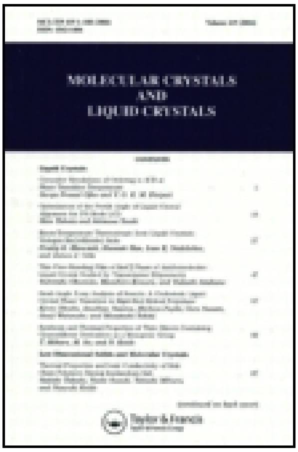

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Study on Image Sticking Problem by Means of Total Reflection Ellipsometry

Yudai Azumai [a], Kazuya Goda [a], Munehiro Kimura [a] & Tadashi Akahane [a]

[a] Department of Electrical Engineering, Faculty of Engineering, Nagaoka University of Technology, Nagaoka, Niigata, Japan

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Study on Image Sticking Problem by Means of Total Reflection Ellipsometry

YUDAI AZUMAI, KAZUYA GODA,
MUNEHIRO KIMURA, AND TADASHI AKAHANE

Department of Electrical Engineering, Faculty of Engineering,
Nagaoka University of Technology, Nagaoka, Niigata, Japan

Dynamic response of molecular reorientation near the alignment surface of bistable cholesteric liquid crystal devices was observed by means of the total reflection ellipsometry. From the experimental results, the deviation from the original switching voltage to which the image sticking problem has a close relationship was confirmed, and the cause of the image sticking problem was considered from the viewpoint of the surface energy and Helfrich-type modulation. Especially when the surface free energy is low, director near the alignment surface seems to be distorted by disclinations and Helfrich-type modulation.

Keywords Bistable cholesteric liquid crystal devices; ellipsometry; Helfrich-type modulation; image sticking problem; surface free energy

1. Introduction

Recently, a large amount of cellulose paper consumption by the computerization according to a rapid advancement of an information-oriented society becomes a serious problem. From this social background, electronic paper (EP) is expected to be one of the substitution for the cellulose paper. EP requires driving electric voltage only when an image is updated, *i.e.*, holding electric voltage is not required. To reduce the cellulose paper consumption, a replacement of paper with appropriate EP would be expected. Recently, bistable cholesteric liquid crystal device (BChLCD) attracts the researchers' interests [1]. BChLCD has two stable states, (1) Reflection state; helical axis is perpendicular to the substrate and molecular alignment is planar to the substrate, which is also called planar state. (2) Transmission state; helical axis is parallel to the substrate, which is also called focal conic state [2]. BChLCD possesses the selective reflection; the circularly polarized light at a certain wavelength corresponding to its chiral pitch is reflected. Full color-EP with high contrast and high resolution can be fabricated by applying BChLCD, because the BChLCD needs

Address correspondence to Munehiro Kimura, Department of Electrical Engineering, Faculty of Engineering, Nagaoka University of Technology, 1603-1 Kamitomioka, Nagaoka, Niigata 940-2188, Japan. Tel.: +81-258-47-9540; Fax: +81-258-47-9500; E-mail: nutkim@vos.nagaokaut.ac.jp

neither polarizer nor color filter. However, as we know, so called 'image sticking problem' has not been perfectly solved yet while some of the solutions were proposed [3].

The electro-optical response was sometimes unstable at each stable state by instabilities of liquid crystal (LC) director near the alignment surface, and the switching voltage from planar state to focal conic state or vice versa is deviated from the original voltage. Therefore, to improve the quality of the BChLCD, reducing the image sticking problem is an important issue. In this study, to reduce the image sticking problem, dynamic response of LC director near the surface with various surface treatments were observed by means of the total reflection ellipsometric method [4].

2. Total Reflection Ellipsometry (TRE) [4]

Figure 1 shows a schematic illustration of the total reflection ellipsometry (TRE). The trapezoidal prism and glass substrate have the same refractive index, which is higher than that of the LC substance. When the incident light is totally reflected at interface between the LC layer and the substrate, the light penetrating into the LC layer is attenuated and does not reach the counterpart substrate. Therefore the light reflected from the cell is modulated by following the LC director reorientation near the alignment surface. The analysis of TRE was described in detail in our previous paper [4]. In this experiment, a trapezoidal prism with a base angle of 75°and glass substrate whose refractive index is 1.80 at 632.8 nm was used. Measurement was performed by the ellipsometer M-150 (JASCO Co.) [5]. In order to analyze the LC director reorientation dynamics near the surface, the reflection layout as shown in Figure 2(a) was adopted. On the other hand, to evaluate the LC director reorientation dynamics in the bulk, the transmission layout for transmission ellipsometry (TE) as shown in Figure 2(b) was adopted. The advantage of this layout is that

