New Optimized Reflective LCD Modes for Direct View and Projection Displays

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Abstract

By searching the parameter space of reflective nematic liquid crystal displays, two new operating modes were discovered that should have applications to both direct view and projection systems. They are the low twist RTN mode and the high twist RSTN mode. We show that they are actually related to the MTN mode, the TN-ECB mode, the SCTN mode and the HFE mode.

Introduction

A simple reflective twisted nematic LCD consisting of just an input polarizer, the LC cell and the rear reflector has many advantages, such as increased brightness, less materials and elimination of parallax. Many different RTN modes have been published in the literature. Examples include:

(1) The 45^o and 90^o hybrid field effect (HFE) mode which was widely used in the LCLV projection systems [1,2]. The output is elliptically polarized.

(2) The TN-ECB mode with twist angles given by $\phi = \pm (2N-1)\pi/2\sqrt{2}$ where N is an integer [3-5]. The twist angles of the TN-ECB mode are therefore $63^\circ, 200^\circ$ and 310°. The TN-ECB modes are improvements over the HFE modes in that the output light is linearly polarized and therefore have 100% reflectance. However, for white light input, this TN-ECB mode is quite color dispersive. Optical compensation technique is often needed for good performance. The first TN-ECB minimum at 63° has the best performance in terms of contrast and color dispersion. However, it requires a very small Δnd (0.19 μm) which makes the LC cell difficult to fabricate.

(3) The recently discovered MTN mode [6] with $\phi = 90^o$ and $\Delta nd = 0.2$ μm has excellent color dispersion properties and high contrast. However, it has to be operated in the normally dark mode and a quarter wave retardation film is needed to make it normally white. The Δnd value is also rather small for cell fabrication.

(4) The self-compensated TN mode [7] has a twist angle of near 60^o and a small Δnd value. Its advantage is the lower operating voltages, at the expense of rather large color dispersion.

In this paper, we shall present two more reflective twisted nematic modes that have excellent optical properties. One has a low twist of 52^o and will be called the RTN mode. The other one has a twist angle of near 200^o and shall be called the RSTN mode. The RTN has a mild reflectance-voltage behavior and is suitable for active matrix LCD. One of its advantages is that it is a normally white mode so that a quarterwave retardation plate is not necessary. It can be used in direct view TFT AMLCD as well as in silicon backplane projective AMLCD [8]. The RSTN is highly multiplexable and is suitable for passive matrix direct view LCD. A parameter space representation can be used to show that all of these reflective TN modes are related to each other.

Parameter space

A reflective TN display has 3 major variables: the twist angle ϕ, the polarizer angle α and the birefringence-thickness product Δnd. Any pair of these variables can be used to generate a parameter space of the reflectance in a contour plot or 3D plot

[9]. The different operating modes can be visualized in the static V = 0 condition on such parameter spaces.

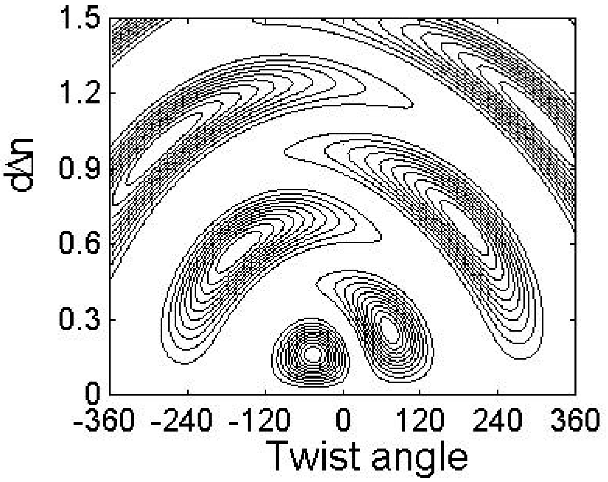

Fig. 1 A ϕ-Δnd parameter space for reflective LCDs. The contour lines of constant reflectance are in steps of 0.1.

Figure 1 shows the ϕ-Δnd parameter space for a reflective display consisting of just an input polarizer, the LC cell and a rear reflector. In this particular example, the polarizer angles α is 15^{o}. It shows an asymmetry in ϕ. For α = 0 or 45^{o}, the parameter space is symmetrical in ϕ. The N = 1 minimum can be called the first TN-ECB minimum and so on. In general, the TN-ECB modes move around the parameter space systematically. It can be shown that the HFE, MTN and SCTN modes are related to the first TN-ECB minimum. A more systematic optimization of the first TN-ECB minimum leads to the RTN mode at 52^{o}.

Additionally, we can optimize the second TN-ECB minimum by adjusting α and Δnd while keeping ϕ near 200^{o}. The result is a supertwisted reflective mode. This RSTN mode operates with just one polarizer and no retardation film. It shows great promise as a practical display mode for passive matrix LCD.

