P-137: Photoaligned Transflective Liquid Crystal Display with Single Cell Gap using OCB and Low Twist Nematic Modes

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Abstract

Transflective liquid crystal display (LCD) with single cell gap consisting optically compensated bend (OCB) and low twist nematic modes has been studied. Since no double cell gap structure is included in the configuration, the fabrication process is easy and only one more step UV exposure is needed during photoalignment process to produce domains. Based on this new configuration, a transflective LCD with high brightness and high contrast could be obtained.

1. Introduction

Recently, transflective liquid crystal displays (LCDs) have attracted much attention in applications of portable information displays due to their superior performance in both indoor and outdoor environments. [1] Normally, a pixel of transflective LCD is divided into two subpixels, transmissive and reflective regions. The cell gaps for these two subpixels are usually different in conventional transflective LCDs to satisfy the same retardation condition. [2] Since the transmissive part and reflective part have the same retardation, a perfect match on the transmittance vs. voltage curve (TVC) could be usually obtained. However, such double cell gap structure brings high complexity in the fabrication process, which is not preferable in transflective LCD manufacturing. Alternatively, various transflective LCD with single cell gap using patterned electrodes [3]-[6] or two different modes [7]-[9] to form transmissive and reflective regions have been proposed. However, the multimode configuration using optically compensated bend (OCB) and low twist nematic modes has not been investigated yet.

In this paper, we demonstrate a new configuration of transflective LCD with a single cell gap. The transflective LCD uses a positive mode OCB cell in reflective region and a low twisted nematic cell in the transmissive region. The alignment domains in pixels could be realized by a photo-alignment technique. Our group has successfully applied photoalignment technology to normal nematic LCD and bistable twist nematic (TN) and FLC displays. [10]-[12]. Pretilt angle as high as 5 ~ 6^o could be obtained for positive nematic liquid crystal, which is suitable for our new configuration.

Figure 1 shows the schematic diagram of our new transflective LC cell configuration with a single cell gap. In this two mode configuration transflective LCD, one pixel can be divided into two parts. One part is reflective part, in which the LC molecules are homogeneous and parallel to the substrates. The other part is transmissive part, in which the LC molecules have a low twist of 45 degree determined by the boundary condition. A low concentration chiral dopant is added to LC material to assist the twist deformation. An ordinary polarizer coated with anti-reflection (AR) layer is used for both transmissive and reflective regions. One compensation film on top in between the polarizer and the ITO glass is shared by the transmissive and reflective modes. Another compensation film is inserted between the glass and the bottom polarizer, which has effect only for transmissive part since the light in reflective part is blocked by the reflector.

2. Methodology

Generally, in the structure of transflective LCDs, the reflective part has less optical elements than transmissive part to optimize the optical performance. So, in order to make the electrooptical performance of the two parts consistent, our basic idea is to optimize the electrooptical characteristics of the reflective part first and then extend it to the transmissive part. To compensate the residual retardation of OCB mode in dark state, a compensation film is used in between the ITO glass and the top polarizer as shown in Fig. 1. By carefully adjusting the orientation of the top polarizer, the orientation and the retardation of the 1st compensation film, an optimized combination of values for the parameters can be obtained. Let the optimal values that have been obtained be fixed when optimizing the transmissive part.

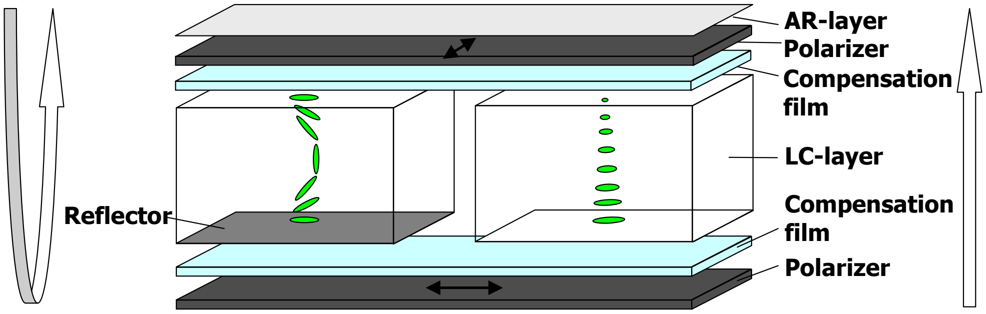

Fig. 1 Scheme of the transflective LCD; Left: reflective part; Right: transmissive part.

