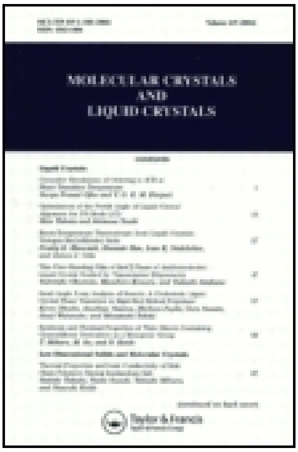

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Insulation Layer Effect on Electro-Optic Properties of Fringe Field Switching Liquid Crystal Display

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Insulation Layer Effect on Electro-Optic Properties of Fringe Field Switching Liquid Crystal Display

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The insulation layer effect on electro-optic properties of fringe field switching (FFS) liquid crystal display (LCD) is simulated in this paper. The simulation results show that the threshold voltage and operating voltage rise when the thickness of insulation layer is increased, while variation of the insulation layer thickness has no affect on transmittance, response time, and optical properties. So decreasing the thickness of insulation layer means easier driving and more power reduction. This rule may be useful for device design and industrial production.

Keywords: Electro-optic property; fringe field switching; insulation layer; liquid crystal display

1. Introduction

Liquid crystal displays (LCDs) are widely used in portable video players and televisions (TVs) at present. However, the image quality of the LCDs is viewing angle dependent, because the effective birefringence is strongly viewing angle dependent [1]. To overcome this viewing-angle problem, many wide viewing angle liquid crystal devices have been proposed, such as in-plane switching (IPS) [2–4], fringe field switching (FFS) [5–8], multidomain vertical alignment (MVA) [9], and patterned vertical alignment (PVA) [10].

FFS mode has been extensively used in large panel LCDs, owing to its high transmittance and wide viewing angle properties. As research continues, optimization of various parameters of FFS LCD has been more and more complete, such as LC parameters and electrode size effect [5], cell gap effect [7], and rubbing direction effect [11], etc. In this paper, we studied the thickness of insulation layer effect on electro-optic properties of fringe field switching liquid crystal display, the conclusion of our simulation may be useful for device design and manufacturing production.

2. Device Configuration and Mechanism

Figure 1 shows the schematic device configuration of FFS LCD (one electrode unit). The electrode structure is divided into two layers, the top stripe electrode works as pixel

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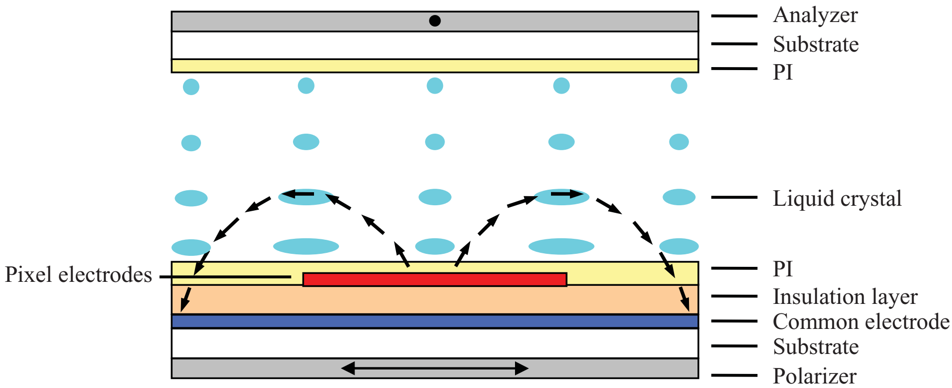


Figure 1. The schematic device configuration of FFS LCD (one electrode unit).

electrode and the bottom plane indium tin oxide electrode works as common electrode. An insulation layer with a thickness of 100–400 nm separates these two electrodes.* Fringe field (black arrow) is generated between pixel electrode and common electrode when a voltage is applied on pixel electrode, causing to an in-plane rotation of LC molecules, leading to a bright state of FFS LCD. When the applied voltage on pixel electrode is removed, LC molecules relax to the homogeneous-aligned dark state.