In the reflective LCD, the input an output polarizers can either be in a //-// geometry or in a //-⊥ geometry. For direct view applications, the input and output polarizers are the same, so the polarizers will have to be a //-// geometry. In both cases, the display can also be operated in the normally white (NW) or normally black (NB) modes. These 4 combinations of //-//, //-⊥ polarizer geometry and NB/NW conditions are related to each other by a quarterwave retardation plate, or by a proper rotation of the polarizer.

RTN Mode

We performed a systematic search for the optimal operating conditions of the 3 parameters by generating a 2D parameter space diagram in Δnd and α for each value of twist angle ϕ. There are many combinations of Δnd and α that will give a reflectance of 0% . The optimal condition is then further refined by finding a (Δnd, α) combination that will produce a broad R = 0% region for different wavelength when a voltage is not applied and that will produce a high reflectance when a voltage is applied. Also the dispersion characteristics of the voltage-on state should be as nondispersive as possible.

In order to obtain the reflectance-voltage curve (RVC), we followed the standard procedure for LC modeling: first the 1D Euler-Lagrange equations for the director deformation were solved to give the director angles ϕ(z) and θ(z) for all values of z inside the cell. Then the reflectance was calculated by dividing the cell into many layers and treating each layer as a birefringent plate, and multiplying together all the Jones matrices.

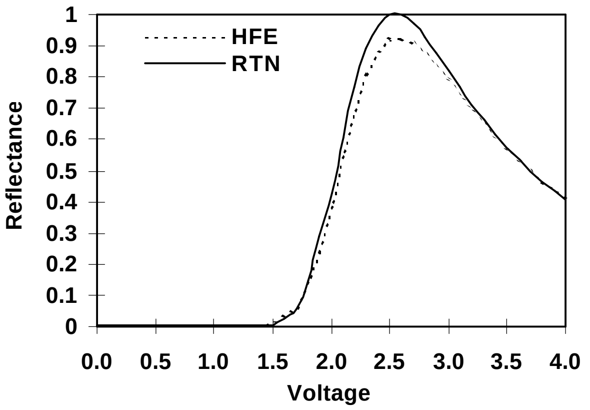

Fig. 2 Simulated RVC of the 45^{o} HFE and RTN LCD.

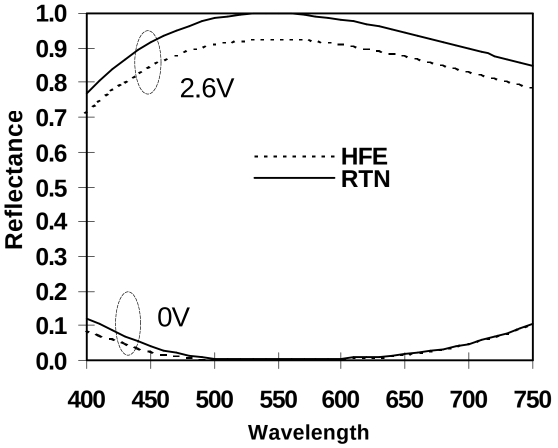

Fig. 3 Calculated reflectance spectra of the RTN and 45° HFE LCD.

Fig. 2 shows one example of such a calculation using the conditions of twist angle $\phi = 52^{\circ}$, $\Delta nd = 0.54\mu m$ and $\alpha = 0^{\circ}$. The values of the elastic constants used for this calculation are those of a typical liquid crystal with a pretilt angle of 1°. It can be seen that a threshold voltage of 1.5V is obtained, followed by an increase in reflectance. When the voltage is 2.6V, the maximum reflectance for both the 52° and 45° cells is obtained. From Fig. 2, we find that the reflectance of the RTN cell is 10% greater than that of the 45° HFE cell. The wavelength of 550 nm is assumed in this calculation.

The complete reflectance vs. wavelength curves are shown in Fig. 3 for both the field-off state (0V) and the field-on state (2.6V). From Fig. 3, we find at the field-off state, the reflectance vs. wavelength of both curves are identical. But at the field-on state, the reflectance of the RTN cell is 10% greater than that of the 45° cell.

To verify our theoretical simulation, two groups of sample cells were fabricated, one with 52° twist and the other with 45° twist. Their measured RVCs for 514nm wavelength are shown in Fig. 4. Also their reflectance vs. wavelength curves are shown in Fig. 5. The agreement between theory and experiment is good. The slight deviation in the threshold voltage is because of the refractive index uncertainty.

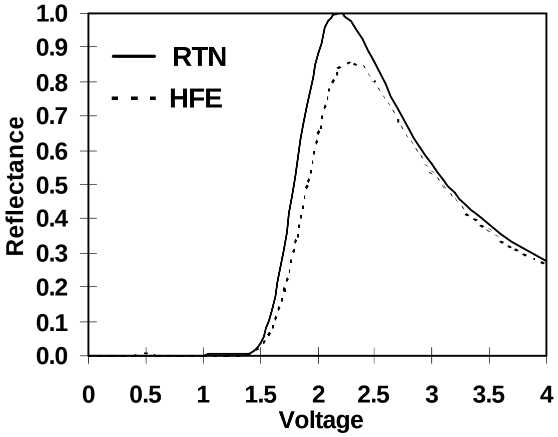

Fig. 4 Experimental RVCs of 45° HFE and 52° RTN sample cells.