Similarly, by careful adjusting the orientation of the bottom polarizer, the orientation and the retardation of the 2nd compensation film, electrooptical characteristics of the transmissive part can be as close as possible to that of the reflective part. Thus, a transflective display with matched transmittance/reflectance voltage curve could be obtained.

The nematic LC material MLC 6080 from E. Merck is used in the simulation. The ordinary refractive index and optical anisotropy for MLC 6080 are $n_o = 1.4944 + 2350/\lambda^2$ and $\Delta n = 0.1786 + 3100/\lambda^2$, respectively. Here, λ is the wavelength of the incident light in nanometers. The dielectric anisotropy and elastic constants for MLC 6080 are $\Delta\varepsilon = 7.2$, $K_{11} = 14.4 \times 10^{-12} N$, $K_{22} = 7.1 \times 10^{-12} N$, and $K_{33} = 19.1 \times 10^{-12} N$. The chiral dopant of S-811 is used to produce a d/p ratio equals to 0.05, where d denotes the cell gap of the LC cell and p denotes the natural pitch. The cell gap for both transmissive and reflective part is 4.5 μm. The surface pretilt angle is 5° for both transmissive and reflective part. The light source used in simulation is D65 ranging from 380 nm to 720 nm.

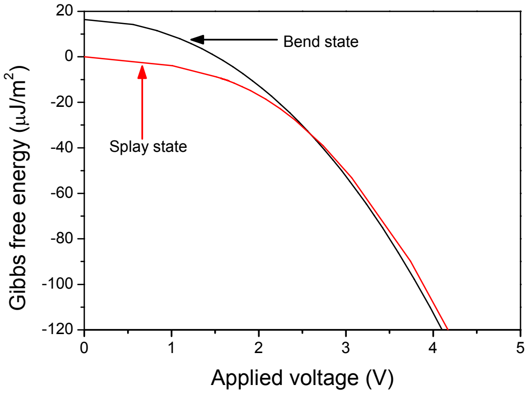

Fig. 2 Dependence of Gibbs free energy in splay and bend states on applied voltage for OCB region

In design of the OCB mode of the reflective part, the critical voltage is very important. [13] The critical voltage is the splay-to-bend transition voltage, which can be obtained by calculating the Gibbs free energies of the splay and bend states with respect to the applied voltage, accordingly. From calculated dependence of Gibbs free energy on applied voltage shown in Fig. 2, it can be clearly seen that the critical voltage for the reflective OCB mode is equal to 2.56 V. Thus, to ensure the LC director is in the bend configuration, the bias voltage for our designed transflective LCD should be larger than 2.56 V. In our configuration, the bias voltage is chosen around 2.8 V.

3. Results and discussion

For our simulation, the commercial available software "MOUSE-LCD" (HKUST, Hong Kong, Saratov, Russia) is used (Figs. 2-6). In our configuration, the optimal values of the parameters for reflective OCB mode are obtained first, which are listed in Table 1. The optimal retardation of the compensation film we used is 270 nm, and the orientation is -13.2° to the x-axis of the laboratory coordinates, while the orientation of LC cell is 66°. The best contrast based on this configuration is around 31:1 when off voltage is 5 V. The calculated spectra for reflective part are shown in Fig. 6 b).