3. Simulation and Discussion

The electro-optic properties of FFS LCD are simulated using a three-dimensional LC simulator (TechWiz LCD developed by Sanayi). The LC distribution is calculated by the finite-element method [12] and the optical property is calculated based on extended 2×2 Jones matrix method [13,14].

In order to research the thickness of insulation layer effect on FFS LCD, in our simulation, we used pixel electrode width $W = 2\ \mu$m and gap $G = 2\ \mu$m, the cell gap is $d = 4\ \mu$m. Pretilt angle and azimuthal angle (the angle between initial LC direction and pixel electrode) of LC molecules near top and bottom substrates are both set to 1° and 5° when positive LC ($\Delta\varepsilon > 0$) is used. The parameters of the positive LC material (MLC-2043) are $\Delta\varepsilon = 10.2$, $\Delta n = 0.0832$, $K_{11} = 9.8$ pN, $K_{22} = 5.2$ pN, $K_{33} = 16.9$ pN, $\gamma_1 = 91$ mPa·s. Azimuthal angle of polarizer and analyzer are -5° and 85°, respectively. When negative LC ($\Delta\varepsilon < 0$) is used in the same cell, the pretilt angle and azimuthal angle of LC molecules near top and bottom substrates are both set to 1° and 85°. The parameters of the negative LC material (MLC-6608) are $\Delta\varepsilon = -3.1$, $\Delta n = 0.0976$, $K_{11} = 13.1$ pN, $K_{22} = 5.5$ pN, $K_{33} = 12.8$ pN, $\gamma_1 = 108$ mPa·s. Azimuthal angle of polarizer and analyzer are -85° and 5°, respectively.

3.1. LC Distribution and Corresponding Transmittance

The LC distribution (bottom black lines are equipotential lines) and corresponding transmittance (top black lines) at the bright state of FFS LCD using positive (a) and negative (b) liquid crystal are shown in Fig. 2. The positive LC molecules tend to parallel to the direction of fringe field as shown in Fig. 2(a), while the negative LC molecules tend to perpendicular to the direction of fringe field from Fig. 2(b). In both of the two cells, only LC

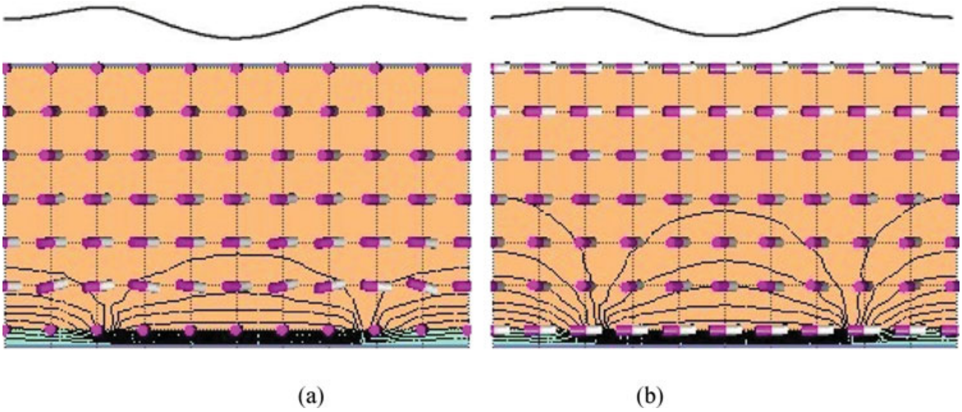


Figure 2. The LC distribution (bottom black lines are equipotential lines) and corresponding transmittance (top black lines) at the bright state of FFS LCD using (a) positive and (b) negative liquid crystal.

