Electro-Optical Characteristics and Responce time of In-plane Switching Twisted Nematic Mode

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1.Abstract

The electro-optical characteristics of the In-Plane switching Twisted nematic (IT) mode were studied. The advantage of this mode is not only the wide viewing angle characteristics without adopting any compensation films, but also the wide cell gap error margin. The electro-optical characteristics of IT mode were evaluated by the experiments and computer simulation. In this paper, we studied the viewing angle characteristics, color-shift and response time.

2.Introduction

In many display application, liquid crystal displays (LCDs) are replacing cathode ray tubes (CRT), because of small size, lightweight and low electric power consumption. However, LCDs have some weak points such as narrow viewing angle, slow response time and high product's price. These weak points should be conquered to improve the quality of LCDs.

One of the most useful LCD driving mode is Twisted Nematic (TN) mode, because of easy driving mechanisms, low electric power consumption and so on. However, conventional TN mode has some problems such as reversal gray scales, decrease of the contrast ratio and the color shift, when it was viewed from an oblique direction. In order to solve these problem, various techniques for improving TN mode has been proposed such as optical compensation by the negative birefringence film[1], amorphous TN mode[2] and four domains formation TN mode[3].

On the other hand, a variety of LCD driving modes, for example, in-plane switching (IPS) mode[4], multi-domain vertical alignment (MVA) mode[5] and optically compensated birefringence (OCB) mode[6] have been proposed for the purpose of solving weak points of LCD. Among them, one of the most unique features of the IPS mode is that the liquid crystal (LC) molecules are driven by the in-plane electric field, and the IPS mode has wide viewing angle characteristics. However, even the IPS mode LCD has some weak points such as the color shift and the narrow cell gap error tolerance. The former has already been solved by adopting a multidomain structure formed by unidirectional rubbing and preparing a zigzag electrode[8]. The latter cannot be settled, because of its fundamental mechanism of the IPS mode[9]. Previously we demonstrated the excellent features of the in-plane switching twisted nematic (IT) mode[10], which has potential to overcome the weak points of the conventional LCD. One of the attractive characteristics of the IT mode is its wide viewing angle realized by the in-plane electric field. Furthermore, the influence of the cell gap error on the optical characteristics seems to be small in comparison with the IPS mode LCD. Generally, the narrow cell gap error tolerance is one of the deadlocks of the LCD manufacturing. It is promising to apply the IT mode for the electrical industry. We has reported the basic electro-optical (EO) characteristics of the IT mode[11], especially, the viewing angle characteristics and the cell gap error tolerance was mainly evaluated by the numerical simulation.

In this paper, the response time and the color shift are demonstrated by means of the experiment and numerical simulation. These are most important properties when LCDs are evaluated.

3.Experimet

Figure 1 shows the driving mechanism of IT mode. The initial LC director alignment of IT mode is controlled to be 90° twist alignment which is as same as the conventional TN mode. In order to realize the normally white mode under the cross nicol, the polarizer and analyzer are set parallel to the LC director at each boundary, respectively.