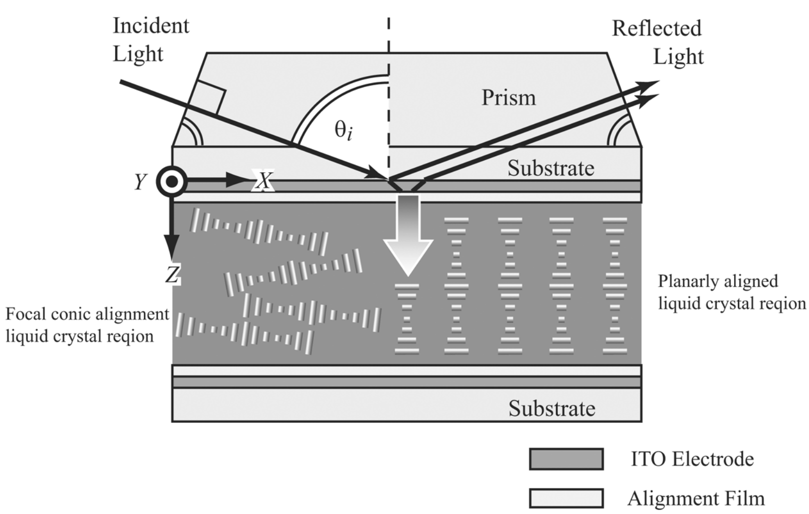
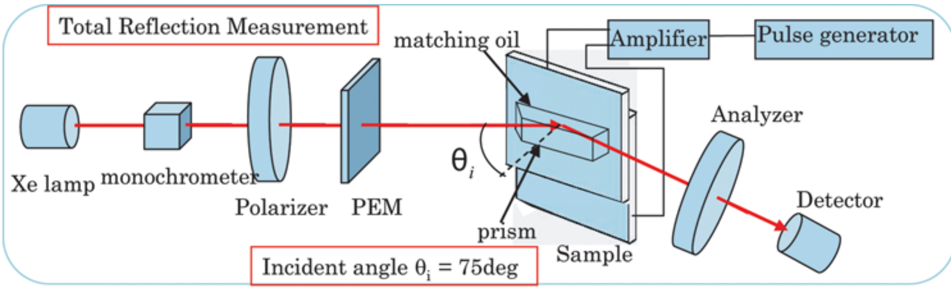
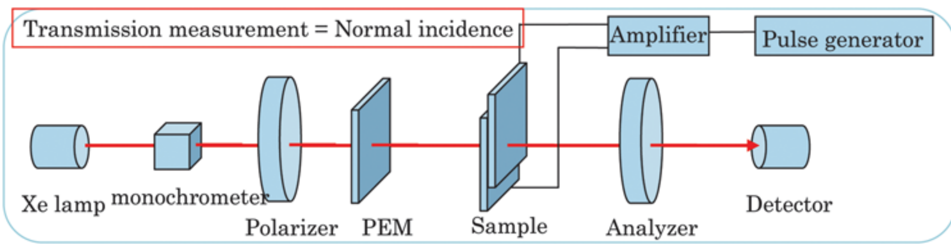


Figure 1. Schematic illustration of the side-view of the total reflection ellipsometry and BChLCD sample.



(a)



(b)

Figure 2. Experimental setup of the Time-resolved ellipsometry: (a) total reflection measurement; (b) transmission measurement. (Figure appears in color online.)

TRE measurement and TE measurement can be carried out by using the same sample successively.

3. Experiments

The conventional sandwich type cell was fabricated with two substrates whose inner surface was coated with polyimide alignment film for vertical alignment (PI-V). In this experiment, four types of polyimide (PI-V1, V2, V3, V4, provided by Chisso) were employed, the difference of the side chain and surface energy of polyimide are listed in Table 1. The cholesteric LC used is ZLI-2293 doped with CB-15 (provided by Merck). The nominal cell gap is 5 μm.

The TRE and TE measurement was done by following step. As an initialization, burst pulse voltage was applied to the BChLCD cell in order to memorize the planar state or focal conic state. Then BChLCD cell was left at the each state for two weeks. After that, 80 V burst pulse voltage with 17 Hz was applied in order to set planar state, and time-resolved TRE and TE measurements were carried out.

