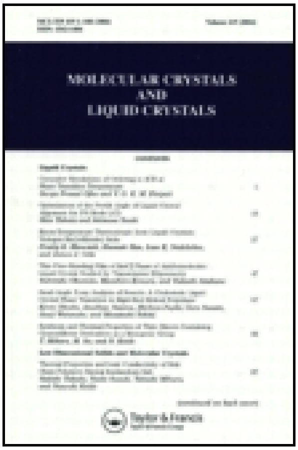

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Mechanism of Fast Response and Recover in Bend Alignment Cell

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Mechanism of Fast Response and Recover in Bend Alignment Cell

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We have proposed a field sequential liquid crystal display using OCB-cell with extremely fast response and have fabricated an excellent full color display without color filter as a trial. In the field sequential LCD the response (and recover) time of the bend cell is less than several milliseconds, which is extremely faster than the TN-cell or the homogeneous cell.

In this paper, the mechanism of the excellent response of the bend cell is analyzed based on the motion equations using Ericksen-Leslie's anisotropic viscosity coefficients. From the results it is clarified that the back flow slows down the response speed in almost all nematic LC cells, while the same flow effect extremely accelerates the response of the bend cell.

Keywords: OCB-cell; Fast Response; Field Sequential Liquid Crystal Display; Flow Effect

INTRODUCTION

We have proposed a field sequential liquid crystal display using OCB-cell (Optically-compensated-bend-cell) with fast response (and recover) and wide viewing angle, and have demonstrated an excellent field sequential full color display without color filter[1-4]. This OCB-cell is composed of bend alignment cell, whose retardation is three-dimensionally compensated by a biaxial retardation film. The response time of this bend cell is extremely faster than the conventional TN-cell. But the detailed mechanism has not yet been analyzed quantitatively.

It is well known that there is the bounce in the optical transmittance of the TN-cell after switching off the applied field as shown by van Doorn[5] and Berreman[6]. This phenomenon was explained by fluid motion of molecules or back-flow based on numerical solution of the Ericksen-Leslie equations[7].

In this paper, we have simulated the dynamics of the bend cell and the homogeneous cell, and analyzed mechanism of fast response of the bend cell in view of fluid motion.

MOTION EQUATION

According to the Ericksen-Leslie equations[7], the motion equations for nematic liquid crystals are expressed as[5]

$$\rho\dot{\upsilon}_x = \frac{\partial}{\partial z}\Big(\alpha_2\dot{n}_x n_z + \alpha_3\dot{n}_z n_x + \tfrac{1}{2}\alpha_3 n_x n_y \frac{\partial \upsilon_y}{\partial z} + \tfrac{1}{2}\left(2\alpha_1 n_x^2 n_z^2 - \alpha_2 n_z^2 + \alpha_3 n_x^2 + \alpha_4 + \alpha_5 n_z^2 + \alpha_6 n_x^2\right)\frac{\partial \upsilon_x}{\partial z}\Big), \tag{1}$$

$$\rho\dot{\upsilon}_y = \frac{\partial}{\partial z}\Big(\alpha_2\dot{n}_y n_z + \alpha_3\dot{n}_z n_y + \tfrac{1}{2}\alpha_3 n_x n_y \frac{\partial \upsilon_x}{\partial z} + \tfrac{1}{2}\left(2\alpha_1 n_y^2 n_z^2 - \alpha_2 n_z^2 + \alpha_3 n_y^2 + \alpha_4 + \alpha_5 n_z^2 + \alpha_6 n_y^2\right)\frac{\partial \upsilon_y}{\partial z}\Big), \tag{2}$$

$$\rho_1\ddot{n}_x = \gamma n_x - \frac{\partial F}{\partial n_x} + \frac{\partial}{\partial z}\frac{\partial F}{\partial n_{x,z}} - \gamma_1\dot{n}_x - \alpha_2 n_z \frac{\partial \upsilon_x}{\partial z}, \tag{3}$$

$$\rho_1\ddot{n}_y = \gamma n_y - \frac{\partial F}{\partial n_y} + \frac{\partial}{\partial z}\frac{\partial F}{\partial n_{y,z}} - \gamma_1\dot{n}_y - \alpha_2 n_z \frac{\partial \upsilon_y}{\partial z}, \tag{4}$$

$$\rho_1\ddot{n}_z = \gamma n_z - \frac{\partial F}{\partial n_z} + \frac{\partial}{\partial z}\frac{\partial F}{\partial n_{z,z}} + \varepsilon_0\Delta\varepsilon E^2 n_z - \gamma_1\dot{n}_z - \alpha_3 n_x \frac{\partial \upsilon_x}{\partial z} - \alpha_3 n_y \frac{\partial \upsilon_y}{\partial z}, \tag{5}$$

where i denotes x, y, or z component, n_i is ith director component, υ_i is ith component of fluid velocity, ρ is fluid density, ρ_1 is moment of inertia per unit vector denoting average molecular orientation, γ is director tension, γ_1 ($\equiv \alpha_3$-α_2) is the rotational viscosity, α_i (i=1 ~ 6) is Leslie viscosity coefficient.