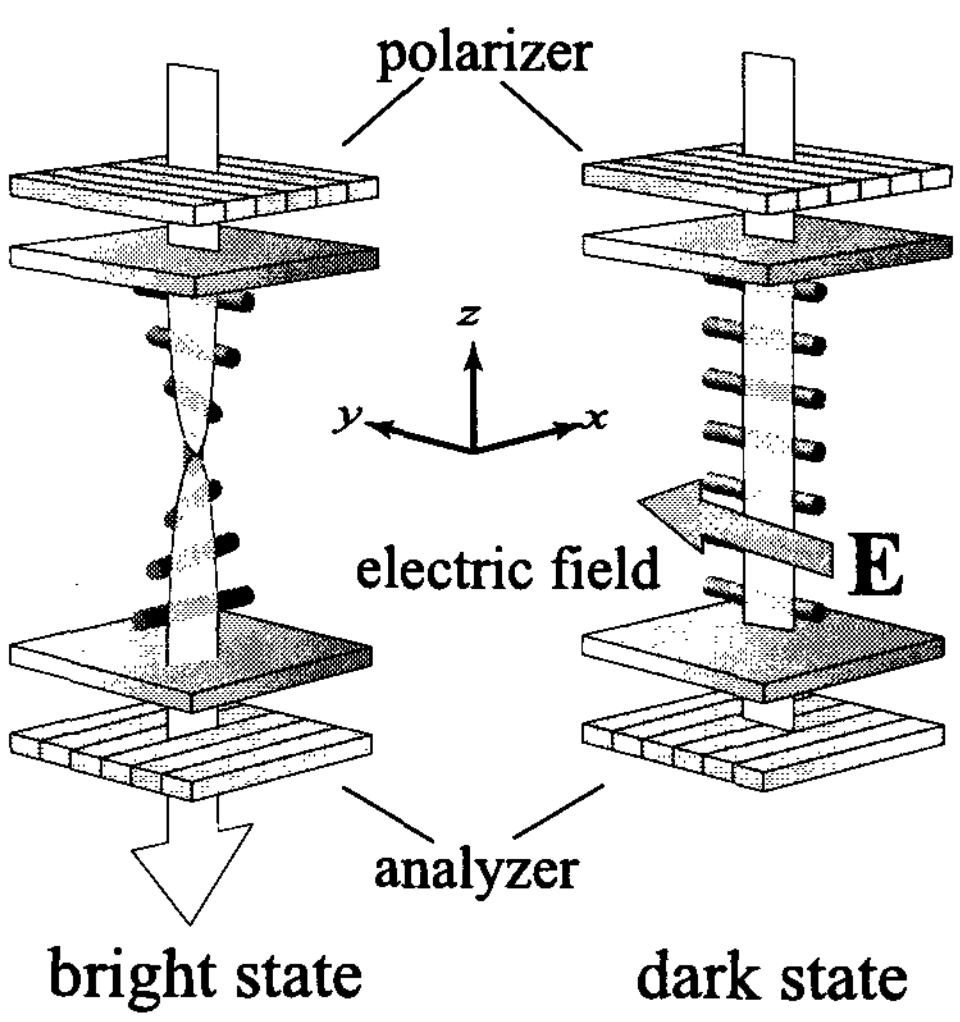


Figure 1: The driving mechanism of the IT mode.

LC material is mixed with a chiral dopant in order to get a uniform alignment and improve the response time. The applied in-plane electric field by interdigital electrodes is used for the drive of LC director. Under certain electric field, LC director alignment becomes quasi-homogeneous alignment, and the dark state can be obtained.

The moving direction of the each LC director motion is restricted to be parallel to the substrate, thus the viewing angle of IT mode would be wider than that of TN mode. Furthermore, the contrast ratio can be obtained by the rotation of the optical polarization along with the director arrangement, thus the deviation of the

Table 1: The wavelength dispersion coefficient of MLC-2051 by Cauchy's equation.

	a	b
0	1.55525	1.45531
1	2.16830×10^{-2}	1.46208×10^{-2}
2	-1.64115×10^{-3}	-8.63845×10^{-4}
3	1.55069×10^{-4}	4.99540×10^{-5}

cell gap from the nominal thickness will not affect the optical transmittance. That is, the color shift factor can be minimized and wide cell gap margin can be realized by IT mode.

IT mode cell was a sandwich structure, which consists of two substrates whose inner surface was coated with PI film as an alignment film. The two substrates were rubbed with perpendicular direction mutually to get the 90° TN alignment. Lower substrate had interdigital electrode in order to obtain in-plane electric field. The LC used was MLC-2051 (Merck) which was mixed with chiral dopant in order to realize a 16[μm] pitch. The IT mode LCD with 4.0μm without the applied electric filed can be indicated most highest transmittance since Mauguin's minimum condition is satisfied at 550nm. The cell gap was controlled by bead spacers. The physical values of MLC-2051 were as follow: dielectric anisotropy: $\Delta\varepsilon$=11.5, viscosity constant: γ=0.086[Pa·s], twist elastic constant: K_{22}=4.6 $\times 10^{-12}$. The wave length dispersion of refractive indices for MLC-2051 are approximated by Cauchy's equation,