Table 1. Polyimide alignment films used in this study

	PI-V1	PI-V2	PI-V3	PI-V4
Side chain length of polyimide	middle	short	long	middle
Density of side chain	high	high	high	middle
Surface free energy [mJ/m^2]	26.5	26.7	24.0	26.5

4. Results and Discussion

First of all, the selective reflection property was confirmed by the conventional transmittance spectrum measurement, as shown in Figure 3. It is reasonable that the selective reflection band was shifted to short wavelength side when the dosage of the chiral additive was increased. Outside of the selective reflection band, multiple beam interference was found; these experimental results were ordinary. The dependence of the dosage of the chiral additive on the selective reflection band is gathered in Table 2.

To understand the influence of the chiral additive and surface alignment film on the image sticking problem, TRE and TE measurements for BChLCD cells with various fabrication specification were carried out. Figures 4 to 7 show the

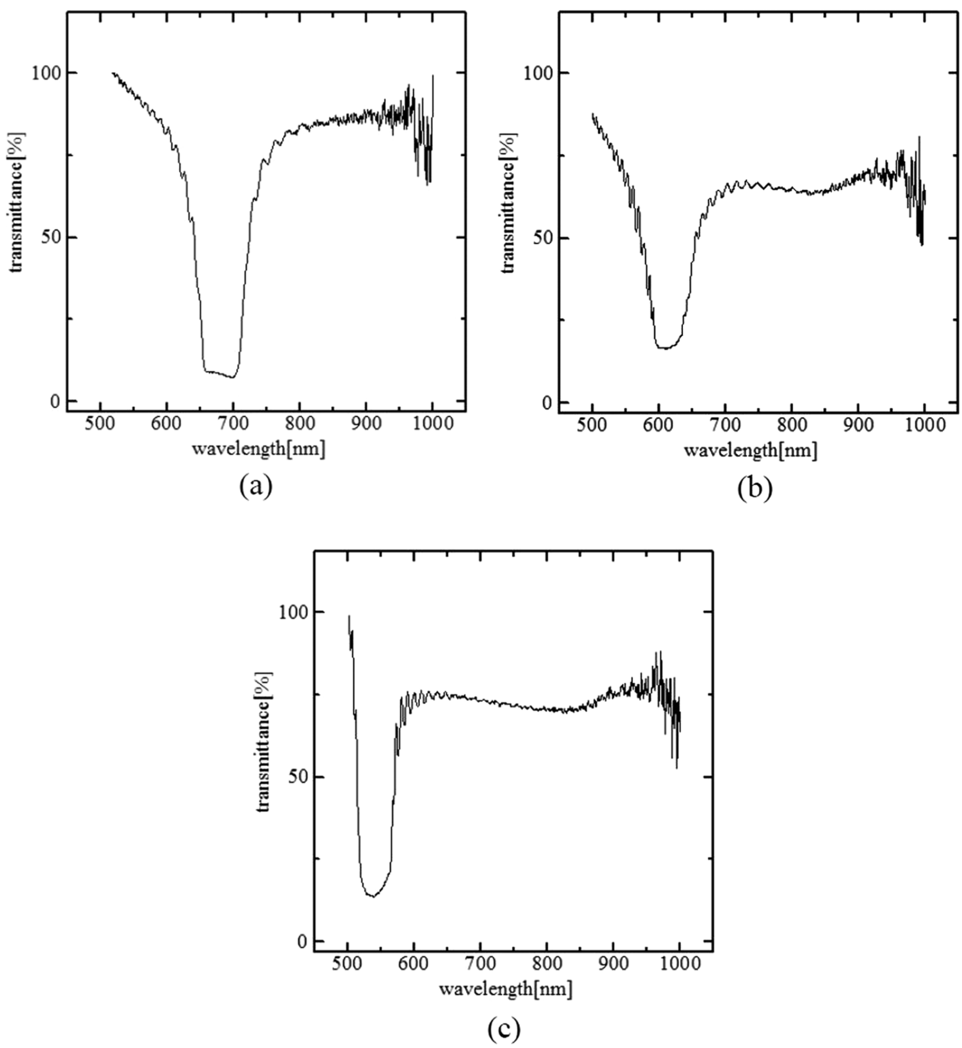


Figure 3. The dependence of the selective reflection band of transmittance spectrum on the dosage of the chiral additive: (a) 30%, (b) 35%, (c) 40%.