Table 1 Optimized Parameters of the configuration for reflective part

Parameter	Value
Polarizer Orientation (deg)	132.4
Compensator Orientation (deg)	-13.2
Compensator retardation (nm)	270
LC cell Orientation (deg)	66
Cell gap (μm)	4.5

When the optimal values of the parameters have been obtained for reflective OCB mode, the optimization for transmissive part can be started. To investigate the effect of the orientation of the 2nd compensation film on transmittance voltage (TV) curve, the dependence of the TV curve on the orientation of the 2nd compensation film is studied. Fig. 3 shows a bunch of TV curves

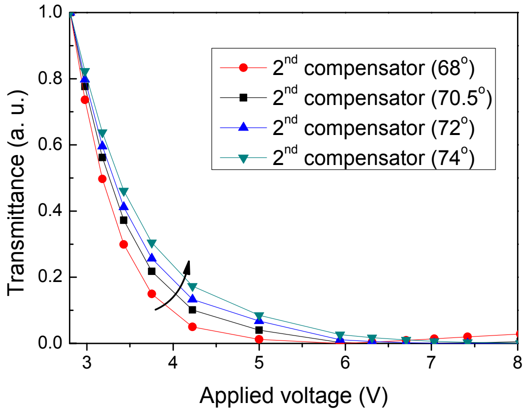

Fig. 3 Normalized voltage dependence of transmission for low twist nematic mode for various orientation angles of 2nd compensator.

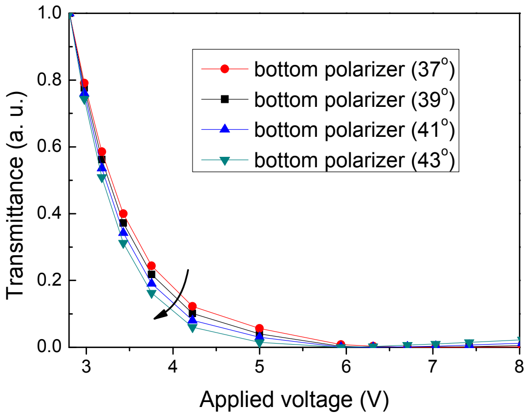

Fig. 4 Normalized voltage dependence of transmission for low twist nematic mode for various orientation angles of bottom polarizer.

for various orientation angles of the 2nd compensation film. From this Figure, we can see that in these small range angles, the TV curve moves up when the orientation angle of the 2nd compensation film increases.

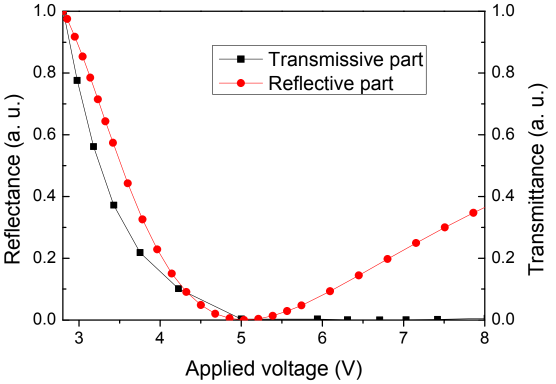

Fig. 5 Normalized voltage dependence of transmission and reflectance for OCB mode and low twist nematic mode.

The effect of the orientation of the bottom polarizer on transmittance voltage (TV) curve is also examined. Fig. 4 shows a bunch of TV curves for various orientation angles of the bottom polarizer. From this figure, we can see that in these small range angles, the TV curve moves down when the orientation angle of the bottom polarizer increases. Since the off voltage for reflective OCB mode is at 5 V, the compromise between the match of TV curve and reflectance voltage (RV) curve and the contrast of the transmissive part has to be made. The optimized TV curve is shown in Fig. 5. Table 2 shows the optimized values of the parameters for transmissive part. The spectra for transmissive part based on this configuration are calculated as shown in Fig. 6 a).

Table 2 Optimized parameters of the configuration for transmissive part

Parameter	Value
Top polarizer Orientation (deg)	132.4
1st Compensator Orientation (deg)	-13.2
1st Compensator retardation (nm)	270
LC cell Orientation (deg)	66
Twist angle (deg)	45
Cell gap (μm)	4.5
2nd Compensator Orientation (deg)	68
2nd Compensator retardation (nm)	230
Bottom polarizer Orientation (deg)	39.1

4. Conclusion

In a summary, a new transflective LCD with single cell gap consisting (OCB) and low twist nematic modes has been investigated. Such a configuration does not include double cell gap structure and only one more step UV exposure is needed during photoalignment process to produce domains, thus, the fabrication process is easy. Based on this new configuration, a transflective LCD with high brightness and high contrast could be obtained. Moreover, the TV and RV curves are very close, which means similar gray scale can be obtained under same operating voltage.

