

A study on hysteresis behaviour of liquid crystals by the nematic-cholesteric phase transition mode on polymer surfaces

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Abstract

The hysteresis behavior of liquid crystals (LCs) on polyimide (PI) surface without side chains in nematic-cholesteric phase transition (NCPT) mode was investigated. The generated pretilt angle of ZLI-1132 was almost the same as that of 4-n-pentyl-4'-cyanobiphenyl (5CB) on a PI surface with both sides rubbed. The phase transition time of ZLI-1132 using NCPT mode on a PI surfaces without rubbing treatment was as fast as that of 5CB. As well, the hysteresis width of ZLI-1132 using NCPT mode on a PI surface without rubbing treatment was larger than that of 5CB. Consequently, the large hysteresis width of NCPT mode is attributed to the random LC alignment and high elastic constants of the NLCs.

Key Words(중요용어) : Nematic liquid crystal(NLC), polyimide, rubbing strength, hysteresis width, pretilt angle, phase transition time

1. INTRODUCTION

The electrically induced nematic-cholesteric phase transition (NCPT) mode on the influences of the electric field induced texture and phase change behaviour of dye-doped, long pitch, cholesteric, LC films as a function of boundary conditions, materials, and LC thickness-to-helical pitch ratio (d/p) using the anisotropic color-absorption properties of the dichroic dye dopant has been discussed by Lin-Hendel^{1,2)}. Applications for projection displays using the light scattering effect of the bistable memory effect of the electric field-induced nematic-cholesteric phase transition phenomenon has been reported by some researchers³⁻⁵⁾. This display needs no polarizers, and so a highly

luminant image is obtained. The NCPT mode uses the memory effect of the NLC, and theoretically the information content has no limitation. In order to keep this display drive stable, the width of the electro-optical hysteresis is very important. Previously, we reported on the hysteresis behaviour of surface LC alignment using the NCPT mode on PI surface⁶⁾. The hysteresis width effects of the NCPT mode in NLC have not yet been reported. The LC alignment of the NLCs on PI surfaces rubbed unidirectionally was demonstrated and discussed by the author group⁷⁻⁹⁾.

In this work, we report the hysteresis width effects of the NLCs using NCPT mode on PI surfaces without side chains.

2. ADDRESSING SCHEME OF NCPT MODE

NCPT mode with positive dielectric anisotropy changes state when the applied voltage is increased, as shown in Fig. 1. It changes from a cloudy state, the cholesteric phase F, to a transparent state, the nematic

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phase H. When the voltage is decreased, it transforms from phase H to a metastable transparent state, nematic phase H', then to phase F. In phase F, the LC in the panel has a helical structure. Because the axes of the helices are parallel to the glass substrates, incident lights is scattered, making phase F cloudy. In phase H, the LC has no helical structure, but instead has a homeotropic structure. Incident light passes through the homeotropic structure, making phase H transparent. In phase H', the structure of the LC is homeotropic, but at the centre of the layer the LC molecules are slightly inclined. Phase H' is a metastable homeotropic state. The hysteresis effect is thought to be affected by the specific balance between surface anchoring and the thermal properties of the helical structure.

The width of the hysteresis effect is designated the width of hysteresis Δ , as shown in Fig. 1, i. e. the difference between the voltage V_u^{90} , which gives 10 percent transmittance for cholesteric-nematic phase transitions and the voltage V_d^{90} , which gives 90 percent transmittance for nematic-cholesteric phase transitions. The drive voltage, V_d , is set between V_u^{90} and V_d^{90} , as shown in Fig. 1.

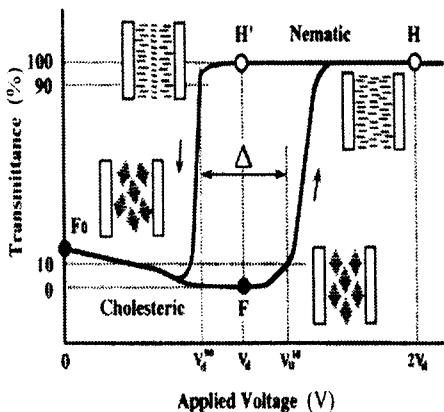


Fig. 1. Phase transition and transmittance changes for the NCPT mode and the definition of hysteresis width Δ .

