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Crucial influence of polar alignment on the dynamics of in-plane switching cells

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We investigated theoretically the dynamics of in-plane switching (IPS) cells with small pretilt angle and found that the liquid crystal director variation causes optical bounce after switching on an applied voltage. We analysed the behaviour of the director by computer simulation and found that the optical bounce occurs during the rising period with the normal twist and tilt angles of the directors in the IPS cell in the absence of the field-induced backflow effect. Pretilt angle is the source of this optical bounce.

1. Introduction

Liquid crystal (LC) displays are widely used in modern person–machine interfaces. The in-plane switching (IPS) cell has been widely studied because of its very wide viewing angle [1, 2]; it also has an excellent contrast ratio [2] making it suitable for display applications. Usually, the in-plane switching cell is constructed from a LC layer sandwiched between two specially treated substrates. The alignment layers of the substrates anchor the directors of the LC, making them almost parallel to the substrate but with a small tilt angle (about 1°–3°) [2]. Although the field-induced optical bounce in some modes has been studied by several researchers [3–6], no information is available on the dynamics of the IPS cell.

In the dynamic behaviour of liquid crystal displays (LCDs), the flow of LC could have important influence under certain circumstances. For example, the well known optical bounce phenomenon of the twisted nematic (TN) LCD which occurs after switching off a high applied voltage [3, 4] and the chiral-homeotropic liquid crystal (CHLC) cell, which occurs after switching on a high applied voltage [5], are caused by the backflow effect. The optical bounce phenomenon of the pure homeotropic LC cell with small azimuthal alignment, which occurs after switching on a high applied voltage, is also caused by the backflow effect [6]. All numerical studies mentioned above were made by solving the dynamic LC equations deduced from the Ericksen–Leslie theory. These results can match experimental observation.

2. Method

In this paper, we report an investigation into the dynamics of the IPS cell. We found that, in the IPS cell, the optical bounce phenomenon that was originally found in the pure homeotropic cell [6] occurred without the backflow effect under crossed polarizers. It is usually recognized that the back flow effect has a significant influence on the dynamic behaviour of LCDs in the decay period. It causes an abnormal twist near the boundaries in CHLC cells, and in pure homeotropic cells with a small azimuthal alignment error, after switching on the applied voltage [5, 6]; it may also cause an abnormal mid-plane tilt in TN cells after switching off the applied voltage [3, 4]. Before our numerical result was obtained, optical bounce was seen only as a backflow effect. However, whether or not the backflow effect should be considered, the field-induced optical bounce of IPS cells occur during the rising period. We have calculated the transient transmittance on the IPS cell by computer simulation. This numerical result shows that the normal twist and tilt angles after switching on the applied voltage also result in an optical bounce during the rising period.

To investigate the bounce phenomenon of the IPS cell, we performed computer simulations to solve the hydrodynamic LC equations deduced from Ericksen–Leslie theory. Inertial and velocity terms in the equation were neglected in the simulation because their influence is very small in comparison with viscous terms. After obtaining the transient director distribution, the transmittance was calculated using the Jones matrix method.

3. Results

Figure 1 shows the calculated transient transmittance of the applied voltage ($V_{\text{applied}} = 5.0$ V); the parameters we used in the simulation are given in the table. The

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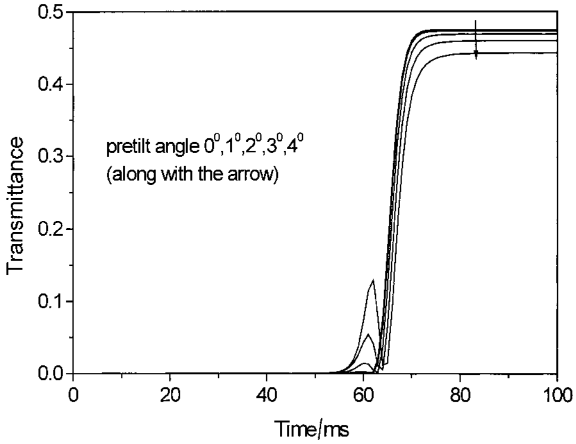

Figure 1. Calculated transient transmittance of the IPS-LC cell. The applied voltage is 5.0 V and switched on at $t = 0$. The traces correspond to pretilt angles of 0°, 1°, 2°, 3° and 4°.

