NEW REFLECTIVE LIQUID CRYSTAL DISPLAY MODES

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Abstract Reflective liquid crystal displays that consist of just one polarizer and a rear reflector are presented. No retardation films are used to compensate for colour dispersion. An operating mode is found that possess excellent quasi black/white contrast and low colour dispersion. In terms of both performance and production cost, this new display mode is better than existing supertwisted nematic displays.

Key Words: Reflective LCD, Single Polarizer

1. INTRODUCTION

Conventional reflective nematic liquid crystal displays (LCD) are actually transflective in which the light beam traverses a transmissive LCD twice in reflection. As such, they use two polarizers, in the front and in the back. It leads to a loss of brightness, not to mention the increased cost in materials and production. Common twisted nematic (TN) and supertwisted nematic (STN) LCDs are of such designs. Since the early years of LCD research, various schemes have been attempted to eliminate the rear polarizer [1-4]. However, none of them were found to be practical. There is a recent push again for designing true reflective LCD (RLCD)[5]. The advantages of incorporating the reflector inside the liquid crystal cell are many, including the elimination of parallax, higher effective pixel density in active matrix LCD (AMLCD), higher brightness, thinner structure and wider viewing angle.

There have been three approaches to the design of reflective nematic LCDs. Type I design consists simply of a front polarizer, a liquid crystal cell and a rear reflector which can be inside or outside the liquid crystal cell [1,3,4,6]. This is the simplest design and would be great if it works. However it was found that such displays were too disperse, and the required cell thickness too small to be practical. To compensate for the strong colour dispersion, Type II design places a retardation film between the liquid crystal cell and the rear reflector [2,7]. Though highly nondispersive reflective displays can be made this way, this design does not allow the reflector to be placed inside the liquid crystal cell and thus a big advantage of reflective displays is lost. Type III design places the retardation film in the front of the liquid crystal cell [8-11]. This is a big improvement over Type II designs. Recently Fukuda et al have successfully analysed and demonstrated such displays.

In this paper, we reconsidered the Type I design more carefully and systematically using the parameter space approach we have recently developed [12]. It will be shown that there is 1 operating mode that is akin to normal STN displays and is excellent in terms of quasi black/white contrast and low colour dispersion. This reflective STN (RSTN) displays is actually better than its STN counterparts. The RSTN especially holds high promise as passive multiplexable displays with high information content.

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2. OPTIMIZATION

Figure.1 shows the structure of the RLCD of Type I designs with single polarizer and no retardation film. The analysis of the RLCD is based on the general Jones matrix approach [12,13]. One important difference between the single polarizer display and the conventional transmissive TN and STN displays is that normally white (NW) and normally black (NB) displays have to be optimized separately. In TN and STN displays, NB can be turned into NW by simply changing the polarizers from a //-// to a //-⊥ geometry. For RLCD, this cannot be done. In this paper, we shall concentrate on the optimization of NW displays since they are more practical. NB designs will be discussed in a later publication.

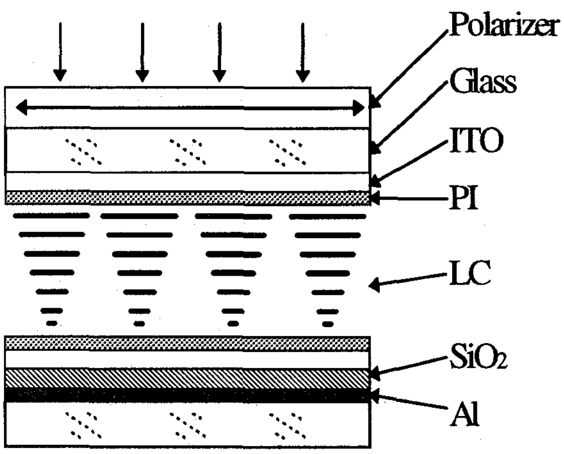

Fig.1 Structure of RLCD with single polarizer and no retardation film.

There are 3 parameters for the Type I nematic reflective LCD: the twist angle ϕ, the cell retardation value Δnd, and the angle α between the polarizer axis and the input director of the LC cell. A simple 2D parameter space can therefore not be used. We performed a tedious search for the optimal operating conditions of RLCD by generating a 2D parameter space diagram in Δnd and α for each value of ϕ. ϕ was varied from 0° to 360° in a semi-systematic manner. Fig.2 is an example of a Δnd - α parameter space for $\phi = 180°$. From this diagram, it can be seen that there are many combinations of Δnd and α that will give a reflectance of 100% (NW). The optimal condition was then further refined by finding a (Δnd, α) combination that will produce a broad R = 0% region when a voltage is applied.

In order to obtain the Reflectance-Voltage curve (RVC), we followed the standard procedure for LC modelling: First the 1D Euler-Lagrange equations for the director deformation were solved to give the director angles $\phi(z)$ and $\theta(z)$ 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. Details of our simulation tool will be published elsewhere [12, 13, 14].

Figure. shows (solid line) one example of such a calculation using the conditions of point A in Fig.2, i.e. Δnd=0.56μm and α = -54°. The values of the elastic constants used for this calculation are those of a typical STN liquid crystal MLC-5300 with a pretilt angle of 5°. It can be seen that a threshold voltage of 2V is obtained, followed by a sharp drop in reflectance. The steepness of this R-V curve is good enough for multiplex applications similar to transmissive STN. The most important observation about Fig.3 is that R reaches to near 0% and over a wide voltage range. Green light at about 550 nm was assumed in this calculation. The complete reflectance spectrum is shown in Fig.4 (solid lines) for both the field-off state and the field-on state at 2.7V.

