P-156: Transflective Double Cell TN Liquid Crystal Display

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ABSTRACT

Double cell Twisted Nematic (DTN) liquid crystal display is optimized for transflective liquid crystal displays, using MOUSE-LCD software. Two configurations of such DTN-LCD were simulated using a double and a single cell gap approach. DTN-LCD exhibits a high contrast ratio, wide viewing angles and achromatic (black/white) switching in both the transmissive mode and reflective mode. It also possesses a perfect dark state. DTN configuration is suitable for the high quality transflective TFT-LCD.

Keywords: transflective LCD; double cell TN-LCD, DTN.

1. INTRODUCTION

Transflective LCDs combine the characteristics of transmissive LCDs and reflective LCDs. The pixels in a transflective display are partially transmitting with backlight illumination. The pixels are also partially reflective, so under ambient illumination they also reflect light from the environment [1]. Conventional transflective single cell TN-LCDs have excellent contrast and viewing angle in transmissive mode but particularly poor contrast in reflective mode due to the dark state. In order to improve the contrast and the viewing angle, a retardation film should be inserted below the front polarizer in a single cell TN-LCD.

A double cell TN-LCD (DTN-LCD) consists of two TN liquid crystal layers. The twisted angle of the TN liquid crystal we used in simulation is 90°. The angle of twist of the liquid crystal molecules in the first cell layer is opposite to that of twist of the liquid crystal molecules in the second cell LC layer [2]. Their rubbing directions are perpendicular to each other. As the dark state is excellent and the color dispersion is minimized, the DTN can produce a black and white display image with a high contrast without giving rise to color and a colored display image with high contrast. The viewing angle is also improved due to the high contrast.

Two transflective DTN-LCD configurations will be introduced using a double [3,4] and a single cell gap approach [5] respectively. For a double cell gap approach, the same phase retardation is kept in the transmissive mode and the reflective mode. Therefore, the normalized transmittance and reflectance dependence on voltage will match. On the contrary, in order to match of a transmittance and reflectance voltage curve in a single cell gap DTN-LCD, a patterned retardation layer and a patterned polarizer [6] should be adopted. The purpose for this study is to optimize the DTN-LCD for the transflective application and to make a comparison between the transflective DTN-LCD and transflective TN-LCD.

2. OPTIMIZATION OF THE TRANSFLECTIVE DTN-LCD

The configuration of the transflective DTN is similar to the transflective TN. It consists of a front polarizer, an active LC cell with ITO, a passive LC cell and a rear polarizer. We find that for transmissive DTN with twisted angle equal to 90˚ in both the active and passive LC layers, the $d\Delta n$ should have a value 0.76μm to get the best performance. Figure.1 shows the cell structure of the transmissive mode DTN. The angle indicates the anticlockwise value against the horizontal axis.

Applying the double cell gap approach, the proper choice of $d\Delta n$ in reflective DTN is 0.38μm for keeping the same phase retardation in the double cell gap DTN. In the single cell gap DTN, a $\lambda/4$ retardation film and a polarizer with different transmission axis were inserted in the reflective mode. Afterwards, the normalized transmittance and reflectance curve can match each other in the single and double cell gap configurations [7]. Figure.2 shows the cell structure of double cell gap and single cell gap reflective DTN.

As typical crown glass surfaces reflect from 4% to 5% of visible light at normal incidence [8], the contrast of the reflective mode of DTN-LCD is seriously affected by the reflectance. In order to reduce the dark state reflectance of the reflective DTN-LCD (RDTN), suitable thickness of indium tin oxide (ITO) around 130-135nm should be used. 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