NCPT type hysteresis enables the following four-stage addressing scheme. The first stage is initialization for writing. Applying twice the V_d changes all the pixels from state F to state H. The second stage is writing using selected pixels. The selected pixels are changed to state F by decreasing voltage and then again applying the drive voltage (V_d). The third stage is writing at non-selected pixels. The non-selected pixels are maintained in state H' or state H by continuous application of the drive voltage V_d or twice the V_d . The fourth stage is maintaining the written images. The selected and non-selected pixels are maintained by re-applying the drive voltage.

3. EXPERIMENTAL

The glass plates were coated with indium-tin-oxide (ITO). The PI film (RN-305 for low pretilt, supplied from Nissan Chemical Industries Co., Ltd.) was applied to a substrate using the spin-coating method : it had a homogeneous alignment. It was polyimidized thermally at 230°C for 1 hour. The NCPT-LC layer had a thickness of $5.0 \pm 0.1 \mu\text{m}$, achieved using polymer beads for spacers, and checked using an LC layer thickness meter made by Otsuka-Electronics Co., Ltd. We used a commercially available mixture for the nematic component (RDP-90613, Rodic Co., Ltd.), as shown in Fig. 2.

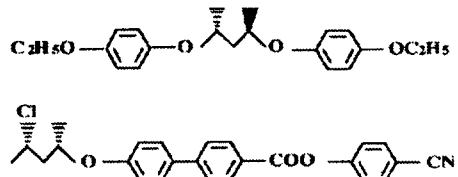


Fig. 2. Structure of the chiral nematic LCs.

The helical pitch of the cholesteric phase was $1.0 \mu\text{m}$ using a 9:1 ratio of nematic to chi-

ral nematic LC components. Helical pitches were measured by using the Cano method. The relationship between LC thickness and helical pitch was determined by the scattering intensity and using a driving voltage of ± 13 V max. General CMOS-LSI was used to drive the bistability of the hysteresis effect. Table 1 shows the physical properties of the NLCs used. Table 2 shows the used NLC components.

Table 1. Physical properties of used NLCs

NLCs	K_{11} ($\times 10^{-12}$ N)	K_{22} ($\times 10^{-12}$ N)	K_{33} ($\times 10^{-12}$ N)	$\Delta\epsilon$
5CB	6.2	3.3	8.4	16.1
ZLI-1132	10.1	5.6	19.7	13.1

Table 2. NLC components used. (unit : %)

NLCs	A	B	C	D	E	F
5CB	100	80	60	40	20	0
ZLI-1132	0	20	40	60	80	100

We used a rubbing technology that controlled the surface alignment direction of the LC molecules and the rubbing direction was antiparallel for the two substrates. We prepared three kinds of cells : both sides unrubbed, one side rubbed, and both sides rubbed.

Rubbing was done with a rotating cylinder, covered with a fabric consisting of vertical nylon (Y₆-15-N, Yoshikawa Chemical Industries Co., Ltd.). The definition of the rubbing strength, RS, is as given in previous papers^{10, 11).}

$$RS = NM(2\pi rn/V-1), \tag{1}$$

where N is the number of the repeated times for the rubbing (usually N=1, in this work), M is the depth of the deformed fibers of the cloth due to the pressed contact (mm), n is the

rotational speed of the drum (1000/60s⁻¹), V is the translating speed of the substrate (7.0 mm/s), and r is the radius of the drum.

In order to measure the pretilt angle, we used the crystal rotation method. The measurements were performed at 20°C. We used the same PI and LC materials, but the LC material was the non-chiral nematic component. Cells were prepared by assembling the substrates antiparallel to the rubbing directions and the rubbing strength was changed. The LC layer thickness was $60 \pm 0.3 \mu\text{m}$. We changed the thickness relative to that of the cell used for measuring the hysteresis behaviour, in order to measure quickly and correctly the relationship between the rubbing strength and pretilt angle.

