respectively. Contrast ratio is over 3000 at on-axis viewing direction.

Keywords: composite uniaxial compensation films; contrast ratio; optically compensated bend; viewing angles

I. INTRODUCTION

Liquid crystal displays (LCDs) is the most popular techniques and applications of flat panel displays in our daily lives. Due to more requirements for high qualitative performance, some native poor

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characteristics of LCDs must be improved including response time, viewing angles, and color shift etc. Response time is an important parameter in LCDs because of its effects on image quality, especially blurred effect on motion pictures. An effective method of improving blurred effect is to simulate behavior as impulse light emitting as in cathode ray tube (CRT) displays. Viewing angle characteristics in LCDs still need more improvement for high level TV applications. Both multi-domain division and compensation films attachment are usual methods to improve viewing angle performance.

Optically compensated bend (OCB) mode possesses much potential for high level LCD applications because of its fast response time [1] and optically self-compensated characteristics. Fast response time is originated from backflow effect; and optically self-compensated is originated from symmetric bend director profile of liquid crystals at rubbing alignment direction. Although OCB mode possesses excellent performance for response time, contrast ratio and viewing angle characteristics are not good enough for high level applications if no compensation films attachment. Compensation films are almost

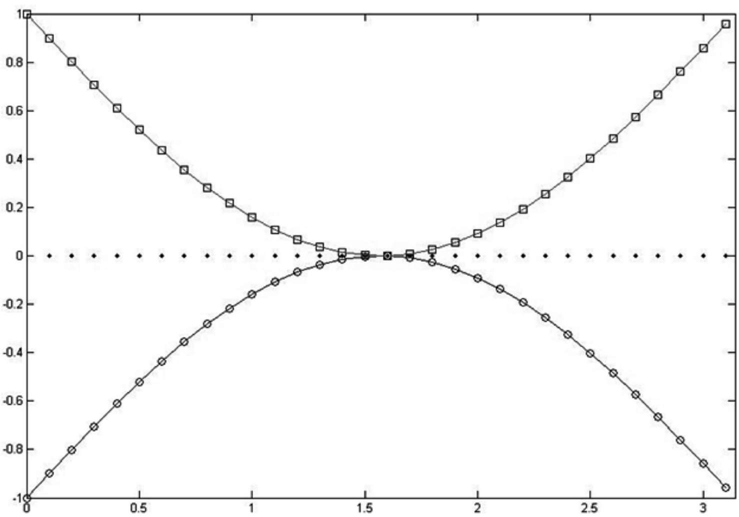
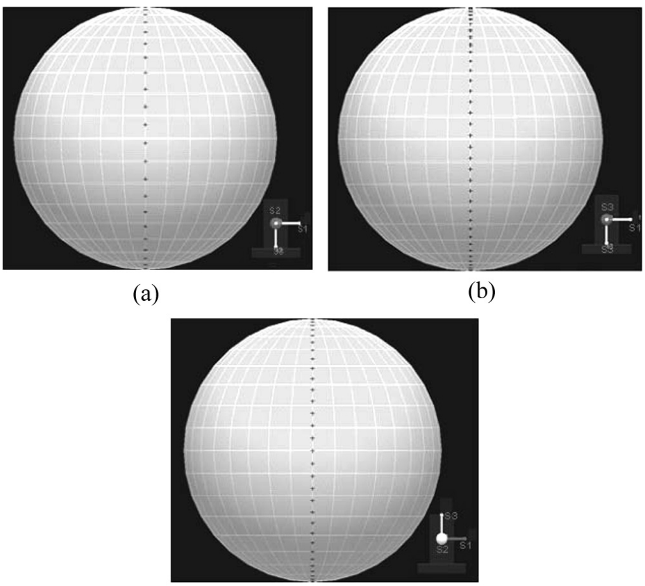


FIGURE 1 Scheme of ideal phase compensation for wide viewing angles. Top line with empty square labels is positive phase variation (vertical axis) of liquid crystals at various viewing directions (horizontal axis) in a dark state. Bottom line with empty circle labels is negative phase variation of compensation film at various viewing directions. Ideal phase compensation is achieved when total phase are zero at all viewing directions showed with dot line.

