57.2: Novel Single Cell Gap Transflective Liquid Crystal Display Without Sub Pixels Separation

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Abstract

Twisted Nematic (TN) liquid crystal display is optimized for transflective liquid crystal displays. This new configuration does not need to separate the pixel into two sub-pixels of transmissive and reflective mode. Each pixel is partially transmissive and reflective with the help of a semi transparent mirror. The electro-optical characteristics in the transmissive mode and reflective mode match each other, which indicates that the transmissive and reflective function could be controlled using the same voltage in a transflective LCD. This TN LCD configuration has a good contrast, viewing angle, response time and color coordination. Also it is very easy to fabricate and suitable for high quality transflective TFT-LCDs.

1. Objective and Background

Transflective LCDs combine the characteristics of transmissive LCDs and reflective LCDs. The pixels of the traditional transflective LCDs are separated into the transmissive and reflective sub-pixels. The transmissive sub-pixels in a transflective display are transmitting with backlight illumination and the reflective sub-pixels are reflecting light from the environment under ambient illumination [1]. Conventional transflective LCDs usually fabricated by a double cell gap approach [2,3] in order to maintain the same optical characteristics along the increasing of voltage. In the double cell gap approach, the cell gap for transmissive mode is doubled to that for reflective mode. So that, both reflective and transmissive mode have same optical path difference. But on the other hand, the fabrication would be much more complicated. When applying single cell gap approach, in order to match the transmittance versus voltage curve (TVC) with the reflectance versus voltage curve (RVC), different LC mode in the transmissive and the reflective sub-pixels had been proposed in recent years [4,5].

In our new configuration, the configuration has a single cell gap in transmissive and reflective part. There is no separate LC mode required for maintaining the equability of the TVC and RVC. Moreover the pixel of the transflective LCD does not separate into the transmissive and reflective region. The pixels are partially transmissive and reflective with the help of a semi transparent mirror or so-called transflector. Therefore, easier fabrication process could be used because no transmissive and reflective sub-pixels requirement. Unlike the traditional transflective LCDs that the light from backlighting will be blocked by the reflective region and the light from surrounding cannot be reflected by the transmissive region, our new configuration could increase the intensity of the whole pixel as the transmissive and reflective mode are working at the same time.

2. Methodology

Our configuration use Twisted Nematic cell for the liquid crystal panel. As it is difficult to obtain good optical performance both in transmissive and reflective mode with the same phase retardation (Δnd), where Δn is the birefringence and d is the cell gap. Therefore two retardation films are inserted into the configuration with one in between the rear glass and the rear polarizer; and the other in between the front glass and the front polarizer to improve the consistent of the electro-optical characteristics in both transmissive mode and reflective mode. The rear retardation film would not affect the performance of the reflective mode as the light had already been reflected by the reflector but will affect the performance of the transmissive mode. As a result we can match the transmittance versus voltage (TVC) with the reflectance versus voltage (RVC) curve [6] by changing the slow axis and the polarizing axis of the rear retardation film and rear polarizer respectively.

Since typical crown glass surfaces reflect from 4% to 5% of visible light at normal incidence [7], the contrast of the reflective mode LCD is seriously affected by the reflectance. Antireflection layer (AR layer) should be inserted which can effectively reduce the reflectance. The optimal refractive index of the AR layer $n_1 = \sqrt{(n_0 n_m)}$. Since the refractive index of air (n_0) is 1.0, the AR film refractive index ideally should be equal to the square root of the refractive index of glass $\sqrt{n_m}$. Unfortunately, there is no ideal material that can be deposited in durable thin layers with a low enough refractive index to satisfy this requirement exactly (n_1= 1.23 for an antireflection coating). Therefore, in our design a triple layer type antireflection coating [8] was used, e.g. a combination of a magnesium fluoride (MgF2) layer, a Zirconium dioxide (ZrO2) and a cerium fluoride (CeF3) layer.

