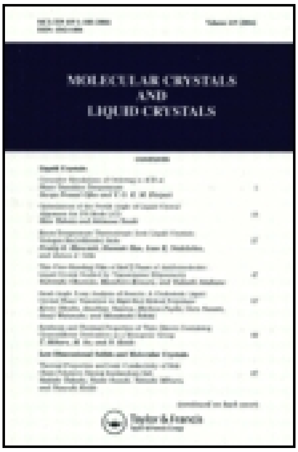

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On the Flow Effect of Super Twisted Nematic Cells

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ON THE FLOW EFFECT OF SUPER TWISTED NEMATIC CELLS

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Abstract The flow effect in TN (Twisted Nematic)-cells has been well known as 'backflow effect'. In addition we found that the flow effect can be also observed in STN (Super Twisted Nematic)-cells as a bounce on the electrooptical property. A simple phenomenological explanation is given in order to understand the essential mechanism of the flow effect.

INTRODUCTION

Dynamic behavior of nematic Liquid Crystal (LC) cells is one of the important and decisive keys for the application of LCDs. Indeed, the slow response of nematic cells to the switching field has been a bottleneck of LCDs. Much effort has been made from the materials supplier's sides [1,2,3] in order to improve the physical properties of the LC mixtures. Also, the LC users have attempted optimizing the display parameters under the given material condition [4]. A new driving scheme has been recently presented [5,6] to take full advantage of the improved response behavior of LC nematic mixtures in STN displays.

We have investigated the dynamic behaviors of LC cells in our previous paper [7] assuming the flow effect to be negligible and derived an analytical expression for the switching dynamics. The analytical results are in a good agreement with those of experiments under the so-called passive static drive condition in which the LC cells are driven by square waves.

However, it is well known that the switching-off dynamics of TN-cells is strongly influenced by the flow effect (so-called backflow effect) [8,9]. Thus, one cannot assume in general that the flow effect is negligible. Indeed, we found a bounce on the electrooptical property also in STN-cells. This was observed not only in passive step-voltage addressing but also in pulse-voltage addressing.

Then we discuss the flow effect using the data of anisotropic viscosity of our commercial mixture (ZLI-2293). In order to treat the flow effect one needs the so-called all Leslie coefficients α_i $(i = 1 - 6)$ or so-called Helfrich viscosity coefficients η_i $(i = 1 - 3), \eta_{12}$ with the rotational viscosity γ_1 .

ANISOTROPIC VISCOSITY COEFFICIENTS OF ZLI-2293

Since the pioneering work of Gähwiller [10] the anisotropic viscosity coefficients have only seldom been measured. And one finds often some considerable discrepancy between the experimental results of the different investigations.

The group of Schneider has performed a considerable amount of experiments of γ_1 by using the so-called rotational field method [11]. In addition to that, one of the authors (H. -H. G.) [12] has recently improved the measurement technique for the shear viscosity coefficients η_i. The physical principle is nothing else than the Poiseuille's law: the relationship between the volume velocity and the pressure drop along the capillary determines the viscosity. However, the orientation direction of the director and the direction of the velocity gradient in the capillary should be exactly controlled by the magnetic field. Here we only report the measurement results of the shear viscosity coefficients η_i and γ_1 of our standard mixture (ZLI-2293).

As is well known the Leslie coefficients α_i are related to the above mentioned viscosities η_i and γ_1 . And noting the Parodi relation, one can calculate all α_i (for $T = 20$ °C) except from α_1 which seems to be of less interest and be negligibly small [13] .

$$\begin{aligned} \alpha_2 &= -0.151 \ [Pa\ s] \\ \alpha_3 &= -0.0015 \ [Pa\ s] \\ \alpha_4 &= 0.0809 \ [Pa\ s] \\ \alpha_5 &= 0.1084 \ [Pa\ s] \\ \alpha_6 &= -0.0437 \ [Pa\ s] \end{aligned}$$

EXPERIMENTALS

We have carried out the electrooptical measurement in our standard experimental TN- and STN-cells. The switching dynamics has been measured in the following three different cases: TN-cells (passive step-voltage addressing), STN-cells (passive step-voltage addressing), STN-cells (pulse-voltage addressing) with ZLI-2293 at $T = 20°C$.