Measurement of the hysteresis, as shown in Fig. 1, was carried out using a scheme for driving of the device. The driving schematic, as shown in Fig. 3, was a special driving method for the NCPT mode, which used the memory effect. Addressing time was t_r , one pulse width (4ms). Resetting time was t_r , for 30 pulses.

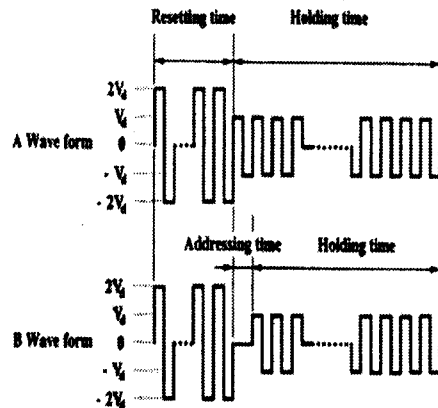


Fig. 3. Schematic of the driving method. (A) Measured wave form : the phase transition from cholesteric to nematic. (B) Measured wave form : the phase transition from nematic to cholesteric.

Holding time was t_r for 2501 pulses of the cholesteric-nematic phase transition and t_r for 2500 pulses of the nematic-cholesteric phase transition. The measurement temperature for the hysteresis behaviour was 30°C.

4. RESULTS AND DISCUSSION

Figure 4 shows the pretilt angles as a function of NLC components on rubbed PI surfaces without side chain at a strong RS region. It is seen that the pretilt angle of NLC did not vary with the NLC components. The generated pretilt angle of NLCs was about 3.6° on a rubbed PI surface without side chains. The behaviour of pretilt angle in 5CB is almost the same as seen in previous results¹⁰.

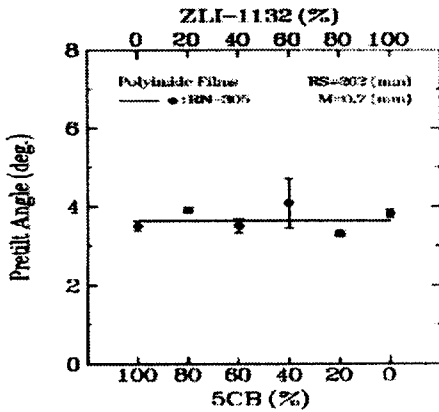


Fig. 4. Pretilt angles of the NLC on rubbed PI surfaces without side chains as a function of nematic components.

The phase transition time of the NCPT mode as a function of NLC components on PI surfaces without side chains is shown in Fig. 5. The phase transition time of ZLI-1132 using the NCPT mode on a PI surface was as fast as that of 5CB. It is shown that the phase transition time of the NCPT mode on a PI surface decreases with increasing the ZLI-1132 components.

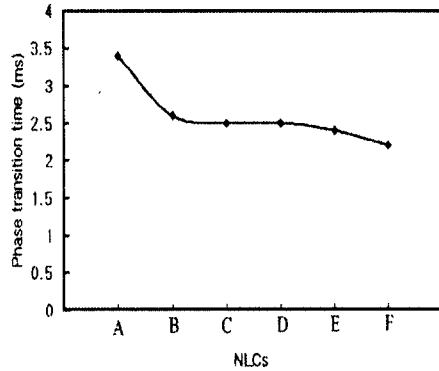
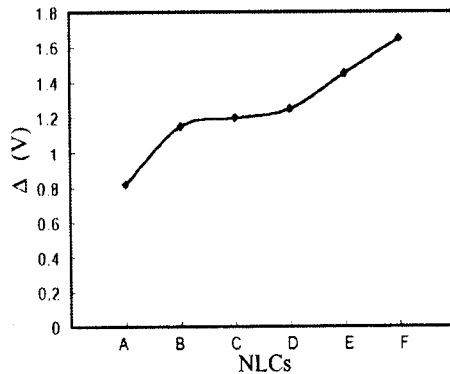
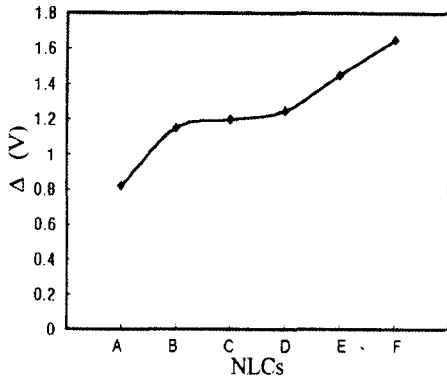


