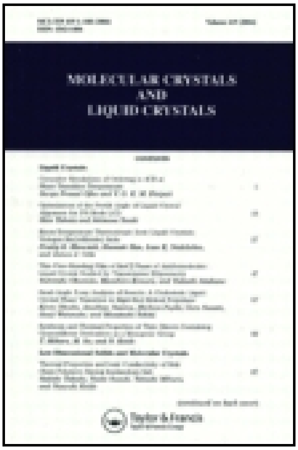

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Molecular Reorientational Motion of a Polymer-Stabilized Ferroelectric Liquid Crystal

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Molecular Reorientational Motion of a Polymer-Stabilized Ferroelectric Liquid Crystal

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The polymer-stabilized ferroelectric liquid crystals (PS-FLC) exhibit monostable and asymmetric electrooptical characteristics with grayscale capability without a threshold. The reorientational motion of FLC molecules can be investigated in terms of two independent optical parameters: the phase difference angle and the angle of the relative amplitude ratio measured with time-resolved ellipsometry. In this study, the time-resolved ellipsometry is applied to the PSFLCs, and we invesitgate the effect of polymer stabilization on the dynamic behavior of molecular reorientation. The measurement results demonstrated the dynamic behavior of PSFLC-molecular reorientation comparatively depends on the tilt angle which FLC takes at the photocure stage.

Keywords: ellipsometry; ferroelectric liquid crystal; polymer; reorientation; tilt angle

INTRODUCTION

Liquid crystal displays (LCDs) are currently used extensively in information display devices, particularly in the displays of computers and even televisions. As the LCDs will be expected to play more important role in the multimedia network era, LCDs that are capable of displaying a moving video image are required to be developed. Therefore, it is necessary to substitute the conventional nematic LC with a new LC

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material in order to realize a high-quality display of a moving image. A leading candidate is ferroelectric liquid crystal (FLC). Surface-stabilized (SS) FLCs are attractive because of their unique characteristics such as high-speed response, wide viewing angle and bistability [1–4]. Although the bistability is suitable for passive matrix-addressed displays, it is disadvantageous for LCDs which possess grayscale or full-color capability [5].

In a previous article, we reported a polymer-stabilized (PS) FLC fabricated by UV photocure of doped photocurable monoacrylates, which have mesogenic side chains, at a temperature where the LC medium is in the SmC* phase under the application of a monopolar electric field [6–9]. This PSFLC exhibits monostable and asymmetric electrooptical characteristics with grayscale capability without a threshold. Although numerous studies mainly concerned with the application research of PSFLC have been reported, it has not been clarified in detail yet how polymer stabilization influences the dynamic behavior of molecular reorientation for an electric field. The reorientational motion of FLC molecules can be investigated in terms of two independent optical parameters concerned with elliptically polarized light: the phase difference angle Δ and the angle of the relative amplitude ratio Ψ measured with time-resolved ellipsometry [10]. It has been known that Δ and Ψ indicate qualitatively the out-of-plane and in-plane molecular motion of the cell substrate, respectively, but not quantitatively. In this study, first we formulate an idea of determining the quantity of the in-plane angle of the molecular alignment direction (i.e., the apparent tilt angle) from the values of Ψ. Then, this analysis method is applied to the measurement results of PS-FLCs, and we invesitgate the effect of polymer stabilization on the dynamic behavior of molecular reorientation.

EXPERIMENTALS

The materials used in this research were as follows: the FLC was FELIX-M4851/100 (Clariant Japan); the photocurable mesogenic monoacrylate was UCL-001 (Dainippon Ink and Chemicals), which was doped with 1 wt% photoinitiator; and the LC alignment film was polyimide RN-1199 (Nissan Chemical Industries), which induced a defect-free FLC alignment with the C2-chevron structure [11,12]. The relevant properties of FELIX-M4851/100 given in the catalogue are shown in Table 1.

A solution of polyimide was spun on glass substrates coated with indium-tin oxide (ITO) and then baked. After the thermal treatment, the substrates were rubbed. Then, the FLC, which was doped with

TABLE 1 Properties of FELIX-M4851/100

Properties	
Phase sequence	Cryst.(<-20)SmC*(67)SmA(71)N*(76)Iso. [°C]
Spontaneous polarization	22.8 nC/cm^2 (20°C)
Tilt angle	30.5° (20°C)
Switching time	38 μs (E = 15 V/μm, 20°C)

the photocurable mesogenic monomer, was injected in the isotropic phase via capillary action into an empty cell, in which the rubbing directions were parallel and the cell gap was 2 μm. Next, the cell was cooled gradually to the temperature where the LC medium was in the SmC* phase. Then, the LC medium was photocured with a UV light source (365 nm, 2 mW/cm^2) under the application of a monopolar electric field (5 V/μm). The concentrations of monoacrylate in the LC medium were set at 2 or 5 wt%. Furthermore, the photocure was done at the temperature where the FLC medium takes the tilt angle of 5, 10, 15 or 20°C, as shown in Figure 1.

