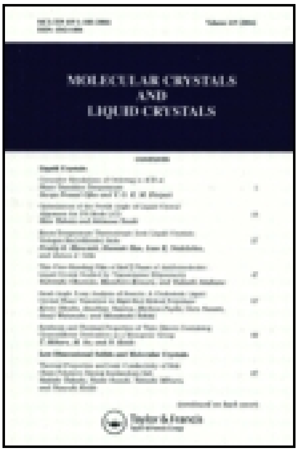

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Transflective Liquid Crystal Display with Pi-Cell

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We present results of optical simulation of a single cell gap transflective liquid crystal display with pi-cell that has two stable states which are parallel aligned LC state and 180° twisted LC state. Here, the parallel aligned LC state is used for transmissive region coupled with back-light source and operated by horizontal field. On the other hand, the 180° twisted LC state is used for reflective region coupled with sunlight or ambient light and operated by vertical field. The simulation shows that very excellent optical dispersion in both dark and bright states are exhibited.

Keywords Bistable LC; electro-optic effects; pi-cell; transflective LCD

1. Introduction

To display visual information of portable electronic devices such as mobile phone, digital camera, and personal digital assistants, small size liquid crystal displays (LCDs) have been used. Transmissive type LCDs, which show very excellent electro-optical properties in indoor environments have mainly used for such LCDs even though they are not suitable under bright sunlight [1,2]. Transflective LCDs improving readability inside and outside are in the limelight at LCD industry due to their portability and low power consumption [3–5]. In general, for transflective LCDs, since the light passes twice through the reflective region, in order to obtain the same amount of retardation in both transmissive and reflective regions, the cell gap in the transmissive part should be double that of the reflective part. However, the manufacturing process to produce multi-cell gaps is cumbersome. Moreover, the response times in both regions are different due to the cell gap difference.

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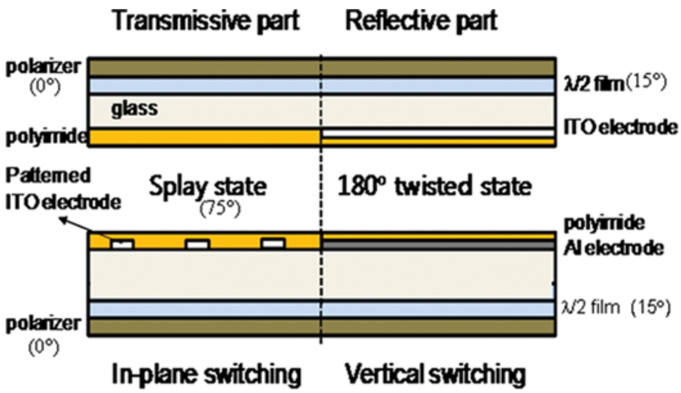

Figure 1. The cell structure of the proposed transflective LC mode. (Figure appears in color online.)

Bistable LC modes [6–10], especially for ultra-low power consumption such as bistable twisted nematic (BTN) and zenithal bistable nematic devices (ZBD) have been applied to realize reflective LCDs [11,12]. However, these modes have substantial limitations, namely that it is difficult to produce various color pictures due to the limitation of gray level.

We present results of optical simulation of a single cell gap transflective liquid crystal display with pi-cell that has two stable states which are parallel aligned LC state and 180° twisted LC state. Here, the parallel aligned LC state is used for transmissive part coupled with back-light source and operated by horizontal field as shown in Figure 1. On the other hand, the 180° twisted LC state is used for reflective part coupled with sunlight or ambient light and operated by vertical field (Fig. 1).