Also the reflectance of the reflective mode in a transflective LCD is related to the thickness of Indium Tin Oxide (ITO). As long as the reflectance is reduced, the reflective mode can obtain a better dark state. As a result a higher contrast level could be reached. Figure 2 shows the reflective contrast versus ITO thickness curve. From the curve, we can find that the transmittance reach the local maximum when ITO thickness equals to 4nm and 136nm. As R=L/A, where R is the resistance, L is the length and A is the cross section area, the 4 nm ITO is not suitable for display purpose with its high resistance, so 136nm was chosen for our calculation.

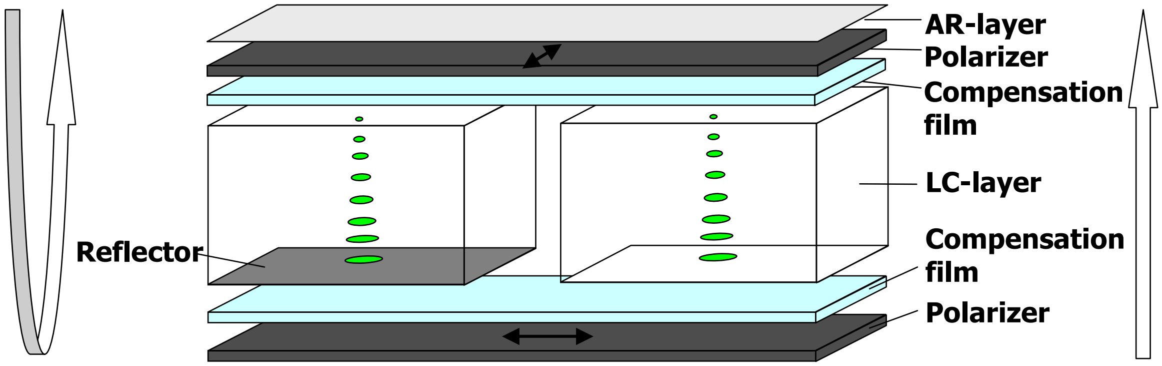

Figure 1. Cell structure of transflective TN LCD

Table 1. The angle of indication in different layers

Layer	Angle
1st Polarizer (Transmission axis)	-79°
1st Compensation Film (Slow axis)	21°
LC layer (Twist angle)	0°-90°
2nd Compensation Film (Slow axis)	10°
2nd Polarizer (Transmission axis)	55°

The configuration of our transflective TN LCD is similar to the traditional one. It consists of a front polarizer, a front retardation film, a LC cell with ITO, a rear retardation film and a rear polarizer. The twisted angle of the LC molecule is equal to 90° in LC layer. Figure 1 shows the cell structure of the TN configuration with sub-pixel separation. Table 1 shows the angle of indication in different layers. The angle indicates the anticlockwise value against the horizontal axis. You can see form Figure 1 that the upper part of the configuration of transmissive part and reflective part are the same, therefore the transmissive sub-pixel and the reflective sub-pixel can be merged together to become a transflective pixel without sub-pixel separation using a transflector.

