P-83: A New Reflective Twisted Nematic Liquid Crystal Display Mode with Large Cell Gap for Direct View Applications

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Abstract

We propose a new reflective twisted nematic display mode, which is called the second minimum RTN mode. This mode has a larger dΔn value compared with the first minimum RTN mode which we proposed previously. A cell gap of 7μm or larger can be used for this mode which makes the fabrication processing of this kind of reflective LCDs easier and more compatible with that of TN LCDs. The color dispersion in both bright and dark states of this display mode is small, and the response is reasonably fast considering the 7μm cell gap. This display mode can be used in conjunction with TFT active matrix for high quality reflective displays for PDAs, and cell phones. It is also suitable for passive low cost applications such as watches and games.

1. Introduction

Conventional reflective TN and STN LCDs are not true reflective displays because the light merely passes through the transmissive cell twice. This type of LCD has two disadvantages:

1. There is parallax, which negates the use of color filters and, thus, the realization of full color displays.
2. Their light efficiency is low because light passes through polarizers a total of four times. The light efficiency is decreased by the absorption of the polarizer (~ 6%). The light efficiency of reflective TN and STN is normally around 20%.

A rear polarizer is not required for a true reflective LCD. When the rear polarizer is eliminated, the reflective layer can be built inside the cell. Normally this kind of display is just called a reflective LCD or single polarizer reflective LCD. Parallax is totally eliminated and the light efficiency is increased (up to 40%). Another advantage of such reflective LCDs is that the LCD cell can be built on a silicon wafer with CMOS active matrix drivers to realize a high resolution display. This kind of display is called LC on silicon (LCoS) microdisplay.

Reflective LCDs [1-6] have been actively studied since the middle of 1990s. The most attractive application is the LCoS microdisplay which can be used for projection or direct view through a lens. Much effort has also been given to developing a larger reflective panel for direct viewing. This kind of display is eagerly awaited for personal information tools (PITs), such as PDAs and games because of its low power consumption (no back light) and full color capability. In 1997 H. S. Kwok proposed the reflective TN (RTN) mode with 52° twist angle [1]. X. J. Wang also proposed a similar reflective LCD mode, called the XTN mode [2]. The RTN mode is an improvement over the HFE mode in that the output light, when voltage is applied, is linearly polarized and, theoretically, has a 100% efficiency. IBM Japan presented a prototype TFT-LCD color display panel using the RTN mode at the 1997 SID symposium [3]. Later in the same year, Sharp demonstrated a MTN mode reflective TFT LCD panel with 260,000-colors and VGA resolution [4]. A series of such reflective TFT LCDs with different resolutions were developed in 1998 [5]. Because the MTN mode with small cell gap (2 to 3μm) was used, requirements for fabrication processing were very critical. To avoid this drawback, T. Ogawa et al. of Matsushita developed a full color TFT LCD with a larger cell gap and a retardation film to reduce the color dispersion [6]. A Game Boy with Sharp's full color reflective TFT LCD has been available in the market since 1999.

There is a potential of using RTN LCDs instead of TN LCDs for some low cost passive applications. While there is no parallax and the display is brighter, RTN LCDs also have a wider viewing angle and faster response compared with conventional of TN LCDs. Furthermore, the reflective display appears as if the pattern is etched on a metal mirror. This unique appearance is attractive for some customers for applications in watches or games. The fabrication process of RTN LCDs is compatible with that of TN LCDs except one polarizer is saved and a reflective layer is added. The cost of the RTN display will be similar to or even less than that of TN LCDs.

In our previous work [1], a RTN mode reflective display with a dΔn value of 0.5μm and a twist angle of 50° was proposed. The 0.5μm dΔn normally requires a 5μm cell gap which is too thin for most of the low end LCD manufactures. In this work, a new RTN mode with a dΔn value of 1μm is proposed. This new RTN mode has similar properties compared with the former RTN mode, but a 7μm or larger cell gap can be used. This display mode is most suitable for low cost products.