2. Optical Structure and Theory

2.1. *Reflective Region*

Figure 2 shows optical configuration of reflective region in LC cell. In reflective region of the proposed transflective LCD mode, the 180°-twist state is used for

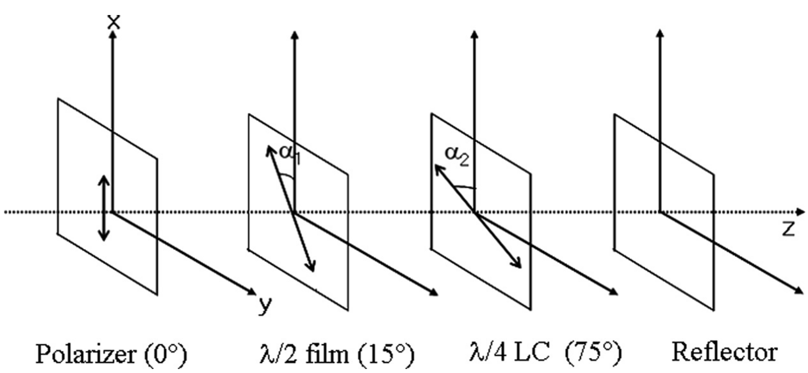

Figure 2. Optical configuration of the reflective region in the proposed transflective LC mode.

the maximum bright state. On the other hand, when the LC layer becomes a bend state which produces $\lambda/4$ by appropriate vertical fields from twist state, it should yield the dark state. In this optical configuration for the reflectance, the α_1, the angle between the optic axes of the $\lambda/2$ film and polarizer and the α_2, the angle between the rubbing direction of $\lambda/4$ LC layer and the optic axis of polarizer, are determined by minimum reflectiance condition for all wavelengthes of visible range.

To find the optic axis of the retardation film and the LC alignment for minimum reflectance, an optical calculation was performed by Jones matrix. Consequently, α_1 and α_2 which satisfy dark state are 15° and 75°, respectively. As a simple description about such optical principle, we express dark and bright states of this reflective region through the polarization of light at each layer. When voltage is 0 V between the electrodes, the light with linear polarization of 0° direction by the polarizer becomes linear polarized light rotated by 30° after passing through $\lambda/2$ retardation film with the optic axis of 15°. After passing twice 180° twisted LC layer by the reflector, it becomes nearly 30°-linearly polarized light again via elliptical polarization. Finally, after passing the $\lambda/2$ retardation layer again, the light returns to the 0°-linearly polarized state which coincides with the optic axis of the polarizer. Therefore, we can obtain a good bright state. When an appropriate vertical electric field is applied to the LC cell, LC layer becomes a low bend state with non-twisted state having comparatively high tilt angle. In this case, the light with linear polarization of 0° direction by the polarizer becomes linear polarized light rotated by 30° after passing through $\lambda/2$ retardation film layer having the optic axis of 15°. After passing twice the LC layer of $\lambda/4$ retardation with the optic axis of 75° by the reflector, it becomes 120°-linearly polarized light. Finally, the $\lambda/2$ retardation film layer is rotated by 30° and then, the light becomes 90°-linearly polarized light. Consequently, it is blocked by the polarizer and becomes dark state.

For reflective mode, the transition from splay to 180°-twist state is achieved via high and low bend states produced by the stronger vertical field generated from the top and the bottom electrodes of the reflective region. Since the free energy difference between the 180°-twist and the low bend states is small [13], it is possible to be operated by low driving voltage. The normal π cell with low pretilt angle is actually stable in the splay state. Thus, the splay state has to be converted to bend state first by applying a critical voltage. After the transition, minimum bias voltage which is needed to maintain low bend state becomes a driving voltage in the reflective mode. When field is off, LCs becomes 180° twisted state. The 180° twisted state is a stable state but has short duration [14]. So it should be refleshed once every ten minutes at least, which means that LCs should go to bend state by field and come back in very short time once every ten minutes at least.