Equation (1)-(5) can be transformed into another set of equations, involving the tilt angle θ and the twist angle ϕ by the substitution of

$$n_x = \cos\theta\cos\phi,$$
$$n_y = \cos\theta\sin\phi,$$
$$n_z = \sin\theta.$$

We calculated the dynamic behavior of the liquid crystal molecular alignment in both time and space.

Transmittance T of the bend cell and the homogeneous cell, using birefringence effect, is expressed as

$$T = \sin^2\left(\pi\frac{\delta(t)}{\lambda}\right),$$

where $\delta(t)$ is the total retardation of liquid crystal layer and biaxial film, and λ is wavelength.

MECHANISM OF FAST RESPONSE

In order to compare the simulation results with the experimental results, optical transmittance of the homogeneous cell and the bend cell was measured. Each cell is composed of two ITO-coated glasses rubbed by cloths with a gap spacing of 7μm and nematic liquid crystal TD-6004XX (Chisso Corp.) whose material constants are shown in Table 1. Pretilt angle at the surfaces is 3.5 degrees in the each cell. The Leslie viscosity coefficients were determined by curve fitting between the simulation and the

TABLE 1 Material constants of TD-6004XX

Quantity	Value
k_{11}	14 (pN)
k_{33}	14 (pN)
$\varepsilon_\parallel$	13.06
$\varepsilon_\perp$	4.12
$n_\parallel(\lambda$=550nm)	1.668
$n_\perp(\lambda$=550nm)	1.505

experiment as mentioned later. The biaxial film for the bend cell is designed to obtain the black state of the bend cell at 6 V, voltage of which is the maximum voltage in the usual driver IC.

In the experiment, the test cells were placed between crossed polarizers with 45 degrees between its polarized direction and the rubbed direction of the bend cell. A 1kHz square wave voltage was applied to these cells. To measure transmittance as a function of time, the photomutiplier was connected to a digital storage oscilloscope.

The solid curves in Figure 1 (a) and (b) show transient behavior of the transmittance of the homogeneous alignment cell when the applied voltage was switched from 10V to 3.4V and that of the bend cell from 6V to 1.8V, respectively. The broken line in Figure 1 (a) shows the theoretical curve in which the Leslie viscosity coefficients are determined by curve fitting with the experimental result (the solid curve). The determined values are shown

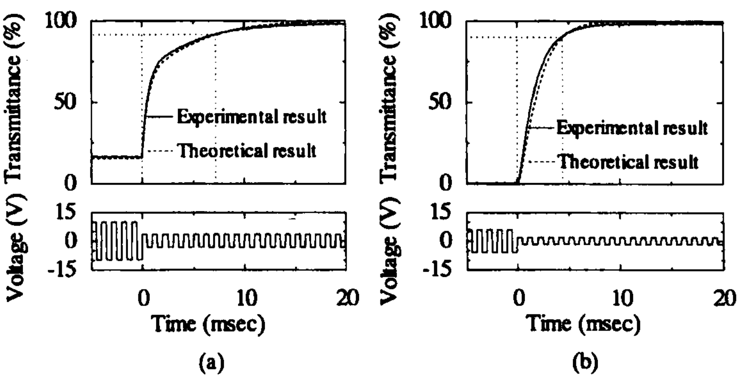


FIGURE 1 Transient behavior of the light transmittance for (a) the homogeneous cell and (b) the bend cell (cell gap is 7μm, and incident light wavelength is 550nm). The cell is sandwiched between crossed polarizers. Applied voltage is switched from 10V to 3.4V for the homogeneous cell, and (b) from 6V to 1.8V for the bend cell at t=0.

in Table 2. By using these coefficients the theoretical curve were calculated also in the case of the bend cell. The results are shown in Figure 1(b) by the broken line. It is seen from this figure that the calculated result fits very well with the experimental one (solid curve), which indicates the validity of this calculation.