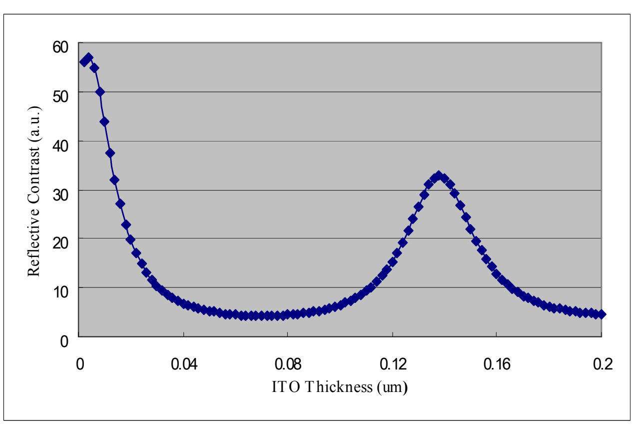

Figure 2. Reflective contrast versus ITO thickness curve

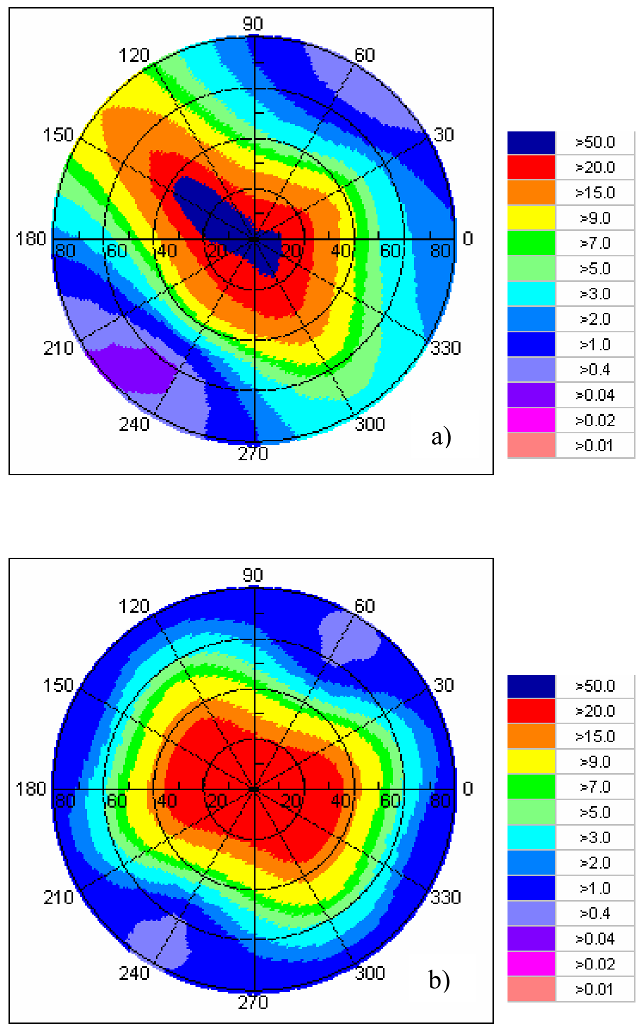

Figure 3. Contrast ratio distribution of a) transmissive TN, b) reflective TN

3. Results

Calculations of the optical characteristics were carried out with the help of MOUSE-LCD software [9, 10]. In order to make the calculation more realistic, real dispersion was included in specific layers. The parameters of ZLI-4792 from E. Merck with Δn equal to 0.099 at 546nm wavelength were used in our calculations. The ordinary and extraordinary refractive indices of ZLI-4792 are n_0 = 1.4939 and n_e = 1.5987, n_0 = 1.4774 and n_e = 1.5734 and n_0 = 1.4774 and n_e = 1.5734 at wavelength of 436nm, 546nm and 633 nm respectively. The dielectric anisotropy and the elastic constants are $\Delta\varepsilon = 5.2$, $K_1 = 1.32 \times 10^{-6}$ N, $K_2 = 6.5 \times 10^{-7}$, and $K_3 = 1.38 \times 10^{-6}$ respectively. The twist angle of the liquid crystal layer was 90° and the cell gap was 2.5μm. The retardation values (Δnd) of the front and rear retardation films are both 135nm.