Fig. 5. Phase transition times of the NCPT mode on PI surfaces without side chains as a function of NLC components.

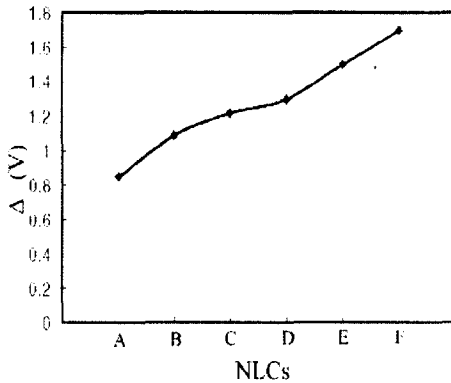
Figure 6 shows the hysteresis width of NCPT mode as a function of NLC components on PI surfaces without side chains. The hysteresis width of the NCPT mode on a PI surface increases with increasing the ZLI-1132 components, as shown in Figures 6 (a), (b), and (c). However, the pretilt angle of NLC did not vary with the increase of the ZLI-1132 components, as shown in Fig. 4. In a previous paper, the surface effects of the threshold electric fields of NCPT mode has been reported¹².



(a) $t_r = 4\text{ms}$



(b) $t_r = 8\text{ms}$



(c) $t_r = 16\text{ms}$

Fig. 6. Hysteresis width of the NCPT mode on PI surfaces without side chains as a function of NLC components. One pulsh width :

(a) $t_r = 4\text{ms}$, (b) $t_r = 8\text{ms}$, (c) $t_r = 16\text{ms}$.

The electric field induced by phase transition from Ch to N is expressed as

$$E_{CN} = \frac{\pi^2}{p_o} \sqrt{\frac{K_{22}}{\epsilon_o \Delta \epsilon}} \quad (2)$$

where E_{CN} is the threshold electric field from Ch to N transition. p_o is the helical pitch in the absence of the electric field, K_{22} is the elastic constant of twist, ϵ_o is the vacuum permittivity and $\Delta \epsilon$ is the dielectric anisotropy of the NLC.

For phase transition from N to Ch is expressed as

$$E_{NC} = \frac{\pi}{p_o} \sqrt{\frac{4 K_{22}^2 - \left(\frac{p_o K_{33}}{d}\right)^2}{\epsilon_o \Delta \epsilon K_{33}}} \quad (3)$$

where, K_{33} is the bend elastic constant.

Equations (2) and (3) indicates that the threshold electric field E_{CN} and E_{NC} are related to K_{22} and K_{33} , respectively. The elastic constants of ZLI-1132 were larger than that of 5CB, as shown in Table 1. From these results, we consider that the large hysteresis width of NCPT the mode on a PI surface can be attributed to the high elastic constants of NLCs. Consequently, the hysteresis width of the NCPT mode depends on the surface LC alignment⁶⁾ and elastic constants of NLCs.

5. CONCLUSION

In summary, the hysteresis behaviour of the NCPT mode on PI surfaces was studied. The pretilt angles of ZLI-1132 was almost the same as those of 5CB on a PI surface with both sides rubbed. The phase transition time of ZLI-1132 using the NCPT mode was as fast as that of 5CB on PI surfaces without rubbing treatment. Also, the hysteresis width of ZLI-1132 using the NCPT mode was larger than that of 5CB. Consequently, the hysteresis width of the NCPT mode depends on the surface LC alignment and elastic constants of NLCs.

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