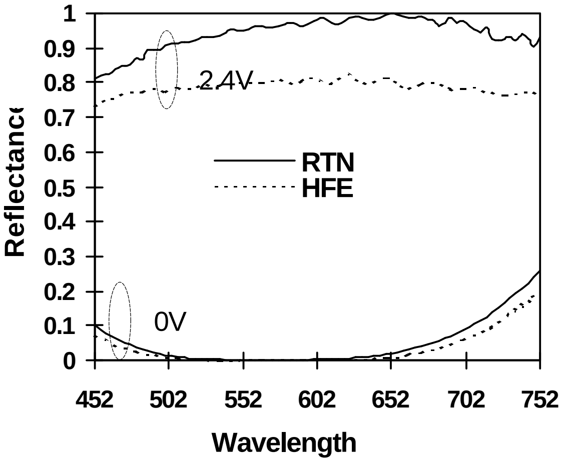

Fig. 5 Experimental reflectance spectra of the RTN and 45° HFE cells.

RSTN Mode

By varying α and Δnd near the second TN-ECB minimum, it is possible to obtain a reflective mode with 100% light efficiency and low dispersion. In searching the parameter space, we concentrate at ϕ near 200°. The same optimization procedure as the RTN was used in optimizing the RSTN. Figure 6 shows the calculated and experimental RVC for this RSTN. The experimental cell was fabricated in the usual manner with a 4-bottle LC system in order to adjust the Δnd value.

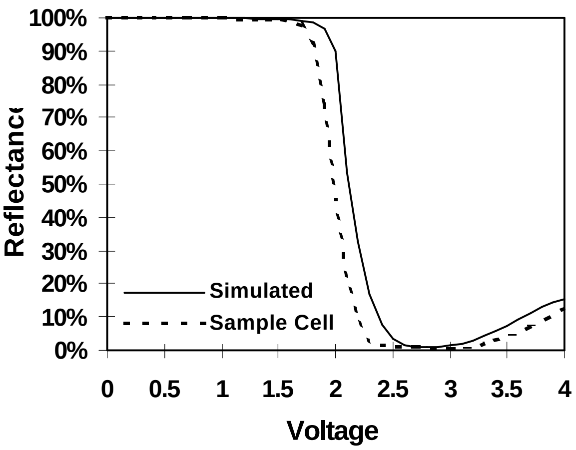

Fig. 6 Comparison of experimental and theoretical RVC for the RSTN display.

From Fig. 6, it can be seen that the RVC of the RSTN is rather sharp. A steepness coefficient of 1.15 can be obtained implying a multiplexing capability of 50 lines. The threshold voltage is also reasonable. This RSTN therefore should be useful for pagers and PDA applications.

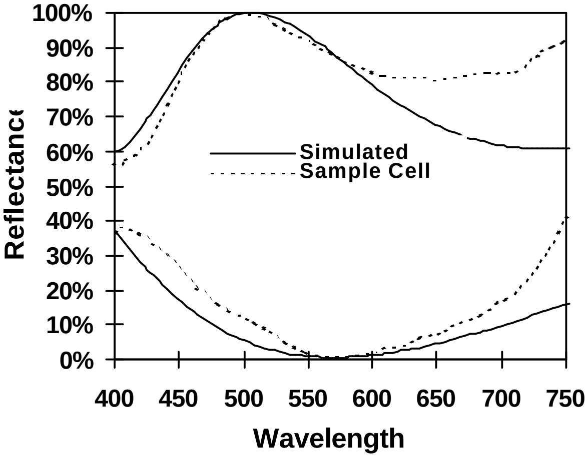

Fig. 7 Comparison of experimental and theoretical reflectance spectra for the RSTN display.

Figure 7 shows the dispersion curve for this RSTN. The dotted line is the experimental result while the solid line is the theoretical simulation. It can be seen that the agreement between the two sets of curves is rather good. More importantly, it can be noted that the RSTN is much more wavelength independent than a comparable STN display without film compensation. Typically the yellow mode of a STN has a 50% variation in reflectance in the visible. The RSTN on the other hand has only a 20% variation. Hence the RSTN can be used to make a good B/W display.

Conclusions

In summary, two new reflective LCD modes were presented. One has a low twist and is suitable for AMLCD in both projection and direct view. The other one has a high twist and is suitable for passive matrix direct view LCD. We showed that the optical properties of both of these new reflective modes are better than existing ones in terms of brightness and color dispersion. The contrast is also excellent.

One aspect of these new LCD modes that has not been discussed yet is the viewing angle. Since the reflective LCD can be regarded as 2 oppositely twisted LC cells in tandem, some form of self-compensation is present, similar to a double cell DSTN. The viewing angle issue is being addressed at present.

Acknowledgments

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