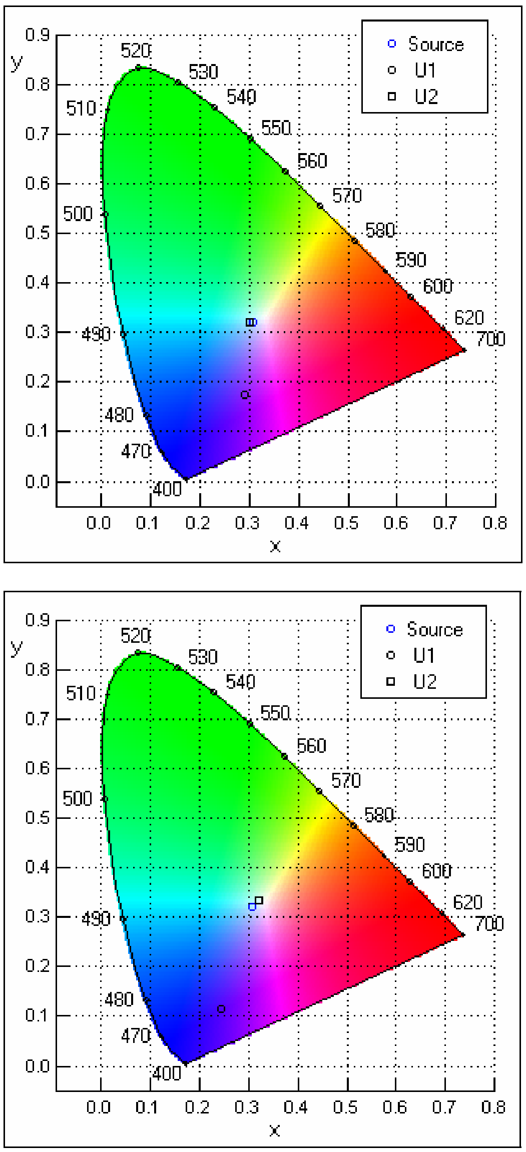

Figure 4. CIE 1931 diagram of a) transmissive TN, b) reflective TN

Table 2. CIE 1931 color coordinate of the configuration.

	Source	Transmissive	Reflective
x	0.31	0.3039	0.3222
y	0.33	0.3138	0.3317
Δx	0	0.0061	0.0122
Δy	0	0.0162	0.0017

Figure 3 shows the contrast ratio distribution of a) transmissive part, b) reflective part. The region where the contrast ratio larger than 5 is wider than 50° in all direction of the TN. Figure 4 show the CIE 1931 chromaticity diagram of a) transmissive part and b) reflective part, where their corresponding data are shown in Table 2. Figure 5 shows the response time of the a) transmissive part and b) reflective part, the response time of the transmissive and reflective part are 11.7ms and 12.3ms respectively. Such switching time is fast enough for different applications.