TN-cells

We found typical switching-off dynamics with the flow effect by varying V_{on} voltage. The bounce of relative transmission has been well known as the flow effect (Fig. 1). This behavior has not been observed in the switching-on dynamics.

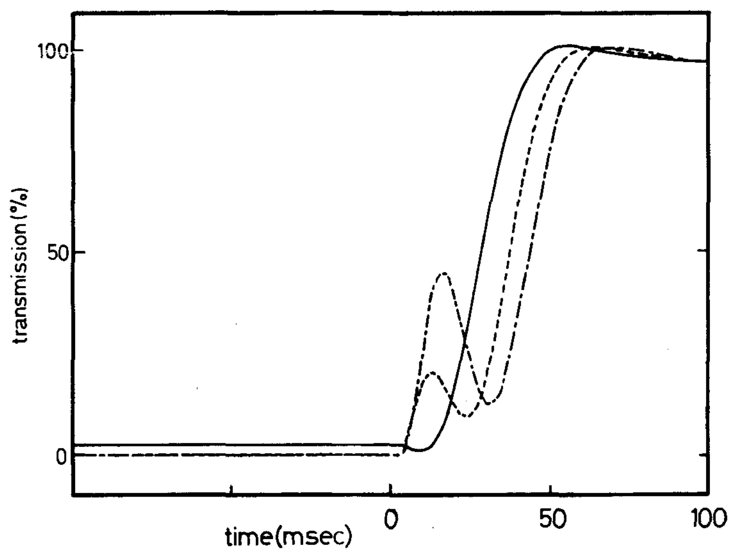

FIGURE 1. The switching-off profile of the relative optical transmission on time in TN-cells. The step voltage is switched off at time = 0. rms values of the step voltage are varied; low (full line), middle (dotted line), high (half dotted line).

STN-cells (passive step-voltage addressing)

A similar behavior as in TN-cells was observed again with the variation of V_{on} in the switching-off dynamics. However, the bounce is now much smaller (Fig. 2) than in TN-cells.

To our knowledge this is the first clear demonstration that the optical bounce occurs also in the switching-off dynamics in STN-cells.

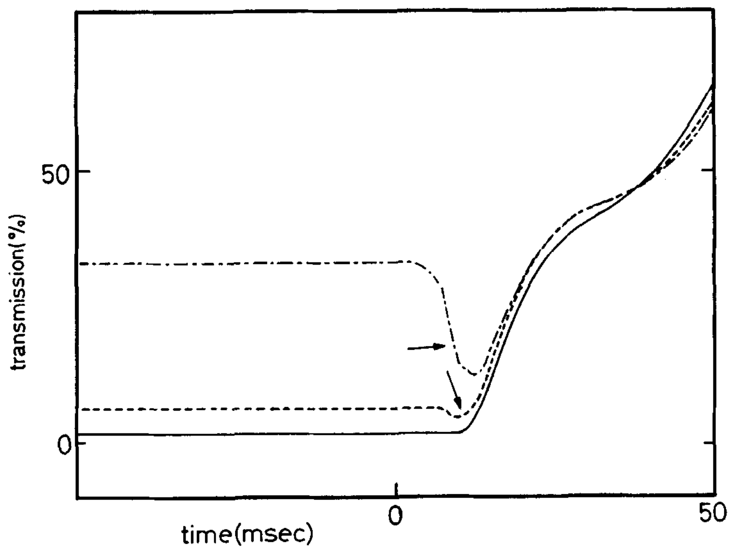

FIGURE 2. The switching-off profile of the relative optical transmission on time in STN-cells. The step voltage is switched off at time = 0. The flow effect is indicated as arrows. rms values of the step voltage are varied; low (full line), middle (dotted line), high (half dotted line).

STN-cells (pulse-voltage addressing)

The cell is now driven by the pulse-voltage as illustrated in Fig. 4a. The overall switching dynamics is accompanied with the so-called frame response [4]. Thus, it is very difficult to differentiate the intrinsic flow effect behavior and the frame response in the switching-off dynamics. However, the optical bounce was also observed in this case (Fig. 3).