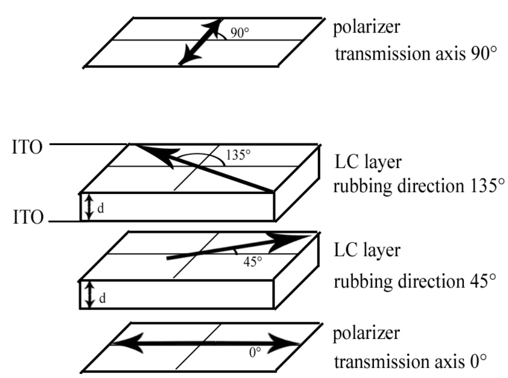

Figure 1. Cell structure of transmissive DTN

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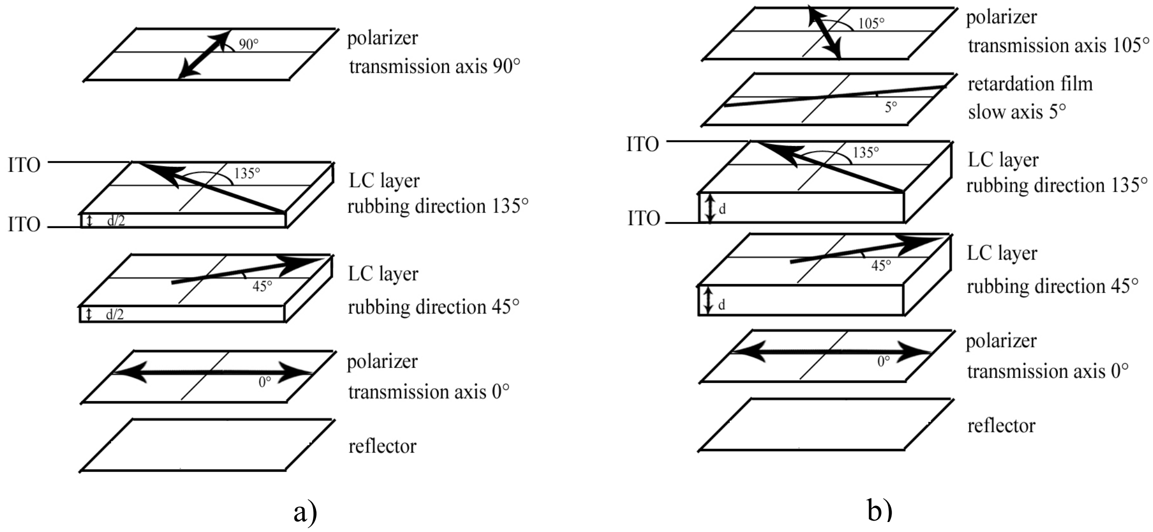

Figure 2a) and b). Cell structure of double cell gap reflective and single cell gap reflective DTN

mainly considered the adoption of the AR layer. The optimal refractive index of the AR layer:

$$\frac{n_0 - n_1}{n_0 + n_1} = \frac{n_1 - n_m}{n_1 + n_m} \Rightarrow n_1 = \sqrt{(n_0 n_m)}$$

where n1 is the refractive index of the antireflection film. Since the refractive index of air (n0) 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= 1.23 for an antireflection coating). Therefore, in the DTN design a double layer type antireflection coating may be used, e.g. a combination of a magnesium fluoride (MgF2) layer and a cerium fluoride (CeF3) layer [9]. Figure.3 shows the reflectance versus voltage curve of the RDTN before and after the insertion of the double layers type antireflection film. The reflectance of the dark state as well as the contrast is improved.