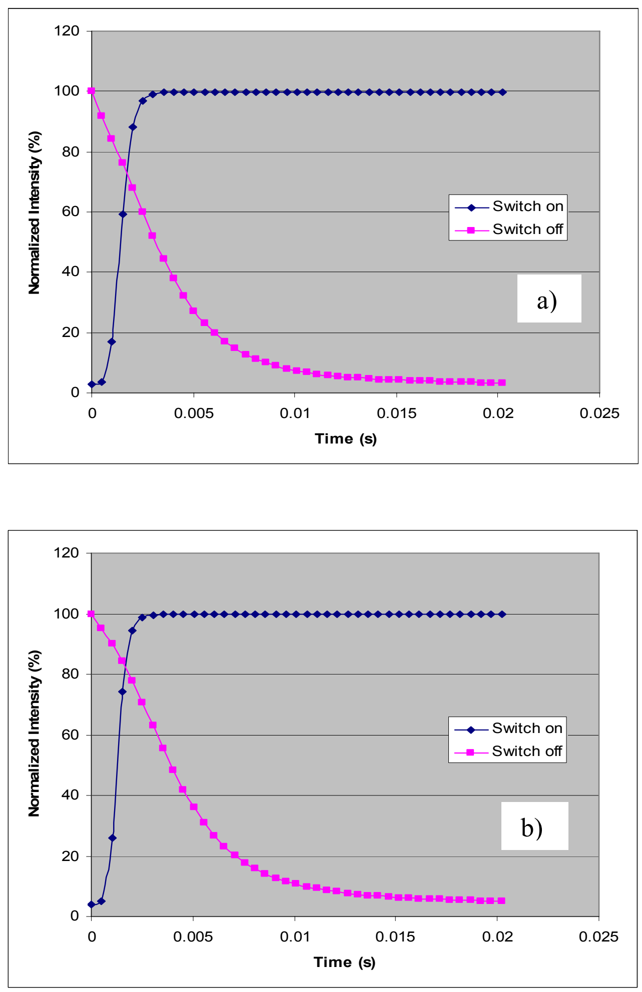

Figure 5. Response time of a) transmissive TN, b) reflective TN

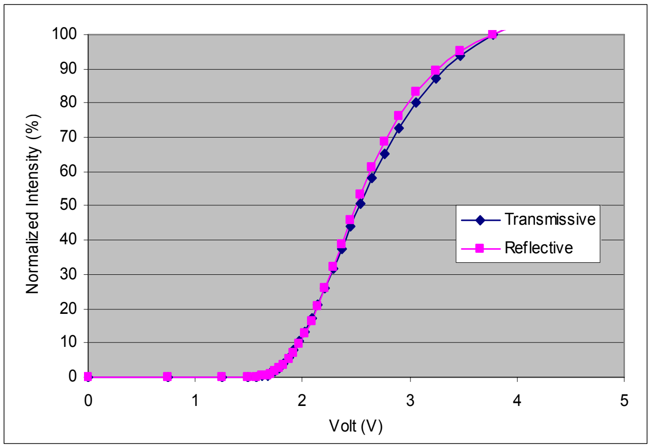

Figure 6. Electro-optical characteristics of transflective TN cell.

The transmittance and reflectance in transflective TN are shown as a function of the applied voltage in Figure 6. The electro-optical characteristics in the transmissive mode and reflective mode match each other. This indicates that the transmissive and reflective TN could be controlled and same grey scale could be obtained using the same voltage in a transflective LCD [11]

4 Impacts

In summary, we proposed a TN configuration for transflective liquid crystal display. Such a configuration does not need the sub-pixel separation in transmissive and reflective part for easier fabrication. In order to keep the same phase retardation in the transmissive part and reflective part, two retardation films are inserted in between the rear glass and the rear polarizer; and in between the front glass and the front polarizer separately. Also, a triple antireflective layers coating with a specific material and special thickness of ITO layer were proposed to reduce the reflectance of the reflective mode TN. The TN LCD configuration resulting a good contrast, viewing angle, response time and color coordination. Moreover, the normalized transmittance and reflectance are matched, and the same gray scale voltage can be used in a transflective display operation. As a result, the TN LCD maintains a perfect performance both in transmissive and reflective mode.

5 Acknowledgement

This work is supported by financial support of HKUST under grant HKUST CERG 612406.
NITTO DENKO (H.K) CO., LTD, provides the retardation film and the polarizer for experiments.

6 References

[1] H-I. Baek, Y-B. Kim, K-S. Ha, D-G. Kim, S-B. Kwon, IDW’00, p.41, (2000)

[2] Chiu-Lien Yang, I-An Yao, Wei-Yi Ling, Pin-Fa Wang, Chueh-Ju Chen, and Jia-Pang Pang, SID’05, p.1876, (2005)

[3] D. H. Suh, Y. I. Park, H.C. Kim, S. M. Rim, W. G. Lee, H. S. Park, IDW’02, p.643, (2002)

[4] T. B. Jung, Y.J. Lim, C.H. Park, H.Y. Kim, Y.H. Jeong, S.K. Lee, S.H. Lee, SID’03 Digest, p.592, (2003)

[5] R. R. Willey, Opto Mechanik, Inc., Melbourne, FL “Broadband Antireflection Coating Design Performance Estimation” ISBN (1991)

[6] Cojocaru. E, Applied Optics (ISSN 0003-6935), vol. 31, no. 16, June 1, 1992, p. 2966-2968 (1992)

[7] Vladimir Chigrinov, Dmitry Yakovlev, and Hoi Sing Kwok, Optimization and Modeling of Liquid Crystal Displays, Information Display, Vol.20, No.8, pp.26-30, (2004).

[8] D. A. Yakovlev, V.Chigrinov and H.S. Kwok, "Contrast and brightness enhancement of RTN- LCDs using antireflective layers", SID’00 Digest, pp. 755-757, Long Beach, California, (2000)

[9] S. J. Roosendaal, B.M.I. vander Zande, A.C. Nieuwkerk, C.A. Renders, J.T.M. Osenga, C. Doornkamp, E. Peeters, J. Bruinink and J.A.M.M. van Harren, SID’03 Digest, p.78, (2003)