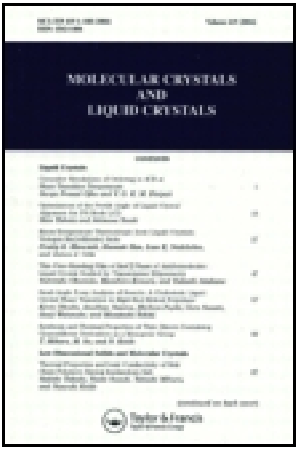

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Electro-Optical Characteristics of Twisted Nematic Liquid Crystal Device Based Upon in-Plane Switching

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ELECTRO-OPTICAL CHARACTERISTICS OF TWISTED NEMATIC LIQUID CRYSTAL DEVICE BASED UPON IN-PLANE SWITCHING

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Previously, we reported unique features of a driving mode, named 'In-plane switching Twisted nematic (IT) mode'. IT mode has excellent features of Twisted Nematic (TN) mode together with a merit of In-Plane Switching homogeneous mode. Remarkable features such as wide viewing angle and small color shift were confirmed by numerical simulation based on a continuum theory and 4×4 matrix method, and further the electro optical (EO) characteristics of IT mode LCD cell were numerically and experimentally shown.

Keywords: IPS mode; IT mode; liquid crystal display; nematic; TN mode

INTRODUCTION

Recently, Liquid Crystal Display (LCD) seems to take the place of Cathode Ray Tube (CRT). The features of LCD are small size, lightweight and low electric power consumption. Most popular LCD driving mode is TN mode [1] whose advantage is simple structure. TN mode LCD can be seen in various places, for example, wristwatch, calculator, cellular phone, etc. However, LCD has some weak points such as narrow viewing angle, slow response time and high product cost. Concerning the visibility, TN LCD has some problems such as reversal gray scales, decrease of the contrast ratio and color shift. In order to solve these problem, various techniques for improving TN mode has been proposed such as optical compensation

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by the negative birefringence film [2,3], amorphous TN mode [4] and four domains formation TN mode [5].

During the first half of the 1970s, the fundamental electro-optical (EO) effects of the homeotropic, the homogeneous and the 90°-twist orientation in nematic LC with the electric field by the interdigital electrode were investigated experimentally [6]. Recently, a driving mode called ‘In-Plane Switching (IPS) mode’, where a homogeneously aligned LC is driven by an in-plane applied electric field [7], has attracted attention, because of its wide viewing angle characteristics [8,9].

Due to the fundamental mechanism of IPS mode, the cell gaps margin of IPS LCD can not be widen enough [10]. Furthermore, the color shift of IT mode can not be negligible. To improve the color shift problem, Kondo *et al.* proposed the multidomain structure obtained by unidirectional rubbing [11]. However this method needs to adopt the zigzag electrode.

Recently, we reported a driving mode named ‘In-plane switching Twisted nematic (IT) mode [12], which has a potential to overcome these weak points of LCD. The main characteristics of IT mode are its wide viewing angle and the wide cell gap margin. Moreover, it is expected that the color shift of IT mode LCD would be small without adopting any compensation.

In this report, the viewing angle and the color shift characteristics of IT mode were evaluated by the computer simulation and experiments. From these results, it will be suggested that IT mode can have the possibility to be a next-generation LCD.

DRIVING MECHANISM OF IT MODE

The driving mechanism of IT mode is illustrated in Figure 1. The initial orientation of LC director is controlled to be 90° twisted alignment. The optical axes of the polarizer and the analyzer are set parallel to the director at the upper and lower substrate surfaces, as same as conventional TN mode (supposed the normally white geometry under the crossnicol). Here, in order to realize the uniform twisted alignment and improve the response time, the chiral dopant is mixed with the host LC. Without an applied field, the incident light can pass through the analyzer. To drive the director, in-plane electric field is applied.

From the viewpoint of LC orientation, in case where the LC director is driven by the in-plane electric field, LC substance with negative dielectric anisotropy (say N_nLC) seems to be preferable rather than LC with positive dielectric anisotropy (N_pLC). The reason is that the director of N_pLC tends to align parallel to the electric field vector, which diverges near the edges of the electrode, and as a result the director near the substrate surface tilts against the surface [13]. However N_nLC has serious disadvantage such as high viscosity and small dielectric anisotropy. Therefore we choose N_pLC

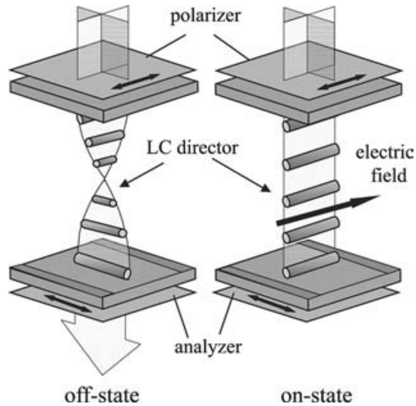


FIGURE 1 Schematic diagram off and on states with IT mode.

in this study. Under a certain electric field, the alignment of the LC directors would be realigned and finally exhibits quasi-homogeneous alignment, and the dark state can be obtained.