TABLE 2 Leslie viscosity coefficients we used in the calculations

Quantity	Value (mPa·s.)
α_1	5
α_2	- 100
α_3	- 1
α_4	80
α_5	66
α_6	- 35

Figure 2(a) shows that the tilt angle of liquid crystal molecules at the center of the cell increases over 90 degrees, which is larger than the initial state (t=0), and then relaxes gradually. This phenomenon is well known as

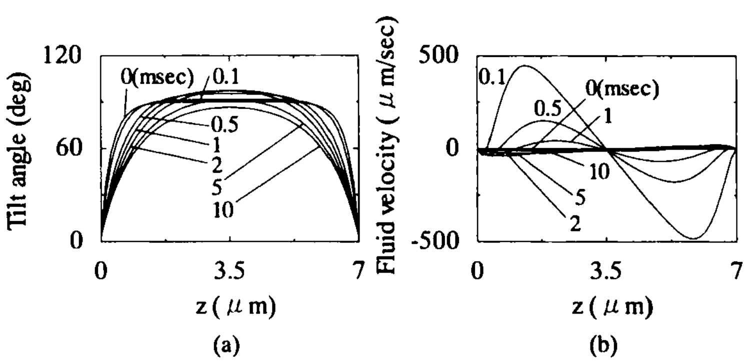


FIGURE 2 Calculated results of (a) tilt angle and (b) fluid velocity in the homogeneous cell.

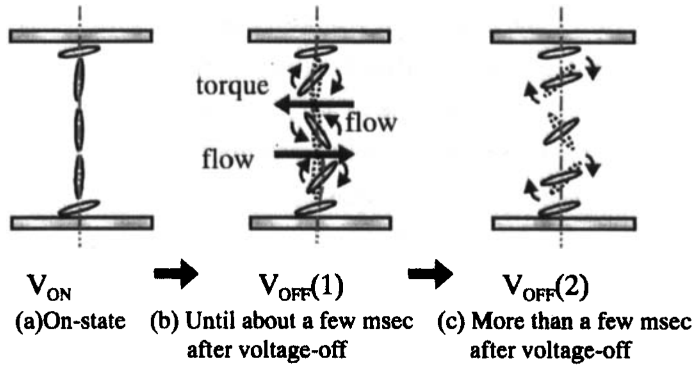


FIGURE 3 Schematic figure of the dynamics in the homogeneous cell. The flow disturbs the relaxation near the center of the cell.

a bounce in relaxation process of the TN-cell and is called "back-flow effect" because it is caused by the opposite flow at the both side of the cell as shown in Figure 2(b). So this flow induces the opposite direction of the torque to the elastic torque at the central region of the cell as shown in Figure 3(b) and it disturbs relaxation of the molecular orientation.

In the bend cell the pretilt direction is the opposite on both surfaces, so

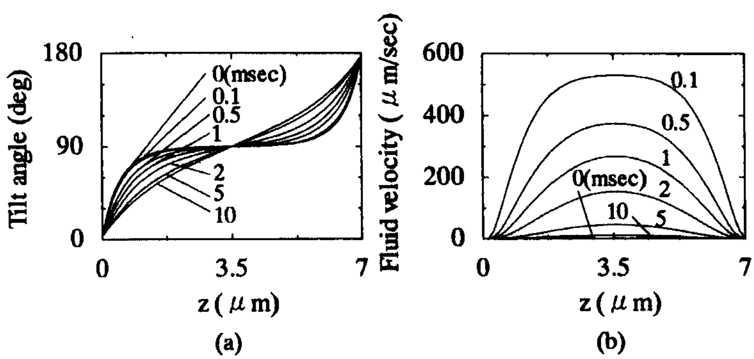
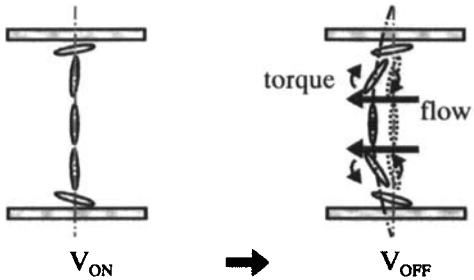


FIGURE 4 Calculated results of (a) tilt angle and (b) fluid velocity in the bend cell.



(a) On-state (b) Off-state

FIGURE 5 Schematic figure of the dynamics in the bend cell. The flow induces the torque to accelerate the relaxation of the molecular orientation.

the same phenomenon does not occur (Figure 4(a)). Figure 4(b) shows the distribution of fluid velocity in the bend cell. The flow directions at the both sides of the cell are the same. The direction of torque induced by the flow is the same as that of elastic torque as shown in Figure 5(b), which accelerates relaxation of the molecular orientation. For this reason, the extremely fast response (and recover) in the bend cell is obtained.

CONCLUSION

We have analyzed the dynamics of molecule movement in the homogeneous cell and the bend cell. From the results we have confirmed that in the homogeneous cell the flow effect slows down the response and recover as is well known in the TN-cell by the name of back-flow effect. On the contrary, we have clarified that this flow effect extremely accelerates the response and recovery speed in the case of the bend cell.

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