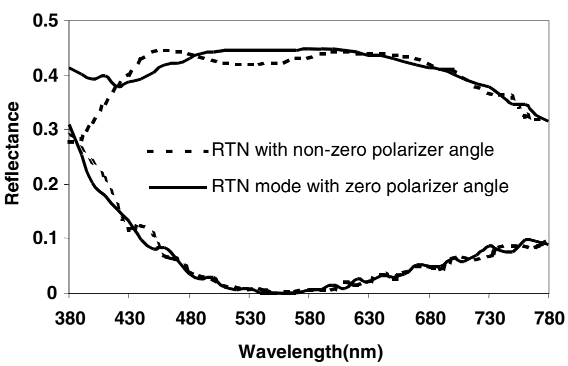
2. The first minimum RTN mode with non-zero polarizer angle

The RTN mode we proposed earlier has almost the same dΔn value (0.5μm) with the first minimum TN mode, while the new RTN mode has a dΔn value of 1μm similar with the second minimum TN mode. These two RTN modes will be referred to as first and second minimum RTN modes, respectively.

The first minimum RTN display has a low threshold voltage and can be applied for both projection and direct viewing applications. For projection, the RTN mode is a normally black display when polarization beam splitter (PBS) is used. On the contrary, when a polarizer is laminated to the front surface of the display, the RTN mode changed to normally white which is suitable for direct viewing applications. The response time of the RTN mode is faster than the first minimum TN mode. However, the large dΔn value prevents it from making use of thin cell gap to further increase the response speed.

 ISSN/0001-0966X/01/3201-0874-$1.00+.00

In previous work, the discussion of the RTN mode was limited to nominal on-axis polarizer alignment with polarizer angle α=0°. In fact, there are many other RTN modes possible with non-zero polarizer angles. Some RTN modes with non-zero polarizer angles have smaller dΔn values and smaller twist angles, and these modes have faster response times. Figure 1(a) shows the output spectra of RTN modes with zero and non-zero (α=-10°) polarizer angles in the bright (voltage-off) and dark (voltage-on) states. It can be seen that the color dispersion of these two RTN modes in both bright and dark states is very close. The color dispersion is small so a black and white display can be achieved. Figure 1(b) illustrates the rise and fall times of these two RTN modes with the applied voltage switching between 0v and 2v. It can be seen that the response of the RTN mode with non-zero polarizer angle is much faster than that of the RTN mode with zero polarizer angle. Thus, the non-zero polarizer angle RTN mode should be suitable for projection applications.



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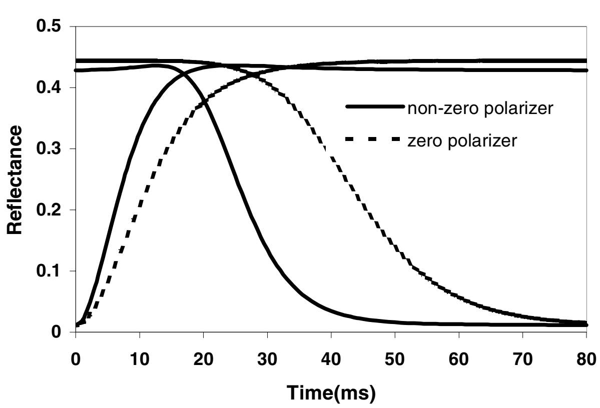
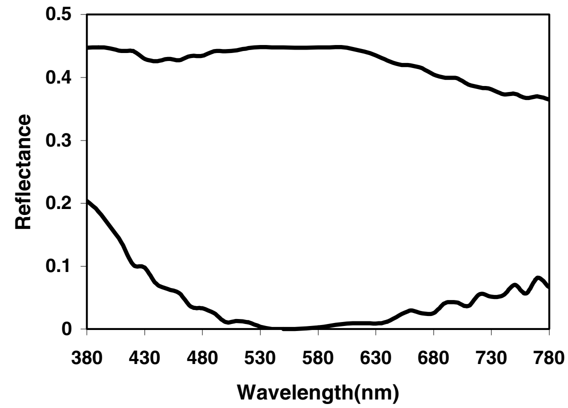


(b)

Figure 1: The simulation results of the first minimum RTN mode with zero and non-zero (α=-10°) polarizer angles. (a) The output spectra in the bright (voltage-off) and dark (voltage-on) states. (b) the response time for white light, the applied voltage is switching between 0v and 2v.