Table 2. The dependence of the dosage of the chiral additive on the selective reflection band

Dosage of the chiral additive (%)	Selective reflection band [nm]
30	658∼701
40	597∼625
50	519∼564

experimental results of the time-resolved TRE and TE measurements, where the dosage of the chiral additive was 30%. Before the series of the experiments, switching square wave voltage from planar state to focal conic state or vice versa was

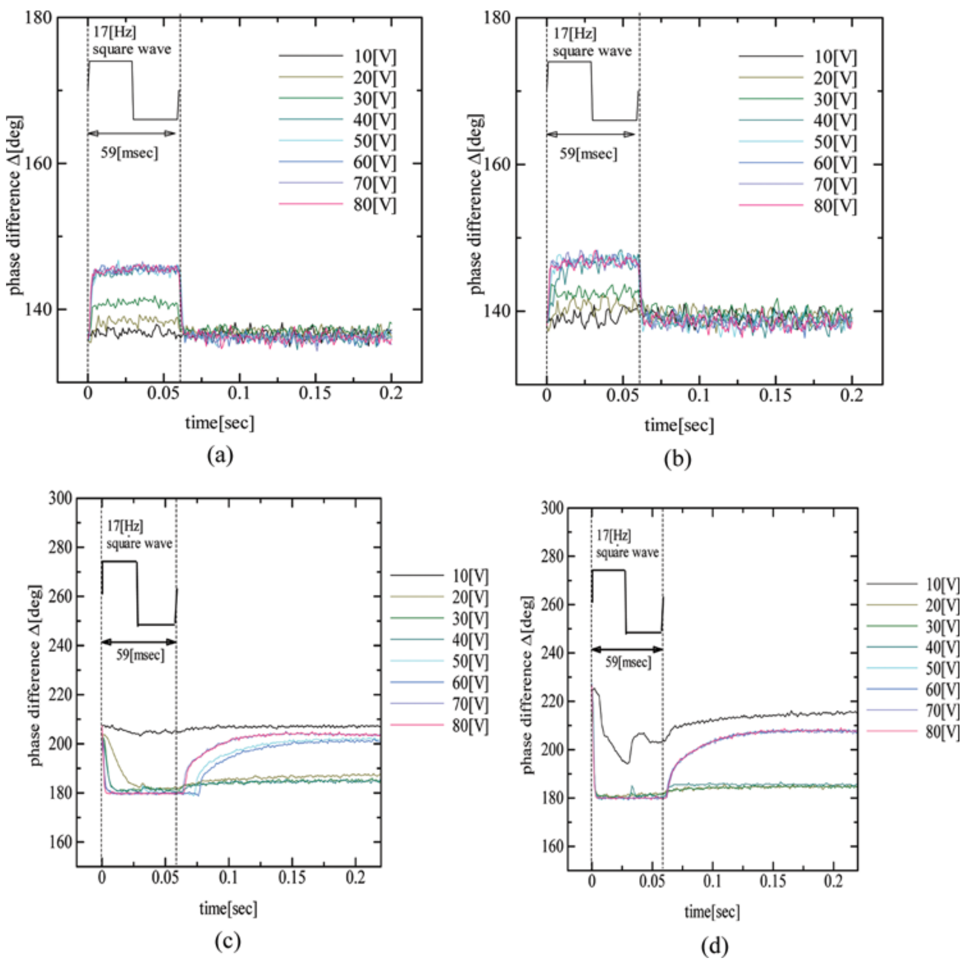


Figure 4. Time-resolved TRE and TE measurement, where the BChLCD cell was fabricated with PI-V1 alignment film: (a) TRE measurement, where the BChLCD cell held the focal conic state for two weeks before the measurement; (b) TRE measurement, where the BChLCD cell held the planar state; (c) TE measurement, where the BChLCD cell held the focal conic state; (d) TE measurement, where the BChLCD cell held the planar state.