attached in every LCD modes in order to achieve better viewing angle performance. The simplest structure of compensation films are uniaxial films such as a-plate and c-plate. The compensation films with hybrid aligned discotic molecules is a special and complicated structure for wide viewing angles in 90° twisted nematic (TN) LCDs. Recently, the similar hybrid aligned discotic compensation film has been used in OCB mode in order to get great progress for viewing angle performance. At horizontal viewing direction, almost 160° viewing angle with contrast ratio over 200 can be achieved. This hybrid compensation film is called as polymerized discotic material (PDM) [2]. However, PDM is difficult to accurately fabricate to copy the similar director profile of liquid crystals in dark states. On the contrary, uniaxial compensation films are more easily fabricated and cost-effective. In this study, we use simulation software based on concepts of optical phase compensation to find the optimized viewing



(c)

FIGURE 2 Polarization variation (label "+") of a normal incident light beam completely passing through the LC cell with various thicknesses of a-plate shows on Poincaré sphere. Polarization states are distributed along the longitude on Poincaré sphere. Coordinate (S_1, S_2, S_3) is represented as Stokes parameters. Polarization variation for incident wavelength of (a) 450 nm (b) 550 nm (c) 650 nm.

angle performance in OCB mode with suitable composite uniaxial films attachment. According to user's manual of DIMOS2.0 [3], a 180° twisted LC cell is capable of optical characteristics as same as OCB mode when suitable voltage applied. With the standard D65 illumination, optical transmission and light leakage are evaluated at various viewing directions when LC cells are non-compensated or compensated. Finally, optimized thicknesses of a- and c-plates are completely evaluated in order to achieve high contrast ratio at on-axis direction and minima light leakage at oblique viewing direction.

II. COMPENSATION CONCEPTS FOR WIDE VIEWING ANGLES IN LCDs

For earlier definition of wide viewing angles in LCDs, it meant what size of area with contrast ratio over 10 for all viewing directions was achieved. Now, contrast ratio 10 is not good enough and must be more improved for high level LCD applications because higher contrast ratio is a great benefit to image quality. A usual definition of contrast

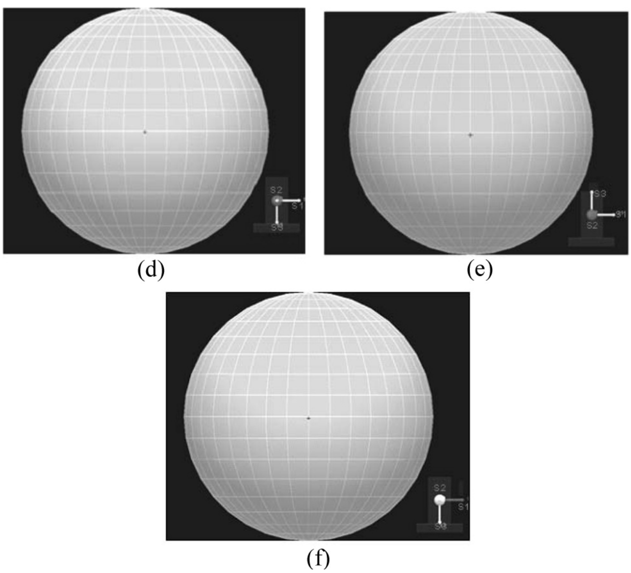


FIGURE 3 Polarization state (label "+") with minimum light leakage at on-axis direction with optimized thickness of a-plate in the LC cell shows on Poincaré sphere. Optimized polarization state is almost orthogonal with transmission direction of exit polarizer, that is represented as label "+" for incident wavelength (d) 450 nm (e) 550 nm (f) 650 nm.