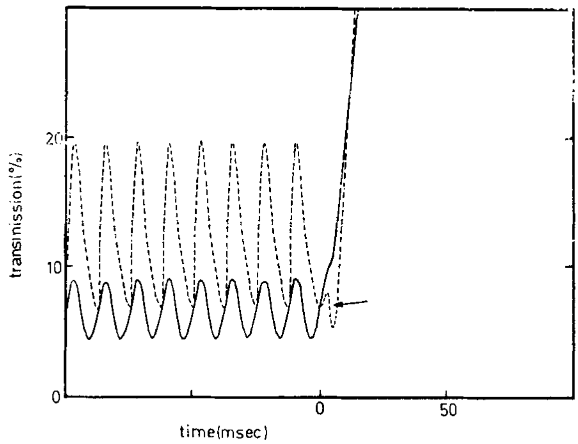

FIGURE 3. The switching-off profile of the relative optical transmission on time in STN-cells driven by the pulse voltage addressing. The flow effect is indicated as arrows. The operating voltage is varied as low (full line), high (dotted line).

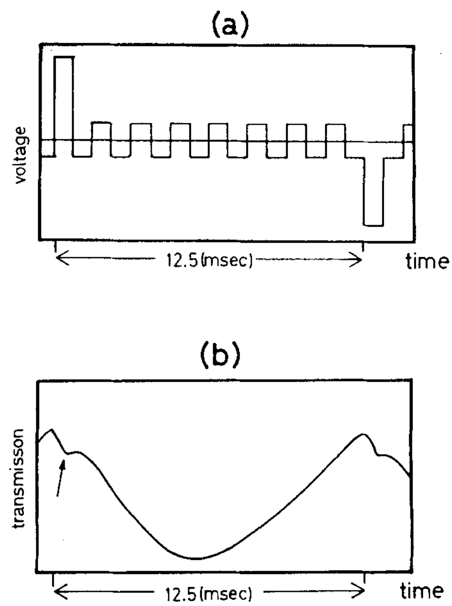

FIGURE 4.

(a) The voltage form of the pulse addressing.

(b) The corresponding transmission change. The flow effect is again indicated as an arrow.

Then, we attempted to follow the optical change within the frame time by varying the operating voltage V_{op}. We found again a strange behavior of the transmission change (Fig. 4b).

We have no other explanation than this behavior comes from the flow effect. The voltage change from the peak of the pulse to the data line would influence the directors to be 'switched-off'. The relaxation time scale of the director is far slower than this abrupt change from the peak to the data line, where the strange behavior of the transmission change occurs. However, the relaxation rate of velocity flow is much faster and thus this effect could induce some instability on the total relaxation of the 'switching-off' dynamics.

DISCUSSION

Instead of treating the flow effect in a rigorous theoretical way we wish to offer an intuitive, however essential understanding by deriving a simplified dynamical equations. Following the formulation of van Doorn [8] and Sprang [14] and applying the following simplifications,

- the Leslie coefficient α_3 is negligibly small in comparison with other coefficients. α_3 of ZLI-2293 is indeed small and this is not a special case in the mixture ZLI-2293 but one could assume in general that α_3 is negligibly small [15].
- to limit ourselves to utilize the measured α_i. This restriction seems to be too strong. However, we know that the LC mixture ZLI-2293 is not an unusual one but well often used in the LC display world. And there are considerable amount of LC mixtures which possess similar physical performance. Thus, the second simplification is rather general.

we obtain the following equations (the detailed derivation of this dynamical equations is not the main aim of this presentation and will be reported elsewhere),

$$\gamma_\theta^{eff}(\theta,\phi)\partial_t\theta = -\frac{\delta F}{\delta\theta} \tag{1}$$

$$\gamma_\phi^{eff}(\theta,\phi)\partial_t\phi = -\frac{\delta F}{\delta\phi} \tag{2}$$

where F is Frank free energy and γ_θ^{eff} and γ_ϕ^{eff} are nonlinear effective viscosities for the tilt angle θ and the twist angle ϕ of the directors, respectively. The both functional forms are shown in Fig. 5.