2.2. *Transmissive Region*

Based on the optical structure of the reflective mode, the optical configuration of a transmissive mode is designed. The dark state of the transmissive region can be obtained using the splay state, in which the LCs are aligned by 75° with respective to the transmissive axis of the light-output polarizer combined with bottom $\lambda/2$ film and top $\lambda/2$ film that was used also at the reflective mode, as shown in Figure 3. The bright state can be achieved when the LC director is rotated by 45° by the horizontal field. In this case, the input light of 0° linear polarization is rotated by about 90° at the LC layer. Such horizontal movement of the LC exhibits an optically high

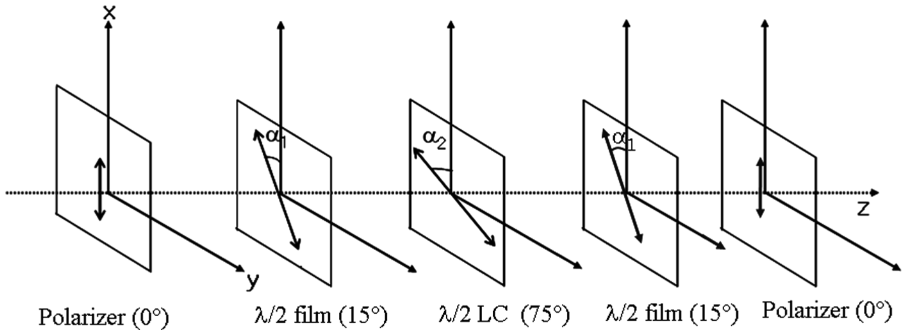

Figure 3. Optical configuration of the transmissive region in the proposed transflective LC mode.

contrast ratio for all viewing directions due to the absence of polarization changes in light of the dark state, even when light is obliquely incident.

As the simple optical description in the reflective region, we express dark and bright states of this transmissive region through the polarization of light at each layer. When voltage is 0 V between the electrodes, the light with linear polarization of 0° direction by the input polarizer becomes linear polarized light rotated by 30° after passing through the bottom $\lambda/2$ retardation film with the optic axis of 15°. After passing $\lambda/2$ LC layer with the optic axis of 75°, it becomes 120°-linearly polarized light. And finally after passing the top $\lambda/2$ retardation film with the optic axis of 15°, it becomes 90°-linearly polarized light which is perpendicular to the optic axis of the output polarizer. Therefore, it becomes dark state. On the other hand, when an appropriate horizontal electric field is applied to the LC cell by in-plane switching, LC director is rotated azimuthally along to the horizontal field. In this case, the light with linear polarization of 0° direction by the polarizer becomes linear polarized light rotated by 30° after passing through the bottom $\lambda/2$ retardation film having the optic axis of 15°. After passing $\lambda/2$ LC retardation layer with the optic axis of 30°, as a result rotated by 45° from the optic axis of 75° by horizontal electric field, it keeps 30°-linearly polarized light. Finally, the top $\lambda/2$ retardation film with the optic axis of 15° returns the 30°-linearly polarized light to 0°-linearly polarized light. Consequently, it passes entirely the output polarizer with the optic axis of 0° and becomes a good bright state.

3. Simulated Result

3.1. *Reflective Region*

In order to confirm the optical characteristics of the proposed transflective LC structure, we used a commercial LCD simulator, TechWiz LCD which has developed simulation software for TFT-LCD, to compute electro-optic property numerically. LC used in this simulation was MLC-6235-000 with $\Delta n = 0.1064$ ($n_e = 1.5958$, $n_o = 1.4894$, and $\Delta\varepsilon = 7.1$). The pretilt angle was 5°. So actual birefringence, Δn of the LC is 0.0962 from a formula expressing the relation between pretilt angle, θ and birefringence, Δn. It is as follow;

$$\Delta n(\theta) = n_e/(1 + z\ sin^2\theta)^{1/2} - n_o,\ z = (n_e/n_o)^2 - 1.$$

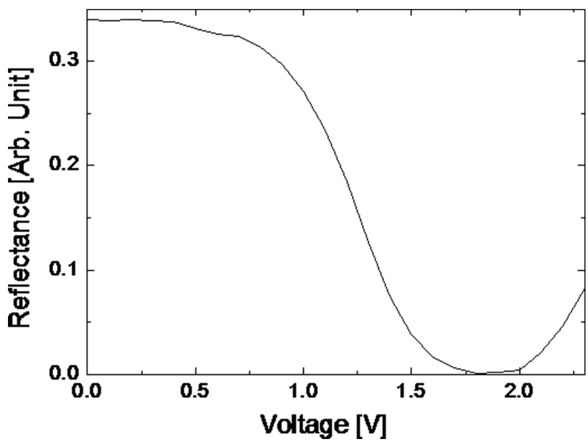

Figure 4. The voltage-reflectance curve of reflective region in the proposed transflective LC mode.