ratio is transmission of bright state versus dark state. Transmission of bright state is major determined by liquid crystals (LCs) and cell gap; and dark state is not usually satisfied for all viewing angles because of native birefringence of LCs. A poor dark state of LCDs usually originated from light leakage due to residual retardation of liquid crystals and/or effectively non-crossed polarizers at oblique viewing direction. Therefore, an ideal compensation concept is to design suitable conditions of compensation films attachment in LC cells so that both polarization states of input and output light beams are orthogonal at all incident directions when light beams passing through the LC cell and compensation films. In other words, making conditions with total zero retardation for all viewing directions as shown in Figure 1 will get better dark states. In Figure 1, the line with empty square labels means positive phase retardation variation of liquid crystals at various viewing directions in a dark state. The line with empty circle labels means negative phase retardation variation of a suitable compensation film at various viewing directions. If total

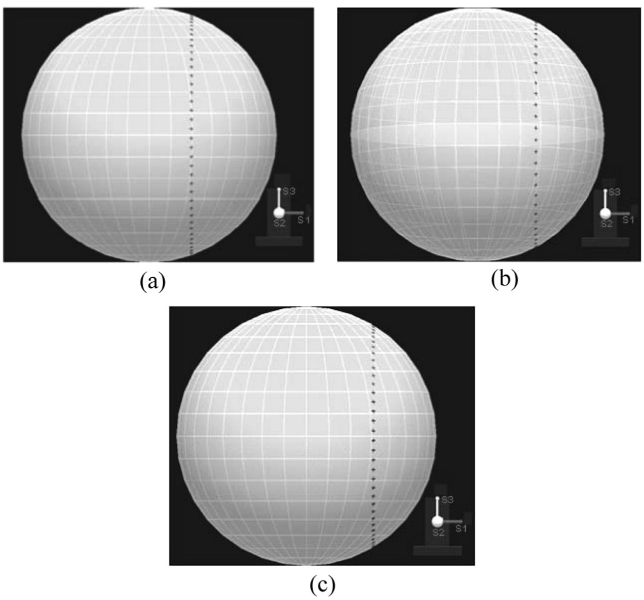
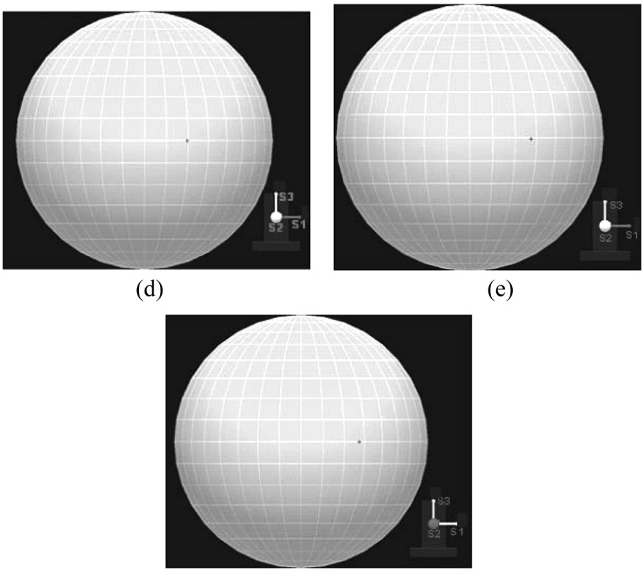


FIGURE 4 Polarization variation (label "+") of an oblique incident light beam completely passing through the LC cell with both optimized a-plate and various thicknesses of c-plate shows on Poincaré sphere. Coordinate (S_1, S_2, S_3) is represented as Stokes parameters. Polarization variation for incident wavelength of (a) 450 nm (b) 550 nm (c) 650 nm.