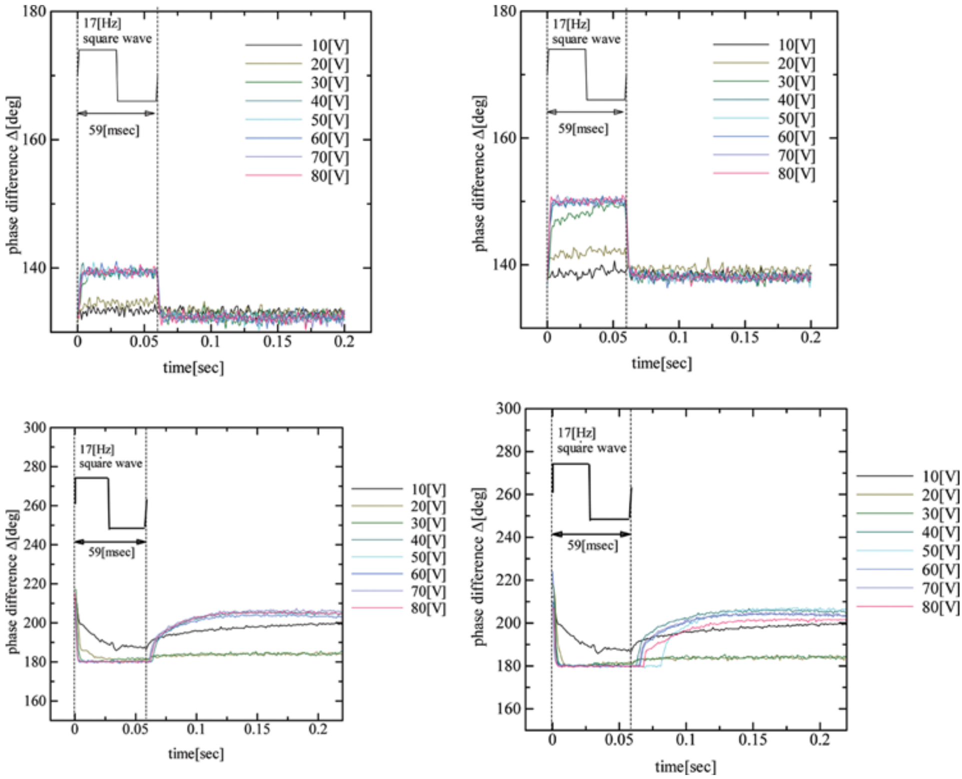


Figure 5. Time-resolved TRE and TE measurement, where the BChLCD cell was fabricated with PI-V2 alignment film. Conditions (a)–(d) are similar as for Figure 4.

confirmed to be above 20–40 V, regardless of the polyimide alignment film used in our experiment. Figure 4 shows the time-resolved TRE and TE measurements, where the BChLCD cell was fabricated with PI-V1 alignment film. Figure 4(a) represents a time-resolved TRE measurement, where the BChLCD cell held the focal conic state for two weeks before the measurement. Right after an adequate switching voltage of driving square wave was applied and removed, rapid change of Δ was recognized. As is reported in the previous paper, the rapid change of Δ corresponds to the director reorientation near the alignment film [6]. Figure 4(b) represents a time-resolved TRE measurement, where the BChLCD cell hold the planar state for two weeks before the measurement. It is found that the outline of dynamic change of Δ in Figure 4(b) is similar to that in Figure 4(a). From the comparison between Figure 4(a) and Figure 4(b), it seems that neither the transition process from focal conic state to focal conic state nor the transition process from planar state to focal conic state via homeotropic alignment affects the director reorientation near the surface. That is, the director near the alignment film doesn't seem to be restricted near the alignment film. Figure 4(c) represents a time-resolved TE measurement, where the BChLCD cell was fabricated with PI-V1 alignment film and held in the focal conic state for two weeks. From Figure 4(c), it is found that the outline of rising and relaxation characteristics of Δ was delayed against the switching square wave voltage because of the elastic effect [6], and the transition to focal conic state via homeotropic alignment was