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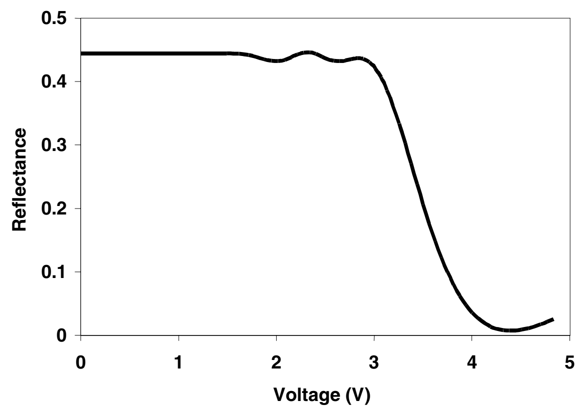

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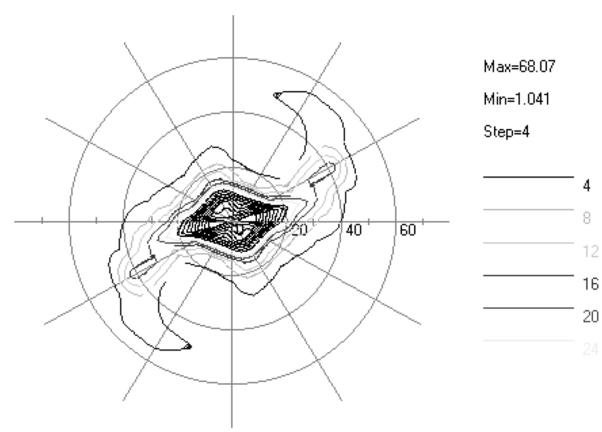
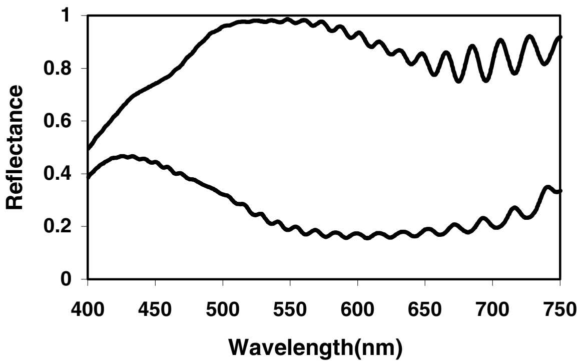


(c) min=1.04, max=68, step =4, the largest contour = 4

Figure 2: The simulation results of electro-optical properties of the second minimum RTN mode. (a) The output spectra in the bright (voltage-off) and dark (voltage-on) states, (b) the reflectance versus voltage curve for white light, (c) the iso-contrast ratio polar plots for white light, the applied voltage of bright and dark states are 0v and 4.3v respectively.



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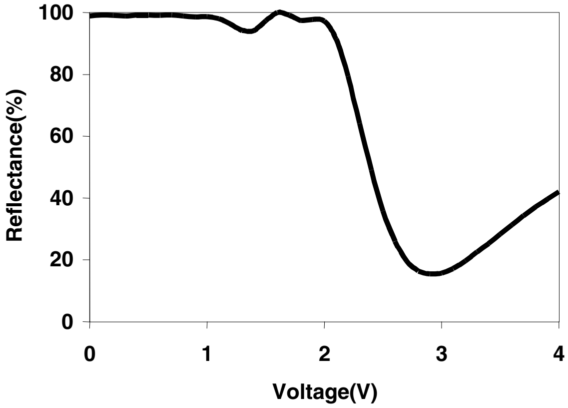

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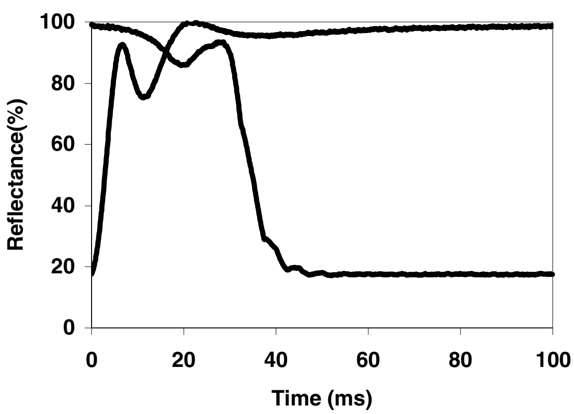


(c)

Figure 3: The experimental electro-optical properties of the second minimum RTN mode. (a) The normalized output spectra in the bright (voltage-off) and dark (voltage-on) states, (b) the normalized reflectance versus voltage curve for white light, (c) the response time for white light, the applied voltage is switching between 0v and 3v.

3. The second minimum RTN mode

The first minimum RTN mode with small $d\Delta n$ value has a small cell gap and fast response time. In some applications, such as for a direct view display, where the response time requirements are not so critical, and a small cell gap would only reduce the yield of the product. In these cases, the larger $d\Delta n$ of the second minimum RTN mode might be preferred.