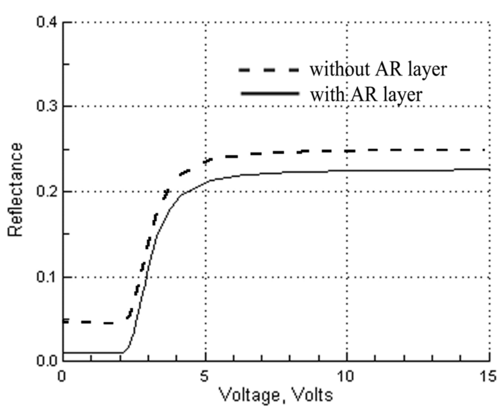

Figure 3. Reflectance of RDTN-LCD vs Voltage

Besides 90°, the simulation had been made using 80°, 70°, 60° and 50° twisted TN liquid crystal. Fig.4 shows the transmittance versus voltage curves of 120°, 90°, 80° and 70° twisted angle. The steepness of the transmittance voltage curve becomes lower for the smaller twist angles of the liquid crystal layer.
Therefore, a better gray scale can be obtained. However, we can observe from Table.1 that a larger color dispersion of the reflective mode will be received.
For twisted angle larger than 90°, the display shows a limited amount of the gray scale levels (Fig. 4). By pondering over a better performance and balancing between color dispersion and gray scale performance, 90° is the most suitable twisted angle configuration for DTN.
In order to compare the performance between transflective DTN and transflective single cell TN with a pattern retardation film, a configuration of transflective single cell TN configurations using the same components of which the transflective DTN consisted were made. Retardation dΔn of the TN LC equals to λ in the transmissive mode TN and λ/2 in the reflective mode were chosen for the configuration of

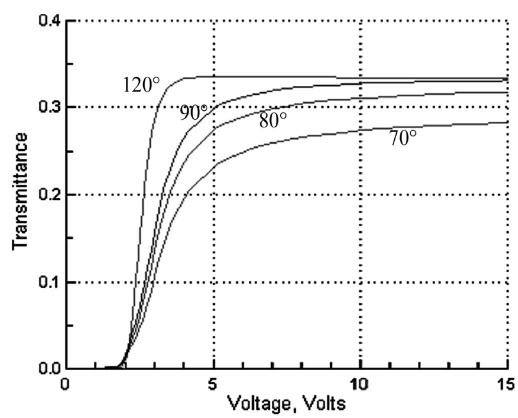

Figure 4. Transmittance of DTN-LCD vs Voltage with twisted angle equal to 120°, 90°, 80° and 70°

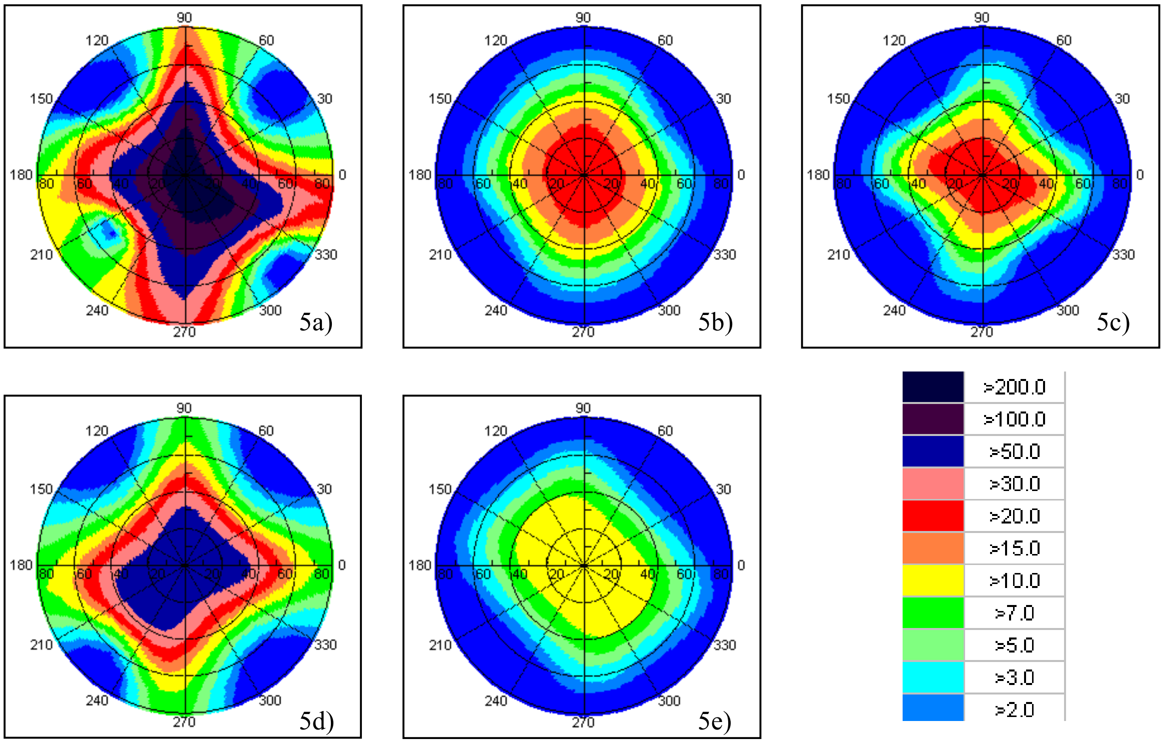

Figure 5a)-e). Contrast ratio distribution of a) transmissive DTN, b) double cell gap RDTN, c) single cell gap RDTN, d) transmissive single cell TN and e) reflective single cell TN

