Transflective Single Cell Gap Twisted Nematic Liquid Crystal Display Using a Patterned Polarizer and a Twisted Liquid Crystal Retarder

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ABSTRACT

A single cell gap Twisted Nematic (TN) liquid crystal display (LCD) is optimized for transflective LCDs, using MOUSE-LCD software. This TN LCD uses a single cell gap approach with patterned and twisted LC retarder for enhancing the optical performance. The display exhibits high contrast ratio, wide viewing angle and achromatic switching in both the transmissive mode and reflective mode. It also possesses perfect dark state. This TN LCD configuration is easy to fabricate and suitable for high quality transflective TFT-LCDs.

INTRODUCTION

Transflective LCDs combine the characteristics of transmissive LCDs and reflective LCDs. The pixels of the 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 TN LCDs have excellent contrast and viewing angle in transmissive mode but particularly poor contrast in reflective mode due to the imperfect dark state. In order to improve the contrast and the viewing angle, a retardation film should be inserted below the front polarizer in the reflective region of the transflective LCD.

Currently, most of the transflective LCDs use a double cell gap approach [2,3] to optimize the optical efficiency. However, when using such approach, the fabrication will become very complicated in order to control the cell gap precisely. In our design, a single cell gap approach [4] was used for easier fabrication process, but the main drawback in using such approach was that the same phase retardation could not be kept in the transmissive mode and the reflective mode. To overcome this problem, a patterned polarizer [5] with indifferent polarizing axis in transmissive and reflective mode should be inserted. As a result, the resulted normalized transmittance and reflectance dependence on voltage were matched.

As a λ/4 retarder can increase the contrast and the viewing angle of the reflective mode and opposite effect to the transmissive mode [6], in order to improve the optical performance of the transflective LCD, a patterned retarder could be inserted to the reflective sub-pixels optionally.

Our previous paper introduced a double cell TN LCD (DTN LCD) that consisted of two TN liquid crystal layers [7]. With the angle of twist of the liquid crystal molecules in the first cell layer, which applied voltage, was opposite to that of twist of the liquid crystal molecules in the second cell LC layer which would not applied voltage [8] as well as their center rubbing directions were perpendicular to each other. The main drawback of such configuration was that the thickness of the display would increase and the fabrication was much difficult for making double cell display. A twisted LC retarder [9] had been used to overcome this problem. Fig.1 shows the structure of the twisted LC retarder. Twisted LC retarder has a twisted internal structure. It is based on a side-chain LC polymer, which is coated on a substrate. The result is a thin, lightweight and stable retarder. Since LCD driving cells have the same structure, this film has the ideal structure for an LCD compensator. And since any size and optical thickness (retardation) can be selected for the twisting, the film can be applied to all types of driving cells. By replacing the second cell LC layer by a twisted LC retarder, the full compensation which acts to an excellent optical performance in the dark state remains the same, while the thickness is reduced compared with the double cell LCD as the extra glass of a passive LC layer can be omitted. Such TN LCD can produce a black and white display image with high contrast without giving rise to color and a color display image with high contrast. The viewing angle is also improved due to the high contrast. The purpose for this study is to optimize such configuration for the transflective application and to make a comparison between it and traditional transflective TN LCD.

As typical crown glass surfaces reflect from 4% to 5% of visible light at normal incidence [10], the contrast of the reflective mode LCD is seriously affected by the reflectance. In order to reduce the dark state reflectance of the reflective TN LCD (RTN), suitable thickness of indium tin oxide (ITO) around 10-20nm or 130-135nm should be used. As R=L/A, where R is the resistance, L is the length and A is the cross section area, the 10-20 nm ITO is not suitable for display purpose with its high resistance, so 130-135nm was chosen for our display. Also, a quarter wave film or antireflection layer (AR layer) should be inserted which can effectively reduce the reflectance. The AR layer is more preferable than the quarter wave film because of its lower price, so in our simulation we mainly considered the adoption of the AR layer. 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 was used, e.g. a combination of a magnesium fluoride (MgF_2) layer, a Zirconium dioxide (ZrO_2) and a cerium fluoride (CeF_3) layer [11]. Fig.2 shows the structure of the triple AR layer coating and Fig. 3 shows the reflectance versus voltage curve of the RTN before and after the insertion of the triple layers type antireflection film. The reflectance of the dark state as well as the contrast is improved.

The configuration of our transflective TN LCD is similar to the traditional one. It consists of a front polarizer, a LC cell with ITO, a twisted LC retarder and a rear polarizer. The twisted angle of the LC molecule equal to 90° in LC layers and the twisted LC retarder. Fig. 4 shows the cell structure of the transmissive mode TN. The angle indicates the anticlockwise value against the horizontal axis.