The transmission time-resolved spectroellipsometry measurement was performed with a polarization modulation ellipsometer ELC-300 (JASCO) with a 20 μs time resolution. The applied electric field into the cell fabricated by the above method was a triangular-wave electric field (1 Hz). The measurement was carried out at the temperature *T*

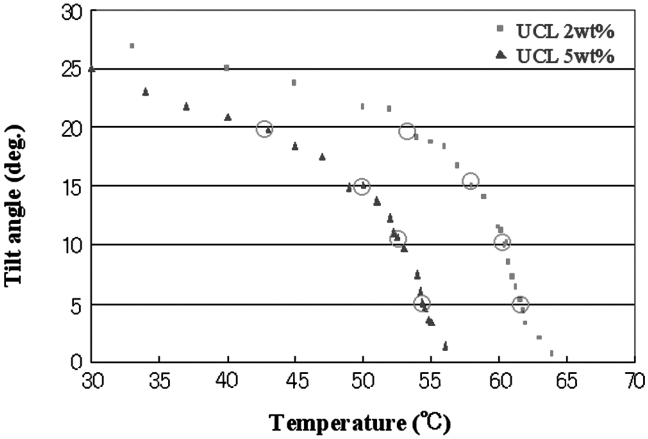


FIGURE 1 Temperature dependence of the tilt angle in a conventional FLC before the UV photocure.

where $T_C - T = 10°\text{C}$ (Tc is the SmA to SmC* phase transition temperature).

RESULTS AND DISCUSSION

Figures 2 and 3 show the time-dependent variation of Ψ in the PS-FLCs doped with 2 and 5 wt% polymer, respectively. It is found that in the case of low polymer concentration such as 2 wt% the photocuring condition of temperature, which the tilt angle of FLC depends on, does not almost influence the reorientational motion of FLC molecules. On the other hand, in the case of high polymer concentration such as 5 wt% the photocuring condition strongly influence the reorientational motion of FLC molecules.

Figure 4 illustrates the optical system of the transmission ellipsometry used in this study. In this system, Stokes vector $\boldsymbol{I}$ is defined as

$$\boldsymbol{I} = \boldsymbol{P}_{45} \bullet \boldsymbol{S} \bullet \boldsymbol{M}_{45\delta} \bullet \boldsymbol{P}_0, \tag{1}$$

where $\boldsymbol{P}_{45}$, $\boldsymbol{S}$, $\boldsymbol{M}_{45\delta}$, $\boldsymbol{P}_0$ are 4×4 muller matrices of the analyzer, sample, PEM having a phase difference δ and polarizer, respectively. The phase difference δ of PEM is modulated periodically as

$$\begin{aligned} \delta &= \delta_0 \sin(\omega t) = \delta_0 \sin(2\pi f t) \\ f &= 5 \times 10^4\ (\text{Hz}) \end{aligned} \tag{2}$$

in this study. The phase difference angle Δ and the angle of the relative amplitude ratio Ψ are given by

$$\Delta = \sin^{-1} \frac{A(\omega)}{\sqrt{1 - A^2(2\omega)}}, \tag{3}$$

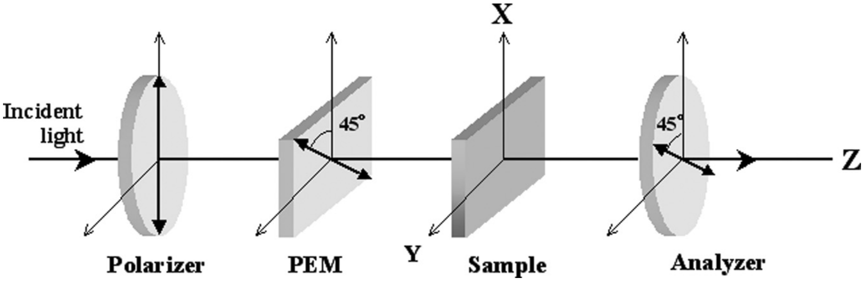


FIGURE 2 Optical system of transmission ellipsometry.