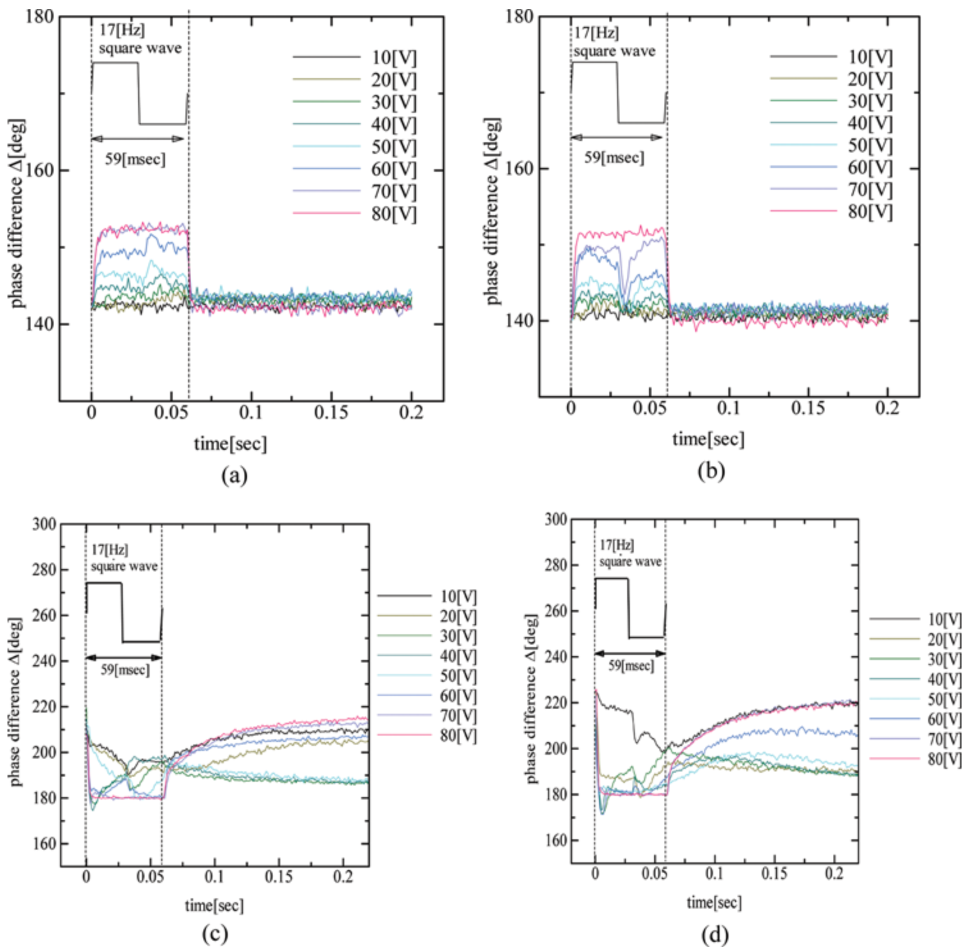


Figure 6. Time-resolved TRE and TE measurement, where the BChLCD cell was fabricated with PI-V3 alignment film. Conditions (a)–(d) are similar as for Figure 4.

completed when the switching square wave voltage was above 20–40 V. Figure 4(d) represents a time-resolved TE measurement, where the BChLCD cell was fabricated with PI-V1 alignment film and held the planar state for two weeks. The similar delayed Δ response was confirmed and the transition to focal conic state via homeotropic alignment was completed when the switching square wave voltage was above 20–40 V. That is, bulk response is independent of the previous state. A series of results shown in Figure 4 is regarded as an example of standard behavior in our experiment.

Figure 5 represents a time-resolved TRE and TE measurement, where the BChLCD cell was fabricated with PI-V2 alignment film. Figure 5(a) and (b) represents a time-resolved TRE measurement, where BChLCD cells were held in the focal conic state or planar state, respectively. As shown in Figures 5(a) and (b), the transition from the focal conic and/or planar state to another state via homeotropic alignment was completed when the switching square wave voltage was above 20–30 V, *i.e.*, switching voltage of BChLCD cell with PI-V2 alignment film is lower