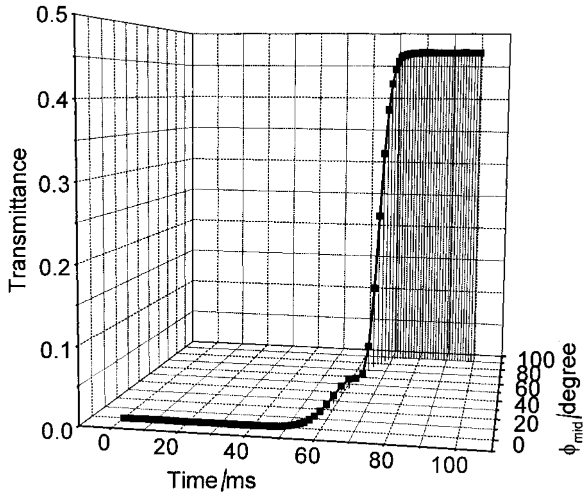

Figure 3. Calculated transient twist angle in the mid-layer, with transmittance. The applied voltage is switched on at $t = 0$ ($V = 5.0$ V). Optical bounce occurs with increasing twist angle.

Table. Material parameters of LC (5CB) used in computer calculation.

K_{11}	5.85 pN	K_{22}	3.50 pN
K_{33}	7.80 pN	n_o	1.539
n_e	1.728	γ	0.074
$\varepsilon_{\parallel}$	18.2	$\varepsilon_{\perp}$	6.9
Cell gap:	7.0 μm	λ	0.55 μm
Electrode distance	10.0 μm		

cell was put under a crossed-polarizers condition and the tilt angle between the director and the substrate was as shown in figure 1. The traces of the transient transmittance correspond to pretilt angles of 0°, 1°, 2°, 3° and 4°. Although it seems that optical bounce has little effect on the rising speed, the pretilt angle still influences the profile of the transmittance curve. From figure 1 it can be seen that the transmittance decreases and optical bounce becomes evident when the pretilt angle increases. Optical bounce cannot be ignored when the pretilt angle is larger than 1°.

Figures 2 and 3 show, respectively, the transient tilt and twist angle in the mid-layer with a pretilt angle of 2°. When the applied voltage ($V_{applied} = 5.0$ V) is switched on, the applied electric field drives most of the directors along with the field direction and parallel to the substrates in a period. The tilt and twist angles reached

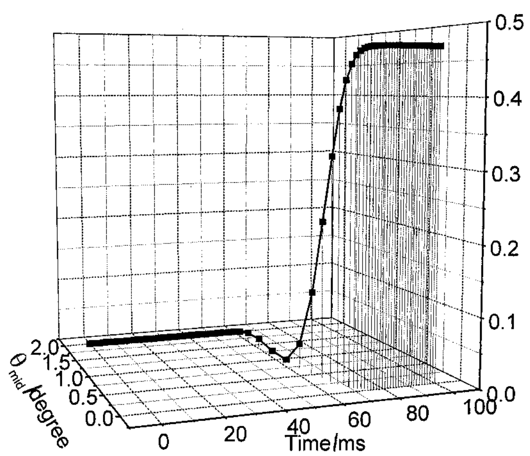

Figure 2. Calculated transient tilt angle in the mid-layer, with transmittance. The applied voltage is switched on at $t = 0$ ($V = 5.0$ V). Optical bounce occurs with decreasing tilt angle.

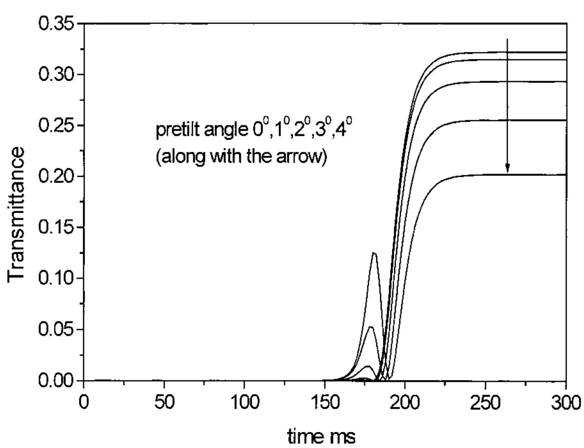

Figure 4. Calculated transient transmittance of the IPS-LC cell. The applied voltage is 3.0 V, switched on at $t = 0$. The traces correspond to pretilt angles of 0°, 1°, 2°, 3° and 4°.

stable values at the same time (about 70 ms, not shown). In both figures, the transient transmittance is given along with the transient tilt and twist angles in the mid-layer. From these figures, it can be seen that when the optical bounce occurs, neither the tilt nor twist angles has reached a saturated value; that is, the optical bounce occurs as a result of the co-instantaneous effect of the tilt and twist angles.

In a lower applied voltage situation, the effect of polar alignment is more important than in the higher applied voltage case. Figure 4 shows the calculated transient transmittance with a lower applied voltage, $V_{\text{applied}} = 3.0$ V. The optical bounce is relatively more important than in the situation of the higher applied voltage, showing that the pretilt angle is the source of optical bounce in IPS cells.

4. Summary

We report the effect of polar alignment (pretilt angle) on the dynamics of in-plane switching cells. We believe this is important to the manufacture of IPS-LC devices and suggest it should be given further attention.

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