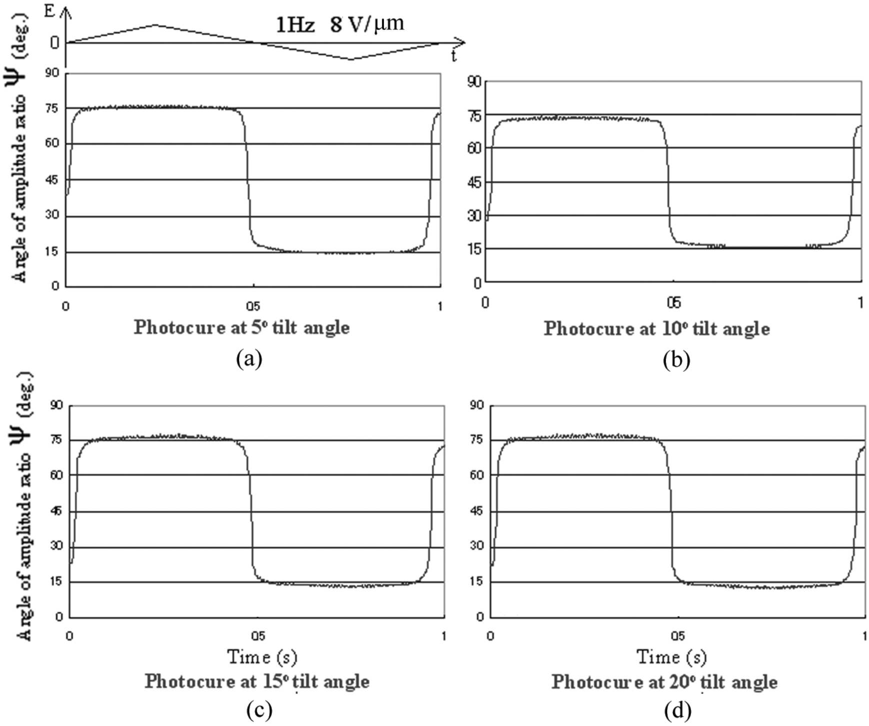


FIGURE 3 Time-dependent variations of Ψ in PS-FLCs having 2 wt% polymer.

$$\Psi = \tan^{-1}\sqrt{\frac{1 + A(2\omega)}{1 - A(2\omega)}}, \tag{4}$$

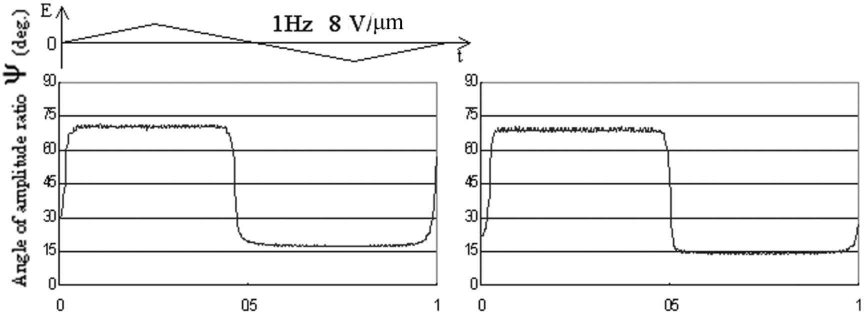
where

$$A(\omega) = \sin(2\Psi)\sin\Delta, \tag{5}$$

$$A(2\omega) = -\cos(2\Psi). \tag{6}$$

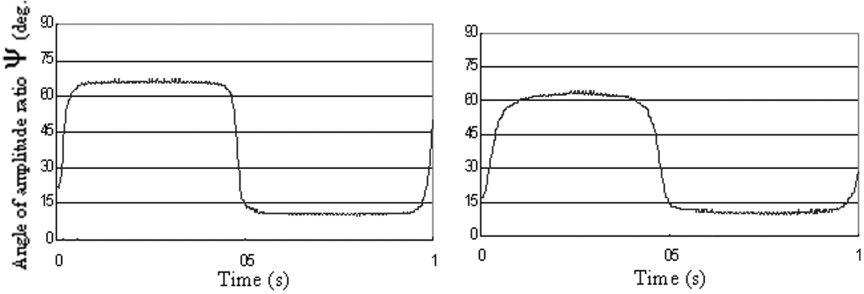
Here, when the sample rotates by Φ from an initial state at which the sample muller matrix is $\mathbf{S}_0$, $\Delta = \Delta_0$ and $\Psi = \Psi_0$, the Stokes vector can be rewritten as

$$\boldsymbol{I} = \boldsymbol{P}_{45} \bullet \boldsymbol{T}_{\Phi} \bullet \boldsymbol{S}_0 \bullet \boldsymbol{T}_{-\Phi} \bullet \boldsymbol{M}_{45\delta} \bullet \boldsymbol{P}_0, \tag{7}$$



Photocure at 5° tilt angle
(a)

Photocure at 10° tilt angle
(b)



Photocure at 15° tilt angle
(c)

Photocure at 20° tilt angle
(d)

FIGURE 4 Time-dependent variations of Ψ in PS-FLCs having 5 wt% polymer.