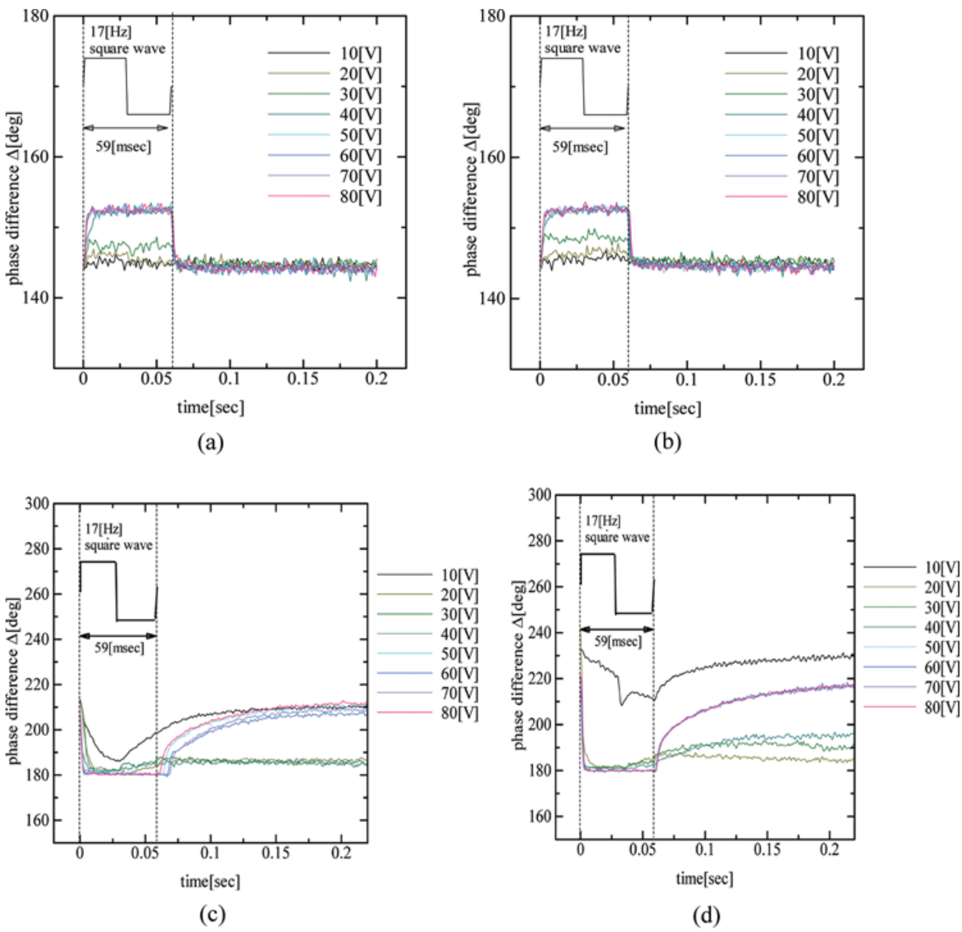


Figure 7. Time-resolved TRE and TE measurement, where the BChLCD cell was fabricated with PI-V4 alignment film. Conditions (a)–(d) are similar as for Figure 4.

than that with PI-V1 alignment film (cf. Figure 4(a) and (b)). From this experimental result, the surface anchoring by PI-V2 alignment film seems to be weaker than that of PI-V1. Furthermore, in case of the transition from the planar state to focal conic state, the change of Δ is larger than that with PI-V1 alignment film (cf. Figure 4(b)). Figure 5(c) represents a time-resolved TE measurement, where the BChLCD cell was fabricated with PI-V2 alignment film and held in the focal conic state for two weeks. Figure 5(d) represents a time-resolved TE measurement, where the BChLCD cell was fabricated with PI-V2 alignment film and held in the planar state for two weeks. From a comparison between the Figure 4(c), Figure 4(d), Figure 5(c) and Figure 5(d), contradicting to the reorientation near the surface, similar dynamic reorientation process in the bulk was predicted.

Figure 6 represents a time-resolved TRE and TE measurement, where the BChLCD cell was fabricated with PI-V3 alignment film. Figure 6(a) and (b) shows a time-resolved TRE measurement, where BChLCD cells were held at the focal conic state and planar state, respectively. It is found that, the amplitude of Δ was drastically changed by raising the switching voltage. Furthermore, as shown in Figure 6(b), the sudden decrease of Δ was found when the polarity of square wave applied voltage was changed, and the amplitude of Δ was larger than that with PI-V1 alignment film (cf. Figure 4(b)). These results imply the dynamic LC reorientation near the surface. It is also found that the transition from the focal conic and/or planar state to another state via homeotropic alignment was completed when the switching square wave voltage was above 20–50 V, *i.e.*, switching voltage of BChLCD cell with PI-V3 alignment film is higher than that with PI-V1 alignment film (cf. Figure 4(a) and (b)) while the surface energy of PI-V3 is lower than that of PI-V1 (as shown in Table 1). That is, the experimental result contradicts to an interpretation that the alignment film with high surface energy tends to increase the switching voltage.

Figure 7 represents a time-resolved TRE and TE measurement, where the BChLCD cell was fabricated with PI-V4 alignment film. It is found that the measured results of TRE and TE response were almost similar to those of PI-V1.

Figure 8 shows the experimental results of time-resolved TRE and TE measurements, where the BChLCD cell was fabricated with PI-V1 alignment film and the