As illustrated in Figure 1, the director near the upper substrate dose not rotate, while the director near the lower substrate is rotated by the applied electric field. To make the driving voltage lower, the azimuthal anchoring strength at the lower substrate should be much weaker than that at the upper substrate.

Since the LC director throughout the cell rotates with maintaining the director parallel to the substrate, the viewing angle quality of IT mode would be better than that of conventional TN mode. Further-more, the optical characteristics of IT mode would not be sensitive to the cell gap error compared with IPS mode, because the off-state is as same as TN mode in principle.

SIMULATION AND EXPERIMENT

The simulation based on the continuum theory and the 4×4 matrix method was carried out. Where physical values of LC material were supposed to be as same as those of 5CB (4-cyano-4′-pentylbiphenyl) [dielectirc anisotropy $\Delta\varepsilon = 9.9$; twist elastic constant $K_{22} = 4.09 \times 10^{-12}$[N]]. The wave length dispersion of refractive indices are approximated by Cauchy's equation,

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

where, coefficients are shown in Table 1. The cell gap d is supposed to be 5.39[μm] from the Mauguin minimum condition at the wavelength of the green color (550[nm]), given by,

$$\Delta nd = \lambda\sqrt{m^2 - \frac{\Phi_t}{\pi}}(m = 1, 2, \ldots) \tag{2}$$

where, Δn is the birefringence of LC material, λ is wavelength and Φ_t is the twisted angle of the director.

IT mode cell is sandwich structure which consists of two substrates whose inner surface were coated with Poly Vinyl Alcohol (PVA) as alignment film. The two substrates are rubbed with perpendicular direction mutually due to get the 90° TN alignment. Lower substrate has interdigital electrode in order to obtain in-plane electric field. The electrode interval and width are set to be 30[μm]. The cell gap was controlled about 4.0[μm] by bead spacers. The liquid crystal used is MLC-2051 (Merck Japan) which is mixed with chiral dopant in order to realize a 16[μm] pitch. To investigate the viewing angle characteristics the incident light source used is He-Ne laser ($\lambda = 632.8$[nm]).

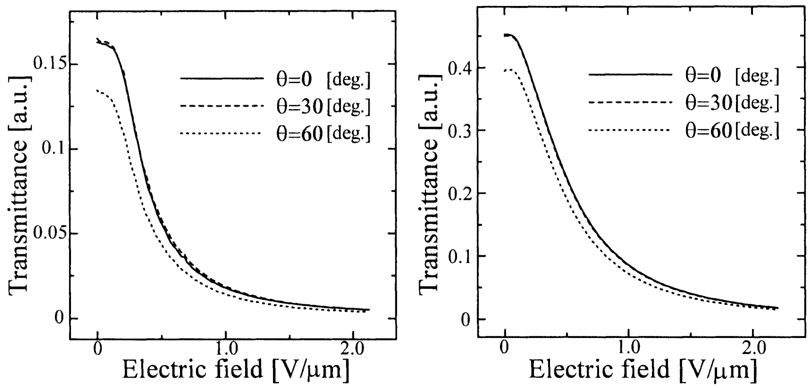
RESULTS AND DISCUSSION

Figure 2(a) shows the experimental results of the EO characteristics of IT mode cell, where θ represents the polar angle with respect to the cell normal and the plane of incident light is parallel to the electrode. To verify the EO characteristics of IT mode, numerical simulations are also shown in Figure 2(b), where the azimuthal anchoring energy both of the upper and lower substrates is supposed to be 1×10^{-4}[J/m^2], the wavelength of the incident light is supposed to be 550[nm] and the cell gap is to be 5.39[μm]. It is clearly recognized that the experimental results and simulations are in good agreement qualitatively. These results indicates that IT mode has excellent viewing angle characteristics.