by using a matrix $\boldsymbol{T}_\Phi$, which indicates a rotatory operation. In this situation,

$$A_\Phi(\omega) = -\frac{\sin(2\Psi_0)\sin\Delta_0\cos(2\Phi)}{1-\cos(2\Psi_0)\sin(2\Phi)}, \tag{8}$$

$$A_\Phi(2\omega) = -\frac{-\cos(2\Psi_0)\cos(2\Phi)+\cos(2\Phi)\sin(2\Phi)-\sin(2\Psi_0)\cos\Delta_0\cos(2\Phi)\sin(2\Phi)}{1-\cos(2\Psi_0)\sin(2\Phi)}. \tag{9}$$

Assuming that the sample rotation about the Z-axis is equivalent to the reorientation of the in-plane tilt of the FLC molecule, the variation of the in-plane tilt angle, i.e., the apparent tilt angle θ can be obtained from the experimental results of Ψ using Eqs. (4) and (9). Figure 5 shows the

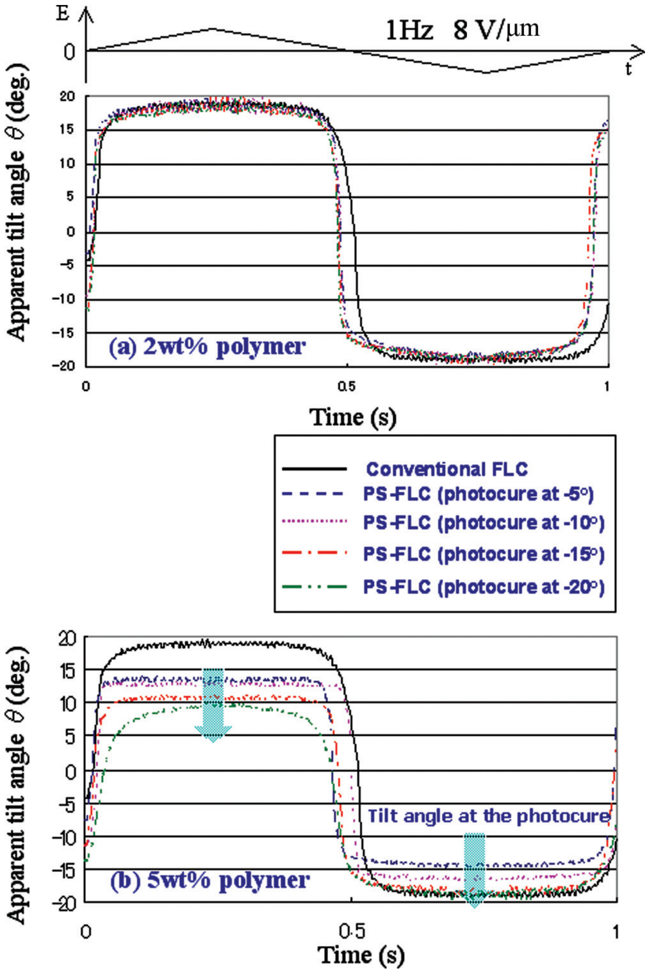


FIGURE 5 Time-dependent variations of the apparent tilt angle in PS-FLCs.

time-dependent variation of θ calculated from the data in Figures 2 and 3, in which the photocure was done at the temperature where the FLC medium takes the tilt angle of -5, -10, -15 or -20°. It is found that in the PS-FLC having 2 wt% polymer the apparent tilt angle arrangement due to the application of a triangular-wave electric field is symmetrical for the field polarity and the maximum apparent tilt angle of PS-FLC is same as that of conventional FLC. However, in the case of PS-FLC with 5 wt% polymer, the apparent tilt angle arrangement becomes asymmetrical for the sign of the electric field and the degree of asymmetry increases as the tilt angle which FLC takes at the photocure stage increases. Therefore, the polymer stabilization may not only transform the bistability of conventional SSFLC into the monostability, but also vary the orbit of molecular reorientational motion.

CONCLUSIONS

The dynamic behavior of FLC molecules has been investigated in terms of the angle of the relative amplitude ratio of elliptic polarized light, measured by time-resolved transmission ellipsometry. The value of the angle of the relative amplitude ratio indicate qualitatively the in-plane molecular orientations of the cell substrate, but not quantitatively. In this study, first we formulated an idea of determining the quantity of the in-plane tilt angle from the angle of amplitude ratio, and then, this analysis method was applied to the experimental results of PSFLCs fabricated by UV photocuring of doped photocurable monoacrylates with mesogenic side chains at a temperature where the FLC medium is in the SmC* phase under the application of a monopolar electric field. As a result, it was found that the orbit of the molecular reorientational motion in PSFLC may become different from that of a conventional SSFLC and the apparent tilt angle arrangement may become asymmetrical for the electric field polarity. It is concluded that polymer stabilization can not only transform the bistability of conventional SSFLC into the monostability, but also vary the molecular reorientational motion.

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