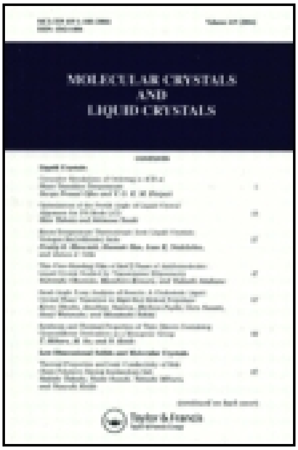

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Viscoelastic Dynamics of Nematic Liquid Crystal in Two-Step Switching Field

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Viscoelastic Dynamics of Nematic Liquid Crystal in Two-Step Switching Field

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Dynamics of a nematic liquid crystal in external switching field was examined for various initial states of electrostatic equilibrium. Two-step electric field was applied to study the switching dynamics from the first step equilibrium at E_0 to the second step equilibrium at E_1 the results of which could be explained by a change in effective rotational viscosity and the Erickson-Leslie theory. Extension to a gray scale switching process is a possible application.

Keywords: effective rotational viscosity; switching time constant; Nematic liquid crystal; Freedericksz transition

INTRODUCTION

Along with the increasing research activities of the liquid crystal applications to the display devices one of the most concerned problems to be improved is about the switching time. A great improvement by use of various methods has been achieved to develop new better modes of display[1]. Gray scale dynamics is also a great concern in

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practical problems for color displays. It is therefore important to analyze the switching dynamics in the gray scale range of the operating voltage and find the relevant parameters of greatest effects. We have studied on the switching time and the rotational viscosity of the homogeneously aligned nematic liquid crystal by use of the two-step field switching. The geometry of the sample configuration with respect to the applied electric field was selected for the splay mode and the Erickson-Leslie theory[2-4] was employed in the analysis.

DYNAMICS OF THE FREEDERICKSZ TRANSITION

Form the Erickson-Leslie theory we can describe the splay, bend, and twist deformation dynamics of liquid crystals under external electric field E as follows[5-7]

$$\gamma_1 \frac{\partial \theta}{\partial t} = K_{11} \frac{\partial^2 \theta}{\partial z^2} + \varepsilon_0 (\Delta \varepsilon) E^2 \sin \theta \cos \theta \qquad (1)$$

where γ_1 represents rotational viscosity, K_{11} Frank elastic constant, and $\Delta\epsilon$ dielectric anisotropy. The case of E=0 corresponds to the equation of the switching off dynamics. We can obtain the solution of the equation as given by[5]

$$\theta = \theta_m(t)\cos\left(\frac{\pi z}{d}\right) \qquad (2)$$

$$\theta_m(t) \simeq \theta_m \exp(t/\tau)$$

where d is the sample thickness, and τ the switching time. The switching time is given by

$$1/\tau = \varepsilon_0 \Delta\varepsilon (E^2 - E_c^2)/\gamma_1 \tag{3}$$

where E_c represents the threshold field of the Freedericksz transition[5-7].

EXPERIMENTAL METHODS

We have measured the time dependent phase retardation of the laser beam passing through the liquid crystal cell to examine the time dependent changes of the director orientational distribution[5,6]. Schematics of the experimental set up is shown in Fig.1, where the liquid crystal cell(5CB, Merck-K15) has the cell thickness of 1.8μm and nematic phase at 25°C with homogeneous alignment.

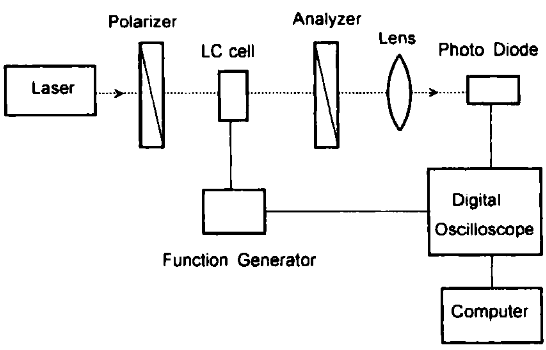

FIGURE 1 Experimental set up

A programmable function generator(HP33120A) was employed for interface with the computer control to apply the switching electric field to the sample in two steps of E_0 and E in any desirable combinations.

EXPERIMENTAL RESULTS AND DISCUSSION

In Fig.2 we have shown the switching time dependence on the initial voltage step V_0 in the two-step switching process of V_0 in the first step and V in the second step. This corresponds to a switching to the same final state of fixed V from various initial states of varying V_0. Fig.2(a) shows the case of $V>V_0$, where we can observe that the switching time(τ) remains to be constant with increasing V_0 before reaching a transition voltage. When V_0 increases above the transition voltage the switching time(τ) resumes again a constant but decreased value.

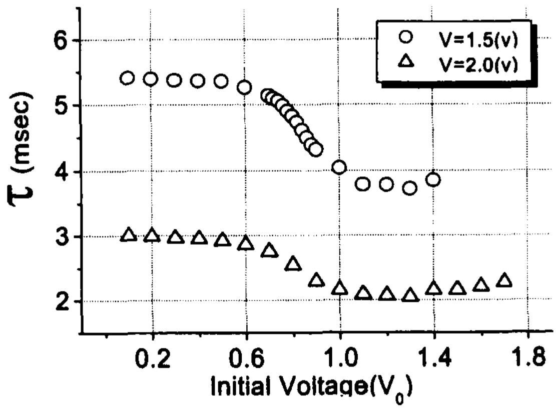

FIGURE 2(a) Switching time(τ) dependence on the first step voltage(V_0) in the two-step field switching from V_0 to V in the case of $V> V_0$.