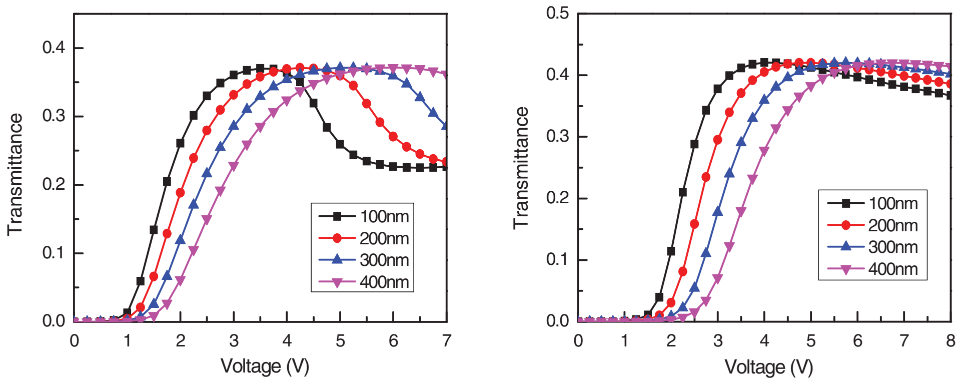
molecules near the bottom substrate have enough in-plane rotation deformation, while LC molecules scarcely in-plane rotate near the top substrate, this depends on the penetration depth of fringe field, which relies on electrode size, insulation layer thickness, and applied voltage. Moreover, through observing the corresponding transmittance, we could find that the transmittance is high at pixel electrode edge but has two valleys at the center of pixel electrode and electrode gap, because the horizontal component of fringe field near pixel electrode edge is strongest, causing enough in-plane rotation deformation of LC molecules, leading to a high transmittance in this region, while the horizontal component of fringe field at the center of pixel electrode and electrode gap is least, LC molecules are only rotated by the elastic torque of neighboring molecules [1], so the transmittance is relatively low.

3.2. Voltage-Dependent Transmittance Curves

Figure 3 gives the voltage-dependent transmittance curves of FFS LCD using (a) positive and (b) negative liquid crystal. For the positive LC, when the thickness of insulation layer changes from 100 nm to 400 nm, the threshold voltages are 1.2 V, 1.4 V, 1.6 V, 1.8 V, and the operating voltages are 3.5 V, 4.25 V, 5 V, 6 V; however, the maximal transmittances (~0.37) are nearly the same. For the negative LC, when the thickness of insulation layer varies from 100 nm to 400 nm, the threshold voltages are 1.6 V, 2 V, 2.4 V, 2.8 V, the operating voltages are 4 V, 5 V, 5.75 V, 6.75 V, and the maximal transmittances (~0.42) are nearly the same too. As the previous section described, the fringe field becomes weaker as the thickness of insulation layer is increased when a constant voltage is applied on pixel electrode. Therefore, when the thickness of the insulation layer is increased, if we want LC molecules have enough in-plane rotation deformation, the threshold voltage and operating voltage must be increased.

3.3. Response Time

Figure 4 shows the time-dependent transmittance curves of FFS LCD using (a) positive and (b) negative liquid crystal. For the positive LC with various thickness of insulation layer, the response times (rise time is 37.5 ms, decay time is 36 ms) are nearly the same



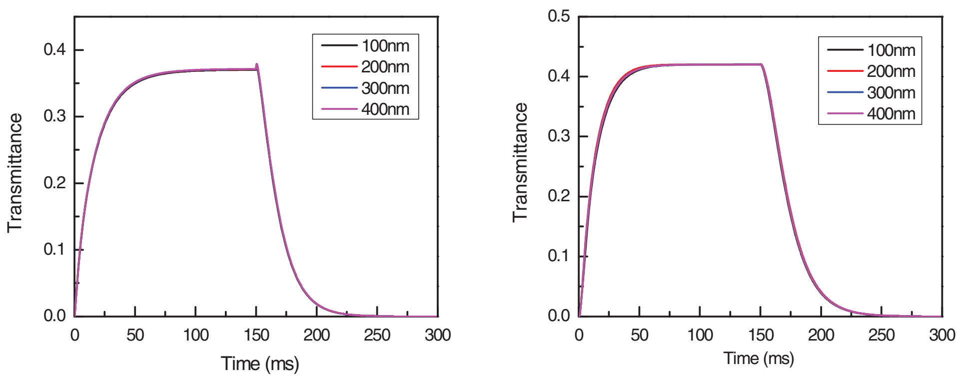
(a) (b)

Figure 3. The voltage-dependent transmittance curves of FFS LCD using (a) positive and (a) negative liquid crystal.

at their own operating voltages; for the negative LC with various thickness of insulation layer, the response times (rise time is 27 ms, decay time is 43 ms) are also nearly the same at their own operating voltages. This means that when the thickness of insulation layer is increased, the threshold voltage and operating voltage are increased too, but the same strength of the fringe field are obtained with different thickness of insulation layer, so the variation of insulation layer thickness has no affect on transmittance and response time. As a result, in the allowed range of charge percolation, the thinner the insulation layer, the lower the threshold voltage and operating voltage, and causing the easier driving and more power reduction.