(d) (e) (f)

FIGURE 5 Polarization state (label "+") with minimum light leakage at oblique viewing direction with optimized thickness of a-plate and c-plate in the LC cell shows on Poincaré sphere. Optimized polarization state is almost orthogonal with transmission direction of exit polarizer at oblique viewing direction, that is represented as label "+" for incident wavelength (d) 450 nm (e) 550 nm (f) 650 nm.

retardation of liquid crystals and the compensation film approach to zero at all directions as shown with dot line in Figure 1, it will achieve an optimized design for wide viewing angles. For OCB mode, light leakage at on-axis direction in a dark state usually occurs due to residual retardation generated from non-completely vertically aligned

TABLE 1 Optical Parameters and Directions in the Simulated LC Cells

	MLC-6080	a-plate	c-plate	Polarizer (0)	Polarizer (1)
n_e	1.718	1.5	1.5	–	–
n_o	1.511	1.7	1.7	–	–
Δn	0.207	−0.2	−0.2	–	–
Directions	Rubbing at x-axis direction	Optical axis at x-axis	Optical axis at z-axis	Transmission direction at 135° with respect to x-axis	Transmission direction at 45° with respect to x-axis

liquid crystals on nearby alignment layers. In addition, light leakages also occur at larger polar viewing angle directions.

III. SIMULATION PROCESSES

All optical simulations are executed with simulation software, DIMOS2.0. A few common simulation conditions are set as follows: A selected liquid crystal material is MLC-6080 which physical parameters exist in data base of DIMOS2.0. Initial cell structure is a 180° twisted LC cell with 3 μm gap and 2° pretilt angle on both inside glass substrates. Bright state is fit for a director profile of liquid crystals in the cell where liquid crystal direction is 90° with respect to glass surface in middle layer when applying voltage is 1.9 volts. We call this bright state as Bend-1 state which optical properties are like a real OCB mode. Dark state is chose when applying voltage is 8.3 volts, that is called as Bend-2 state. The cell gap with 3 μm is a reasonable value for real OCB panel. The wavelengths of input light beam are evaluated including 450 nm, 550 nm and 650 nm. The transmission directions of two polaizers are at 45° and 135° with respect to x-axis of

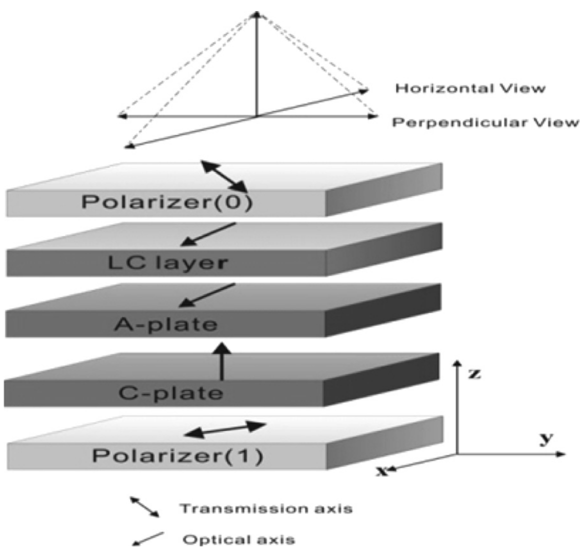


FIGURE 6 Scheme of the simulated LC cell. Bi-arrow lines are transmission directions of polarizers, which are at 45° for polarizer (0) and 135° for polarizer (1) with respect to x-axis of coordinate. Uni-arrow lines are directions of optical axes of a-plate and c-plate, which are also rubbing direction of LC alignment.

coordinate. The rubbing direction of LC alignment is at 0° with respect to x-axis. Both a-plate and c-plate possess same negative birefringence ($n_e = 1.5$, $n_O = 1.7$). Optical axis of a-plate is as same as rubbing direction. Optical axis of c-plate is along z-axis. Horizontal viewing angle directions are various on the xz-plane. Perpendicular viewing angle directions are various on the yz-plane.