The ratio between the two switching times observed at below and above the transition voltage respectively was a constant value of about 1.45 for both V=1.5V and V=2.0V.

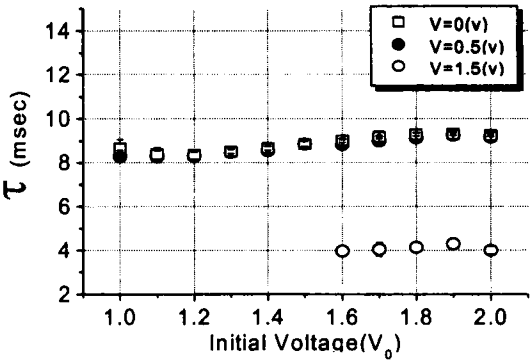

FIGURE 2(b) Switching time(τ) dependence on the first step voltage(V_0) in the two-step field switching from V_0 to V in the case of $V<V_0$.

However, in the case of $V<V_0$ the switching time(τ) was observed to be constant and nearly independent of V_0 as shown in Fig.2(b). Comparing the two results of Fig.2(a) and Fig.2(b) for the switching time(τ) the same switching time of ~4 msec is obtained irrespectively whether V_0 is larger or smaller than V. We can thus express our results of switching time measurements in the same graphic plot of Fig.3 for all values of V smaller or larger than V_0.

From Fig.3 we can observe three distinctive regions of the first step voltages(V_0) which we may call as static region(A), transition region(B), and dynamic(or gray scale) region(C). In this two-step switching process from an equilibrium of V_0 to another equilibrium of V we can thus see the switching time from the dynamic region of V_0 becomes shorter than the switching time from the static region of V_0.

However, switching time remains to be constant and independent of V_0 within each separate regime of the dynamic or static region. The switching time(τ) changes only when V_0 is in the transition region.

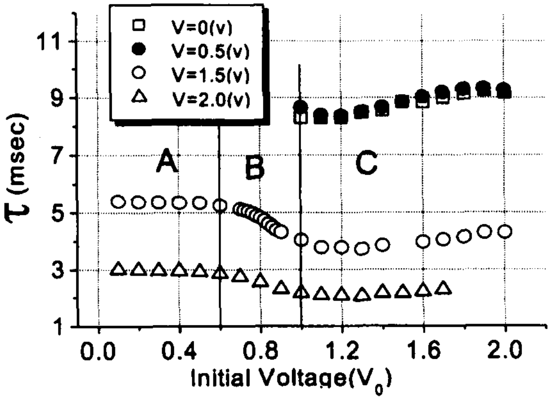

FIGURE 3 Switching time(τ) dependence on the first step voltage(V_0) for various 2nd step voltages(V).

In Fig.4 we have shown the 2nd step voltage V dependence of the switching time for various selected values of the 1st step voltage V_0 . Although the magnitudes of the switching times are different from each other between the static region of V_0= 0.0V, 0.5V and the dynamic region of V_0=1.5V, 2.0V, the V dependent functions of the switching times are found to be same for both of the two regions. We have made a best fit to the data for V>1.0V in the two regions by

$$1/\tau = \varepsilon_0 \Delta\varepsilon (E^2 - E_c^2)/\gamma_1 \tag{3}$$

as depicted in the inset of Fig.4.

The slopes(b) of the linear plots in the inset correspond to an effective rotational viscosity, and best fits suggest a difference by about 1.5 times between the static region and the dynamic region.

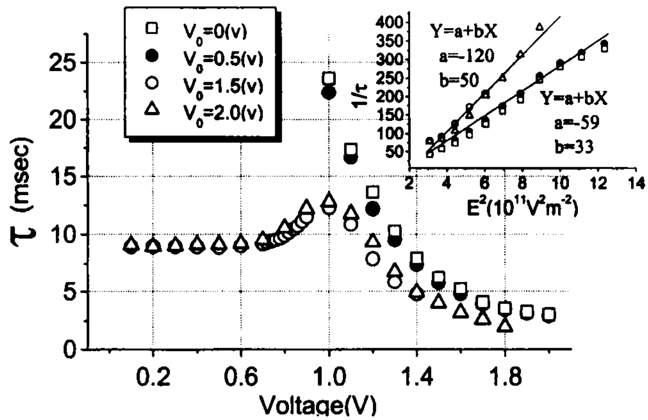

FIGURE 4 Switching time dependence on the 2nd step voltage(V) for various 1st step voltages(V_0).

That is, the static viscosity of the static region switching dynamics is about 1.5 times larger than the dynamic viscosity of the dynamic region switching dynamics. This result also conforms with the result of Fig.2. Although a possible theory for reduction of effective rotational viscosity is available[5,6,8-10] as due to the back flow effect, this back flow effect is negligible in the case of the planar to homeotropic transition[6] as for the present work of ours.

CONCLUSION

When a switching field is applied to the liquid crystal sample, the switching time to a new equilibrium state depends on the kinematic nature of the initial state. When we make use of the two-step field switching we can define three different initial states of static, transition, or dynamic region, depending on the voltage amplitude V_0 of the first step field. A significant change in the effective rotational viscosity and thus the switching time was observed between the static region and the dynamic region. The transition region in between the static and dynamic regions has a variable effective rotational viscosity, the range of which depends on the surface anchoring energy of the sample. Switching dynamics in the dynamic region should be further explored for application to the gray scale control of switching process.

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