Numerical analysis on the dynamical behavior of the TN and OCB modes including flow

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Abstract: *We have performed a numerical calculation for the director flows in TN and OCB cells using Ericksen-Leslie hydrodynamic equation. As a numerical technique, we used a finite difference method (FDM) suitable for highly nonlinear equations. From the results, we can hardly observe the influence of the flow effect on the director motion during switch-on state. In a TN cell during switch-off state, however, the flow causes an abnormal twist resulting in an optical bounce. On the other hand, in a OCB cell during switch-off state, the director flow is generated in one side to accelerate the director motion, thereby leading to fast response time.*

Keywords: flow effect; Ericksen-Leslie; FDM; TN cell; OCB cell.

1. Introduction

Recently, as applications of nematic liquid crystal display have expended to many information display system, the demand for high image quality has abruptly increased. The image quality of the liquid crystal display is largely affected by a switching dynamics. Problems related to the switching dynamics of nematic liquid crystals have been studied mainly in terms of the Ericksen-Leslie hydro dynamic continuum theory of the liquid crystals[1-4].

In this paper, we demonstrate that the solution of the Ericksen-Leslie equation including the fluid flow provides a good description of the back flow effect of a twisted nematic (TN) cell, which causes the abnormal behavior of the director motion resulting in the optical bounce. Further, we calculate numerically the dynamic response of an optically compensated birefringence (OCB) cell[5,6]. We also show that the fast response of an OCB cell can be explained quantitively from the numerical solution of the Ericksen-Leslie equation.

2. Numerical calculation

For liquid crystals, the director $n(x,y,z)$ of a unit vector as a function of position can be described as a mean value of the directions of the molecular long axes. To analyze the dynamic behaviors of nematic liquid crystals, we use the Erickson-Leslie theory, neglecting the inertial momentum of the molecules [7]. Since the electric field is applied along the z-axis in a liquid crystal cell, the flow of nematic liquid crystals along the z-axis is considered to be relatively very small, thus, we assume that the flow is generated in the (x,y) plane, not having v_z component. Finally, we assume that the surface effect can be neglected under the condition of strong anchoring and the fluid components v_x and v_y equal zero at the substrate boundaries, $z=0$ and $z=d$. From these assumptions and boundary conditions, the Ericksen-Leslie equation for the flow reduce to follows :

$$\alpha_2 \frac{\partial n_x}{\partial t} n_z + \alpha_3 \frac{\partial n_z}{\partial t} n_x + \{\frac{1}{2}(\alpha_3 + \alpha_6) + \alpha_1 n_z^2\} n_x n_y \frac{\partial v_y}{\partial z} + \frac{1}{2}\{2\alpha_1 n_x^2 n_z^2 (\alpha_5 - \alpha_2) n_z^2 + \alpha_4 + (\alpha_3 + \alpha_6) n_x^2\} \frac{\partial v_x}{\partial z} = c_1 \tag{1}$$

$$\alpha_2 \frac{\partial n_y}{\partial t} n_z + \alpha_3 \frac{\partial n_z}{\partial t} n_y + \{\frac{1}{2}(\alpha_3 + \alpha_6) + \alpha_1 n_z^2\} n_x n_y \frac{\partial v_x}{\partial z} + \frac{1}{2}\{2\alpha_1 n_y^2 n_z^2 (\alpha_5 - \alpha_2) n_z^2 + \alpha_4 + (\alpha_3 + \alpha_6) n_y^2\} \frac{\partial v_y}{\partial z} = c_1 \tag{2}$$

The α 's are Leslie viscosity coefficients. c_1 and c_2 are constants of integration. The equations for the director component is also expressed as follows:

$$\gamma \frac{\partial n_x}{\partial t} = -[f_g]_{n_x} + \lambda n_x - \alpha_2 n_z \frac{\partial v_x}{\partial z} \tag{3}$$

$$\gamma \frac{\partial n_y}{\partial t} = -[f_g]_{n_y} + \lambda n_y - \alpha_2 n_z \frac{\partial v_y}{\partial z} \tag{4}$$

$$\gamma \frac{\partial n_z}{\partial t} = -[f_g]_{n_z} + \lambda n_z - \alpha_3 n_x \frac{\partial v_x}{\partial z} - \alpha_3 n_y \frac{\partial v_y}{\partial z} \tag{5}$$