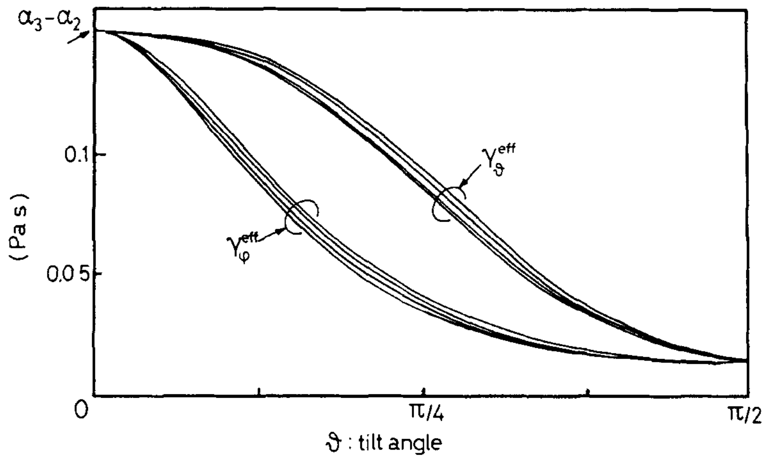

FIGURE 5. The functions γ_θ^{eff} ,γ_ϕ^{eff} on the tilt angle θ with the variation of the twist angle ϕ in the range of zero to the total twist angle. A more detailed variation of the twist angle ϕ leads to only a dense sweep within the change shown in the figure.

The flow effect results in modifying the constant rotational viscosity $\gamma_1(=\alpha_3-\alpha_2)$ to the nonlinear effective viscosities γ_θ^{eff} and γ_ϕ^{eff}. The results of equations (1),(2) with Fig. 5 are very instructive. As has been shown in the previous paper [7] the relaxation rate of electrooptical change is proportional to the coefficient of $\partial_t\theta$. Because of the nonlinearity one cannot discuss the dynamics with the flow effect by one single relaxation rate. Let us introduce the following phenomenological interpretation in order to understand the flow effect intuitively. We consider the director dynamics of two cases; case 1, switching-on dynamics and case 2, switching-off dynamics.

Case 1: The directors are almost planar (the tilt angles are almost zero) till V_{on} voltage is applied. As shown in Fig. 5 the effective viscosity is almost equivalent to the original rotational viscosity $\alpha_3-\alpha_2$. Thus, the flow effect does not affect the dynamics essentially. One could expect that the electrooptical property can be well understood by the discussion without the flow term.

Case 2: In contrast with the case 1 the effective rotational viscosity is small far from the original rotational viscosity. The typical relaxation rate is now relatively fast. Due to this fast relaxation rate it could happen that the director follows the fast changing mode induced by the flow terms.

Altogether if the flow effect would play an essential role it will be only the case 2.

CONCLUSIONS

The experimental analysis has been performed in STN-cells as well as TN-cells. In addition to the well known flow effect in TN-cells we found the bounce of the optical transmission also in STN-cells. These effects have been observed only in the switching-off dynamics.

When the STN-cell is driven by the pulse-voltage the optical transmission is overlapped with the so-called frame response so that the intrinsic flow effect is not so clear as in the case of the passive step-voltage. However, as shown in Fig. 4 the strange bounce of the optical transmission was found within the frame time where the pulse voltage changes from the peak to the data line. This can be well understood by means of our analysis.

In this paper all experiments are carried out by utilizing the mixture ZLI-2293. We have also found the similar optical bounce in STN-cells by using other mixtures with different physical performances. Thus, the experimental findings with ZLI-2293 are not the exceptional ones.

If the flow effect influences the optical property only in the switching-off dynamics, it could be of minor interest since the optical bounce is small in comparison with the frame response as shown in Fig. 3. But it turned out that the flow effect could affect the optical performance in LC display of STN-cells within each frame time, which might give rise to a considerable effect as a summation.

Wöhler and Becker [16] have presented a numerical model including the flow effect. Their numerical model showed a smaller relaxation time than the model without flow terms, which is a fairly good agreement with the measured values.

As we discussed in DISCUSSION the contribution of the flow effect results in the modified effective rotational viscosity γ_θ^{eff}, which has a smaller value than the original rotational viscosity (Fig. 5). It means the relaxation time decreases due to the flow effects. This would be the reason why the calculated relaxation times without the flow terms are often much larger than the measured ones.

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