Applying the single cell gap approach, the cell gap of the reflective TN (RTN) should be the same as the transmissive mode. But as we want to keep the same phase retardation, patterned polarizer was added to correct the over phase retardation in the reflective mode. Also, a λ/4 retardation film could be inserted optionally below the front polarizer to improve the contrast. Afterwards, the normalized transmittance and reflectance curve can match each other [12]. Fig. 5 shows the cell structure of RTN. The angle indicates the anticlockwise value against the horizontal axis.

In our pervious paper [13], we had simulated the twisted TN LC with twisted angle using 120°, 90°, 80°, 70°, 60° and 50°. The steepness of the transmittance voltage curve becomes lower for the smaller twist angles of the liquid crystal layer. However, a larger color dispersion of the reflective mode will be received (as shown in Table 1). Also from Fig.6, for twist angle larger than 90°, the display shows a limited amount of the gray scale levels. By pondering over a better performance and balancing between color dispersion and gray scale performance, 90° is the most suitable twist angle configuration for our design.

RESULTS

Calculations of the optical characteristics were carried out with the help of MOUSE-LCD software [14,15]. In order to make the simulations more realistic, real dispersion was included in specific layers. The parameters of ZLI-4792 from E. Merck with Δn equal to 0.152 were used in our calculations. The ordinary and extraordinary refractive indices of ZLI-4792 are n_0 = 1.4819 and n_e = 1.6339 at wavelength of 546 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 5μm. Fig. 7 shows the contrast ratio distribution of different LCD configurations. A higher contrast level can be obtained in the TN LCD with a twisted LC retarder when compared with the TN LCD without. The maximum contrast ratio approached 300 in the transmissive mode and 50 in the reflective mode at a normal light incidence.

As shown in Table 2, the contrast of the transflective TN with twisted LC retarder was doubled when compared with the transflective TN without. The region where the contrast ratio larger than 5 is wider than 50° in all direction of the RTN. Also, the viewing angles transflective TN with twisted LC retarder is larger than transflective TN without twisted LC retarder along the horizontal axis and along the vertical axis in the transmissive mode and opposite in reflective mode.

The transmittance and reflectance in transflective TN are shown as a function of the applied voltage in Fig. 8. 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 using the same voltage in a transflective LCD [16].

IMPACTS

In summary, we proposed a TN configuration with a twisted LC retarder for transflective liquid crystal display. Such configuration is using the single cell gap approach for easier fabrication. In order to keep the same phase retardation in the transmissive mode and reflective mode, a patterned polarizer as well as a patterned retardation film should be used. Also, a triple antireflective layers coating with a specific material was proposed to reduce the reflectance of the reflective mode TN. 90° twist was selected for TN LCD cells to improve the color and the gray scale of the reflective mode. As a result, the TN maintains a perfect performance both in transmissive and reflective mode. Transflective TN with twisted LC retarder shows a higher contrast at normal direction than the one without. As the normalized transmittance and reflectance are matched, the same gray scale voltage can be used in a transflective display operation.

ACKNOWLEDGMENT

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TABLES AND FIGURES

	Source	90°	80°	70°	60°	50°
x	0.31	0.3071	0.3135	0.3208	0.3252	0.3574
y	0.33	0.3381	0.3506	0.3596	0.3605	0.3791
Δx	0	0.0079	0.0035	0.0108	0.0142	0.0474
Δy	0	0.0161	0.0236	0.0296	0.0305	0.0491

Table 1. CIE 1931 color coordinate in reflective mode of different twisted angle and the source.