Therefore, the cellgap d to fit Δnd into $\lambda/2 = 280\,\text{nm}$ ($\lambda = 560\,\text{nm}$ as a central wavelength) is 2.91 um. Here, $\Delta nd = \lambda/2$ is for the transmissive region. In case of the reflective region, $\Delta nd = \lambda/4$ is needed, and it is attained at low bend state with an appropriate voltage.

Figure 4 is the voltage-reflectance curve of reflective region. It shows that for transition from 180° twisted state to lowest bend state, just about 2 V is needed. Figure 5 shows spectrum characteristics simulated by 2×2 Jones matrix method at the optical configuration of reflective part. As expected, it shows a good dispersion properties at each gray level.

3.2. *Transmissive Region*

Figure 6 is the voltage-reflectance curve in transmissive region showing typical electro-optical characteristics of IPS mode. Figure 7 shows spectrum characteristics

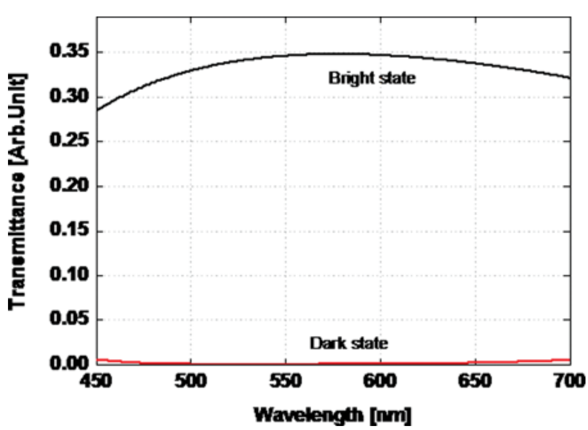

Figure 5. Optical dispersion characteristics of the reflective region in the proposed transflective LC mode. (Figure appears in color online.)

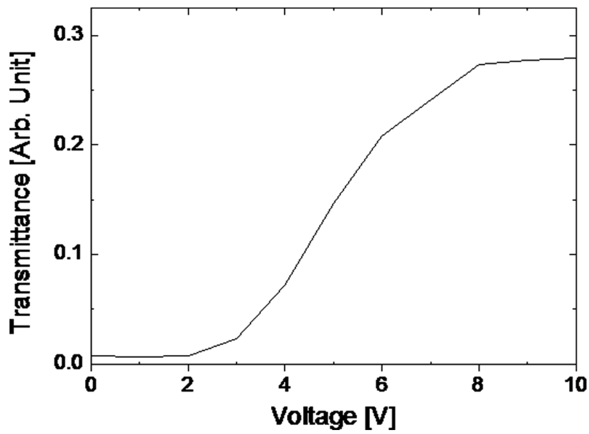

Figure 6. The voltage-reflectance curve of transmissive region in the proposed transflective LC mode.

simulated by 2×2 Jones matrix method at the optical configuration of transmissive region. It exhibits good dispersion properties in an entire visible range at dark and bright states as expected. The resultant electro-optical characteristics of the proposed transflective liquid crystal display is excellent.