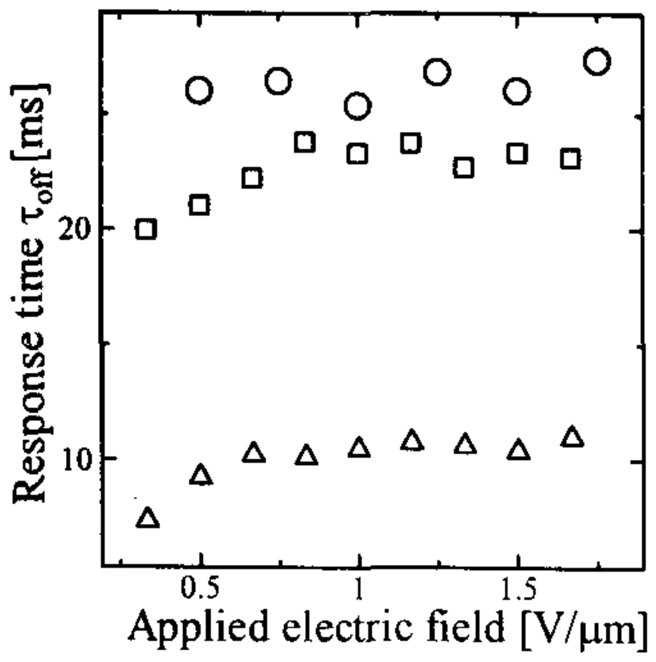
$$n_e = a_0 + \frac{a_1}{\lambda^2} + \frac{a_2}{\lambda^4} + \frac{a_3}{\lambda^6}$$
$$n_o = b_0 + \frac{b_1}{\lambda^2} + \frac{b_2}{\lambda^4} + \frac{b_3}{\lambda^6}, \qquad (1)$$

where coefficients are shown in Table 1.

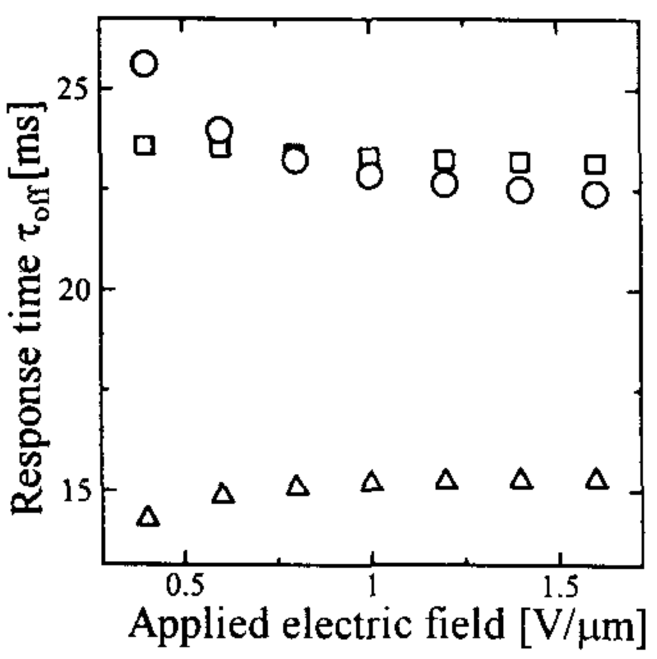
We carried out an experiment of response time and color shift characteristics.

4.Results and Discussion

One of the most important properties for the LCD is the response characteristic of the transmittance. The response time has been one of the weak points of LCD compared with CRT.