γ is the rotational viscosity, n_i is the Cartesian component of the molecular director $n(x,y,z)$, λ is a Lagrange multiplier introduced to maintain the director as unit vector $|n|=1$. $[f_g]_{n_i}$ is Euler-Lagrangian equation for the Gibbs free energy density. $[f_g]_{n_i}$ can be expressed as follows[8]:

$$\begin{aligned} -[f_g]_{n_i} &= \frac{1}{3}(-K_{11} + 3K_{22} + K_{33})(n_j Q_{ji,ll}) + (K_{11} - K_{22}) n_j (Q_{il,lj} + Q_{jl,li}) \\ &+ \left(\frac{K_{33} - K_{11}}{2}\right) n_j (2Q_{lm,m} Q_{ji,l} + 2Q_{jm} Q_{jl,lm} - Q_{lm,i} Q_{lm,j}) \\ &+ 2q_0 K_{22} n_j (e_{iml} Q_{lj,m} + e_{jml} Q_{li,m}) + \varepsilon_0 (\varepsilon_{\parallel} - \varepsilon_{\perp}) n_j \phi_{,j} \phi_{,i} \end{aligned} \tag{6}$$

K_{11}, K_{22} and K_{33} represent the splay, the twist, and the bend elastic constants of the liquid crystals, respectively, and q_0 stands for the chirality of the liquid crystals. The order tensor, Q_{ij}'s, is expressed as $Q_{ij} = n_i n_j - \delta_{ij}/3$ for the director n. Dielectric tensor of the liquid crystals is expressed as $\varepsilon_{lm} = \varepsilon_{\perp}\delta_{lm} + (\varepsilon_{\parallel} - \varepsilon_{\perp})n_l n_m$, where $\varepsilon_{\parallel}$ and $\varepsilon_{\perp}$ are the parallel and the perpendicular dielectric constants of the liquid crystal, respectively. The electric potential distribution $\phi(x, y, z)$ can be obtained by computing the following Laplace equation derived from Maxwell's equation :

$$\left(\varepsilon_{ij}\phi_{,j}\right)_{,i} = 0 \tag{7}$$

3. Results and Discussion

The calculated results show that the fluid velocity in switching-on state is about a few $\mu m/\sec$ and hardly affect the director motion. Fig 1. shows the distribution of the flow velocity within a cell. Just after the applied field is removed, the fluid velocity increases upto several tens of $\mu m/\sec$ and vanishes with the lapse of time. The fluid velocity in the off state affect considerably the director distribution. Fig 2 represents the schematic diagram describing the director motion within a cell $1m\sec$ after switch-off. These results coinside with the explanation given by the other researchers.

In a OCB cell, the director moves in the xy -plane. Thus, the component n_y is assumed always to be zero within a cell; consequently, the component v_x have only to be taken into consideration as a flow velocity. The calculated results reveal that there is no noticeable difference between modelings with fluid flow and without fluid flow like a TN cell. Switching off the cell leads to momentary increase in flow velocity. However, the velocity distribution is quite different from that of a TN cell. Fig 3 shows the director distribution with the lapse of time in a switch-off state. Fig 4 shows the flow velocity distribution $3m\sec$ after switching off the cell. From the figure, it is revealed that the fluid flow occurs in one side of $-x$ axis and reaches a maximum value at z/d of around 0.25 and 0.75. Fig 5 shows a schematic diagram describing the director flow in the upper, middle and lower sides of the cell $3m\sec$ after switching off. It is revealed that the director flow in a OCB cell after switching off occurs in the direction accelerating the director motion, thereby leading to fast response time

4. Conclusion

In this paper, we have performed a numerical simulation for the flow effect of a liquid crystal using Ericksen-Leslie hydrodynamic equation. As a result, we confirmed that both for TN and OCB cells, in switch-on state, there is no noticeable difference between modelings with fluid flow and without fluid flow. Thus, the flow effect is negligible. However the flow velocity increases momentarily just after switching off the cell. In a TN cell, these flows cause an abnormal twist resulting in an optical bounce. In a OCB cell, the director flow is generated in one side to accelerate the director motion, thereby leading to fast response time.