transflective TN. Also, a λ/4 retardation film in the reflective mode was inserted for increasing the contrast. From simulation, if we apply dΔn equals to 0.76μm in the single cell transmissive TN LC, the viewing angle will be extremely bad. Therefore, we can only apply dΔn equals to λ in transmissive mode and λ/2 in reflective mode instead of 0.76μm and 0.38μm from the transflective DTN configuration.

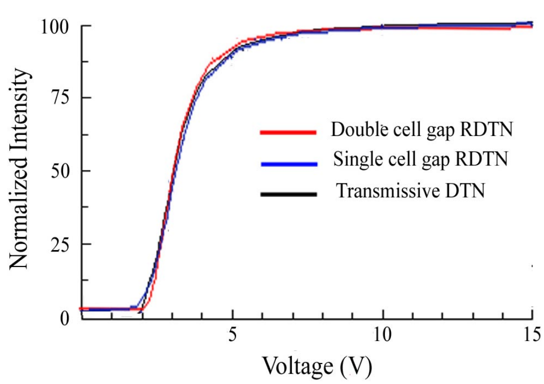

Figure 6. Electro-optical characteristics of transflective DTN cell.

3. SIMULATION PERFORMANCES OF DTN-LCD

Calculations of the optical characteristics were carried out with the help of MOUSE-LCD software [10,11]. In order to make the simulations more realistic, real dispersion was included in specific layers. The nematic LC material used in this work was ZLI-4792 from E. Merck. 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 cell gap was 5μm in the transmissive mode and single cell gap reflective mode, and 2.5μm for double cell gap reflective mode The twisted angles of the liquid crystal layers were 90°.

Figure 5 shows the contrast ratio distribution of different LCD configurations. A higher contrast level can be obtained in DTN when compared with TN. The maximum contrast ratio approached 300 in the transmissive mode and 25 in thereflective mode of DTN at a normal light incidence.

As shown in Table 2, the contrast of the transflective DTN was nearly doubled when compared with the transflective TN. The region where the contrast ratio larger than 5 is wider than 50° in all direction of the RDTN. Also, the viewing angles of the double cell gap RDTN are slightly better than the single cell gap RDTN along the horizontal axis and smaller along the vertical axis while the maximum contrast remained the same.

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

	Source	90°	80°	70°	60°	50°
x	0.31	0.3021	0.3135	0.3208	0.3252	0.3574
y	0.33	0.3461	0.3536	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 2. Maximum contrast of the configurations in Figure 5a-e

	5a)	5b)	5c)	5d)	5e)
Contrast	297	25	25	120	13

The transmittance and reflectance in transflective DTN are shown as a function of the applied voltage in Figure 6. The electro-optical characteristics in the transmissive mode, the double cell gap reflective mode and single cell gap reflective mode match each other. This indicates that the transmissive and reflective DTN could be controlled using the same voltage in a transflective LCD [12].

4. CONCLUSIONS

In summary, we proposed a double TN cell (DTN) configuration for transflective liquid crystal display. Both double and single gap transflective LCDs were considered. In the latter case a patterned polarizer as well as a patterned retardation film should be used. In order to reduce the reflectance of the reflective mode DTN, a double antireflective layer with specific material was proposed. 90° twist was selected for DTN-LCD cells to improve the color and the gray scale of the reflective mode. As a result, the DTN maintains a perfect performance both in transmissive and reflective mode. DTN shows a higher contrast at normal direction than a single TN cell. As the normalized transmittance and reflectance are matched, the same gray scale voltage can be used in a transflective display operation.

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