The color coordinate diagram is often used in evaluation of color shift. Here, the color shift of IT mode LCD was plotted with the color coordinate

TABLE 1 The Wave length Dispersion Coefficient of 5CB by Cauchy's Equation

	a	b
0	1.65260	1.50500
1	2.80087×10^{-2}	1.06259×10^{-2}
2	-3.40029×10^{-3}	-1.12581×10^{-3}
3	5.04190×10^{-4}	1.75449×10^{-4}

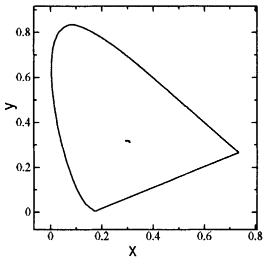


(a) The experimental (b) The simulation

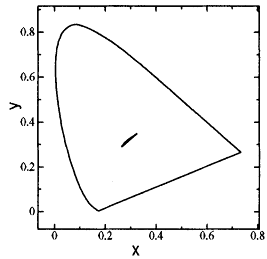
FIGURE 2 The transmittance characteristics of IT mode cell.

by the computer simulation as shown in Figure 3, where the incident light is supposed to be 50° against the cell normal and the trace was plotted for all azimuthal angle ($0 \leq \phi \leq 360$).

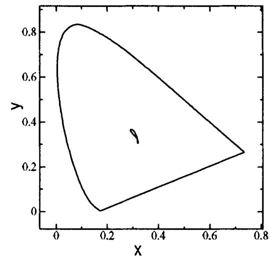
Figure 3(a) shows the color coordinate diagram at the maximum transmittance, where the director alignment is controlled to be 90° at off state. Here the azimuthal anchoring energy of the upper substrate is supposed to be 1×10^{-4}[J/m^2], the azimuthal anchoring energy of the lower substrate is supposed to be 1×10^{-6}[J/m^2], and the cell gap is 5.39[μm], respectively. A tiny color shift can be found since the off state of IT mode is the same with that of TN mode. Figure 3(b), (c) and (d) show the color coordinate at 50% gray level, where the cell gap which satisfied the first, the second and the third Mauguin's minimum condition is changed to 2.16, 5.39, 8.40[μm], discretely. From the comparison with Figure 3(b), (c) and (d), it is recognized that the color shift increases with decreasing the cell gap while the color shift is rather small than that of TN mode. It is interpreted as follows; when the cell gap is not too narrow, the polarization can be appropriately rotated following the director alignment. However, if the cell gap is too narrow, the polarization can hardly follow the director alignment, because the director field under a certain voltage does not satisfy the Mauguin's condition ($\lambda \ll p\Delta n$, where p is the twist pitch) any longer. This problem seems to come from the choice of LC substance, especially from Δn. In our simulation, we supposed 5CB as LC substance while 5CB was not tuned for IT mode. To improve the optical performance of IT mode, suitable physical properties of LC materials such as low viscosity and large Δn are necessary, and will be prepared near future. Figure 3(e) shows the



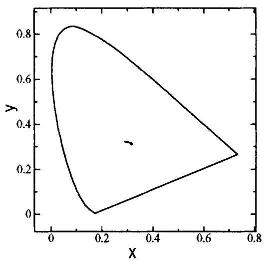
(a) maximum transmittance



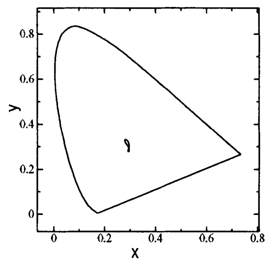
(b) 50% gray level for cell gaps 2.04μm



(c) 50% gray level for cell gaps 5.39μm



(d) 50% gray level for cell gaps 8.40μm



(e) 50% gray level for azimuthal anchoring energy $1{\times}10^{-4}$J/m^2

FIGURE 3 (a): the color shift coordinate of the maximum transmittance at the cell gaps 5.39 µm, azimuthal anchoring energy of the lower substrate 1×10^{-6} J/m^2.(b),(c) and (d): that of 50% gray level, azimuthal anchoring 1×10^{-6} J/m^2, the cell gaps as follow: (b) 2.16 µm, (c) 5.39 µm and (d) 8.40 µm.(e): that of 50% gray level, the cell gap 5.39 µm, the azimuthal anchoring energy 1×10^{-4} J/m^2.

color coordinate at 50% gray level, where azimuthal anchoring energy of lower substrate is changed 1×10^{-4}[J/m^2], the cell gap is 5.39[µm]. Even if the azimuthal anchoring energy was changed, there is no influence in a color shift, when the cell gap is not too small.

CONCLUSION

In this report the fundamental structure and its mechanisms of IT mode were described. From the comparison of simulation and experimental results, it is suggested that IT mode LCD has the wide viewing angle characteristics. The color coordinate calculated indicates that the color shift of IT mode is relatively small compared with TN mode. The anchoring energy does not seem to affect on the color shift, while the Δn and Mauguin's condition govern the EO characteristics.

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