	7a)	7b)	7c)	7d)
Contrast	297	48	120	18

Table 2. Maximum contrast of the configurations in Figure 7a-d

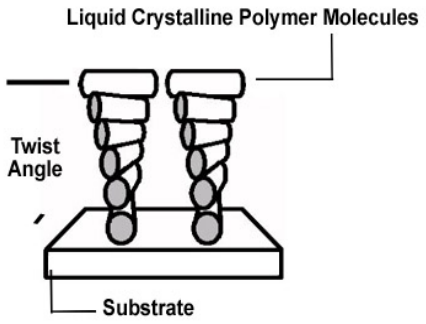

Figure 1. Structure of the twisted LC retarder

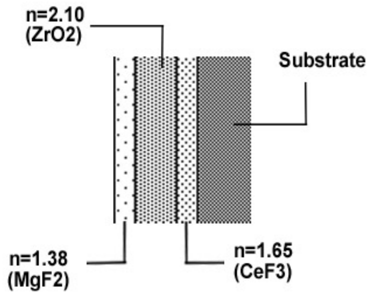

Figure 2. Structure of triple antireflection layer coating

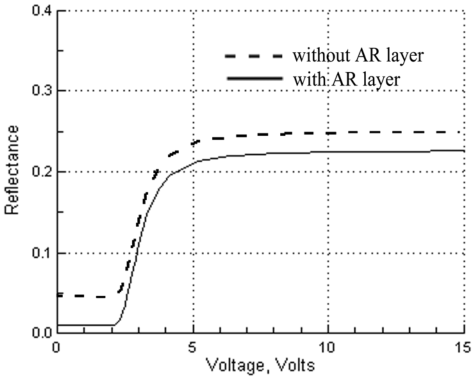

Figure 3. Reflectance of RTN LCD versus Voltage

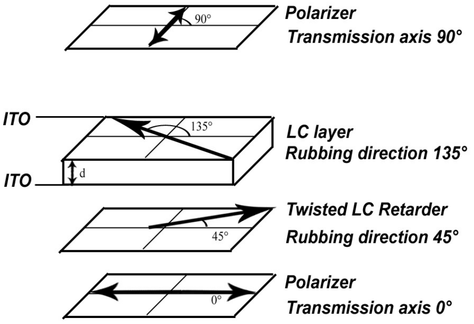

Figure 4. Cell structure of transmissive TN LCD

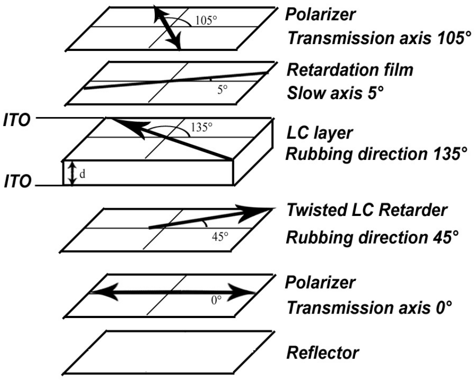

Figure 5. Cell structure of reflective TN

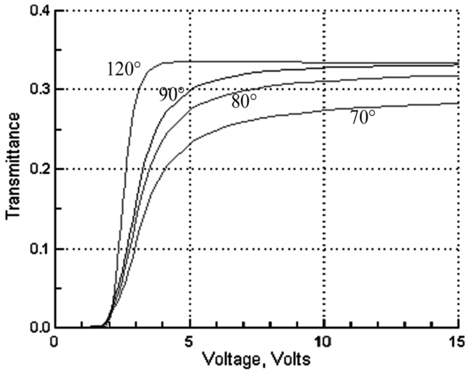

Figure 6. Transmittance of TN-LCD vs Voltage with twisted angle equal to 120°, 90°, 80°and 70°

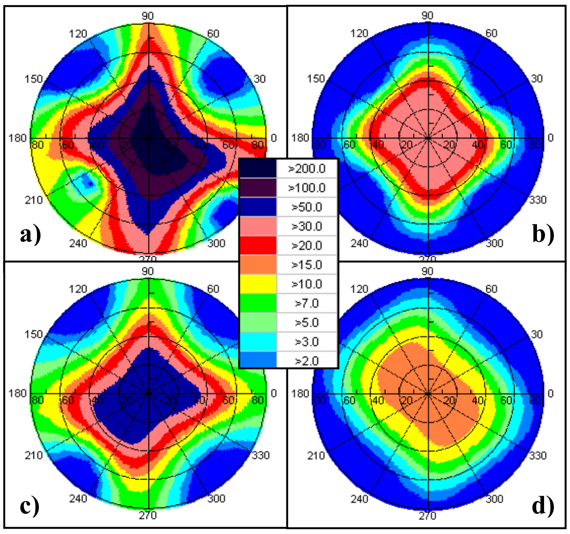

Figure 7a)-d). Contrast ratio distribution of
a) Transmissive TN with twisted LC retarder,
b) Reflective TN with twisted LC retarder,
c) Transmissive TN without twisted LC retarder,
d) Reflective TN without twisted LC retarder

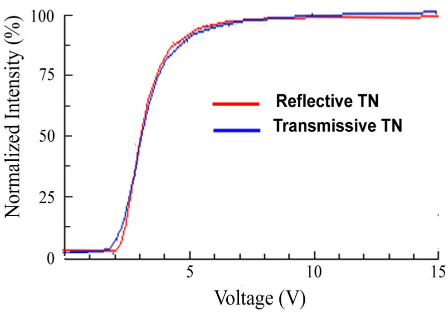

Figure 8. Electro-optical characteristics of transflective TN cell.