The strategy for improving viewing angles is to decrease light leakage at larger polar viewing angle directions with a-plate and c-plate in the dark state. We firstly use an a-plate sandwiched between exit polarizer and LC layer to reduce light leakage at on-axis (normal) direction in dark state. Only adjust thickness of a-plate in order to achieve most significant decrement of light leakage compared with the non-compensated cell. Meanwhile, Poincaré sphere is an assistant tool to trace polarization variations of light beams from input to output terminals (see Fig. 2). The individually evaluated wavelengths of light beams are 450 nm, 550 nm and 650 nm. Three optimized thicknesses of a-plate fitted for individual three wavelengths are found out by point

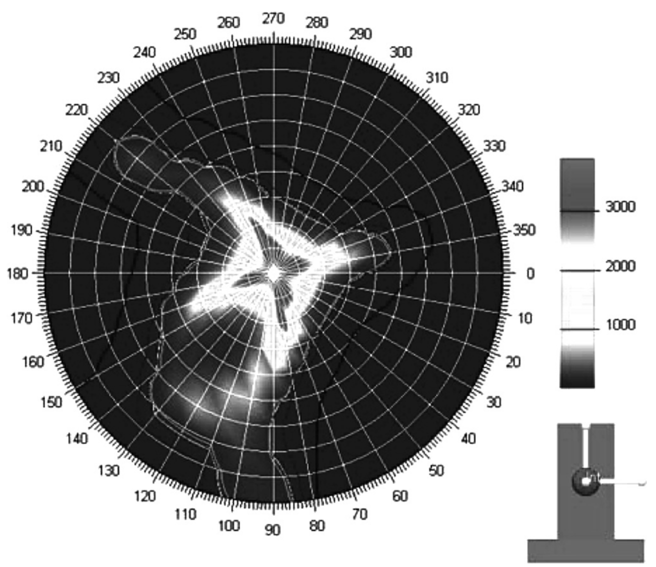


FIGURE 7 Contrast ratio distributions for all viewing angles with optimized uniaxial composite compensation films attachment with D65 illumination. Contrast ratio is from luminance of Bend-1 state (1.9 volts) versus Bend-2 state (8.3 volts). The outer black curve is contrast ratio with 10. Contrast ratio of individual area is defined by color bar. The area of contrast ratio over 10 is distributed almost 100° at horizontal viewing directions and 130° at perpendicular viewing directions. Contrast ratio is over 3000 at on-axis direction.

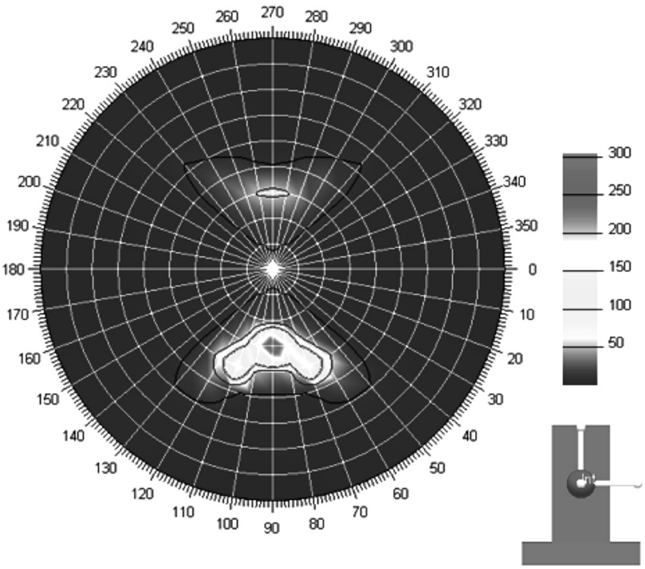


FIGURE 8 Contrast ratio distributions for all viewing angles in the non-compensated OCB cell with D65 illumination. Contrast ratio is from luminance of Bend-1 state (1.9 volts) versus Bend-2 state (8.3 volts). The outer black curve is contrast ratio with 10. Contrast ratio of individual area is defined by color bar.