5. Acknowledgements

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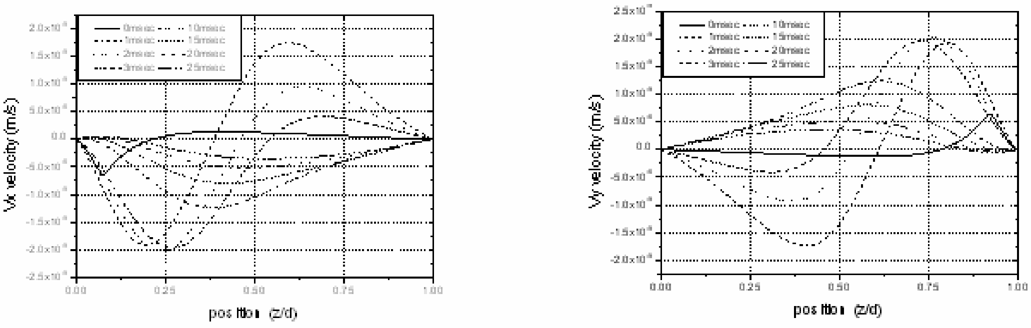

(a) Component Vx of the director flow

(b) Component Vv of the director flow

Figure 1. The distribution profile of the flow velocity with the lapse of time after switching off a TN cell

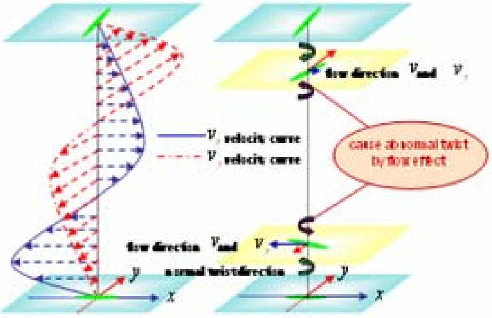

Figure 2. (a) The distributions of V_x and V_y and (b) schematic diagram representing the torque on the director in a TN cell 3msec after switching off a TN cell.

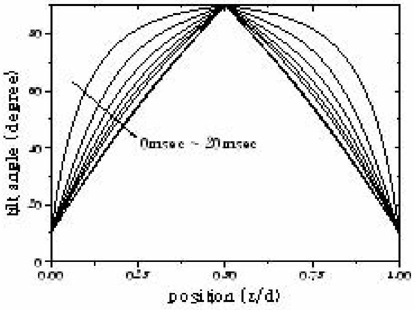

Figure 3. Tilt angle distribution with the lapse of time after switching off an OCB cell.

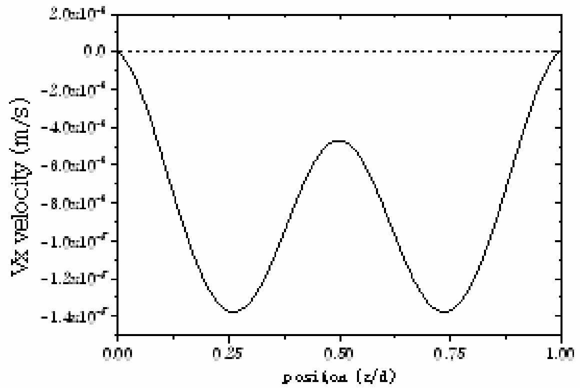

Figure 4. The distribution profile of V_x 3msec after switching off an OCB cell.

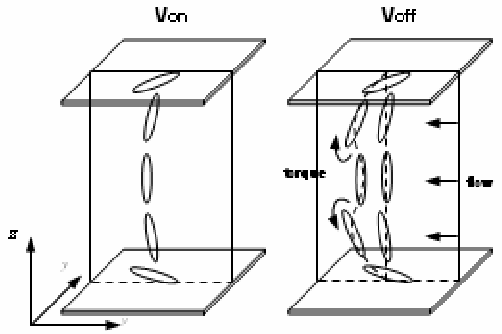

Figure 5. Schematic diagram describing the director flow in an OCB cell (a) during switch-on state (b) just after switch-off state