3.4. Viewing Angle

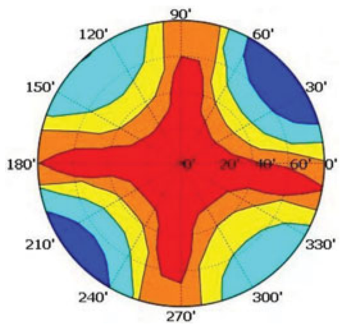
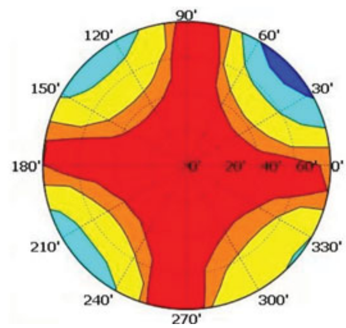
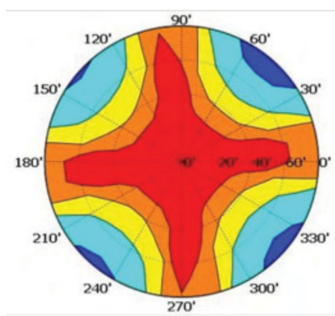
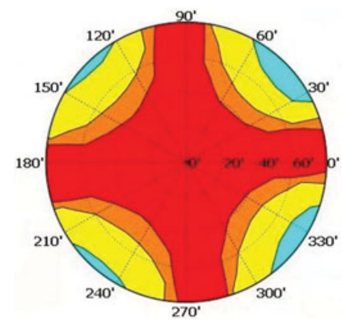
The variation of insulation layer thickness only affects the strength of fringe field, while barely influences the optical property of the device, so it has no impact on the wide



(a) (b)

Figure 4. The time-dependent transmittance curves of FFS LCD using (a) positive and (b) negative liquid crystal.

Table 1. The iso-contrast viewing angles of FFS LCD using positive and negative liquid crystal (without compensation and with compensation)

	Without compensation	With compensation
Positive LC		
Scale	0 10:1 30:1 100:1 500:1	0 50:1 100:1 300:1 800:1
Negative LC		

viewing angle and chromatic properties of FFS LCD as described in introduction. The iso-contrast viewing angles of FFS LCD using positive and negative liquid crystal (without compensation and with compensation) are shown in Table 1. FFS LCD (both positive and negative liquid crystal) has intrinsic wide viewing angle property without any compensation, the contrast ratio (>10:1) exists up to ∼60° of the polar angle in all azimuthal directions of the positive LC FFS LCD, while because the negative LC FFS LCD has a relative high transmittance at bright state, the contrast ratio (>10:1) exists up to ∼70° of the polar angle in all azimuthal directions. With a simple biaxial-optical compensation film, there is a substantial increase of the iso-contrast viewing angle of FFS LCD (both positive and negative liquid crystal), the contrast ratio (>50:1) exists up to ∼70° of the polar angle in all azimuthal directions of the positive LC FFS LCD, while the contrast ratio (>50:1) exists up to ∼80° of the polar angle in all azimuthal directions of the negative LC FFS LCD.

4. Conclusion

In summary, we have studied the insulation layer effect on electro-optic properties of FFS LCD. The simulation results show that the threshold voltage and operating voltage rise as the insulation layer thickness increases, but the variation of insulation layer thickness has no affect on transmittance, response time, and optical properties. It means that a thinner insulation layer leads to an easier driving and more power reduction. The results and discussion of our simulation might be useful for device design and manufacturing production.

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