4. Conclusions and Perspectives

We presented results of optical simulation of a single cell gap transflective liquid crystal display with bistable states that are splay LC state and 180° twisted LC state obtained from the pi-cell combined with three terminal electrodes. Here, the splay LC state is used for transmissive region coupled with back-light source and operated

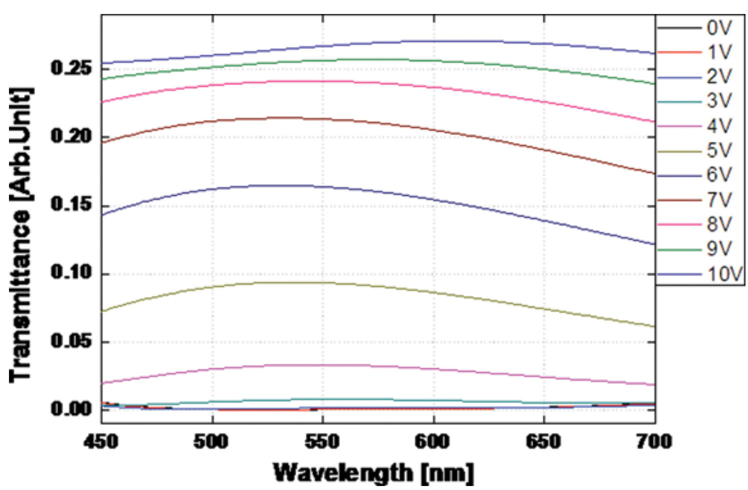

Figure 7. Optical dispersion characteristics of the transmissive region in the proposed transflective LC mode.

by horizontal field, while the 180° twisted LC state is used for reflective region coupled with sunlight or ambient light and operated by vertical field.

The results of simulation of the proposed transflective liquid crystal display shows that an excellent optical dispersion in both reflective and transmissive regions are exhibited and the resultant electro-optical characteristics of it is also excellent. So we expect that this is applicable to LCD industry. However, there remain some demerits in our transflective LCD. It cannot easily obtain single gamma characteristics due to the different LC modes of the reflective and transmissive regions. So, more complex driving schemes is required to adjust the electro-optic characteristics of the two modes. Therefore, hereafter, our research work will be concentrated to overcome this.

Acknowledgment

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References

[1] Oh-e, M., & Kondo, K. (1995). *Appl. Phys. Lett.*, *67*, 3895.
[2] Lee, S. H., Lee, S. L., & Kim, H. Y. (1998). *Appl. Phys. Lett.*, *73*, 2881.
[3] Kim, H. Y., Ge, Z., Wu, S.-T., & Lee, S. H. (2007). *Appl. Phys. Lett.*, *91*, 231108.
[4] Lee, S. H., Park, K.-H., Gwag, J. S., Yoon, T.-H., & Kim, J. C. (2003). *Jpn. J. Appl. Phys.*, *42*, 5127.
[5] Lim, Y. J., Song, J. H., & Lee, S. H. (2005). *Jpn. J. Appl. Phys.*, *44*, 3080.
[6] Berreman, D. W., & Heffner, W. R. (1980). *Appl. Phys. Lett.*, *37*, 109.
[7] Bryan-Brown, G. P., Brown, C. V., Jones, J. C., Wood, E. L., Sage, I. C., Brett, P., & Rudin, J. (1997). *SID 97 Dig.*, 37.
[8] Clark, N. A., & Lagerwall, S. T. (1980). *Appl. Phys. Lett.*, *36*, 899.
[9] Gwag, J. S., Fukuda, J., Yoneya, M., & Yokoyama, H. (2007). *Appl. Phys. Lett.*, *91*, 073504.
[10] Gwag, J. S., Kim, J.-H., Yoneya, M., & Yokoyama, H. (2008). *Appl. Phys. Lett.*, *92*, 153110.
[11] Tang, S. T., Yu, F. H., Chen, J., Wong, M., Huang, H. C., & Kwok, H. S. (1997). *J. Appl. Phys.*, *81*, 5924.
[12] Wu, S.-T., & Wu, C.-S. (1996). *Appl. Phys. Lett.*, *68*, 1455.
[13] Gwag, J. S., Park, J., Lee, Y.-J., & Kim, J.-H. (2008). *Appl. Phys. Lett.*, *93*, 121103.
[14] Jhun, C. G., Chen, C. P., Lee, U. J., Lee, S. R., Yoon, T.-H., & Kim, J. C. (2006). *Appl. Phys. Lett.*, *89*, 123507.