6. Acknowledgements

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7. References

[1] C. J. Yu, D. W. Kim, and S. D. Lee, Appl. Phys. Lett. **85**, 5146 (2004).

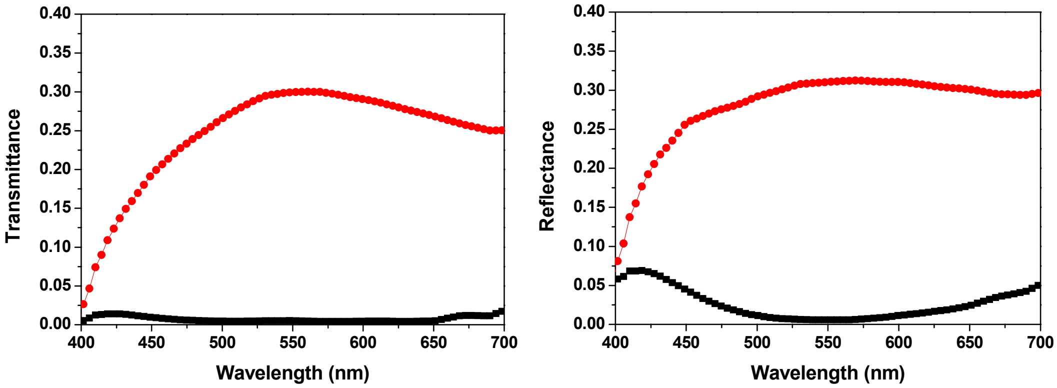
[2] H. I. Baek, Y. B. Kim, K. S. Ha, D. G. Kim, and S. B. Kwon, IDW'00, 41, 2000.

[3] T. B. Jung, J. C. Kim, and S. H. Lee, Jpn. J. Appl. Phys., **42**, L464 (2003).

[4] S. H. Lee, H. W. Do, G. D. Lee, T. H. Yoon, and J. C. Kim, Jpn. J. Appl. Phys., **42**, L1455 (2003).

[5] J. H. Song and S. H. Lee, Jpn. J. Appl. Phys., **43**, L1130 (2004).

[6] Y. J. Lee, T. H. Lee, J. W. Jung, H. R. Kim, Y. Choi, S. G. Kang, Y. C. Yang, S. Shin and J. H. Kim, Jpn. J. Appl. Phys., **45**, 7827 (2006).



a) b)

Fig. 6 Simulated spectra for a) transmissive part and b) reflective part of our transflective LCD.

[7] S. H. Lee, K. H. Park, J. S. Gwag, T. H. Yoon, and J. C. Kim, Jpn. J. Appl. Phys., **42**, 5127 (2003).

[8] C. J. Yu, J. Kim, D. W. Kim, and S. D. Lee, SID'04 Digest, 642 (2004).

[9] Y. Y. Fan, H. C. Chiang, T. Y. Ho, Y. M. Chen, Y. C. Hung, I. J. Lin, C. R. Sheu, C. W. Wu, D. J. Chen, J. Y. Wang, B. C. Chang, Y. J. Wong, and K. H. Liu, SID'04 Digest, 647 (2004).

[10] D. D. Huang, V. Kozenkov, V. Chigrinov, H. S. Kwok, H. Takada, and H. Takatsu, **44**, 5117 (2005).

[11] X. H. Li, F. S. Y. Yeung, V. G. Chigrinov, H. S. Kwok, IDW/AD'05, 883 (2005).

[12] P. Z. Xu, X. H. Li and V. G. Chigrinov, **45**, 200 (2005).

[13] T. Miyashita, P. Vetter, Y. Yamaguchi, and T. Uchida, J. SID, **3,** 29 (1995).

[14] V. Chigrinov, D. Yakovlev, and H. S. Kwok, Information Display, **20**, 26 (2004).