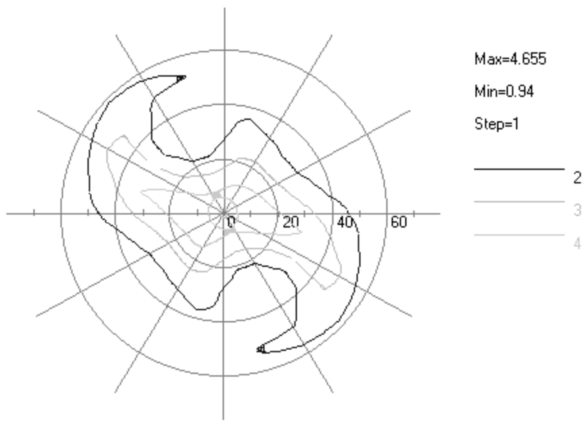
We optimized the parameters of the second minimum RTN mode using commercial LCD simulation software: DIMOS. Figure 2 shows the simulation results of the electro-optical properties. The second minimum RTN mode, just like the first minimum RTN mode, is normally white. Figure 2(a) illustrates the output spectra of the display in both the bright (voltage-off) and dark (voltage-on) states. Comparing with Figure 1(a), it can be seen that the color dispersion of the second minimum RTN mode in both bright and dark states is similar to that of the first minimum RTN mode, so a black and white display can also be achieved with this mode.

Figure 2(b) shows the reflectance versus voltage curve (RVC). The threshold voltage is about 3.3v and much higher than that of the first minimum RTN mode which is normally 1.5v. The reason for the higher threshold voltage can be understood from the larger change in the effective birefringence that has to occur before the reflection reaches the dark state. Starting from the second minimum the cell must first pass through the first minimum before reaching the final state. Because of the twisted structure, the appearance of the dark state between the first minimum and the second minimum is almost completely suppressed and only a slight dip in the RVC is seen at the lower voltage. The steepness of the RVC curve is greater than that of the first minimum RTN making this display mode suitable for a higher level of multiplexing. In the simulation result, the selection ratio $s=V_{90\%}/V_{10\%}=1.27$, corresponding to 16 multiplexed lines.

Compared with the first minimum RTN mode, the main disadvantage of the second minimum RTN mode is that its viewing angle becomes narrower because of the larger $d\Delta n$. Figure 2(c) shows the simulated viewing angle polar plot. It is still better than the second minimum transmissive TN mode.

4. Experimental results

A second minimum RTN mode test cell with 7µm cell gap was prepared for verifying the simulation results. Figure 3 illustrates the electro-optical properties of the test cell. The reflectance versus voltage curve in Figure 3(b) was measured with the DMS 501 Display Measuring System made by Autronic-Melchers of Germany. The contrast ratio of the test cell is about 5:1, similar to the typical value for a reflective TN cell. The low contrast ratio is mainly due to surface reflections since no antireflective layer is employed. In Figure 3(b), the selection ratio $s=V_{90\%}/V_{10\%}=1.22$, corresponding to 24 multiplexed lines. Figure 3(c) shows the response of the display with the voltage switching between 0v and 3v. It should be noticed that the response of this mode is extremely fast considering the 7µm cell gap. Figure 4 shows the experimental results of the polar viewing angle plot. The experimental results and the simulation results were in reasonable agreement.



min=0.93, max=4.67, step=1, contour: 2,3,4

Figure 4: The experimental iso-contrast ratio for white light of the second minimum RTN mode, the applied voltage of bright and dark states are 0v and 3v respectively.

5. Conclusions

In this paper, a new reflective display mode, called the second minimum RTN mode, is proposed. This mode has a larger $d\Delta n$ value compared with the first minimum RTN mode which we proposed previously[1] . A cell gap of 7um or larger can be used for this mode which makes the fabrication processing of this kind of reflective LCDs is easier and more compatible with that of conventional TN LCDs. The color dispersion in both bright and dark states of this display mode is small so a black and white display can be realized. The response of this display mode is reasonably fast considering the 7µm cell gap. The multiplexability is better than that of the first minimum RTN display. This display mode can be used in conjunction with TFT active matrix to produce good quality reflective displays in applications such as cell phones and PDAs. Passive display applications in watches and games are also possible.

6. References

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