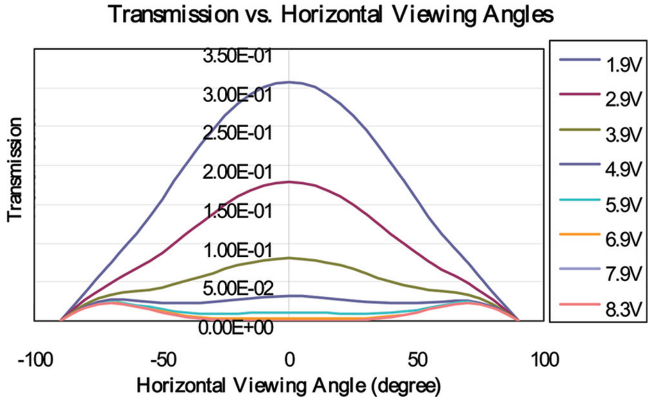


FIGURE 9 Transmission at horizontal viewing angle directions when applying various voltages to the LC cell. No gray scale inversion occurs within range of 70° polar angles at horizontal viewing angle directions when optimized composite uniaxial compensation films are attached.

positions on Poincaré sphere, which is shown in Figure 3. After most completely decreasing light leakage at normal direction, we add a c-plate sandwiched between exit polarizer and a-plate in order to reduce light leakage at horizontal viewing directions. Similarly, the polarization variations are traced with various thickness of c-plate for individual three wavelengths on Poincaré sphere (Fig. 4). Three optimized thicknesses of c-plate fitted for three wavelengths are found out by point positions on Poincaré sphere, which possess minima light leakage at larger polar horizontal directions (Fig. 5). In order to evaluate viewing angle performance with D65 illumination, we choose optimized thickness of a- and c-plate which are averaged optimized thicknesses fitted with individual three wavelengths. All simulation conditions and parameters are summarized and shown in Table 1 and Figure 6.

IV. RESULTS

According to simulation conditions mentioned in previous sections, the optimized performance for wide viewing angles with uniaxial composite compensation films in OCB mode are described as follows: The area of contrast ratio over 10 is distributed almost 100° at horizontal viewing directions and 130° at perpendicular viewing directions when suitable composite uniaxial compensation films attachment, which is shown in Figure 7. An original performance of OCB without compensation film attachment is shown in Figure 8. No gray scale inversion occurs within range of 70° polar angles at horizontal viewing angle

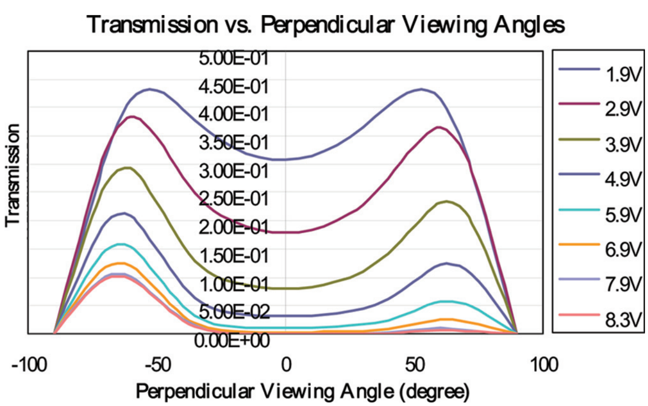


FIGURE 10 Transmission at perpendicular viewing angle directions when applying various voltages to the LC cell.

directions when composite uniaxial compensation films are attached (Fig. 9). Figure 10 shows transmission at perpendicular viewing direction when the LC cell applied with various voltages. According to CIE 1931, the values of color coordinate of white point at on-axis direction are (0.27339, 0.29578) without compensation films attachment and (0.29667, 0.3254) with compensation films attachment, respectively. Contrast ratio is over 3000 at on-axis direction.

V. CONCLUSIONS

We use DIMOS2.0 to study improvement of viewing angles in OCB mode LCDs. By means of a-plate and c-plate compensation films attachment, light leakages are effectively reduced at on-axis, horizontal and perpendicular viewing angle directions so that viewing angle performance is improved. Comparing with PDM films attachment, the performance of viewing angles is not so good when uniaxial composite films are used in OCB mode. But for those small or middle size OCB panel applications, attaching uniaxial composite films seems to be a worth way for wide viewing angles.

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