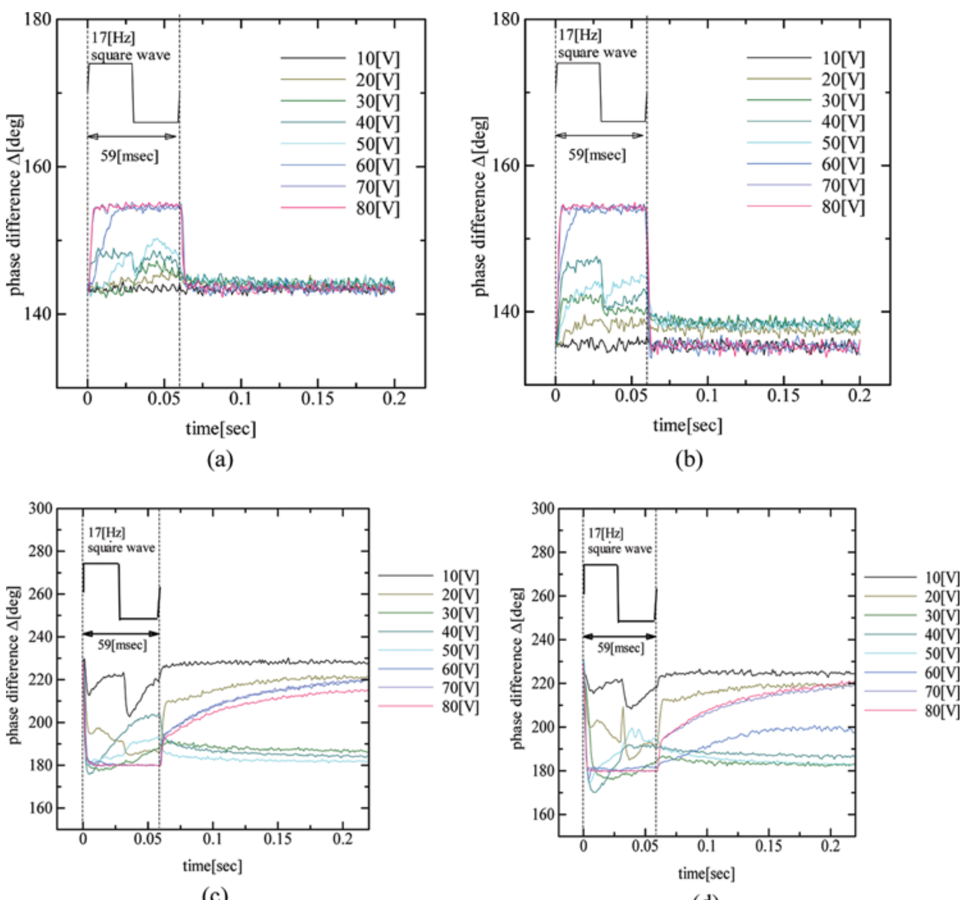


Figure 8. Time-resolved TRE and TE measurement, where the BChLCD cell was fabricated with PI-V1 alignment film and LC doped with 40 wt% chiral dopant. Conditions (a)–(d) are similar as for Figure 4.

Table 3. Switching voltage confirmed by the time-resolved TRE and TE measurements for BChLCD

		Switching voltage [V]			
Dosage of CB-15	Memorized state	PI-V1	PI-V2	PI-V3	PI-V4
30wt%	Focal conic	20~40	20~30	20~50	20~40
	Planar	20~40	20~30	20~60	20~40
35wt%	Focal conic	20~40	20~40	20~50	20~40
	Planar	20~50	20~50	30~60	30~40
40wt%	Focal conic	30~50	20~50	30~60	20~50
	Planar	30~60	20~50	40~60	30~50

dosage of the chiral additive was 40%. Compared with Figure 4, it is found that the switching voltage of BChLCD cell whose dosage of the chiral additive was 40% is higher than those of 30%. This experimental result implies that the switching voltage rises as the dosage of chiral additive increases.

Generally, polyimide alignment film with low surface energy is suitable for vertical alignment and inhibits the image sticking problem. Table 3 summarizes the switching voltage confirmed by the time-resolved TRE and TE measurements for BChLCD, which was kept at each of the states for two weeks. It could be natural that the switching voltage is relatively high due to the image sticking problem caused by the memory effect, which is induced by a strong planar surface anchoring effect and high surface energy. From Tables 1 and 3, however, it is found that the switching voltage rose even when the polyimide alignment film with low surface energy was used (*e.g.*, PI-V3); this result is different from expectations. This phenomenon can be interpreted by the presence of disclinations and the Helfrich-type modulation. From previous studies [7–11], it follows that the Helfrich-type modulation tends to deform the director alignment throughout the LC layer yielding an increase of the total free energy in LC layer. As a result, a high switching voltage is required. That is, director near the surface is likely to be under the control of the Helfrich-type modulation rather than the surface aligning property itself. Actually, as is found in Table 3, the switching voltage rises as the helical pitch is shortened by the increase of the chiral additive (*e.g.*, 40%), which is also caused by the increase of the total free energy in LC layer. From these investigations, it is suggested that a polyimide alignment film with moderate surface energy is better to be applied to BChLCD with moderate chiral dopant.

5. Conclusions

Dynamic response of LC director reorientation near the surface of BChLCD with various surface treatments was observed by means of the total reflection ellipsometry. After the BChLCD samples were fabricated with various surface alignment films and maintained the planar state for two weeks, the deviation from the original switching voltage to which the image sticking problem has a close relationship were confirmed in some BChLCD samples. The relationship between the image sticking and surface free energy of alignment film was investigated. It is well known that in the case where the surface alignment film possesses the strong planar surface anchoring, the switching voltage is relatively high due to the image sticking problem caused by the memory effect. In the case of alignment film with low surface free energy, however, the director near the surface is under the control of the Helfrich-type modulation rather than the surface alignment property. As a result, high switching voltage seems to be required. It is concluded that an alignment film with moderate surface energy should be adopted with moderate chiral dopant.

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