(a) Experimental results

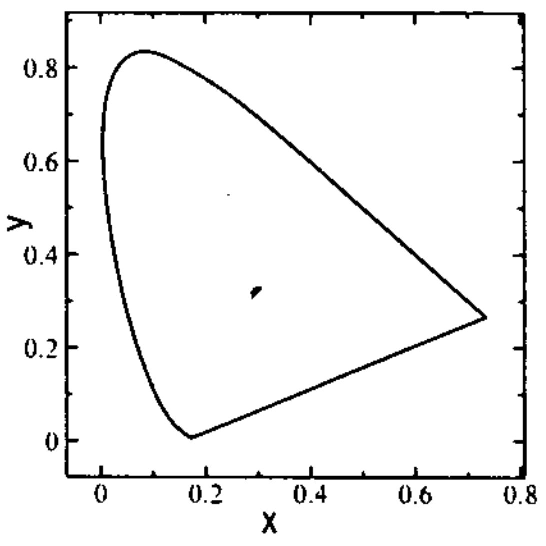


(b) Numerical results

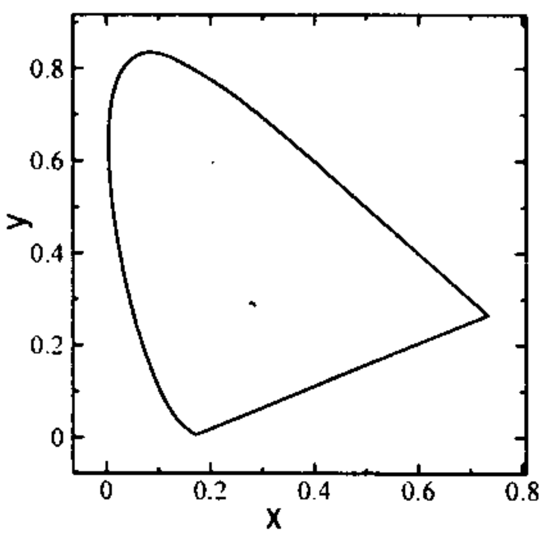
Figure 2: The applied electric field versus relaxation time of transmittance. The cell gap was supposed 3.0μm (triangle), 4.0μm (square) and 5.0μm (circle).

The LCD, which can attain good response, has a potential to indicate the beautiful image and high resolution. The response time τ_{on} and the relaxation time τ_{off} of IT mode LCD was evaluated by the experiment and the simulation. τ_{on} was dominated by the dielectric torque rather than the elastic or surface energy. On the other hand, τ_{off} is less influence by the electric field, because τ_{off} is dominated by the elastic and surface energy. In this report, only τ_{off} is discussed. τ_{off} represents the relaxation time when transmittance was changed from 0% to 90%. The cell gaps of the IT mode cell is 3.0, 4.0 and 5.0μm. Figure 2 shows the experimental and the numerical results of the response time and relaxation time of the IT mode, respectively. The experimental result shows a good agreement with the numerical result qualitatively. In the case of the TN mode or IPS mode, it is well know that the thinner the cell gap, the faster the response is. In the case of the IT mode, however, the dependence of τ_{off} on the cell gap exhibit an anomalous change. It can be interpreted that the elastic relaxation from the quasi-homogeneous alignment to twist alignment is governed by the elastic torque rather than the surface energy. When the cell gap is different from the quarter of p, the bulk elastic energy exceeds the nominal value and realignment to the twist alignment seems to be accelerated. Besides, as is reported in our previous paper, EO response is insensitive to the cell gap compared to the TN mode and IPS mode[11]. From the experimental and numerical studies, it is found that the cell gap as well as the appropriate chiral pitch can be effective to improve the response time of IT mode LCD.

The color coordinate diagram is often used in evaluation of color shift. The transmittance spectrum was measured under the following condition; the incident angle was 50° and the azimuthal angle was varied ($0° \leqq \phi \leqq 180°$). Then the color coordinate diagram was drawn from these results. On the other hand, the theoretical color shift was calculated by using the continuum theory and 4×4 matrix method under the same condition. The cell gap was set to be 4.0[μm]. Figure 3 shows the color coordinate diagram by the experimental and the theoretical results, respectively. The color shift was estimated when a certain electric voltage was applied so that the transmittance was reduced to 50%. Both the experimental results and simulation demonstrated sufficiently small color shift. Comparing these experimental results and simulation, however, it is found that the trace of the color shift was slightly different. Strictly speaking, the electric field was not *uniform* between the electrode in case of the in-plane switching, therefore such slight difference seems to be acceptable.



(a) Experimetnal results



(b) Numerical results

Figure 3: The color coordinate diagram by the experimental and numerical results. The color shift was estimated when a certain electric voltage was applied so that the transmittance was reduced to 50%.

5.Conclusion

The electro-optical characteristics of IT mode were demonstrated by the experimental and numerical investigations. The response speed is good enough to realize the video rate driving. It was confirmed that the numerically predicted characterization such as the small color sift was demonstrated experimentally. From these results, we propose that IT mode has an outstanding potential to realize an excellent LCD.

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