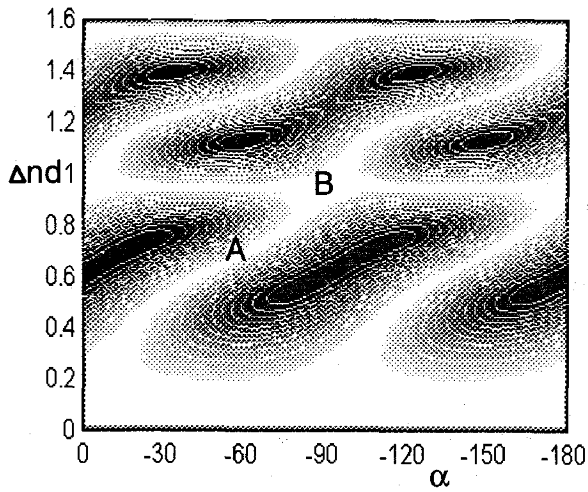

Fig.2 Example of a Δnd—α parameter space for ϕ = 180° The successive contours are in steps of 10%

The significance of the results presented in Fig.3 and Fig.4 (solid lines) is that (1) A good contrast can be obtained in RSTN. For a single wavelength, the contrast can be as high as 200:1. (2) The dispersion of the reflectance is excellent. It is better than transmissive STN without film compensation. If a display is made using these particular optimized values, its performance using these particular optimized values, its performance will definitely be much better than a transflective STN using 2 polarizers.

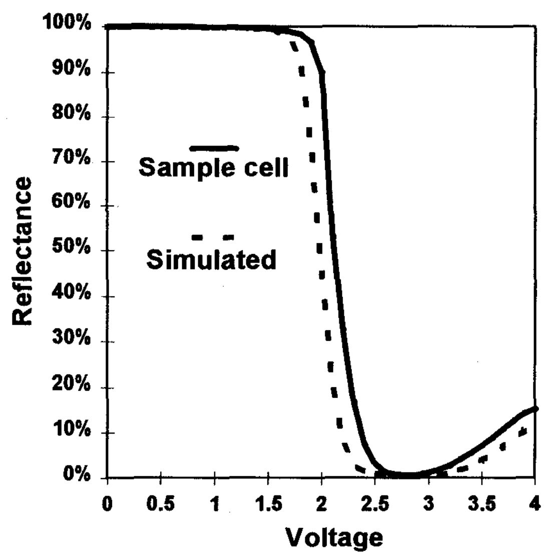

Fig.3 Comparison of Simulated and sample cell TVC using the conditions of point A in Fig. 1, i.e. Δnd=0.56 μm and α = -54°, twist angle ϕ

3. EXPERIMENT

An experimental cell was made using the conditions discussed above. the Δnd value was adjusted using 4 bottle system. The measured reflectance (dot line) as a function of voltage for green light is shown with the simulated result in Fig.3. The complete reflectance spectrum is shown in Fig.4 (dot lines) for both the field-off state and the field-on state at 2.7V. It can be seen that there is good agreement with the predictions. A low dispersion, high contrast display can be obtained in reflection mode, and with a good steepness. Hence it is concluded that the above approach in searching for a good Type I RLCD is plausible. The particular conditions presented in Figs. 1-4 can be referred to as reflective STN (RSTN).

There is some deviation between the solid lines and dot lines in Fig.3 and Fig.4. This is because for different wavelength, there is also some deviation of the refractive index difference Δn of the liquid crystal. The values of the elastic constants we used for the simulation is different with the sample cell, because we need to adjust the LC refractive index difference Δn using 4 bottle system. Cell parameter deviations are also exist in the fabrication process. Also in the simulation, we used a commonly defined polarizer parameters. In practice, however, different polarizers are with their owns parameters. The whole shapes of these two curves are still the same.

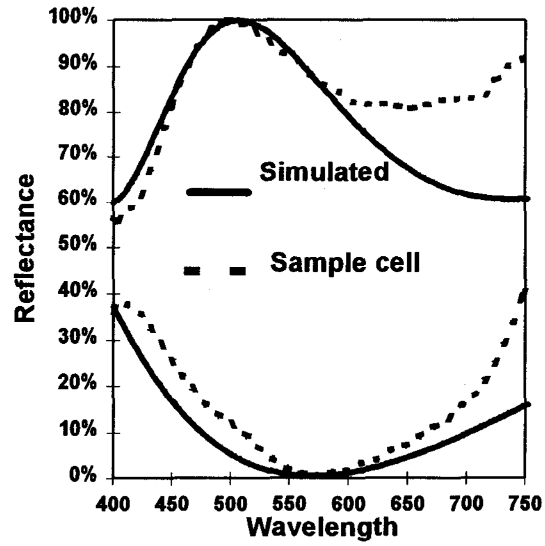

Fig.4 The complete reflectance spectrum for both the field-off state and the field-on state of simulated and sample cell at 2.7V. using the conditions of point A in Fig. 1, i.e. Δnd=0.56 μm and α = -54°, twist angle ϕ

Referring back to Fig. 1, it is interesting to note that there are many combinations of (Δnd and α) that will give a NW state. We found that states that are directly above a black state, such as B point with Δnd = 0.9 μm and α = -90°, does not produce a good R = 0% state when a voltage is applied. Since ϕ can vary over a wide range, it is a daunting task to find all the possible operating points for this RLCD. It is especially difficult since the R-V curve has to be obtained in order to evaluate the appropriateness of any combination of (ϕ, α and Δnd).

4. CONCLUSION

In summary, we have discovered some operating conditions of Type I reflective displays that can produce excellent contrast and brightness. These conditions are obtained through a tedious and laborious search of the parameter space for the RLCD. These conditions have been experimentally confirmed. We are hopeful that such displays will find commercial usage as they compared very favourably with existing displays, in terms of contrast, colour dispersion, brightness and simplicity in design.

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